Timber bridges: developments and trends in North America

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Timber Bridges — Developments and Trends in North America

Les ponts de bois — développements et tendances en Amérique du Nord

Der Holzbrückenbau in Nordamerika — Entwicklung und Tendenzen

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SUMMARY
In North America, timber bridge engineering has undergone a resurgence of activity in the past decade. This paper describes the recent developments in materials, manufacturing, construction, analysis and design that have marked this time period. Activity concerning a systems approach, analysis for composite behavior, laboratory and field testing, and trends in research and design provisions are reviewed.

RESUME
En Amérique du Nord, la construction de ponts en bois connait depuis 10 ans un renouveau d'activité. Ce rapport décrit les développements obtenus dans les matériaux de construction, leur fabrication, les méthodes de calcul, le dimensionnement et la construction durant cette période. On passe encore en revue les diverses activités déployées dans les domaines suivants: étude de systèmes, comportement d'éléments mixtes, essais in situ et en laboratoire, ainsi que les tendances dans la recherche et les règles de dimensionnement.

ZUSAMMENFASSUNG
In Nordamerika hat der Holzbrückenbau im letzten Jahrzehnt einen Wiederaufstieg erlebt. Die neuesten Entwicklungen in Materialien, Herstellung, Bau, Analyse und Entwurf in diesem Zeitabschnitt werden hierin beschrieben. Dieser Bericht umfasst eine Systemstudie, die Analyse des Verbundverhaltens, Labor- und Feldversuche, sowie eine Beschreibung der Tendenzen in Forschung und in den Bemessungsvorschriften.

1. BACKGROUND

The earliest application of timber in bridges was probably the incidental use of logs to cross small waterways. The close availability of material and short span requirements made this selection a natural expedient. As time passed, this simple structural form evolved into a many types of framed timber bridge structures. With each progression increased use has been made of wood's primary engineering advantages (high strength to weight ratio, ease of fabrication and erection, and a ready supply) while minimizing the disadvantages of its low modulus of elasticity and gradual degradation when exposed to the elements.

Covered timber bridges are excellent examples of the service longevity possible in timber bridges. Many over 100 years old are still in service. Protection of the superstructure from weathering is the key feature contributing to long life. In the United States interest in such bridges has been revived in recent years. A number of older bridges have been strengthened, restored for preservation, or transported to new sites. The 168 ft span Hunsecker Bridge (lattice construction) built in Pennsylvania in 1975 is one example of new covered bridges. The native round log stringer bridge is another older timber bridge type still in use. Such bridges are primarily employed for temporary logging bridges in the U.S. National Forests but more permanent installations exist in the remote regions of Alaska. These and other types of timber bridges continue as viable structures. However, evaluation of the structural soundness of older bridges is a prerequisite to the determination of load limitations. An excellent guide to the investigation of existing bridges is given by Hurlbut [1].

2. DECK SYSTEMS

The most common deck system used in older timber bridges was a nail-laminated assembly of nominal two-inch dimension lumber placed transverse to the supporting stringers. Connections consisted of through nailing of the laminations and toe-nailing to the stringers. In many instances a second layer was achieved by adding longitudinal planking atop the laminated deck to add strength and serve as a wearing surface. Performance of nail-laminated deck was quite satisfactory until the advent of glued-laminated timbers (glulam) led to increased stringer spacings. Despite adequate strength performance, the increased deck live load deflection contributed to loosening of the connections. Subsequent shrinking and swelling due to repeated wetting furthered the deterioration.

To improve deck stiffness, use has been made of reinforced concrete in recent years. In one approach concrete deck is employed in combination with timber deck to achieve a composite system. The timber deck laminations are grooved and dapped to provide a means of interlayer connections. As an alternative, a concrete deck can be compositely connected to specially prepared T-beams consisting of a glulam web and a poured in-place reinforced concrete top flange.

3. DEVELOPMENT OF PRESERVATIVELY TREATED GLULAM MEMBERS

Two significant factors have extended the use of timber in modern bridges: (1) development of glulam manufacturing methods and design criteria, and (2) technological advancements in preservative treatment of wood.

Glulam is an assembly of wood laminations (suitably selected and prepared) bonded together with adhesives. Glulam products are engineered and stress-rated according to established procedures. Basic criteria for fabricating glulam and establishing permissible design stresses based on grade of lumber and natural strength reducing criteria(e.g. knots, slope of grain, grain deviation) and end joint type and placement were developed by the U.S. Forest Products Laboratory (USFPL). To establish these criteria, extensive analytical and experimental programs were conducted, beginning about 1940, and details are available in a complete report [2]. Subsequent test programs conducted by the USFPL and Oregon State University led to the initial development of industry specifications for fabrication glulam members from visually graded and machine graded (E-rated) materials. An extensive bibliography on timber highway bridge design is available in the literature [3] and includes a listing of several standard specifications for both glulam and wood members in general.

Wood is a biological material and susceptibility to decay is its most serious drawback. However, when properly protected from the elements it is highly durable. The service life of timber bridges can be extended to 50 years or more by the introduction of modern pressure impregnated preservative treatments. Chemicals used as preservatives in timber bridge materials should be selected in accordance with the current standards for glulam members. The basic standards are those prepared by the American Wood preservatives Association and the American Wood Preservers Institute. The AWPA and AWPI standards are listed in the bibliography cited earlier [2]. Some research has also been conducted on arresting or delaying decay of older timbers [4]. It is also possible to employ fire retardants to reduce the rate of flame spread. However, most treatments do not reduce fire endurance and result in some reduction (10-25%) in member strength.

4. MODERN TIMBER BRIDGES

Significant advances in the engineering and construction of timber bridges have been made in the past two decades [5]. Glulam timber members have virtually eliminated the use of solid sawn members as the main structural elements and nail-laminated decking has been replaced by glulam deck panels. Simple connections and prefabrication of components contribute to rapid erection. Economical, straight girder bridges are now practical for spans up to 100 feet. For aesthetics and material savings, flat arches are often used in place of straight stringers. For greater spans or low water clearance sites, truss or deck arch configurations are employed.

Parallel chord bridges are economical for a span range of 100 to 250 feet. When clearance is an issue, bowstring trusses are employed in two configurations: the pony and the through span. The former is recommended for 50 to 100 foot spans and the latter for longer spans. In each the chord members are glulam timbers while the smaller web members are usually solid sawn. Prefabrication at the plant, field assembly at the site, and lifting into position for connection is the normal construction sequence. All glulam components are preservatively treated using pressure impregnated creosote.

Deck arch bridges are efficiently utilized for spans up to 300 feet. Generally, three-hinged arches are used as the main support elements and loads are transferred from the deck to the arch by means of timber bents. All wood components are glued-laminated. An early example is the 104 foot span Loon Lake Bridge in Oregon built in 1948. The bridge has a 20 foot roadway width, but employs a nail-laminated deck. The upper level of the Keystone Wye Interchange is a more recent example of a deck arch bridge. This compositely designed bridge spans 290 feet and employs glulam-concrete T-beams in combination with a concrete deck.

Harvesting of remote forest land creates a high demand for bridges intended for low volume traffic consisting of heavily-loaded logging trucks and related heavy equipment. Scarisbrick [6] describes some notable glulam bridge configurations, used in British Columbia. Simple-span bridges in which deep I-beams or double I-beam glulam girders are employed are most common. Typically, girders dimensions range up to an 86 in. depth, a 12 in. web width, and a 20 in. flange width. A number of trussed girder configurations have been employed for spans between 127 ft and 270 ft. Cable-suspended bridges in which glulam is used in the superstructure (including towers) are also described.

In 1973 the Ontario Ministry of Transportation and Communications undertook a long term program [7] aimed at assessment of the load carrying capacity of existing wood bridges and development of methods for improving capacity as an alternative to replacement. As a result of extensive field studies and tests performed as one phase of this program, an effective means of post-tensioning laminated timber deck has been developed [8]. Another aim of the development program is to incorporate the developed methods into new bridge design and construction practices.

5. STRAIGHT STRINGER BRIDGES

5.1 Description

Standardization and systems approach to construction have a long history of usage in timber structures. Bridge engineers identified a need to incorporate a systems concept in the design and construction of timber bridges. Also, declining supplies of large solid-sawn timbers were a deterrent to the continued viability of timber bridges. In response, the timber industry developed construction concepts and design criteria for a glulam girder-glulam panel deck system to be implemented in highway bridges.

The conventional glulam stringer bridge system employs preservatively treated glulam stringers and the glulam deck panels and includes an asphalt wearing surface. Typical dimensions and design aids [9] as well as case studies [5] are available in trade association publications. Deck panels are made of nominal 2 in. dimension lumber vertically laminated to form a flat slab. Individual panels are generally 4 feet wide and the laminations traverse the entire roadway width. Steel dowels provide shear and moment transfer between adjacent deck panels. Stringers and deck panels are interconnected by lag bolts.

5.2 Research And Development

In addition to being the most inefficient part of the conventional timber bridge, the nail laminated deck did not provide a sufficient "roof" over the bridge structure as is desirable to extend overall bridge service. In 1978, research was undertaken by USFPL to evaluate the concept of utilizing a glued laminated deck panel. Basic structural properties of glued laminated deck panels were compared with those of the commonly used nail-laminated deck. Load transfer under static loads was studied in laboratory tests. Experimental bridges were also constructed using the panel deck concepts to study field construction and performance. Experimental investigations of the panel deck systems were supplemented with a theoretical analysis by orthotropic plate theory to develop the necessary design criteria. Details of the work are given in two reports [10, 11] and are the basis of the current AASHTO specifications for glulam bridge deck.

The connection devices in the glulam stringer were devised for ease of construction. Proper lead hole size for the dowels is essential both for adequate load transfer and ease of alignment of adjacent deck panels during jacking. However, the present recommendation (1/32" oversize) hinders desired erection. The influence of this parameter was investigated in a recent study [12]. Mechanical interconnection also produces a degree of composite action. However, the inherent interlayer slip and gaps at the deck panel interfaces render the interaction incomplete. Recent research [13, 14] describes a proper analytical model for analyzing the partial composite behavior. Analytically generated "composite action curves" (e.g. Fig. 1) are employed to study the influence of the significant parameters; affecting composite action, namely, interlayer slip, gap condition and deck material properties. These studies reflect the reserve strength that is generally possible due to composite action. Generally, the ratio of composite to non-composite displacement, Δ/Δ_N is used as a measure of performance. Use of such curves and tests of large scale models of bridge cross-sections point to the potential for a high degree (≈ 50%) of composite action in prototype glulam bridges.

5.3 Recent Developments

Other stringer bridge configurations have been developed which incorporate special features designed to enhance service life. One manufacturer (Weyerhauser Co., Tacoma, Washington) has marketed a panelized glulam bridge system which features a patented aluminum clip angle connection for which no bolt holes are needed in the stringers. This simplifies erection by eliminating dowels, avoids direct entry of moisture into the stringers, and facilitates easy replacement of damaged components. In another system [15] Press-Lam is used (in place of glulam) for all components of the superstructure. Press-Lam (Fig. 2) is a Parallel Laminated Veneer product manufactured by adhesive bonding of rotary-peeled veneer. When compared to solid-sawn lumber, the Press-Lam exhibits less variability in mechanical properties and improved penetration and retention of chemical preservatives. A prototype highway bridge has been constructed and is being field tested. In service performance is to be monitored over a five year period.

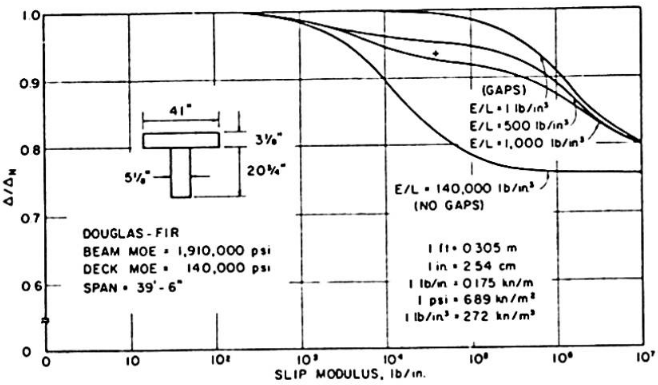

Fig. 1 Example Composite Action Curves

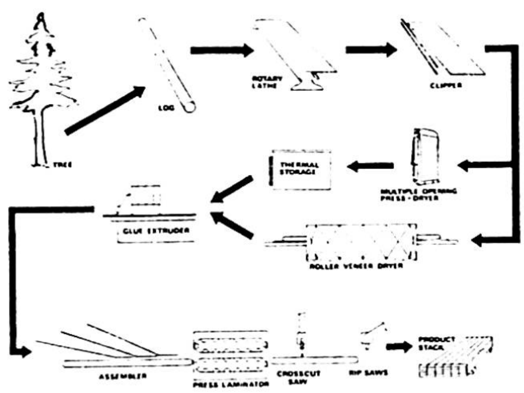

Fig. 2 Press-Lam Processing

6. CURRENT TRENDS IN RESEARCH AND DESIGN

Future design codes are certain to reflect the great activity by the engineering community on several issues. Rationalization of limit states design for uniformity in the various structural codes, incorporation of reliability based strength, and development of a systems approach to the analysis of structures, are among the most significant. A complete report on research needs has recently been compiled [16].

Material variability has been long recognized in the development of allowable stresses for wood. The use of a 5% exclusion limit in the statistical analysis of small specimen properties is well known. Currently, the measurement of in-grade strength of full-size members as a basis for future allowable design stresses is of considerable concern. Further, many researchers point to brittle fracture as the initiator of structural failure in wood and are applying fracture mechanics theories in an attempt to better understand the ultimate strength limit state.

Probabilistic methods offer a means of incorporating reliability (safety) into the investigation of a structure's limit states. Theories have been derived and applied to steel [17] but some difficulties exist when applied to wood [18]. Some researchers believe the use of a lognormal distribution in the codification is inappropriate for wood, preferring a Weibull probability distribution in its place. Also, the load duration characteristics of wood (time dependency) is not included in present formulations. A method for developing allowable stresses for temporary glulam structures which accounts for load duration is available [19]. However, the results are presented in a working stress design format.

There is some feeling amongst bridge engineers that the distribution of wheel loads by timber deck produces stringer loads measurably below those currently specified in AASHTO provisions (which predate modern analytical methods). This belief is supported by recently conducted service and ultimate load field tests [20, 21]. The findings suggest some modification of current code provisions is justified.

7. CLOSING REMARKS

In light of modern materials, improved construction methods and rigorous engineering methodology, one can produce durable, safe timber bridges configured for contemporary secondary highway loads. Wood is an abundant, lightweight, naturally aesthetic, renewable construction material. Its application in bridges on secondary road systems is certain to increase rapidly in face of rising construction costs and world-wide energy constraints.

REFERENCES

1. Hurlbut, B. F., "Basic Evaluation of the Structural Adequacy of Existing Timber Bridges", Transportation Research Record 647, Transportation Research Board, National Academy of Sciences, 1977.

2. Freas, A. D. and Selbo, M. L., "Fabrication and Design of Glued Laminated Wood Structural Members, USDA Technical Bulletin 1069, Forest Products Laboratory, U.S.D.A., Madison, Wisconsin, 1954.

3. Committee on Wood of the Structural Division "Bibliography on Timber Highway Bridge Design", J. Structural Division, ASCE, Vol. 101, No. ST1, Jan. 1975.

4. R. D. Graham, M. E. Corden, and T. C. Sheffer, "Controlling Biological Deterioration of Wood with Volatile Chemicals", Forest Research Laboratory, Oregon State University, 1975.

5. Modern Timber Highway Bridges. - A State of the Art Report, American Institute of Timber Construction, Englewood, Colorado 1973.

NB. The references 6. to 21. are given on page 176.