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Portable Glulam Timber Bridge Systems

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Abstract

Recent interest in portable bridge systems has increased due to a heightened awareness for reducing environmental impacts at road stream crossings. This paper discusses general design criteria for portable timber bridges and three case studies of portable longitudinal glued-laminated timber (glulam) deck bridges. Two of the bridges use simple longitudinal glulam deck panels. The third bridge uses two longitudinal glulam deck panels constructed in a unique double-tee cross section. AU three bridges have performed well in service and appear to be cost effective when compared with the cost of installing traditional permanent stream crossings. In addition, they can be installed with minimal environmental impacts.

Keywords: Portable bridge, timber bridge, glued-laminated timber, glulam, double-tee.

Introduction

Portable or temporary bridges have been used traditionally in military or construction applications. In typical civilian construction applications, portable bridges are used when a permanent highway bridge is being replaced and a temporary bypass is needed during the construction period. Also, portable bridges are needed to serve as temporary structures during disaster situations, e.g. when a flood washes out a highway bridge. In addition, there are many situations where temporary access is needed across streams in remote areas for the construction or maintenance of utility structures.

Currently, much interest in portable bridge systems is occurring in the forestry and related natural resources industries. Access to our nation's forest resources requires an extensive roadway network over a wide spectrum of geographical conditions. In general, these roads are designed for low-volume traffic conditions and are often single lane and unpaved Because forest management activities are both diverse and sporadic, traffic volumes and loads can vary significantly. During resource management periods, traffic volumes are low and consist primarily of light passenger vehicles. However, during forest harvesting operations, roadways may be subjected to higher-volume truck traffic with loads in excess of the maximum legal highway load. In either case, roadway use is commonly limited to short periods over a relatively long forest management period. For example, roadway access may be required for only a six-month period over a 10-year cycle. As a result, there is a trend to close these roads when they are not needed for management activities.

Forest roads typically require a large number of structures to cross streams and other topographical features. Rothwell (1983) and Swift (1985), in separate studies on forest roads, found that stream crossings were the most frequent sources of erosion and sediment introduction into streams. Bridges, fords and culverts are the common stream crossing structures on forest roads, Thompson et al. (1996) reported that during the construction of a gravel ford, peak sediment concentration in water samples taken downstream from the ford was nearly 2810 mg/1 higher than that of samples taken upstream from the ford. Also, when light vehicular traffic drove through the stream downstream sediment concentration was as much as 255 mg/1 higher than that of the upstream samples.

While some of the problems with fords are alleviated by culverts, there can be considerable sediment loads introduced into the stream during the excavation and fill work that accompanies culvert installation. Thompson (1996) reported that during installation of a corrugated metal pipe culvert, sediment concentration in water samples taken downstream of the culvert was over 950 mg/l higher than that of the upstream samples. Also, culverts may clog with debris and may be washed out during heavy runoff periods, thereby introducing additional sediment into the stream. In the case of roads or trails that are not permanent, the stream crossing structure may be removed after activities are complete. Removal of a culvert also appears to introduce heavy sediment loads into the stream.

Historically, bridges for low-volume forest roads have been of two types: permanent or temporary. Permanent bridges, which are typically designed for service lives of 40 to 50 years, are not economically feasible for short use periods and often require expensive maintenance for continued service. Also, permanent bridges for limited-use low-volume forest roads are commonly designed to a lower standard than most public access facilities and can be a potential liability to the bridge owner if public access is possible. A common temporary bridge has been the log stringer bridge that is either removed or left to deteriorate at the end of the use period. The use of temporary log stringer bridges has substantially declined over recent years because of the difficulty in locating logs of the size and quality required for bridge construction. In addition, if the temporary bridge is not installed or removed properly, there may be adverse water quality impacts.

One solution to short-term bridge needs is the concept of portable bridges. If properly designed and constructed, portable bridges can be easily transported, installed, and removed for reuse at multiple sites. This ability to serve multiple installation makes them more economically feasible than a permanent structure. In addition, if they are installed and removed so that disturbance to the site is minimized, they can alleviate many water quality and other potential environmental problems. Thompson et al. (1995) reported that proper installation of a portable bridge could significantly reduce levels of sediment introduced into the stream compared to other crossings such as fords and culverts.

Many of the advantages of timber bridges make them ideal for temporary stream crossings. This paper will discuss general design criteria for portable bridges and then review three cases studies of portable glued-laminated timber (glulam) bridges. Design, installation, general performance, and cost of these three bridges will be discussed.

Portable Bridge Design Criteria

Important characteristics that must be considered in the design and selection process for portable bridges include the design life, traffic type and traffic volume. These characteristics are used by the designer to select the initial design concept and determine many important design criteria. For example, if the average daily traffic is less than 50 vehicles per day and consists primarily of light vehicular traffic, it may be possible to use a curb instead of a full guardrail. Also, for many types of low-volume road bridges with short design lives, it may not be necessary to install a wear surface on the bridge deck or use high levels of preservative treatments. However, if the bridge is expected to carry heavy off-highway vehicles, design loads must be accurately determined.

Taylor et al. (1995) presented a matrix of proposed design criteria for portable timber bridges. These criteria are listed in Table 1 for three traffic volume categories: Sub-Low-Volume, Low-Volume, and High-Volume. The Sub-Low-Volume road category might include skid trails and other temporary roads constructed during forest harvesting or management activities. These types of roads may be used by very light vehicles or by heavy off-highway vehicles. The Low-Volume road might include major haul roads carrying higher volumes of truck traffic. The High-Volume roads would consist primarily of public highways where temporary bridges are needed during construction or replacement of permanent bridges. The authors invite comments on these example criteria or suggestions for additional criteria. A more extensive discussion of other general design characteristics for portable timber bridges was given by Taylor et al. (1995).

Portable Timber Bridge Case Studies

Background

A variety of portable bridge designs have been constructed from steel, concrete and timber with steel and timber bridge designs being the most prevalent types (Taylor et al., 1995). Although log stringer bridges and non-engineered timber mats or “dragline mats” have been used for many years, the recent advances in timber bridge technology include several engineered designs that can be easily adapted for use as portable bridges. Probably the most promising designs for spans up to 12 m (40 ft) consist of longitudinal glulam or stress-laminated decks that are placed across the stream. These designs can be quickly and easily installed at the stream crossing site using typical forestry or construction equipment such as hydraulic knuckleboom loaders, skidders, or backhoes. Also, it is possible to install these bridges without operating the equipment in the stream, which minimizes site disturbance and associated erosion and sediment load on the stream.

Examples of portable stess-laminated timber bridges were presented by Hassler et al. (1990) and Taylor and Murphy (1992). Both of these bridges were designed to support truck traffic in logging activities. Although the two bridges were different sizes, they used the same concept of placing two prefaabricated stress-laminated deck panels side by side on the streambanks. The panels were not designed to be interconnect; however, the bridge described by Taylor and Murphy (1992) had provisions for a nailer to be attached that would cover the gap between the two bridge panels. Both bridges have been used with favorable results. Potential

Table 1 - Suggested design criteria for portable bridges installed on various road types.

Criterion	Sub-Low Volume	Low Volume	High Volume
Design Life	≤ 5 years	≤ 15 years	> 20 years
Traffic Type	1. Off-Highway 2. Light vehicles	1. Trucks 2. Light Vehicles	1. Highway
Average Daily Traffic	75	100	Unlimited
Design Speed	8-16 kph	8-16 kph	> 40 kph
Load Criterion	Off Highway Loads	Off Highway or Highway Loads	AASHTO HS20 or HS25
Load Application Period	6 months	24 months	36 months
Deflection Criterion	None	None	AASHTO Criterion
Span Length	< 10 m	≤ 15 m	≤ 25 m
Width	4 - 5 m	4 - 5 m	4 - 5 m
Rail	Curb or None	Rail or Curb	AASHTO Rail
Wear Surface	Wood or None	Wood or None	Asphalt

disadvantages to these bridges are the need to retension the steel bars periodically and the possibility of damaging the bars during bridge installation, removal, and transport. An alternative to stress-laminated deck designs is the use of longitudinal glulam decks. The following text will describe three case studies of portable glulam bridges.

Longitudinal Deck Bridge for Truck Traffic

Design - Taylor et al. (1995) presented the results of using a portable longitudinal glulam deck bridge designed for use by logging trucks and other forestry equipment. The design vehicle for the bridge was an American Association of State Highway and Transportation Officials (AASHTO) HS20 truck (AASHTO, 1993) with a deflection limitation of L/240, where L represents the bridge span. The bridge is 4.9 m (16 ft) wide and 9.1 m (30 ft) long. It uses four Combination 47 (AITC, 1993) glulam deck panels, 1.2 m (4 ft) wide and 267 mm (10.5 in.) thick. The bridge was designed to be installed on a mud sill, with the bridge deck extending 0.6 to 1.5 m (2 to 5 ft) on either side of the stream banks, thereby leaving an effective span of approximately 6.1 to 7.9 m (20 to 26 ft). Transverse glulam stiffener beams of combination 16F-V5 glulam (AITC, 1993) measuring 171 mm (6.75 in.) wide, 140 mm (5.5 in.) deep, and 4.9 m (16 ft) long were bolted on the lower side of the deck. Glulam combination 16F-V5 curb rails on glulam curb risers measuring 216 mm (8.5 in.) wide and 127 mm (5 in.) deep were bolted to the outside deck panels. All wood components were treated with creosote to a retention of 194 kg/m^3 (12 lb/ft^3). Photographs of one bridge installation are shown in Figure 1.

Although it was possible to install the deck panels directly on the stream banks with no abutments, the placement of a mud sill or spread footer under each end of the bridge was preferred to prevent differential settling of the deck panels into the soil. A wear surface was not installed on the bridge deck; however, steel angles were attached to each end of the bridge to prevent wear on the ends of the deck panels from vehicle traffic. Steel tie-down brackets were provided at each of the bridge comers to allow the bridge to be secured to nearby trees or deadmen. This ability to secure the bridge is an important feature in its design since flood waters have risen over the bridge several times during its use. All steel hardware was galvanized.

Installiation and Removal - The bridge can be installed in less than six hours and removed in less than three hours by typical forestry or construction equipment. It has been lifted into place using equipment such as knuckleboom loaders, backhoes, or truck-mounted cranes and it has been winched into place using a crawler tractor. To lift the panels into place, slings or chains were attached to eye-bolts placed in holes drilled through the deck panels. AU bridge installation and removal activities were accomplished without operating equipment in the stream or disturbing the stream channel or banks. Therefore, based on visual appraisal, there were no adverse impacts on water quality during construction.

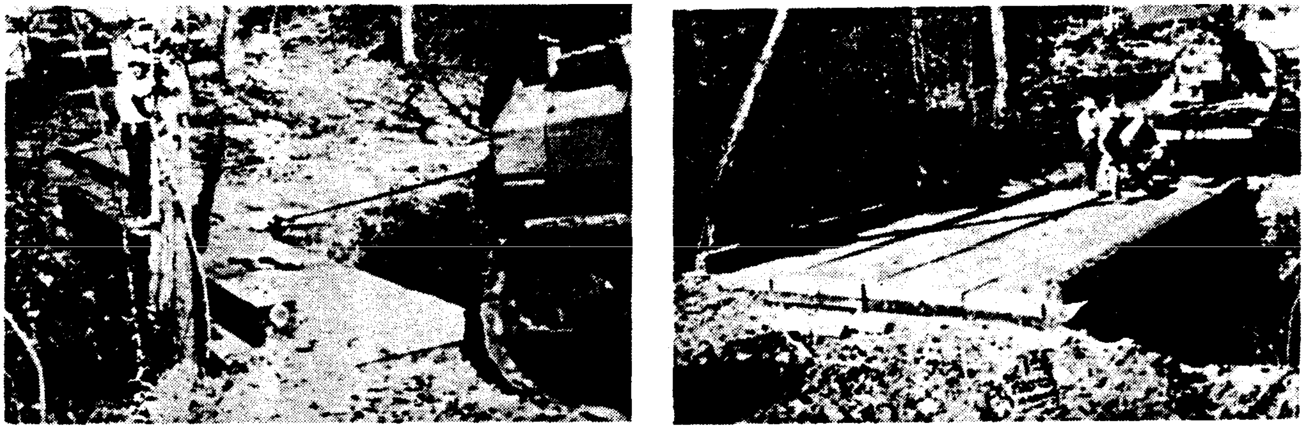


Figure 1 - Portable longitudinal glulam deck bridge for truck traffic. Installation by winching into place with crawler tractor is shown on left. Finished bridge installation is shown on right.

Cost – The bridge components (including the mud sill) had an initial cost of $15,500. Based on a total deck area of 44.6 m^2 (480 ft^2), the cost per square meter was $347 ($32/ft^2). Average cost to install and remove the bridge was approximately $1,000 per site. Distributing these costs over 10 sites, the bridge would cost $2,550 per site, which is competitive with the cost of installing permanent culverts or

Performance **-** Taylor et al. (1995) provided detailed discussions of the results from bridge evaluations. These included stiffness testing of individual lumber laminations and the completed bridge panels, load tests of the bridge, and general condition assessments of the bridge.

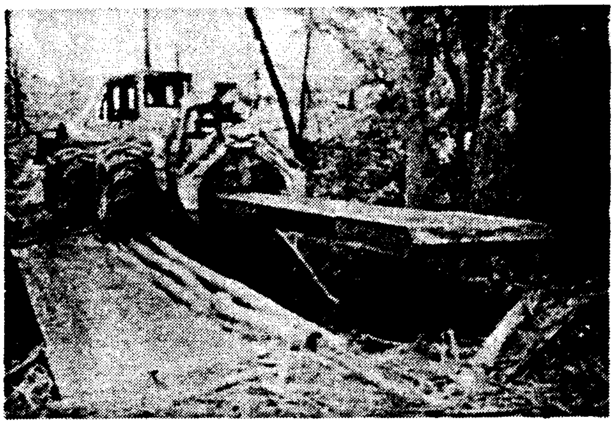
The bridge has performed satisfactorily under periodic use in logging operations over the last four years. It can be easily installed and removed with typical forestry or construction equipment. One area identified for potential improvement was the use of transverse stiffener beams. Installation and removal times could be reduced with an easier method of attaching the stiffener beams or by using an alternative to them. Results from static load tests of the bridge indicated that maximum bridge deflections at mid-span were approximately L/300 at 119% of design bending moment. When actual deflection data were compared to those predicted using AASHTO design procedures, there was more apparent load distribution among deck panels than predicted using AASHTO procedures. Vehicle traffic on the unprotected bridge deck surface did not result in significant damage, thereby supporting the decision not to use a wear surface. The bridge appeared to be cost effective, compared with traditional fords and culverts, if it could be reused on at least ten sites. Thompson et al. (1995) showed that in addition to being installed with no adverse impacts on water quality, the bridge produced less sediment after installation than that of a nearby culvert crossing, based on water samples taken upstream and downstream of the crossings during storm events.

Longitudinal Deck Bridge for Off Highway Vehicies

Design **-** Keliher et al. (1995) described the use of a longitudinal glulam deck bridge designed for off-highway vehicle traffic. The bridge was designed for rubber-tired log skidders used in forest harvesting operations. The design vehicle was a 15,454 kg (34,000 lb) skidder with a 3 m (10 ft) wheelbase. This bridge consists of two Combination 48 (AITC, 1993) glulam panels 1.2 m (4 ft) wide, 216 mm (8.5 in.) thick, and 8 m (26 ft) long. The bridge panels were not intended to be interconnected; therefore, each panel was designed to carry one wheel line of the vehicle. No curb or rail was used in this design. The panels were preservatively treated with creosote to a retention of 194 kg/m^3 (12 lb/ft^3).

After the deck panels were preservatively treated, 6 mm (0.25 in.) thick steel plate was attached to the ends and sides of the panels to prevent damage from skidder grapples. Also, a steel lifting bracket with chain loops was attached at the center of the panel to facilitate loading and unloading by typical knuckleboom loaders. Instead of using bolts or lag screws to attach the steel hardware to the glulam panels, 19 mm (0.75 in.) diameter steel dowels were placed through the glulam panels, welded to the steel plate, and then ground flush. This method of attachment eliminated exposed bolt heads that could be damaged during skidding operations. All steel plate, angles, and dowels conformed to ASTM A36 or ASTM A307. Since this bridge was projected to have a service life of approximately 10 years, steel hardware was not galvanized. Instead, a primer coat of paint was applied to all steel hardware after installation. Photographs of the bridge are shown in Figure 2.

installation and Removal - The glulam panels were placed directly on the stream banks and were not



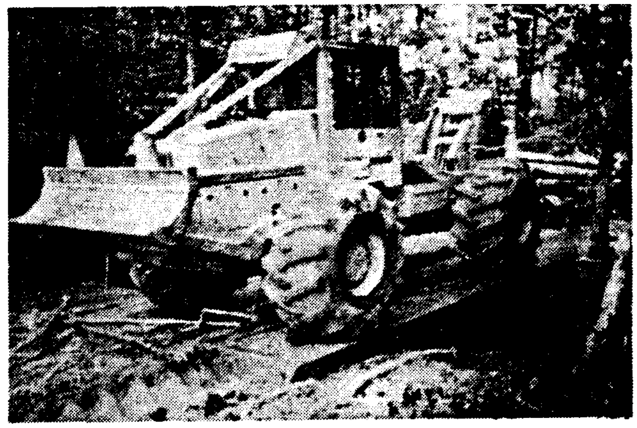


Figure 2 - Portable longitudinal glulam deck bridge for off-highway traffic. Placement of panels by rubber-tired log skidder is shown.

interconnected. The bridge panels were placed by using the skidder's grapple to pickup the panel, back over the stream, then lower the panel onto the stream banks as shown in Figure 2. The panels could also be winched into place with a skidder or crawler tractor. A gap was left between the panels so that the wheel lines of the skidder matched the center line of each panel. Logs were then placed between the panels to prevent excessive debris from falling into the stream during skidding operations. A conservative estimate for the total time to install and remove the bridge was 2 hours. This includes skidding the bridge to the stream crossing site, placing the bridge deck panels, placing logs between the panels, removing the panels and logs, and skidding the panels back to a loading area. The actual time required to place the panels at the stream was approximately 30 minutes. The bridge can be installed by one person. Since the stream channel and stream banks were not disturbed during installation, there were no impacts on stream water quality.

Cost -- The initial cost of the finished prototype glulam panels (including preservative treatment, installation of steel hardware, and delivery to the job site) was $9,300. However, current estimates for fabricating the bridge panels are approximately $8,000. Based on the actual deck area of 19.3 m^2 (208 ft^2), the cost would be approximately $414/$m^2$ ($38/$ft^2$). Installation and removal costs are estimated at approximately $165 per site. Using these data, if the bridge was installed at 10 different sites, the cost per site would be $965.

Performance -- Keliher et al. (1995) provided a more detailed discussion of initial bridge performance. The monitoring program for the bridge included testing individual lumber laminations and the finished bridge deck panels, conducting field load tests of the bridge, and assessing the general condition of the bridge.

In its initial use period, the bridge performed well and proved to be easy to install and remove. In early installations, the skidder grapples resulted in some damage to the sides of the glulampanels in areas that were not protected by steel plates. This damage did not affect the structural adequacy of the bridge or expose any untreated wood. Subsequently, additional steel plates were added along the sides of the deck panels and no additional damage has occurred. The steel lifting hardware also has been helpful in loading and unloading the deck panels from trucks.

Using stiffness data collected on the bridge deck panels, the predicted deflection of the panels under the design skidder was approximately L/173. This level of deflection was essentially unnoticed by the skidder operators as they drove across the bridge. Overall, the bridge has been well received by forest landowners and loggers that used it because it is easy to install and remove and it reduces environmental impacts at stream crossings. However, its relatively high initial *cost* may discourage some users from purchasing this type of bridge over the non-engineered designs frequently used for off-highway vehicles.

Longitudinal T-Section Bridge for Truck Traffic

Design -- The portable longitudinal deck timber bridge designs discussed previously have been limited to spans of approximately 9 m (30 ft) due to practical limitations on the thickness of the glulam deck panels. However, there is a need for more efficient technology to allow the use of portable timber bridges on spans up to 15 m (50 ft). Therefore, to test the feasibility of achieving longer spans for portable bridges, Taylor and Ritter (1996) presented the design of a longitudinal glulam deck bridge constructed in a double-tee cross section.

The bridge consists of two longitudinal panels 12 m (40 ft) long and 1.8 m (6 ft) wide giving a total bridge width of

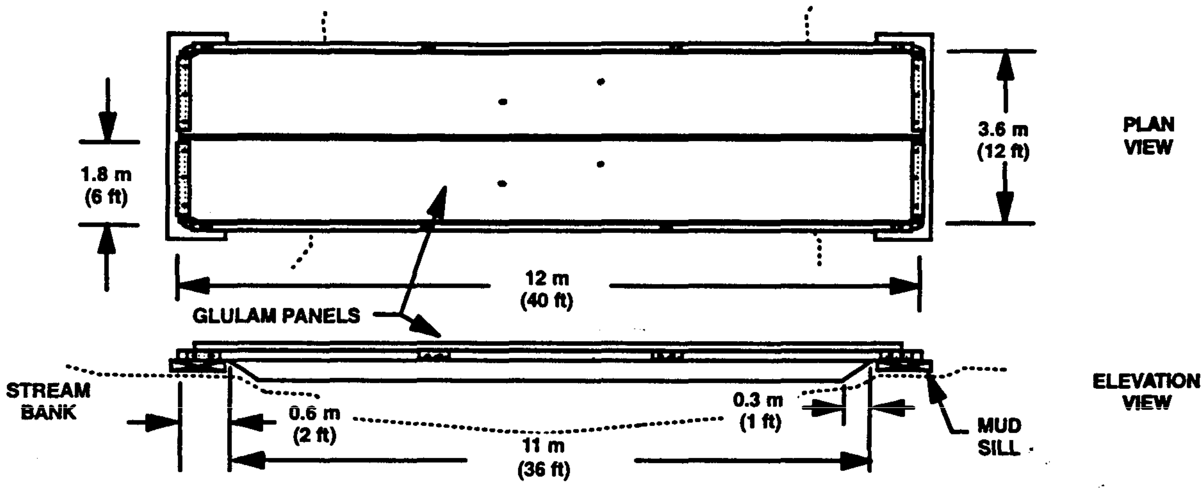


Figure 3 - Sketch of portable longitudinal T-section glulam deck bridge for truck traffic.

approximately 3.6 m (12 ft) as shown in Figure 3. The design vehicle for the bridge was an AASHTO HS20 truck (AASHTO, 1993) with no specified deflection limitation. The panels are not interconnected; therefore, each panel carries one wheel line of the design vehicle. The panels were designed to be placed side by side on a mud sill, which can be placed directly on the stream banks. Each panel was constructed in a double-tee cross section with dimensions given in Figure 4. Vertically-laminated flanges were 171 mm (6.75 in.) thick, 1.816 m (71.5 in.) wide, and were fabricated using No. 1 Southern Pine nominal 50 by 203 mm (2 by 8 in.) lumber. Two 286 mm (11.25 in.) wide and 314 mm (12.375 in.) thick webs were horizontally laminated to the lower side of the flange. The webs were fabricated using Southern Pine nominal 50 by 305 mm (2 by 12 in.) lumber that met specifications for 302-24 tension laminations (AITC, 1993). At the ends of the bridge panels, the flange extended 0.6 m (2 ft) beyond the end of the webs. This extension of the flange was intended to facilitate the placement of the bridge panel on a mud sill.

Interior wood diaphragms measuring 286 mm (11.25 in.) wide and 210 mm (8.25 in.) thick were provided between the webs at three locations along the length of the panels: one at each end, and one at midspan. In addition, to provide additional strength in the weak axis of the flange, 25 mm (1 in.) diameter ASTM Grade 60 steel reinforcing bars were epoxied into the glulam flange and the diaphragms. The reinforcing bars were placed in holes drilled horizontally through the flanges at the panel third points. Additional reinforcing bars were placed horizontally through the diaphragms near the ends of the panels.

A curb rail was attached to steel angles, which were bolted to the outside edges of each flange. The rail consisted of a single 140 mm (5.5 in.) deep, 127 mm (5 in.) wide, and 11.6 m (38 ft) long Southern Pine Combination 48 (AITC, 1993) glulam beam running the length of the bridge. For economic considerations, the curb rail was intended only for delineation purposes and was not designed as a structural rail.

A wearing surface was not provided on the bridge. However, a steel angle was attached to the top face of the flange at each end of the bridge to prevent damage as vehicles drive onto the bridge. In addition, to prevent damage during installation of the bridge, a 6 mm (0.25 in.) thick steel plate was bolted to the exposed end face of each web.

To facilitate lifting of the bridge panels, lifting eyes were placed 0.9 m (3 ft) from either side of the bridge panel midspan. These eyes consisted of a 51 mm (2 in.) inside diameter steel pipe with a steel plate flange welded to one end. The eyes were installed in holes drilled through the bridge deck flanges and attached using lag screws. The intent of the lifting eye was to allow a chain or wire rope to be fed down through one eye and back up through the other eye to form a sling. Then, the ends of the chain or wire rope could be attached to a crane, loader, or backhoe. To assist in lifting and securing the panels at the site, additional steel plates, with chain loops welded to the plate, were bolted to the ends of each panel. All steel plate, angles, lag screws, and bolts conformed to ASTM A36 or ASTM A307. A primer coat of paint was applied to all steel hardware before installation.

The steel hardware was installed on the finished deck panels before they were shipped from the laminating plant. The deck panels were then shipped to a treating facility where they were preservatively treated with creosote to a retention of 194 kg/m^3 (12 lb/ft^3) in accordance with American Wood Preservers' Association (AWPA) Standard C14 (AWPA, 1991). The treating process had no detrimental effect on the

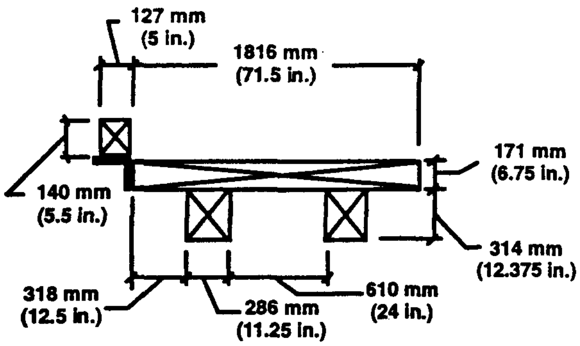


Figure 4 - Cross section view of longitudinal T-section glulam deck panels with curb rail.

steel hardware and did not affect preservative penetration or retention in the wood. The installation of hardware before shipping to the treating facility allowed the finished bridge to be installed with no further fabrication or assembly on the part of the bridge owner.

Installation - Installation of the bridge deck panels has been accomplished by using a tracked backhoe to unload the bridge panels from a truck, carry them to the stream bank, and set them in place. A chain was placed through the lifting eyes on the bridge panel and secured in a hook on the bucket of the backhoe to lift and carry the panel. The bridge panels were placed on a mud sill sitting directly on the stream banks. It was not necessary to operate any equipment in the stream or disturb the stream channel during the installation. Clearing the stream banks and placing the bridge panels was completed in approximately 2.5 hours. After the panels were in place, wire ropes were secured to the chain loops at each of the bridge corners and to nearby trees. This securing of the bridge required an additional hour. Removal of the bridge was accomplished in a manner similar to the installation.

Cost - Cost for the materials, fabrication, treating, and shipping of the glulambridge was $17,000. Based on a deck area of 44.6 m^2 (480 ft^2), the cost was approximately \$381/m^2 (\$35/ft^2). The cost for the mud sills was $600. At the first installation of the bridge, the cost for labor and equipment to install and remove the bridge was approximately $3,360. Therefore, the projected total cost to install and remove the bridge at 10 different sites is approximately $33,600. When this is added to the initial cost of the bridge and mud sill, the total cost to install the bridge at 10 sites is $51,200 or $5,120 per site.

Petrformance -- The monitoring plans for the bridge called for stiffness testing of the individual lumber laminations prior to the fabrication of the deck panels and the completed bridge panels after fabrication. These tests were designed to evaluate the amount of composite behavior achieved in the double-tee cross section. In addition, static load test behavior and general bridge condition were assessed. Taylor and Ritter (1996) provided a more detailed discussion of the test procedures and bridge evaluation results.

The performance monitoring of the bridge is still in its initial stages; however, data on the initial bridge performance are promising. Using bending test data, the modulus of elasticity (MOE) values of the two finished bridge deck panels were 16,341 MPa ($2.370x10^6$ psi) and 15,845 MPa ($2.298x10^6$ psi) for Panels 1 and 2, respectively. Based on the force-deflection plots from these tests, the deck panels appeared to exhibit linear elastic behavior. Predicted values of MOE's, based on a transformed section analysis using actual lumber MOE data, were 17,686 MPa ($2.565xl0^6$ psi) and 17,252 MPa ($2.502xl0^6$psi), for Panels 1 and 2, respectively. Since the actual panel MOE's were approximately 92% of the predicted values, it appears that the finished deck panels achieved 92% composite behavior. However, test conditions where the overhanging flange supported the bridge deck panel, may have resulted in a loss in apparent stiffness of the deck panels. Further tests will help determine how much stiffness was lost due to shear lag at the supports, and in turn will help refine the evaluation of composite behavior. In load tests of the bridge under a tandem axle dump truck when the wheel lines were placed over the centerline of the panel, the maximum deflections corresponded to a value of approximately L/975, at 55% of design bending moment. Since this deflection is comparable to that currently recommended by AASHTO for highway bridges, stiffness requirements may be relaxed for similar portable bridges designed in the future.

The first installation of the bridge was easily accomplished with the use of the backhoe. There were no impacts on water quality during the installation since no equipment disturbed the stream channel. Slight damage to the the tension lamination of one of the webs ocurred during installation; however, this did not appear to reduce the structural adequacy of the bridge. The small amount of overall damage may be attributed to the use of the lifting eyes, which eliminated the need for the-construction crew to wrap chains or cables around any exposed wood surfaces.

Summary and Conclusions

Recent interest in portable bridge systems has increased due to heightened awareness for reducing environmental impacts at road stream crossings. Many of the advantages of timber bridges make them attractive for use as portable bridges. In particular, longitudinal deck timber bridges can be quickly and easily installed without adverse impacts on the stream. Based on testing of the three portable longitudinal glulam bridges discussed here, the following specific conclusions can be made at this time:

1. It is feasible and practical to construct portable timber bridges.

2. Installation of the bridges was easily accomplished using common construction or forestry equipment. Because there was no disturbance of the stream channel or stream banks, there were no water quality impacts during construction activities. Installation times ranged from one hour to 6 hours.

3. The longitudinal glulam deck designs discussed here were cost effective for the applications noted. The projected total costs (including the initial costs and installation and removal costs) of the bridges if they were used at 10 different sites ranged from $965 to $5,120 per site, which is competitive with other traditional stream crossing structures on similar size streams.

4. For longer span portable bridges, the T-section glulam deck is a promising bridge alternative. Test results indicated that the double-tee glulam panels exhibited linear elastic behavior and they achieved at least 92% composite behavior.

5. Results from load tests indicated that all bridges exhibited acceptable levels of deflection even though they were greater than that currently recommended for highway bridges.

6. Minor damage to the bridge components has occurred during installation and removal activities. However, the damage apparently has not reduced the structural adequacy of the bridge components.

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