Engineered Timber Systems for Short-Span Bridges

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Statistics reveal a large number of short-span bridges in this country, many of which are, or soon will be, in need of replacement. Timber has traditionally been used as a low-cost building material for short-span bridges on low-volume roads. With the development of superhighways during the past 3 or 4 decades, timber use in bridge construction has declined. Timber has good strength characteristics as well as being resistant to impact loading and damage from road salts. Proper preservative treatment can make wood a durable, long-term building material. Development of engineered timber products and systems has made modern timber bridges practical, reliable, and often the lowest-cost alternative. Products such as glued laminated beams and panels, laminated veneer lumber, and stressed deck systems have increased durability and feasible span lengths. Experience on USDA Forest Service roads has shown that the costs of timber bridges are consistently competitive for shorter spans, up to 30 ft, particularly on low-volume roads. Timber should be considered as a viable building material for many of the nation's deteriorating bridges.

Current figures, based on FHWA's January 1989 Coding Guide for the National Inventory of Bridges, show 225,462 substandard bridges in this country. These bridges are deficient for either structural or functional reasons; 140,552 of these bridges are under city, county, or township jurisdiction. Approximately 100,000 of these bridges are short-span bridges on low-volume roads (*1*). Adding federally owned bridges would push the low-volume-road short-span bridge total to more than 120,000 bridges. Existing bridge systems must be improved and new economical systems must be developed to meet the growing demand to replace these bridges. The timber bridge is a viable replacement option in many cases.

Timber is particularly suited to short-span bridges, especially spans shorter than 40 ft, and its low weight and simple fabrication make timber an excellent building material for rural, isolated locations. Timber's low modulus of elasticity (in relation to concrete and steel) and the difficulty of attaching a guardrail system often preclude its use on longer-span, high-volume, high-speed locations.

Wood is an adaptable, dependable construction material, which, because of its structural characteristics and widespread availability, has been used in construction for thousands of years. From early stone age time, when man crossed ravines and rivers on fallen logs, until the end of the 19th century, wood was the predominant bridge building material.

Properly designed, constructed, and maintained timber bridges can generally carry heavy loads without material fatigue, can resist the deteriorating action of deicing chemicals, can be constructed by unskilled labor, and will last for long periods of time. The covered bridges built in the 1800s are a part of the nation's heritage. Great timber truss bridges beyond 400 ft in span length and the magnificent railroad trestles of the Rocky Mountains testify to the skill of our early timber bridge designers and builders. There are approximately 1,000 mi of such railroad trestles still in use today in the United States.

Timber was one of man's first building materials. However, as modern 20th-century technology spurred development of new building products such as high-strength steel, aluminum, prestressed concrete, fiberglass, etc., the use of timber dropped. Timber is still the predominant building material in residential construction, but for the most part, the use of timber in highway bridge construction has dropped from its peak in the 1940s, to almost nothing in 1985. This drop in timber bridge design and construction has resulted in a shortage of knowledgeable, experienced timber bridge designers just when the United States is experiencing a crisis in the needed replacement of more than 120,000 short-span bridges. Timber should be considered a viable construction material for many of these local short-span bridges. Bridge designers should be informed of the viability of timber as bridge construction material and educated in proper timber design procedures. This is one of the major emphasis areas of the timber bridge initiative being administered by the USDA Forest Service (*2*).

Over 11,000 road bridges are maintained by the Forest Service, of which about 1,600 are located in the Northern Region (Montana and Idaho). Approximately 55 percent of the total has been constructed with timber superstructures (*3*). In the Northern Region, about 1,200 of the 1,600 bridges have been constructed using some type of timber bridge superstructure system. Most of these bridges also have treated timber substructures. The Forest Service designs and constructs 10 to 25 new bridges per year, about two-thirds of which use timber for either the superstructure or substructure.

CHARACTERISTICS OF WOOD

The fibrous nature of wood strongly influences how it is used. Specifically, wood is composed mostly of hollow, elongated, spindle-shaped cells that are arranged parallel to each other along the trunk of a tree. When lumber, or timber, is cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage, as well as grain pattern of the wood. These cellulose cells vary in length from 1 mm for hardwoods to 8 mm for softwoods and comprise about 60 percent of the wood by volume. The thickness of the cell walls is the principal strength-determining characteristic of the wood. These hollow cells are cemented together by a water-soluble material called lignin.

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The water solubility of lignin causes reduced strength properties for wood with higher moisture content.

Wood may be described as an orthotropic material; that is, it has unique and independent strength properties in the direction of three mutually perpendicular axes—longitudinal, radial, and tangential. The longitudinal axis is parallel to the fiber; the radial axis is normal to the growth rings; and the tangential axis is perpendicular to the grain but tangential to the growth rings. The modulus of elasticity of wood in the longitudinal direction is generally 13 to 23 times greater than in either of the other two directions; compressive strength is about 9 times higher in the longitudinal direction than the other two. The ratios are based on testing of clear wood samples (*4*).

Clear wood has a surprisingly low coefficient of variability for strength properties. The coefficient of variability is generally from 20 to 25 percent. Clear defect-free timber has good strength and stiffness characteristics, and is highly predictable, in its longitudinal direction. However, designers and users must be aware of the problems that can develop because of various strength-reducing defects as well as wood's weakness in its other two axes.

Because of its growth process, single-direction strength properties, and susceptibility to moisture-induced strength reduction, wood has some inherent weaknesses. Knots, slope of grain, and high moisture content can substantially reduce both its strength and stiffness.

A knot is that portion of a branch that has grown into the trunk of the tree. A knot interrupts the grain continuity and changes the direction of the wood fibers. The strength properties are reduced because the clear wood is displaced by the knot and the fibers around the knot are distorted, causing cross grain. Knots have a greater effect on strength in axial tension and bending than in axial compression.

Sloped grain causes lines of stress to be only partially in the longitudinal fiber direction, thereby reducing strength properties. Moisture causes a reduction in the cementing strength of the lignin, which holds the cells together. Other localized defects such as pitch pockets and rot, along with knots, slope of grain, and moisture, will also reduce the strength properties. Moisture contents in excess of 19 percent, in most sawn-lumber species, or 16 percent, in glued laminated lumber, cause reductions in allowable design values.

The quantity and location of defects are limited by timber grading, but there is no feasible way to eliminate all defects in large sawn timber members. The presence of defects can substantially increase the coefficient of variability, and therefore reduce the allowable design values. The design values published by the National Forest Products Association (NFPA) are based on computations that use the strength levels of clear green wood provided by the Forest Products Laboratory. The ASTM methods used predict strength levels that are expected to be exceeded by 95 percent of clear wood tested. Standard ASTM reductions are made from these clear wood values to account for safety and duration of load. For individual grades, the resulting values are further reduced, in accordance with ASTM standards, to reflect the predicted effect of knots or other differences from clear wood permitted by each grade classification. This basically means that clear green wood strength properties, which are met by 95 percent of the samples, are reduced by a factor of 2.1 as a factor of safety and to account for duration of load. Further reductions are made in grading to account for defects. Higher moisture content further reduces allowable design values. Timber graded as "select structural" (SS) is basically defect free. This quality of material is becoming difficult to find and therefore expensive (*5*). Table 1 shows NFPA design values for Douglas fir structural joists and planks.

More precise and therefore higher design values for any particular single-member design may be obtained by using machine-stress-rated lumber. Machine-stress-rated lumber is actually tested to determine its modulus of elasticity. The remaining strength properties are then established by predetermined relationships between the modulus of elasticity and other strength properties.

PRESERVATIVE TREATMENT

A major problem encountered by users of timber throughout history has been premature deterioration of the wood because of fungal decay. In nature, wood decay is inevitable. If this were not the case, the forests would soon be cluttered with the remains of dead trees.

Fungal decay depends on adequate moisture content. The moisture content at which most species of wood will begin to decay is about 30 percent (or the fiber saturation point). Keeping bridges dry is seldom feasible. Many covered bridges were built in this country during colonial times. A waterproof roof structure was built over the bridge to keep it dry. These bridges were durable as long as the roofs were maintained. Generally, such bridges are no longer economically practical.

John Levy, a leading expert in preservative treatment at the Imperial College of Science and Technology in London, observed that "as far as the fungus is concerned, wood consists of a large number of conveniently oriented holes surrounded by food." Simply stated, preservative treatment is the addition of chemicals to the wood to make this "fungus food" toxic to the fungi.

Preserving wood through the application of chemicals is not new. Oils, tars, and pitches have been used by builders for thousands of years. Widespread use of preservative treatment developed with the expansion of the railway systems in Europe and this country during the 19th century. Preservative treatment creates a protective shell or envelope around the wood. This envelope of toxic material prevents the fungi from getting to the edible wood. Treatment with the proper preservative and process dramatically increases the useful life of wood exposed to the elements. The most effective means of applying the preservative chemical is with a pressure system, hence the term "pressure treatment." Proper pressure treatment will

TABLE 1 NFPA DESIGN VALUES FOR DOUGLAS FIR STRUCTURAL JOISTS AND PLANKS

Grade	Extreme Fiber Stress in Bending, F_b (psi)	Tension Parallel to Grain, F_t (psi)	Modulus of Elasticity, E (psi)
Select structural	1,800	1,200	1.8×10^6
No. 1/appearance	1,500	1,000	1.8×10^6
No. 2	1,250	650	1.7×10^6
No. 3/stud	725	375	1.5×10^6

generally increase the life of a timber product or structure by 5 to 10 times (*6*).

The effect of pressure treatment can be totally negated if the protective shell or envelope is broken. Therefore, wood should be completely fabricated before being treated, and drilling, cutting, or driving nails into treated wood should be avoided.

ENGINEERED TIMBER

In the past, there seemed to be a never-ending supply of high-quality, relatively defect-free timber. Economical design and use of timber seemed to be of minor importance. Today, although wood is a renewable resource, the sizes and quality of available timber are not what they used to be. In addition, the ever-increasing cost of construction products dictates more attention to efficient use of all structural materials, including wood. These circumstances necessitate better engineering design of wood structures.

Glulams

In the 1940s, the concept of gluing small select pieces of wood together to create a large structural timber was developed. These engineered structural timbers are generally referred to as "structural glued-laminated timbers" or "glulams."

Glulams are any members made from two or more layers of wood glued together with the grain of all layers approximately parallel. The laminations may vary as to species, number, size, shape, and thickness. The individual laminations cannot exceed 2 in. in thickness and are typically made from nominal 1- or 2-in. sawn lumber. Glulam timber is an engineered, machine-stress-rated product of a timber laminating plant, made of selected and prepared wood laminations glued together with waterproof adhesives.

An engineered timber product like glulam has many advantages over solid sawn timber. Smaller, easier-to-find, less-expensive pieces of wood are used. Large defects are totally removed and smaller defects are dispersed once they are combined into a larger structural unit. The effect of dispersing defects is illustrated by the reduction in the coefficient of variability for multiple laminate members. The coefficient of variability has been found to be 0.25 for 1 Douglas fir lamination, 0.15 for 4 laminations, 0.10 for 10 laminations and 0.08 for 16 laminations (*7*). Lower coefficients of variability result in more predictable, and therefore, higher allowable design values.

Lower-quality (and lower-cost) timber can be used in the low-stress areas of glulam beams, usually the center area near the neutral axis. This increases the efficiency of the timber usage and further lowers material costs.

Individual laminations can be finger-jointed with very little strength reduction, allowing fabrication of beams whose length is limited only by fabrication equipment, storage, and shipping.

Air-drying bridge timbers thicker than 2 in. requires 6 to 12 months—more time than lumber merchants can justify, because of high inventory costs. Even then, drying large timbers often causes excessive warping and checking. Kiln-drying is not practical for timbers more than 2 in. thick. Because glulams are made from nominal 1- or 2-in. laminations, air- or kiln-drying is practical and warpage can be controlled.

Glulams can be manufactured into many configurations, including curved girders and arches, giving bridge designers a wide selection of structural shapes with which to work. Glulam components are prefabricated at the laminating plant reducing field construction time. The efficiency of prefabrication usually saves money.

Laminated-Veneer Lumber

Laminated-veneer lumber (LVL) is a member of a larger group of wood-based composite lumber products called structural composite lumber (SCL). SCL is a composite of wood elements such as veneer sheets, wood strands or strips, and combinations thereof. The wood elements are glued with a waterproof adhesive to create a wide variety of products.

Laminated veneer lumber is made from thin sheets of wood glued together. Although LVL looks like plywood in cross section, it is structurally different. Plywood is cross laminated, with the grain of each layer running perpendicular to that of adjacent layers. In veneer lumber, the grain runs parallel in all of the layers. This produces a material that is extremely strong and reliable when a load is applied parallel to the grain. It is so reliable, in fact, that is was originally used to make airplane propellers during World War II.

As with glulams, LVL allows conversion of smaller-diameter, relatively low-grade logs into a wider and longer dimension of products. Veneers are not sawn pieces of lumber like the laminations used in glulams. Veneers are actually peeled from the circumference of the log. LVL uses the same wood in the log as solid-sawn, but the process of producing the wood elements and regluing them disperses the strength-reducing solid-wood characteristics even more so than for glulams. Because veneer lumber is made of overlapping ⅒- or ⅛-in.-thick layers of veneer, any defects that might have existed in the original wood are widely dispersed.

Solid sawn lumber may have knots, splits, or grain defects that go clear through the member. Glulams may have ¾- or 1½-in.-deep defects, but laminated veneer lumber will only have defects that are ⅒ or ⅛ in. deep. The result is a finished product that is more uniform in quality, lower in variability, and therefore has more predictable and higher allowable design values. Laminated-veneer beams can theoretically be manufactured to any length. Current machinery, storage, and shipping limit the beam length to about 80 ft. The increased strength and predictability, combined with the unique sections that can be fabricated give the bridge designer much greater flexibility than has been available in the past. Structurally efficient I, tee, or box beam sections can be fabricated (*8*).

The process used to peel the veneers creates access for preservative penetration that is much better than that for solid wood or glulams. The veneer peeling process creates minute cracks perpendicular to the wood grain. The minute cracks (lathe checks) do not damage the wood fibers, but they allow excellent preservative penetration. Essentially, LVL allows full penetration of preservative treatment. Table 2 shows how design values are increased by the use of multiple pieces of wood, as in glulams or LVL.

TABLE 2 INCREASED DESIGN VALUES BY USING MULTIPLE PIECES OF WOOD AS IN GLULAMS OR LVL

Timber Type	Extreme Fiber Stress in Bending, F_b (psi)	Tension Parallel to Grain, F_t (psi)	Modulus of Elasticity, E (psi)
Douglas fir joists and planks			
Select structural grade	1,800	1,200	1.8×10^6
No. 2 grade	1,250	650	1.7×10^6
Douglas fir, glulam panel, Combination Symbol 5			
2 lams	1,800	1,600	2.0×10^6
3 lams	2,100	–	–
4 or more lams	2,400	–	–

TIMBER BRIDGE SYSTEMS IN THE FOREST SERVICE

Log and Solid Sawn-Timber Bridges

The first bridges built by the Forest Service were log superstructures on log crib abutments (Figure 1). Up until about 1945, short-span bridges in the Northern Region of the Forest Service were built almost exclusively of untreated logs. The abutments were log cribs and the superstructures were logs with transverse sawn timber decking. Many bridges constructed between 1945 and 1953 still had log crib abutments, but the beams in the superstructure were solid sawn timbers. Most of the sawn lumber was pressure treated to increase its resistance to decay. The transition from round logs to square sawn lumber made for better fit-up and faster installation.

FIGURE 1 Typical log bridge.

Treated superstructures lasted longer than untreated log crib abutments. In 1953, Forest Service bridge designers began designing and building pressure-treated, sawn-timber abutments to go with the superstructures. The bridges being built in the mid-1960s used beams as large as 12 in. wide by 26 in. deep and spanning up to 40 ft. A typical solid sawn-timber bridge is shown in Figure 2.

Glulam Beam Deck and Panel Bridges

In 1971, the Forest Service began using glulam beams as the main longitudinal load-carrying members in its bridges. Solid sawn beams were still used for the shorter-span bridges (less than 30 ft), but engineered structural members made possible higher allowable design values as well as deeper beams, which in turn made longer spans possible. The glulam beams used in the early 1970s ranged in size from 9 in. wide by 27 in. deep to 11 in. wide by 42 in. deep and spanned from 30 to 55 feet. Engineered timber had opened a whole new span range for timber bridges. These bridges used glulams only as the longitudinal beams. All other components of the bridge were still solid sawn timber.

Glulam beams proved to be so economical that in about 1974, most of the Forest Service stopped using solid sawn beams altogether. Virtually all timber bridges were being built with glulam beams. In 1974, the Forest Service also began using glulam deck panels placed transversely over the glulam beams. The glulam panel decks replaced nail-laminated decks that were constructed from edgewise 2- by 6-in. lumber nailed together. The individual nail-laminated pieces had been pressure treated, but the many nails penetrating the treatment envelope caused premature decay. The nail-laminated deck was also labor intensive at a time when labor costs were accel-

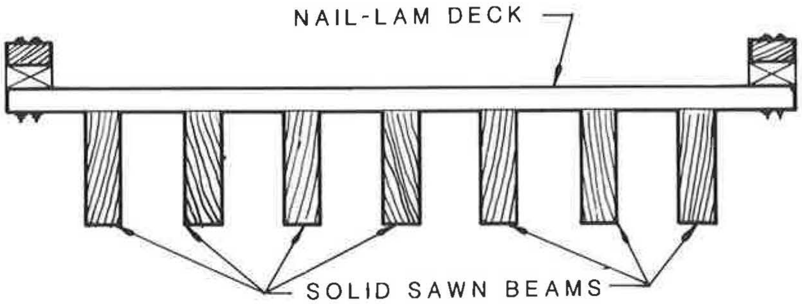

FIGURE 2 Typical solid sawn-timber bridge.

erating rapidly. Since 1974, virtually the entire bridge superstructure of all Forest Service timber bridges has been constructed using glulams. The Forest Service has built between 80 and 100 of these bridges in the Northern Region. The use of standardized components, such as glulam girders and panel deck systems, simplifies design and drafting details, and reduces field labor costs and jobsite construction time.

The panel deck system was originally developed with interconnecting steel dowels between the panels. This system created a very rigid, watertight deck that is still used by several regions of the Forest Service. The primary purpose of the dowels is to prevent differential movement of the deck panels that could cause cracking of a bituminous asphalt overlay. Because most of the bridges to be built in the Northern Region are not overlayed with asphalt, the use of dowels was discontinued in 1978. If a bridge constructed with undowelled deck panels is later paved, a geofabric material is placed between the deck panels and the overlay to reduce cracking.

Several methods of attaching the deck panels to the beams are available. The Forest Service typically nails the deck panels to the beams with 10- or 12-in. ring shank nails. The deck panels are drilled before treating. The beams are then drilled after the deck panels are placed across them. Because drilling breaks the preservative envelope, the holes are filled with liquid preservative before driving the nails. This reestablishes the protective envelope. Other systems, particularly the deck bracket developed by Weyerhaeuser Company, eliminate the need for nailing (Figure 3). This system should provide better durability.

The Forest Service has designed and constructed six glulam beam deck bridges in the last 2 years and the average cost for the superstructures was about $38 per square foot of bridge deck. Span lengths varied from 15 to 35 ft. Figure 4 shows a typical glulam beam deck bridge.

In 1977 Weyerhaeuser Company developed and tested a bridge system consisting of glulam panels set with the laminations vertical and spanning from abutment to abutment. The deck panels ran longitudinally instead of transversely and were designed to support the load without additional longitudinal support members. Transverse beams were placed under the deck panels to distribute the wheel loads to adjacent panels. These distributor beams allow the panels to be designed for less than a full wheel load and prevent the panels from moving independently of each other (*9*). See Figure 5.

This type of bridge has a shallow superstructure that, particularly in flat terrain, can be very desirable. A conventional timber bridge would generally require a roadway elevation several feet higher than a longitudinal glulam panel bridge. The structural inefficiency of the thin solid-slab cross section precludes this system for longer spans. A 10¾-in.-thick glulam panel will span about 25 ft. Using panels thicker than 10¾ in. is seldom cost effective.

The distributor beams developed by Weyerhaeuser Company were glulams. In the Northern Region of the Forest Service, steel channels are used to reduce the cross section of the distributor beams and to make installation easier.

The Forest Service has designed and constructed five longitudinal glulam panel bridges with distributor beams in the last year, and has been pleased with the appearance and ease of installation. The average cost for the superstructures of these bridges was about $36 per square foot of bridge deck. Span lengths varied from 15 to 27 ft. Figure 6 shows a typical longitudinal glulam panel bridge.

The Rocky Mountain Region of the Forest Service has used a similar system, but instead of distributor beams, the wheel loads are distributed by panels dowelled together with steel dowels. The dowel arrangement is similar to what is used on glulam beam deck systems. These bridges require more fabrication because of the dowel holes, and possibly more installation effort to insert the dowels. The final result has a clean look and there is nothing below the bridge to snag debris.

Stressed-Deck Bridges

The Forest Service has developed a slightly hybrid system for some of our temporary bridge needs. Many Forest Service access needs are short term. When the road system is no longer needed, the bridge is removed and the road obliterated. The Forest Service has designed a longitudinal glulam panel bridge that uses transverse bolts in place of distributor beams. The bolts are spaced at approximately 5-ft centers and the nuts are torqued to 200 ft-lb. The dowelling effect of the bolts is not sufficient to fully transfer wheel loads. Tightening the bolts creates friction between the deck panels that helps laterally transfer the wheel loads. Because wood has a tendency to compress when subjected to long-term loads, the panels are designed to fully support a single line of wheel loads. Therefore, the only need for the bolts is to prevent independent movement of the panels. The glulam panels are much lighter than the conventional portable temporary bridges and can generally be installed or removed by a small crew using light equipment. The supply cost of these bridges has been about $27 per square foot of bridge deck. Installation would add about $3 per square foot.

A system using unglued laminations compressed perpendicular to the lamination and the grain was developed in 1976 by the Ontario Ministry of Transportation and Communication in Canada. This system induces high interlaminar friction that, in effect, takes the place of the glue in a glulam. The concept was originally intended as a method for rehabilitating existing nail-laminated decks, but has been extended to new bridge decks as well. The system is similar to a longitudinal glulam panel deck except the individual laminations are held together by a compressive force imposed by posttensioning, high-strength steel rods. The rods are threaded through holes drilled in the center of the laminations at a spacing of 2 to 4.5 ft. These high-strength steel rods are perpendicular to the span direction and tensioned against steel bearing surfaces along the two outside edges of the bridge. When a bridge is fully tensioned, the friction between the individual laminations causes the entire bridge to function as an orthotropic plate.

This system has a number of disadvantages. The steel rods must be installed perpendicular to the laminations, which creates difficulties with any skewed bridge. The ends of the skewed bridge may have to be notched so that bearing plates can be installed. The system reduces prefabrication and generally increases field construction time. The high-strength steel rods and bearing plates are expensive and must be galvanized to protect against corrosion.

Wood has a tendency to compress slowly when subjected to long-term compressive forces. This compression of the wood

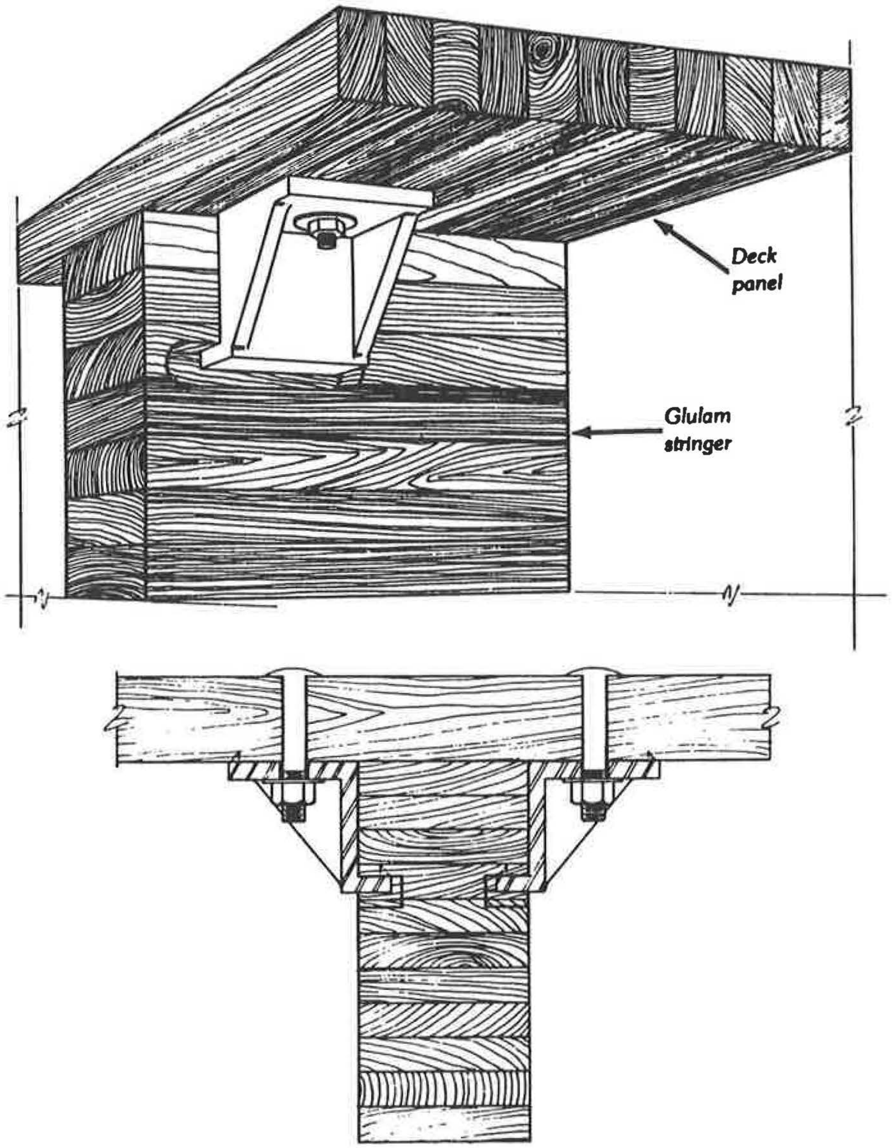

FIGURE 3 Glulam deck bracket.

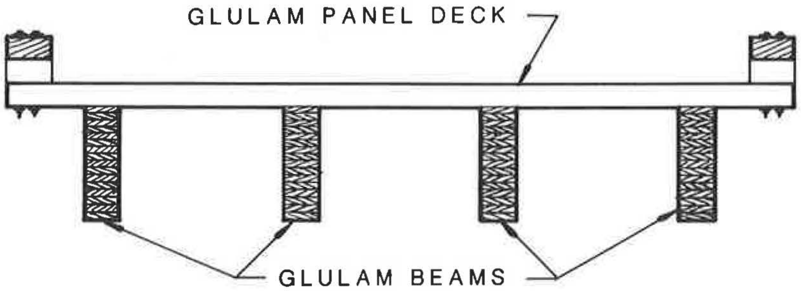

FIGURE 4 Glulam beam deck bridge.

FIGURE 5 Steel distributor beams.

reduces the force in the high-strength steel rods and thereby reduces the friction between the individual laminations. To counteract this effect, the steel rods must be retensioned several times. Testing has shown that the rate of compression decreases with time and most deformation has occurred within 6 months. Figure 7 shows a typical stressed-deck bridge.

Available cost data for 1988 and 1989 indicate that nine stressed-deck bridges were built nationwide by the Forest Service. The average cost for the superstructures of these bridges was about $75 per square foot of bridge deck.

A modification of this technology uses prefabricated LVL sections that are stressed together. The prefabrication reduces field time and cost substantially. Because LVL can be fabricated into a variety of shapes, structurally efficient tee or box sections can be used. The Forest Service has constructed two stressed LVL bridges in the Northern Region. One bridge

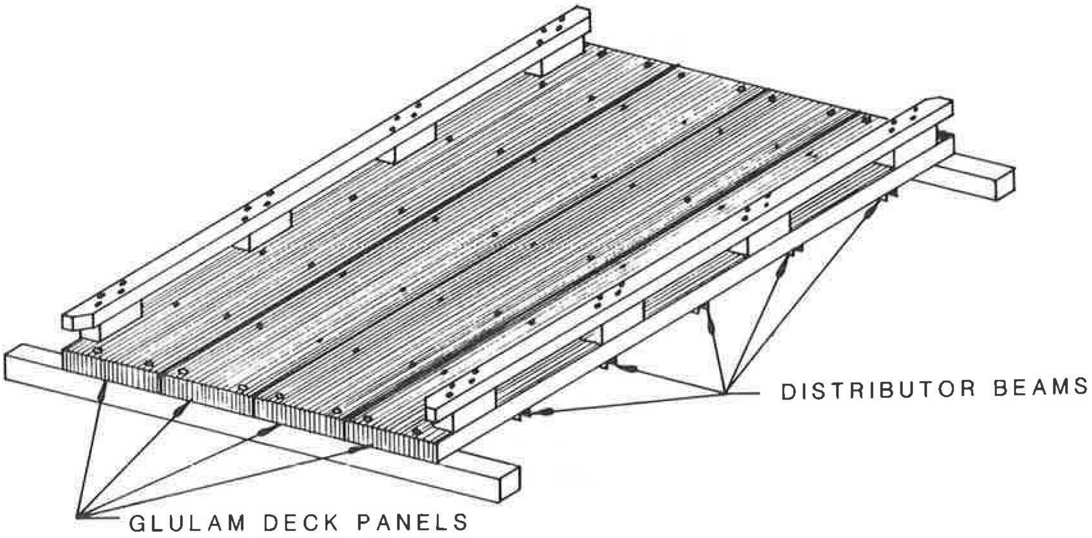

FIGURE 6 Two views of a longitudinal glulam panel bridge.

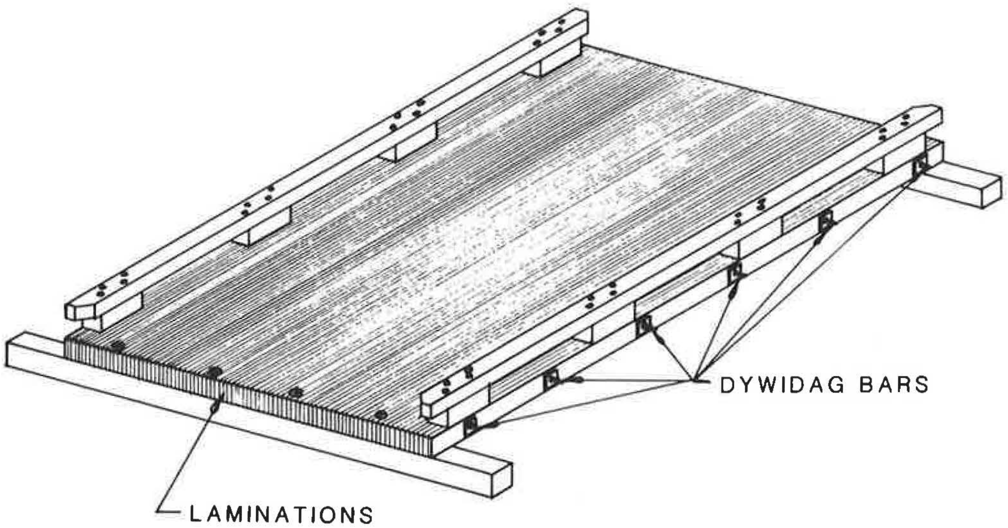

FIGURE 7 Two views of a typical stressed-deck bridge.

was a solid rectangular slab, 30 ft long. The other was a tee section, 38 ft long. Another stressed LVL tee section bridge was constructed in Nevada in 1989. The average cost for the superstructures of these three bridges was about $47 per square foot of bridge deck.

Costs of Concrete Versus Timber

Instead of a detailed comparison of timber versus concrete bridges, the following cost comparisons relate to short-span (less than 60 ft long) bridges in the Northern Region of the Forest Service.

Costs for short-span bridges are site-specific. The most economical 30-ft bridge at one site may be concrete, whereas at another site a 30-ft timber bridge may be preferred. Generally, easily accessible sites near concrete-prestressing plants can be most economically constructed using prestressed multibeam decks. Sites where concrete transportation costs will be high, such as remote rural areas, are often more economical for timber bridges. The lighter weight of timber makes it more easily transportable. The availability of cranes and the work area around the bridge site are also factors affecting the cost comparison. Concrete beams require heavy lifting equipment and an area for the equipment to maneuver. Timber beams and deck panels can often be set in place with a moderately sized backhoe or front-end loader.

Span length is probably the major factor in determining the cost-effectiveness of one bridge material over another. As the span length of a timber bridge increases, the depth of the timber beams or longitudinal glulam panels also increases. Increased material costs result in the cost per square foot increasing faster than the span length.

As the span of a concrete bridge increases, the concrete section used will remain the same throughout a certain span range. As an example, a 27-in.-deep section with three stems (commonly referred to as a "Trideck" beam) is used for spans from 30 to 60 ft. As the span increases, more prestress strands are added. Prestressing strand is relatively inexpensive. Therefore, because of economy of scale, the cost per square foot of a concrete bridge will often decrease as span lengths increase. The cost per square foot of concrete bridges will generally jump at span lengths at which deeper, more massive sections are needed.

Forest Service experience in the Northern Region has been that timber bridges are more economical than concrete bridges up to a span of about 28 ft. Beyond 28 feet, prestressed concrete multibeam bridges are generally more economical (Figure 8). This relationship changes slightly from year to

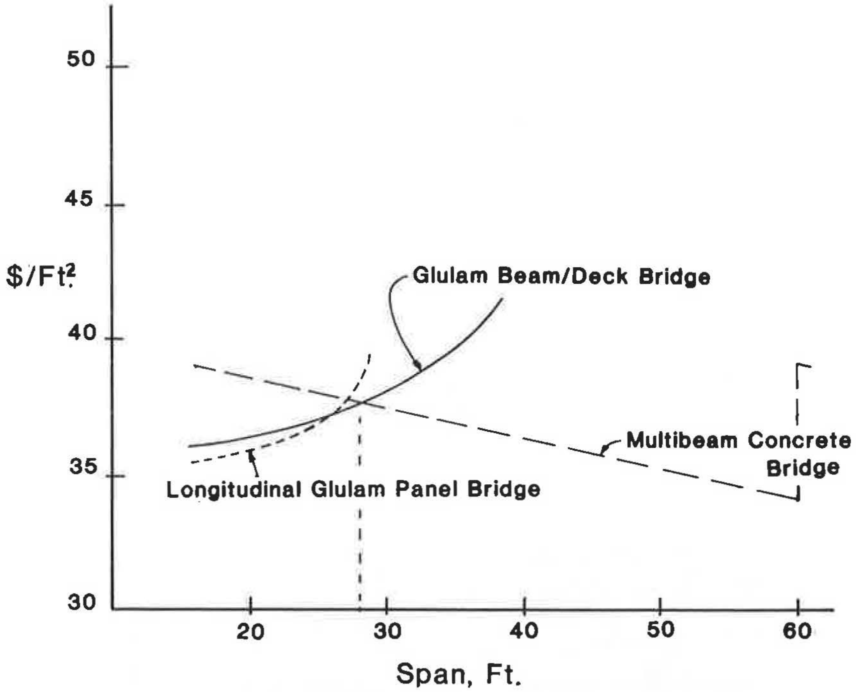

FIGURE 8 Cost comparison for timber and concrete bridges.

year, depending on timber and concrete material costs. As previously stated, location can also be a major variable.

SUMMARY

Technological advances in engineered wood products have made modern timber bridges a practical, reliable, and often economical solution to the problems encountered in replacing bridges on low-volume roads. Proper preservative treatments make wood resistant to decay. Engineered wood products, like glulam and LVL, allow use of smaller, defect-free pieces of wood. Designs that use prefabricated sections that are joined together at the bridge site reduce construction costs and overcome problems associated with using nails and field fabrication.

The performance characteristics of wood make a durable and reliable material for use in bridge construction. Wood is very resistant to impact loadings and damage from road salts. Timber bridges fit well into a natural setting and can also be an aesthetic addition to an urban environment.

Costs of glulam beam/deck bridges and glulam longitudinal panel bridges are consistently competitive in shorter spans, up to 30 ft, particularly on low-volume roads. Stressed deck systems using LVL sections show promise, particularly as timber prices increase.

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