Timber Bridges: Background, Attributes, National Direction, and Stressed Timber

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The interest in, and momentum for use of, timber bridges has been growing in the last few years and is expected to mushroom in the near future. This trend effectively reverses the declining trend of the last four decades. Why all the sudden interest? There are four broad reasons, termed driving forces, that are generating the interest. These driving forces are (a) economic development (especially rural), (b) awareness, (c) need, and (d) the new stressed timber concept. All of these driving forces are examined and the concept of stressed timber for bridges is expanded. The U.S. Congress appropriated $3.35 million to continue research on stressed timber bridges and construct 80 demonstration bridges across the nation in 1989. That funding level was maintained in 1990. Stressed timber is catching the eye of innovative bridge engineers across the United States. The progress of stressed timber and the potential for its increased use and more innovation are greater than ever. Stressed timber is not new; in Ontario, Canada, stressed-timber bridges are more than 10 years old and show outstanding performance characteristics. The process of approving AASHTO standards for stressed-timber bridges has begun.

Historically, timber played an important role in the road, highway, and railroad structures of the United States. The trend decreased in the 1940s when concrete and steel became engineers' materials of choice. Several recent events have brought attention back to timber and its inherent attributes.

Most of the weaknesses of timber have been solved. The potential life of pressure-treated timber bridges easily competes with steel and concrete.

The driving forces that have brought attention back to timber, the opportunities available to the timber industry, the attributes of timber (wood), the timber bridge initiative, and the new concept in timber design—stressed timber—are discussed.

DRIVING FORCES

The driving forces that are generating the revived interest in timber bridges are (a) economic development (especially rural), (b) new awareness, (c) need, and (d) the new stressed timber design concept.

Economic development, particularly rural development and diversity, is much in the mind of the public and its elected representatives. Timber bridges offer an opportunity to use abundant, underutilized, local species and capture the value added through all phases, from stump to bridge, of harvesting, milling, fabrication, and construction. Coupled with this opportunity for increased employment, the installed bridges upgrade the transportation infrastructure, thereby making rural areas more accessible for further economic development. The new stressed timber concept has allowed the use of most local species and local fabrication.

The public also has increased awareness of the properties of wood as a material and its performance when used in engineered structures such as bridges. Wood is such a common material that it has been taken for granted in the past. The general public has a growing awareness, albeit maybe still small, of the attributes of wood and the possibilities of using it to upgrade the deficient transportation system. The public has also been made aware of deficient bridges through the national media's dramatic coverage of bridge collapses, including loss of life.

The awareness of our deficient bridges leads to the third driving force—need. The nation, according to the inventory by the FHWA, has 575,000 bridges. Of these, 242,000 (42 percent) are structurally deficient or functionally obsolete, and are in need of rehabilitation or replacement. Of the nation's bridge inventory, currently 12.6 percent of all bridges are constructed of timber and that percentage has been declining. Timber bridges are predominantly located in the off-federal-aid system and are located on rural and secondary roads. The total number of bridges on rural and secondary roads is 470,000. Of these, 414,000 (88 percent) are 40 ft or less in length. Bridges of this length are ideally suited for timber construction.

The last and main driving force in making timber more attractive is the new concept in design—stressed timber. This topic will be discussed in detail.

OPPORTUNITY

The national need to upgrade deficient bridges can be turned into a greater opportunity for local industry in forest products and stump to participate in bridge fabrication. Stressed timber allows for the use of many underutilized local species.

An average size timber bridge contains approximately 10,000 board feet (bf) in the deck and superstructure. If timber is used for the abutments or substructure, an additional 10,000 bf will be used. Multiplying the amount of timber used in a typical bridge by the number of deficient bridges gives a gross approximation of the maximum potential market of 5 billion bf. Recognizing that all deficient bridges will not be replaced, and that all replaced will not be constructed with wood, an optimistic goal might be 20 percent of the maximum potential.

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Probably a bigger opportunity, although more intangible than markets, is favorable visibility. Timber bridges offer the forestry profession the opportunity to greatly increase its cooperators or network by working with individuals and organizations interested in transportation, in the welfare of people, and in rural communities.

ATTRIBUTES OF WOOD

Properties and attributes of wood become advantages when used in modern timber bridge systems. Wood is easy to fabricate using ordinary hand and power tools that are available in local municipal highway shops. Local crews can do much of the fabrication with cost savings to a local government or owner.

Wood also has a high ratio of strength to weight. In bridge rehabilitations, deteriorated concrete decks can be removed from structurally sound steel or concrete stringers and replaced with timber decks. When old HS–15 designed bridges need upgrading to highway design HS–20 loads, a timber replacement deck may reduce the dead load enough to allow the high live load carrying capacity. Timber weight density is approximately ⅓ that of concrete. The weight savings gained by using wood can allow for use of existing abutments to achieve greater weight limits on existing or rehabilitated structures.

Another major attribute of wood is its immunity to deicing salts. This property is one of the main reasons why timber bridges have long life expectancies and low maintenance costs.

Other properties of wood that contribute to timber bridge attractiveness are the excellent fire performance of large timbers, the high degree of sound and thermal insulation provided, and the high impact resistance. AASHTO requires no reduction in strength for impact on timber bridges. The warmth and beauty of wood are evident in timber bridges, and the slim profile of modern designs are aesthetically pleasing and blend into many rural and local settings.

TIMBER BRIDGE INITIATIVE

In 1989, the U.S. Forest Service funded construction of stressed timber bridges as follows: five in the eastern region, three in the southern region, two in the northern region, and one in the Pacific coast region.

Congress funded $3.35 million to do research, set up a Timber Bridge Information Resource Center, and construct demonstration timber bridges outside of national forest lands. The 1989 Congressional appropriation was divided in major programs as follows:

Program	*Amount ($)*
Cost-share demonstration bridges	2,000,000
Research	650,000
Technology transfer	700,000

Seventy-nine timber bridges, 60 of which use the stressed-timber concept, were selected and constructed in the spring of 1989 through fall of 1990. The bridges ranged from slab decks, through stressed T-sections and boxed girders. Many species of wood were used, both hardwoods (elm, red oak, black oak, yellow poplar, and maple) and softwoods (ponderosa pine, red pine, douglas fir, and lodgepole pine).

The funds for demonstration bridges were increased by $5.5 million through matching funds from local and state governments. These funds allowed bridge projects in 30 states across the nation. The demonstration bridges were picked for visibility. Visibility is often increased by the project being done in conjunction with major conferences. The designs were typically innovative designs. Many will be monitored to develop performance data. Information on performance will be presented to AASHTO to gain approval for these innovative designs. AASHTO approval is necessary if federal funds from the FHWA are to be expended in future installations. Also, many state transportation departments require AASHTO-approved designs if state funds are to be expended for county or local installations.

Again in 1990, Congress funded $3.35 million to do research, continue the technology transfer program through the Morgantown, West Virginia, Timber Bridge Information Center (TBIRC), and construct demonstration timber bridges outside of national forest lands.

TIMBER BRIDGE CONFERENCES

There have been many timber bridge conferences held to date: one in 1986 in Oregon; two in 1987, in Pennsylvania and in Colorado; two in 1988, in West Virginia and in Wisconsin; and several in 1989 in Idaho, Vermont, Michigan, and Alabama, with several more held in 1990. Attendance at each of the conferences was near 150 participants. The Forest Service's northwest region and representatives of industry held training sessions in Oregon, Pennsylvania, Ohio, West Virginia, and Wisconsin in 1988 and 1989. A number of other states and Forest Service regions have requested timber bridge conferences as well, and are planning follow-up technical training sessions.

TRB, AASHTO, AND NFPA TIMBER BRIDGE COMMITTEE PROGRESS

The AASHTO standards exist for rough-sawn and glulam bridges. The Forest Service, in cooperation with the University of Wisconsin and West Virginia University, is currently writing AASHTO specifications for stressed timber. AASHTO is rewriting all bridge specifications into load resistance factor design (LRFD) through TRB and NCHRP. The NCHRP Timber Bridge Technical Committee has been commissioned to write the LRFD specifications within 3 years. A rough draft of those specifications was completed in 1990. The stressed-timber concept was included in that writing.

The AASHTO Timber Bridge Technical Committee had excellent meetings in 1988 and 1989, with presentations by Michael Oliva of the University of Wisconsin, Hota V. S. GangaRao of the West Virginia University, Ralph Mozingo of Pennsylvania State University, and David Pollard of the National Forest Products Associations (NFPA). Strategies have been set to present specifications for stressed slab decks, T-sections, and parallel-chord and boxed-girder structures.

The timber industry in the United States has been disjointed in the past, so the NFPA established a timber bridge task force that has started to coordinate national efforts in the timber bridge arena. This task force will help the AASHTO Timber Bridge Technical Committee staff write specifications and do public relations for timber bridges. The task force is made up of experts from industry, academia, and government.

The Forest Service published a book, *Timber Bridges—Design, Construction, Inspection, and Maintenance*. This excellent book will offer guidance to the practicing engineer for designing all types of timber bridges. It is deficient on design of stressed-timber bridges. Hota GangaRao of West Virginia University and the Forest Products Laboratory is working on specifications for stressed-timber bridges, slab decks, T-sections, and boxed girders to supplement the book.

The timber bridge technical committees are seeking greater involvement from the ASCE, TRB, AASHTO, and NFPA. ASCE has selected Paul Nicholas of Trus-Joist Corporation as chairman of the Timber Bridge Committee. Don Flemming of the Minnesota Department of Transportation has been doing an excellent job for the AASHTO Timber Bridge Technical Committee. The TRB timber bridge subcommittee met for the first time at the January 1988 TRB meeting in Washington, D.C. Papers were given by Mike Oliva, University of Wisconsin; Mike Ritter, U.S. Forest Service; and Ken Johnson, Wheeler Consolidated, Inc. Weller presented a paper at the January 1989 TRB meeting of the Structures Committee, which is concerned with current technologies in timber bridges. As mentioned, the NFPA Timber Bridge Task Force has recently become a driving force in timber bridges, and will be expected to provide continued leadership in the technology transfer arena. Tom Williamson of the American Institute of Timber Construction chairs that task force.

STRESSED-TIMBER BRIDGES

Description

Stressed-timber bridge superstructures consist of timber planks of varying lengths, longitudinally laminated on edge, butt jointed to allow for short members, and transversely stressed with high-tension stressing rods (150 ksi) to achieve an orthotropic slab, T-section, boxed-girder, or parallel-chord structure. These structures can be used for buildings as well as the bridges for which the concept was conceived.

History

Csagoly and Taylor of the Ontario, Canada, Ministry of Transportation and Communication (MTC), conceived the concept when trying to rehabilitate delaminated nail-laminated timber decks. The MTC researched the subject extensively. In 1984, the time was ripe to incorporate and expand the stressed-timber concept in the United States. The Forest Service performed additional research through the Forest Products Laboratory in Wisconsin and through the University of Wisconsin. The first bridge fabricating company to investigate and incorporate stressed-timber bridges in the United States was Wheeler Consolidated, Inc. Research in the United States has been done at Pennsylvania State University, West Virginia University, Colorado State University, and several other universities.

Concept and Existing Bridges

Stressed-wood bridges compare with the glue-laminated wood bridges that are fabricated into panels of 4-ft widths and jointed in the field with spreader beams or close-fitted dowels. Stressed-wood bridges can also be compared to reinforced, stressed-concrete structures. Total composite action is achieved through the stressing process, which is not easily achieved with glue-laminated wood panels. The composite action is achieved through the high friction forces created between the laminates under stress. Of the many stressed-timber bridges in the United States, configurations such as slab decks, parallel chord, T-sections, and boxed girders exist. Composite action has been achieved with all of these configurations.

As part of the national timber bridge conferences at Pennsylvania State and Colorado State Universities, Wheeler Consolidated, Inc., of St. Louis Park, Minnesota, constructed two stressed-timber slab decks. In addition, the state of West Virginia and West Virginia University have constructed, and are monitoring the performance of, a stressed T-section timber bridge in which they used hardwoods (red oak) for decking. West Virginia Department of Transportation has used GangaRao's designs for slab decks, T-sections, and boxed girders for over 30 bridges. Continued monitoring is being done. The Forest Service, as part of its service-wide technology transfer plan involving coordination with the U.S. Department of Agriculture, FHWA, NFPA, states, and universities, is continuing to collect data and evaluate the performance of many of the 100 timber (mostly stressed-timber) bridges that were part of the timber bridge initiative.

On the 16-in.-deep, 46-ft-span Pennsylvania State University bridge shown in Figure 1, the relaxation in the stressing rods stabilized within 2 months and the bridge is performing well. No cracks exist in the 2- to 3-in. asphalt wearing surface. Ralph Mozingo of Pennsylvania State University designed and constructed the prototype reinforced stressed structure that he feels can make the bridge less limber while decreasing the slab thickness, thus reducing costs. The Colorado State University bridge is a 40-ft span with 4- by 14-in. laminae.

Both for the Pennsylvania State and Colorado State bridges, Wheeler Consolidated, Inc., used 8-, 12-, 16-, and 20-ft-long planks. The design requires three of four laminae to be continuous at any point. Some bridge engineers question whether the bridge is stiff enough. The deflection on these two bridges is about 1 in. with one highway load truck (or 1 in 600 stiffness). These bridges are two laned so deflection is 1 in 360 if both lanes are loaded (the odds of which are very low).

The Forest Service is exploring the use of parallel-chord trusses to increase longitudinal stiffness. At the University of Wisconsin at Madison, Mike Oliva, in cooperation with the Forest Service's Forest Products Laboratory, has been testing many configurations of the stressing rods. The individual trusses are made of 4-in. by 6- to 12-in. chord members of the 12-, 16-, and 20-ft lengths, and the webs are 4- by 12-in. by 4-ft blocks on 8-ft centers. The chords are connected to the web with ⅜-in.-wide by 18-in.-long dowel spikes. (These mechan-

FIGURE 1 Trout Creek Bridge, College Township, Pennsylvania.

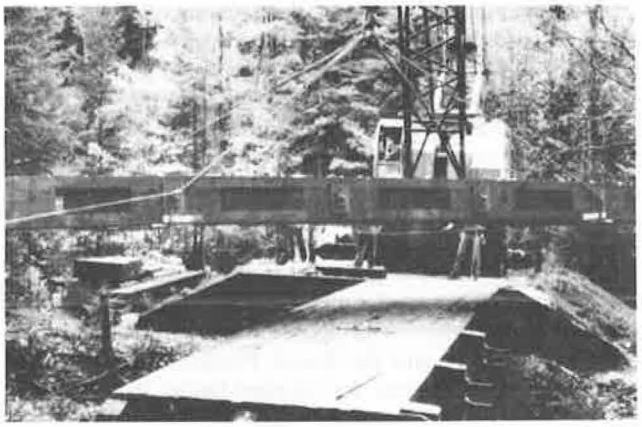

FIGURE 2 Parallel-chord stressed-timber bridge, Hiawatha National Forest, Michigan.

ical connections highly reduce the effectiveness of composite action achievable with stressed timber, and alternate solutions are being evaluated.)

The Forest Service constructed a 40-ft span demonstration bridge (shown under construction in Figure 2). Wheeler Consolidated, Inc., constructed the bridge superstructure in two panels and delivered them to the site for a simple field installation of 3 hr by novice Forest Service employees.

The Chequamegon National Forest also installed a two-span, 36-ft-long, continuous 8-in.-deep stressed slab deck on existing abutments and piers. The Forest Products Laboratory should be able to evaluate potential composite action. This continuous slab will help increase longitudinal stiffness while reducing deflection.

The Forest Service's northern region constructed a 30-ft span stressed microlam slab deck on the Idaho Panhandle National Forest. Trus-Joist has designed the stressed microlam superstructure similar to T-section concrete panels. These panels can be shop fabricated for simple field installation. Figure 3 shows the profile and cross-section views of the stressed

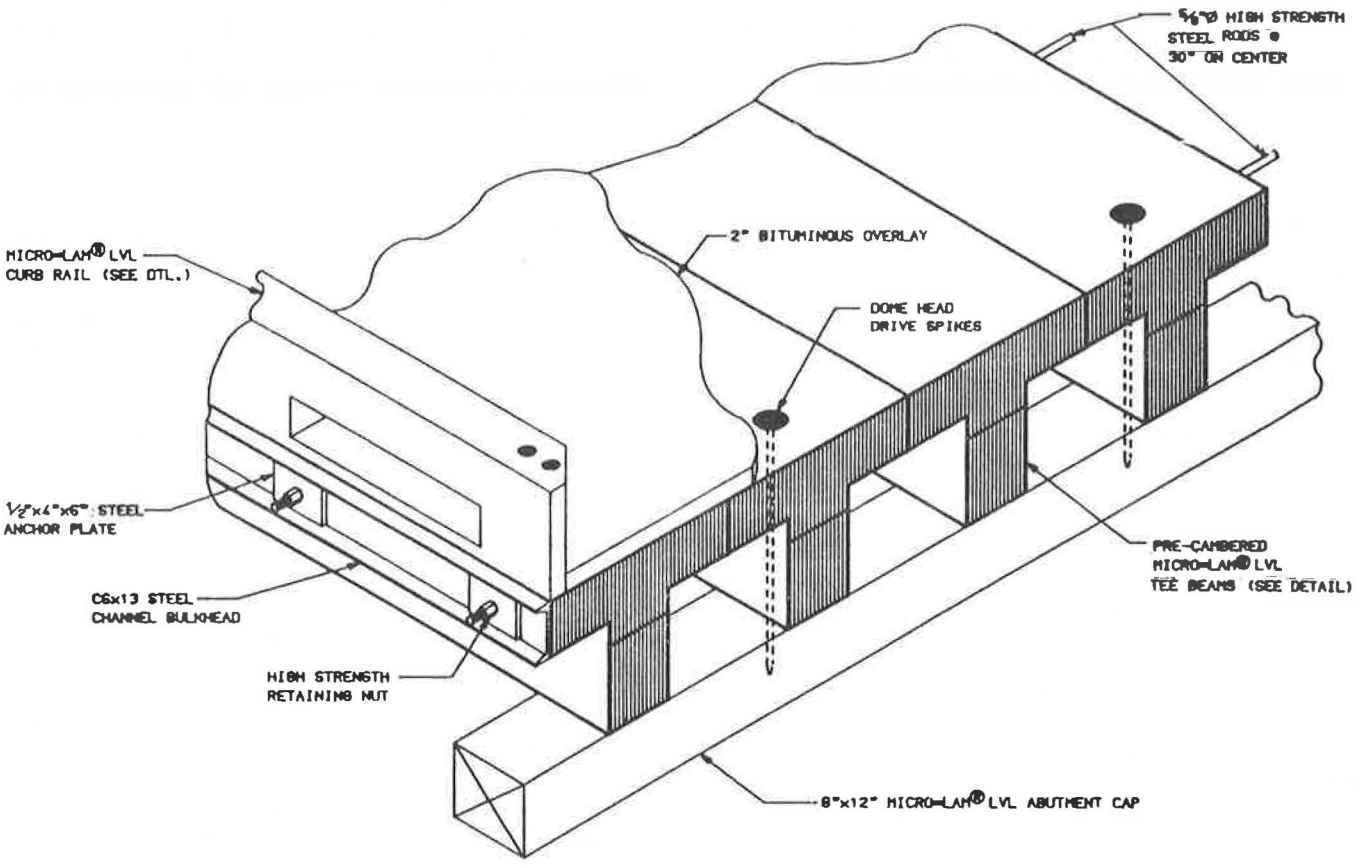

FIGURE 3 Pictorial view of bridge components.

microlaminated T-section design. A demonstration project of the stressed T-section laminated veneer lumber was constructed in Idaho as part of the Timber Bridge Conference in 1989, the bridge was 47 ft long with a 41-degree skew.

The state of West Virginia constructed a T-section stressed-timber bridge as part of the May 1988 Timber Bridge Conference. The red oak decking is stressed integrally with the laminated veneer lumber stringers that are 6 by 42 in. in cross section. The red oak deck laminates are 2 by 9 in. Load tests on the bridge indicate that this composite action is achieved in the field. Deflections from a recent load test show less than ½ in. with a 26-ton HS–20 load on the bridge. Longitudinal stiffness is about L/900 with an HS–20 load. A photograph of the 73-ft span bridge is shown in Figure 4. The results were predicted by the research at West Virginia University conducted by Hota V. S. GangaRao. Total composite action between the deck and stringers was achieved. The research was done in a 16-ft inverted W section using 2- by 6-in. red oak decking and 3- by 16-in. laminated veneer lumber stringers. Additional research was accomplished on a bulbed T-section (Figure 5). The bulbed T-section allows greater longitudinal stiffness and visual inspection of the underside of the superstructure.

FIGURE 4 Charleston, West Virginia, stressed T-section timber bridge, 73-ft span.

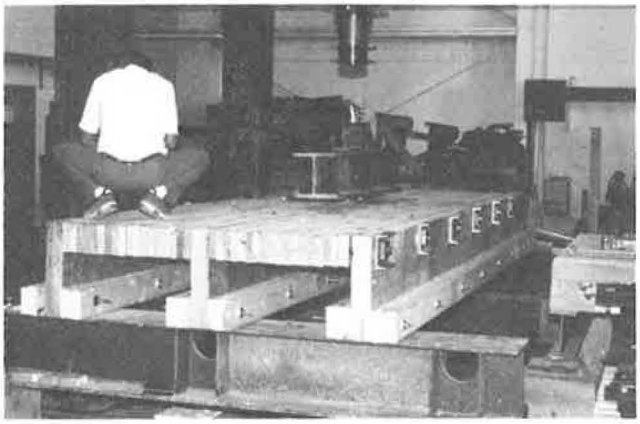

FIGURE 5 Stressed bulbed T-section model at West Virginia University, 16-ft span with 2- by 6-in. decking and 3- by 16-in. stringers.

West Virginia University has researched a stressed boxed girder that exhibits longitudinal stiffnesses three times those of the stressed T-section. (This result is easily predictable by calculating relative moments of inertia.) The laboratory study was performed on the section shown in Figure 6. West Virginia Department of Transportation has constructed six GangaRao-designed, stressed, boxed-girder bridges, and deflections as predicted in the laboratory have been observed. One of the first prototype stressed, boxed-girder systems was the Field Crest Bridge near Morgantown, West Virginia (see Figure 7). Figure 8 shows the two prefabricated boxed-girder panels of the Field Crest Bridge being placed on the abutments.

In 1989, Wheeler Consolidated, Inc., constructed a continuous 150-ft stressed deck over three spans and plans another bridge with a 200-ft continuous stressed deck over several spans in the Dakotas. The 150-ft deck was constructed on the road by the bridge site and launched over the abutments and piers (Figure 9). Composite action was accomplished with the steel girders. Drilled recessed holes in the deck were grouted to studs welded to the girders' wide flanges. The deck was then stressed further, ensuring the composite action. The deck of the continuous stressed deck picturing the grouted, drilled

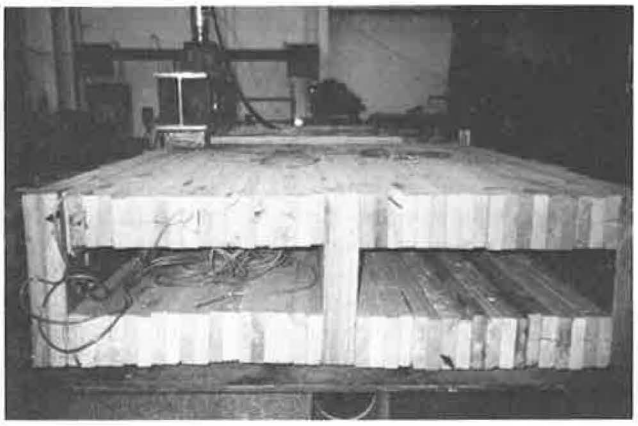

FIGURE 6 Stressed boxed-girder model at West Virginia University, 16-ft span with 2- by 6-in. top and bottom flanges with 3- by 16-in. webs, which are continuous through the top and bottom flanges.

FIGURE 7 Stressed boxed-girder timber of Field Crest Bridge, Morgantown, West Virginia.

FIGURE 8 Prefabricated, stressed, boxed-girder bridge panels being lifted onto abutments at Field Crest Bridge, Morgantown, West Virginia.

recessed holes for composite action on the steel stringers is shown in Figure 10.

In all, the United States now has more than 100 stressed-timber bridges, as compared to just 5 years ago when it had none.

CONCLUSION

In summary, timber bridges have been revived in the United States. Stressed timber can reduce the historical deficiencies of wood for building bridges. Stressed timber is less sensitive to moisture, decay, and joints. The composite action displayed by stressed timber tremendously increases load distribution and load-carrying capabilities of wood bridges.

Stressed timber plus other traditional designs will help fill the need for bridge replacements for the 240,000 deficient bridges in the United States and for other countries with similar bridge problems.

FIGURE 9 Continuous 150-ft stressed deck being readied to be launched or skidded onto the steel stringers.

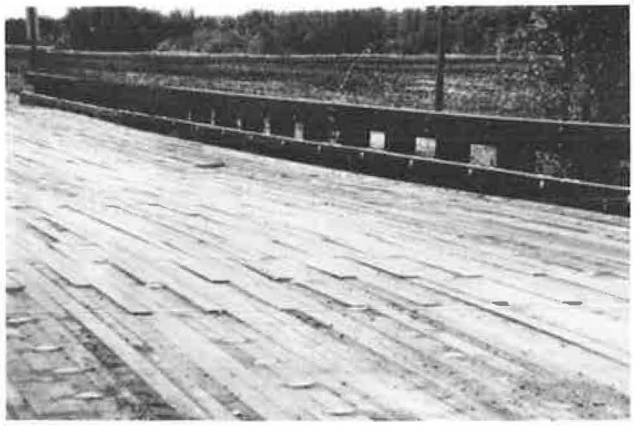

FIGURE 10 Deck with grouted, drilled recessed holes for composite action on a continuous 150-ft stressed-timber deck bridge.