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DEVELOPMENT OF LONGER SPAN WOOD BRIDGES

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ABSTRACT

Since the Ministry of Transportation of Ontario (MTO) directed its attention towards wood bridge development in the early 1970's there have been significant advances in technology as a result of their work. Beginning with the development of the Stressed Wood System (SWS) in 1976 MTO has been instrumental in reviving the use of wood bridges across North America. There are probably more bridges being constructed or rehabilitated now, using wood, in both Ontario and the United States (US) than has been performed for more than 20 years.

Over the last 5 years there has been a great deal of development work performed on wood bridges surrounding the SWS system. Work has been performed by government agencies such as transportation and forestry, as well as Universities and several industries. Most of the work has been aimed at longer span wood bridges and much of it has been published in one form or another. However, although there has been some contact between the various groups there exists no consolidation of the varied works.

The objective of this paper is to summarize all the major activities that have taken place using the SWS in both Ontario and the United States. It represents the first stage of a cooperative program between the USDA Forest Service, Forest Products Laboratory and the MTO. These two agencies represent the centres of information and activity on the SWS in the US and Ontario respectively. The paper briefly reviews the development of the Stressed Wood Deck leading into the new longer span concepts being developed using the SWS.

INTRODUCTION

Although long span wood bridges of up to 64 m spans have been constructed in the past, the economic feasibility of constructing similar bridges has diminished over the last few decades. The Sioux Narrows bridge Taylor 1986c) shown in figure 1 has a 64 m main span composed of solid sawn Douglas Fir members forming a box Howe truss. Built in 1936 this bridge is believed to be the longest single span wood bridge in North America. The bridge is still open to full highway traffic and stands as a monument to the durability of wood for highway bridge construction. However, these wood trusses utilize very large size timbers which are no longer economically available. In fact, in todays market the most economically available material sizes in most areas of North America are dimension lumber which range from 38 mm X 89 mm to 76 mm X 292 mm. With lengths of up to only 6 or 7 m this material provides little possibility of constructing bridges like the Sioux Narrows.

By the beginning of the 1970's the use of wood for bridges in Ontario was virtually reduced to nailed-laminated decking using dimension lumber providing spans of up to only 6 m (Csagoly & Taylor 1979). In addition, these decks were producing some serious maintenance problems due to delamination. It appeared that unless some major changes occurred in the engineered use of wood for bridges it seemed unlikely that wood would continue to play a serious role in bridge construction.

The objective of this paper is to provide an updated summary on the developments that has taken place over the last 15 years as a direct result of the work which began in Ontario in the early 1970's (Batchelor et al 1979, Taylor et al 1982). The paper will briefly discuss the development of the stressed wood system (SWS) by the Ministry of Transportation of Ontario (MTO) in 1976 (Taylor & Csagoly 1979). This will lead into a summary of the work currently being performed around North America which utilizes the SWS concept to produce longer span wood bridges. Each concept has the same objective and that is to utilize the more readily available smaller size materials to form large span wood bridges.

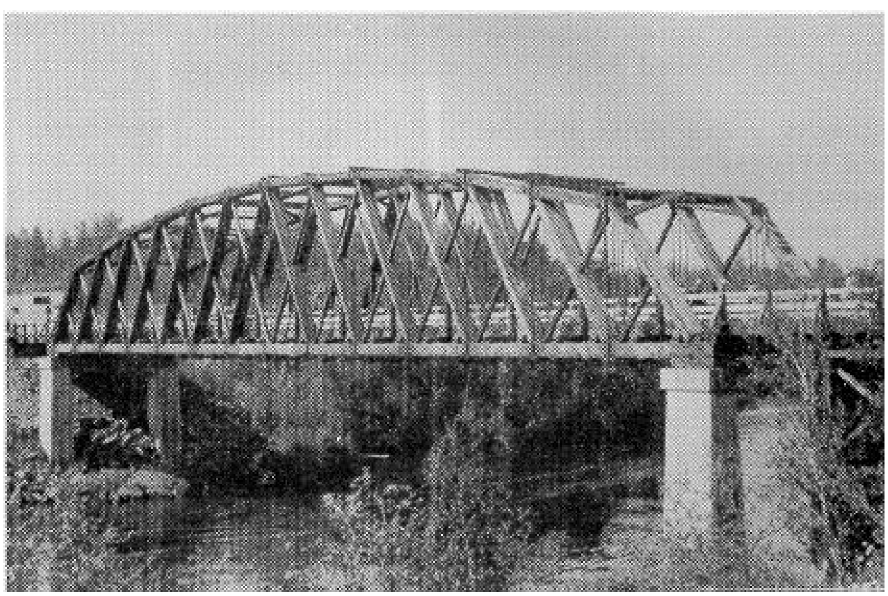


FIGURE 1. SIOUX NARROWS BRIDGE, KENORA, ONTARIO

DEVELOPMENT OF THE STRESSED WOOD DECK

When the MTO directed its attention towards wood bridges in the early 1970's the main emphasis was to develop a method of repair for the existing nailed laminated wood decks. These decks lacked long term resistance to the more frequent and heavier vehicle loadings that they were being subjected to. The nails joining the laminates successively crushed the wood surrounding them creating increasing mechanical movements resulting in a serious maintenance problem. The benefits of developing a successful method of repair for these decks was twofold. First, there were literally hundreds of bridges throughout Ontario which contained these decks and therefore could eventually begin to delaminate. Secondly, these bridges utilized the most readily available sizes of wood and therefore they represented the best possibility for future development if the problems associated with them could be solved.

The SWS system was originally developed as a means of rehabilitating the existing nailed laminated wood decks that had suffered serious mechanical deterioration. Using pairs of high strength bars, as shown in figure 2, the old deck would be squeezed back together creating adequate friction between the laminations to re-establish continuity and load distribution. Figure 3 shows the method being applied to the Pickerel R. bridge on highway 11 which forms part of the Trans Canada Highway in Northern Ontario. The success of this method has been well documented and numerous load tests (Taylor 1986b) have confirmed the superior performance of these rehabilitated bridges.

The success of the initial work led to extensive research and development and the formation of a long range program by MTO (Csagoly & Taylor 1980) based on the SWS. New stressed wood decks using a single bar system, as shown in figure 2, now replace the nailed deck in many designs. The Ontario Highway Bridge Design Code (1983) provides design specifications for the design of decks using the SWS.

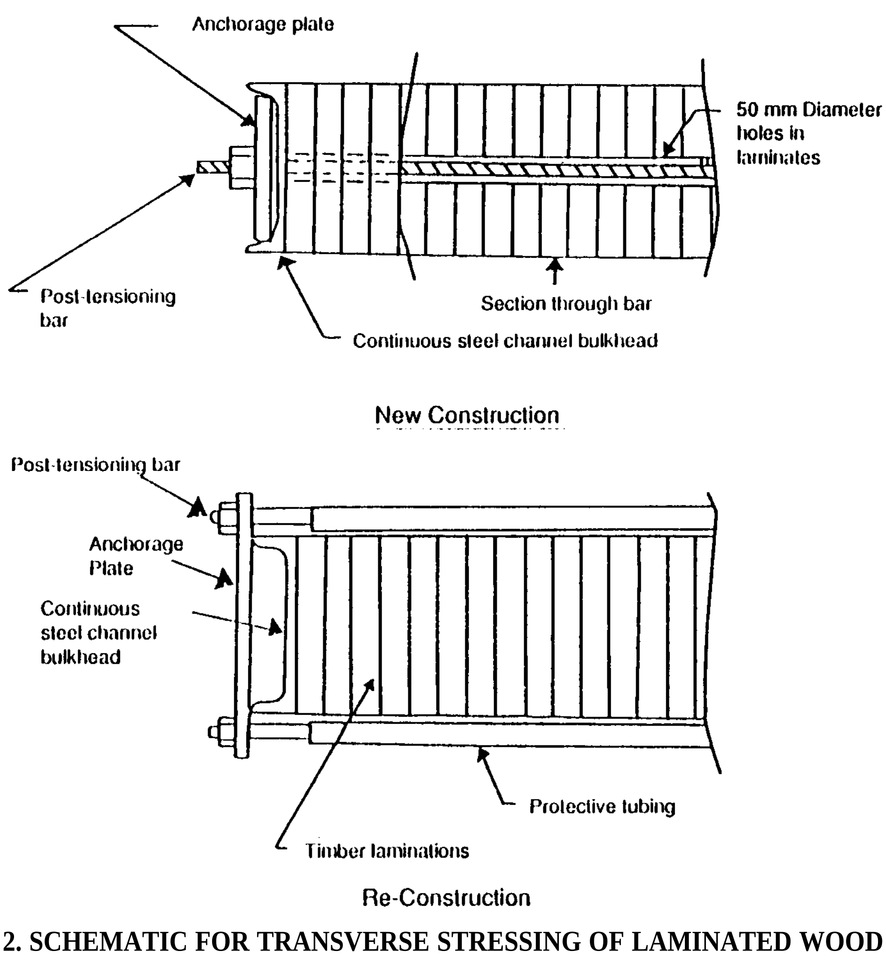
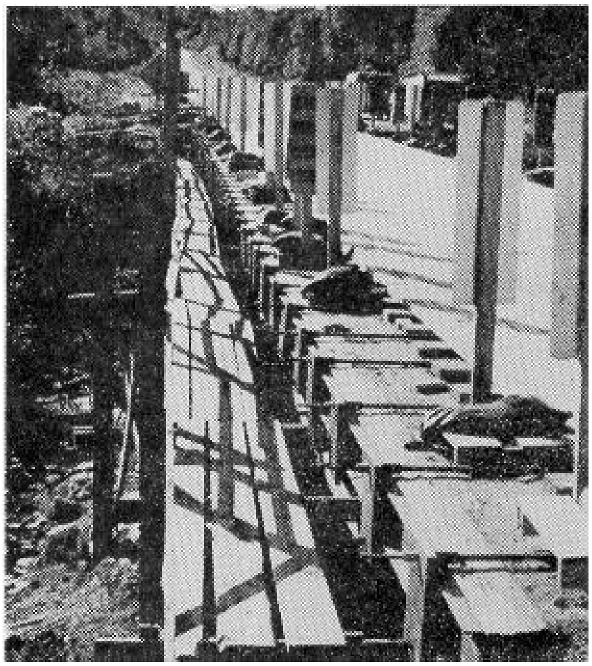


FIGURE 2. SCHEMATIC FOR TRANSVERSE STRESSING OF LAMINATED WOOD DECKS.

FIGURE 3. TRANSVERSE STRESSING OF AN EXISTING NAILED LAMINATED DECK.

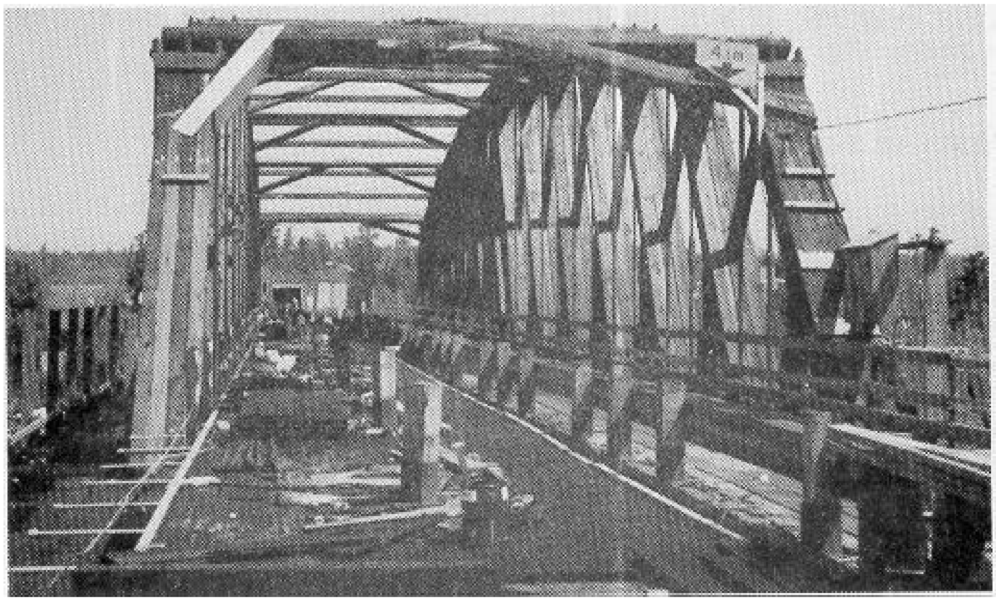


BRIDGE NAME AND LOCATION	DATE	DECK TYPE	STRUCTURE TYPE	OVERALL LENGTII (m)	WOOD SPECIE
FOX LAKE RD., ESPANOLA, ONTARIO	1981	N,LL	FRAME	13	DF
SIOUX NARROWS, KENORA, ONTARIO	1982	DR,LL	WT	120	DF
AQUASABON R, TERRACE BAY, ONTARIO	1983	N,TL	SG	43	RP
DORFLI-BRICK, SWITZERLAND	1984	N,LL	WA	31	-
GARGANTUA, MITCHIPICOTEN, ONTARIO	1984	N,LL	DECK	19.5	DF
RAGGED CHUTES, OTTAWA, ONTARIO	1984	DR,TL	SG	300	DF
LAURA SECORD, ST. CATHERINES, ONT.	1985	DR,LL	ST	60	-
EAST ABINETTE, MITCHIPICOTEN, ONT	1985	N,TL	SG	16	HEM
LITTLE CURRENT, LITTLE CURR., ONT.	1986	DR,LL	ST	173	WP
WITCH DOCTOR, MITCHIPICOTEN, ONT.	1986	N,TL	SG	16	HEM
MAKOBIE R., NEW LISKEARD, ONTARIO	1986	DR,LL	DECK	60	-
CROSS R., COOK COUNTY, MINNESOTA	1987	N,LL	DECK	13	DF
TROUT RD., STATE COLLEGE, PENN.	1987	N,LL	DECK	14	DF
WELD COUNTY, WINDSOR, COLORADO	1987	N,LL	DECK	30	DF
ZUNI CRK., ID. PANHANDLE NF, IDAHO	1987	N,LL	DECK	9	LVL
INVERMAY, TARA, ONTARIO	1988	DR,LL	ST	40	RP
CREMORE, CREMORE, ONTARIO	1988	DR,LL	ST	42	RP
IRON RIVER, CHEQUAMEGON NF, WI.	1988	N,LL	DECK	10	DF
LITTLE SALMON, ALLEGHENY NF, PA.	1988	N,LL	DECK	7.6	RO
TEAL R., SAWYER COUNTY, WI.	1989	N,LL	DECK	10	SP,RP
WHITE OAK GAP,CHATTAHOOCHEE NF, GA	1989	N,LL	DECK	9	SP
CIPHERS, ROSEAU, MINNESOTA	1989	N,LL	DECK	12	RP
PUEBLO, PUEBLO COUNTY, COLORADO	1990	N,LL	DECK	10	PP

NOTES: N=New Structure, DR=Deck Replacement, LL=Longitudinal Laminated, TL=Transverse Laminated, SG=Steel Girders, ST=Steel Truss, WT=Wood Truss, WA=Wood Arch, WG=Wood Girders, NF=Nationnl Forest, DF=Douglas Fir, RP=Red Pine, HEM=Hemlock, WP=White Pine, LVL=Laminated Veneer Lumber, RO=Red Oak, SP=Spruce, PP=Ponderosa Pine.

TABLE 1. NEW PRESTRESSED WOOD DECKS ACROSS NORTH AMERICA

FIGURE 4. DECK REPLACEMENT ON TllE SIOUX NARROWS BRIDGE.



Although the United States does not yet have formal specifications for the SWS there is significant research and development activity (Dimakis & Oliva 1987, Oliva et al 1990). In addition, the SWS is included in a new Timber Design Manual (Ritter 1990) published by the USDA Forest Service, Forest Products Laboratory (FPL).

The SWS for new decks has now been successfully used in dozens structures both in Ontario (Taylor 1986a) and in the United States and Table 1 provides some information on a few of these applications. One of the more interesting applications involved the deck replacement on the Sioux Narrows bridge as shown in figure 4. This 120 m long continuous stressed wood deck was constructed in two halves in order to maintain traffic flow (Taylor 1986c). Subsequently the two halves were coupled together and stressed to form a continuum.

The first application of a transverse laminated deck was introduced at the Aquasabon River bridge as shown in figure 5. The pre-assembled deck panels were prestressed before being brought to the site. Each panel was then sequentially coupled and stressed to the previous one before being tied down to the steel girders. This method avoided the possible instability that could

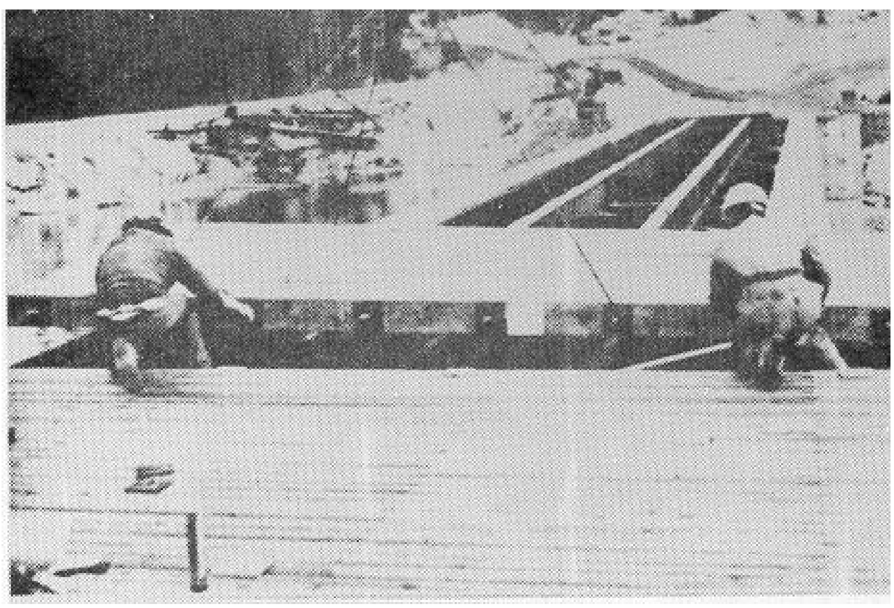


FIGURE 5. SEGMENTAL DECK CONSTRUCTION ON THE AQUASABON R. BRIDGE.

occur if the 42 m long deck was stressed over its full length at one time. In this regard, if any restraint against buckling were to have been provided in order to stress over the 42 m length, this restraint would have seriously affected the stressing procedure.

NEW DEVELOPMENTS USING THE SWS

While successfully applying the SWS system to both the rehabilitation and new construction of wood decks MTO was also evaluating its uses for larger span composite systems (Csagoly & Taylor 1979 and 1980). The suggested concepts included Stress Laminated Arches, Steel-Wood Composites, T Beam Decks, King Post supported Decks and an Integrated Deck System. In each case the objective was to increase the span capacity of the SWS design using the more readily available small size materials.

The subject of the subsequent discussion is a summary of the activities that have taken place over the last 10 years towards the use of the SWS for longer span wood bridges. Currently there are numerous development projects both in Ontario and throughout the US. In some cases field prototypes have already been constructed and even some field testing has been performed.

Frames

The first application of the SWS concept on something other than a simple deck occurred in Ontario in 1981 (Taylor & Walsh 1983). The Ministry of Natural Resources (MNR) had expressed interest in the SWS concept and had selected a site near Espanola, Ontario to try out an application. Originally the application was to have been a transverse laminated wood deck on steel stringers providing a single span of about 20 m. However the site provided a unique opportunity as it consisted of sound bedrock formations, as shown in figure 6, which would provide excellent support for a frame structure of the type shown in the figure.

The design of the structure was performed by MTO and constructed by MNR's own construction crew. The deck consists of 38 mm X 292 mm laminates and the legs are made up of 38 mm X 190 mm laminates. Each of the leg laminations were attached to deck laminations using hot dip galvanized truss plates to form individual laminate frames. Subsequently these frames were placed side by side and the stressing rods threaded through the pre-drilled holes as shown in figure 7 and the entire assembly was stressed together, including the legs, at the same time. The completed structure has since

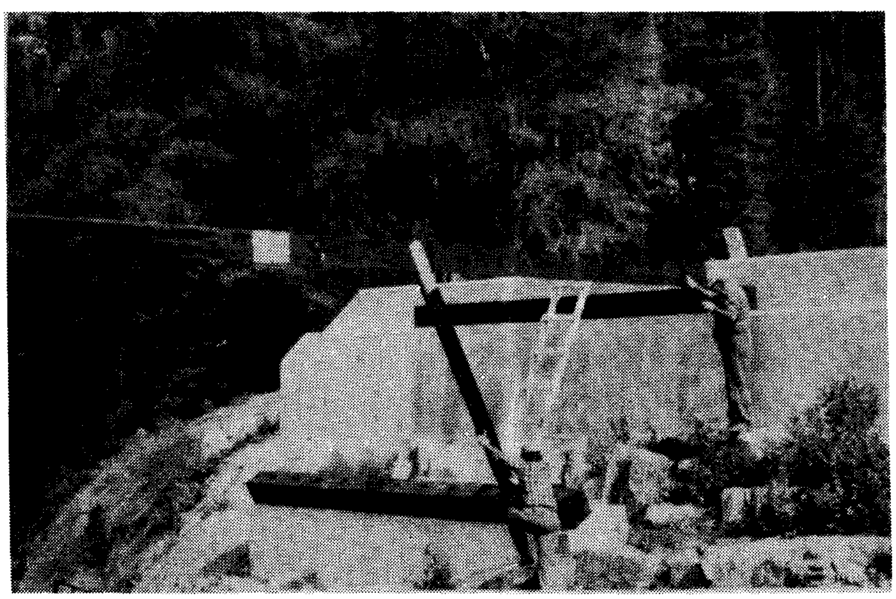
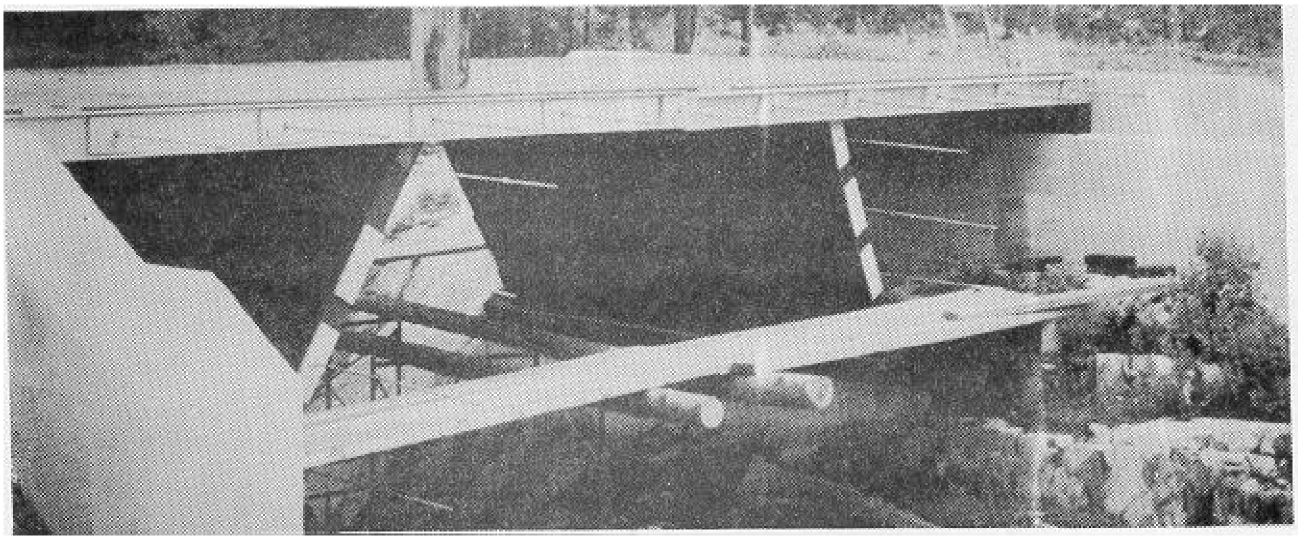


FIGURE 6. PREFABRICATED FRAME FOR THE FOX LAKE BRIDGE.

FIGURE 7. ASSEMBLED STRESSED LAMINATED FRAME AT FOX LAKE.



undergone full scale load testing supporting one of MTO's test vehicles weighing over 90,000 kg (200,000 lbs) and the maximum deflection was only 9 mm. The MNR estimated the structure cost about two thirds of the structure originally intended for the site.

Although this form of bridge is limited by the type of site available the success of this application did demonstrate the feasibility of utilizing the SWS on more complex structural forms.

Steel-Wood Composite

The first composite design to receive extensive research and development was the steel-wood system as displayed in figure 8. Calculations indicated that a longitudinal deck made composite with steel girders could compete with the traditional steel-concrete structure. Its major application was to be as a rehabilitation tool on existing steel girder bridges where the increased weight of concrete could severely affect the capacity. A research project was carried out by MTO beginning in 1984 and culminating in a detailed research report in 1986 (Tharmabala & Bakht 1986).

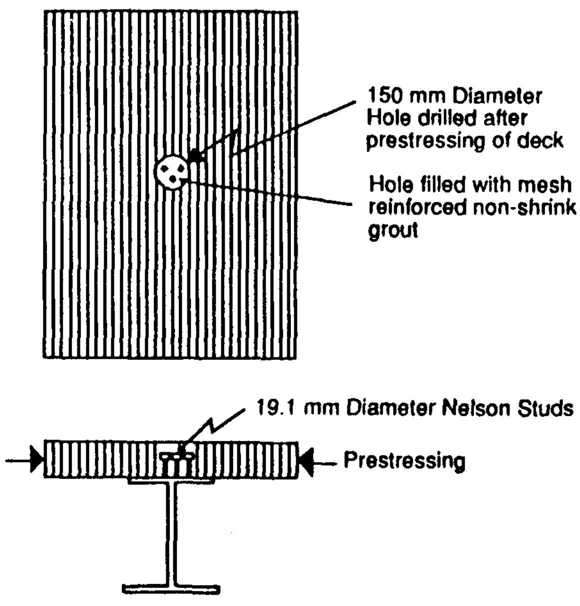


FIGURE 8. STEEL-WOOD COMPOSITE SYSTEM.

In selecting possible shear connectors to provide shear transfer between the steel and the wood deck several important points were considered. Priority was first given to the practical side where it was desirable to have a connector which could be installed after the wood deck had been transversely stressed. Since a wood deck undergoes significant movement when being transversely stressed any restraint could have a detrimental effect on both the connector and the deck. In addition, the connector must be resistant to the effects of repeated loads.

One connector finally developed by MT0 is detailed in figure 8. It consists of a 150 mm diameter hole drilled into the wood deck directly over the steel girder flange. Three 19.1 mm diameter Nelson studs are welded to the flange, strategically placed within the hole. The hole is then filled with non-shrink grout. The MT0 research project included extensive cyclic testing of the connector in accordance with the design requirements of the OHBDC. Several large scale models up to a 6 m span were also tested which demonstrated that the proposed connector provided significant composite action and excellent resistance to fatigue. Additional work was still to be performed by MT0 (Bakht & Tharmabala 1987).

A prototype bridge consisting of three 50 ft. spans was constructed in 1988 in Cass County, North Dakota by Wheeler Consolidated Inc. No formal publication is yet available, however an internal report was produced by Wheeler (Wheeler Log 1986) which is identified in the references. Although no contact with MT0 was made during design or construction it is our understanding that the design was performed utilizing the MT0 research information. The FPL has tentatively placed this structure on a list of structures to be monitored over the next few years.

Currently the MT0 is continuing the research work and is designing its first full scale prototype structure which will be built over the North Pagwatchuan River in Northern Ontario in 1991. This will be a single 50 m span structure of two lanes supporting a 292 mm deep deck. Due to the remote site and the difficulty of obtaining quality concrete in quantity the structure, except for the steel girders, will be built entirely of wood including the abutments. The bridge will be located on highway 11 which forms part of the Trans-Canada Highway and so is expected to receive some of Ontario's heaviest loads.

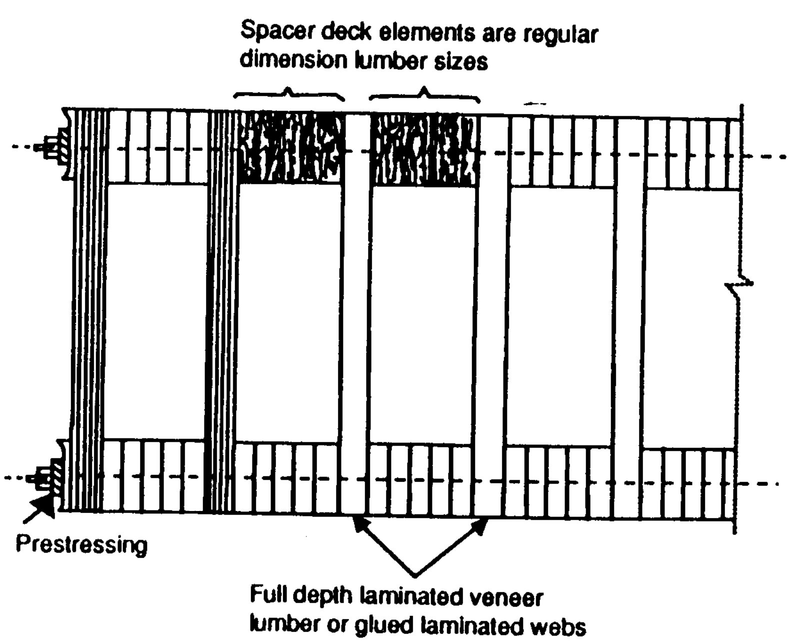


FIGURE 9. CELLULAR WOOD DECK SYSTEM.

Integrated Deck Systems

The original integrated deck concept is presented by figure 9 and essentially consists of two levels of stressed wood decking separated by vertical webs which are integrated into the stressed wood decks to form a composite system. Several variations of this idea including the T-beam are being actively developed around North America.

Prefabricated Deck Truss. One of the original MT0 concepts was to use prefabricated trusses, as are frequently used in buildings, to form the webs. These trusses are easily fabricated, reasonably inexpensive and can be constructed to virtually any size. The main concern was the susceptibility of the galvanized truss plates to the effects of repeated loads. These plates would have to provide all the shear transfer between the web members and the deck flanges. A preliminary investigation was conducted in 1985 at the University of Western Ontario (Whittington 1986). The results of the investigation, which included the testing of a 6 m span model, confirmed that these truss plates are susceptible to fatigue under repeated loadings. However the static testing demonstrated that composition between the web and deck system can be achieved. The use of these trusses was discarded and consideration was given to using solid webs using either Laminated Veneer Lumber (LVL) or Glued Laminated members.

Parallel Chord Truss. A variation of the truss idea was introduced in the United States in 1986 through a cooperative research project between the University of Wisconsin (UW) and the FPL (Dimakis & Oliva 1988, Oliva 1987). The stress-laminated parallel chord, which uses a Vierendeel truss, is shown in figure 10. Connection between the decking and the webs is provided by large size steel spikes driven from the top and bottom of the decking into the webs. Extensive laboratory testing conducted at the UW included a 15.8 m long prototype. The laboratory testing indicated that the system provided up to 40% of the stiffness that would be present if full composite action were present. The testing also indicated that the system did not display any significant deterioration of the spike connection or additional loss of stiffness under half a million cycles of loading equivalent to an HS-20 vehicle. Even with the cyclic testing there is still some concern as to the fatigue resistance of the web-deck connection using the discrete spikes considering the previous problems with nailed decking.

A field prototype structure, displayed in figure 11, was installed in the Hiawatha National Forest in late 1987 by the USDA Forest Service. The bridge has received some static load testing and is currently being monitored by the FPL.

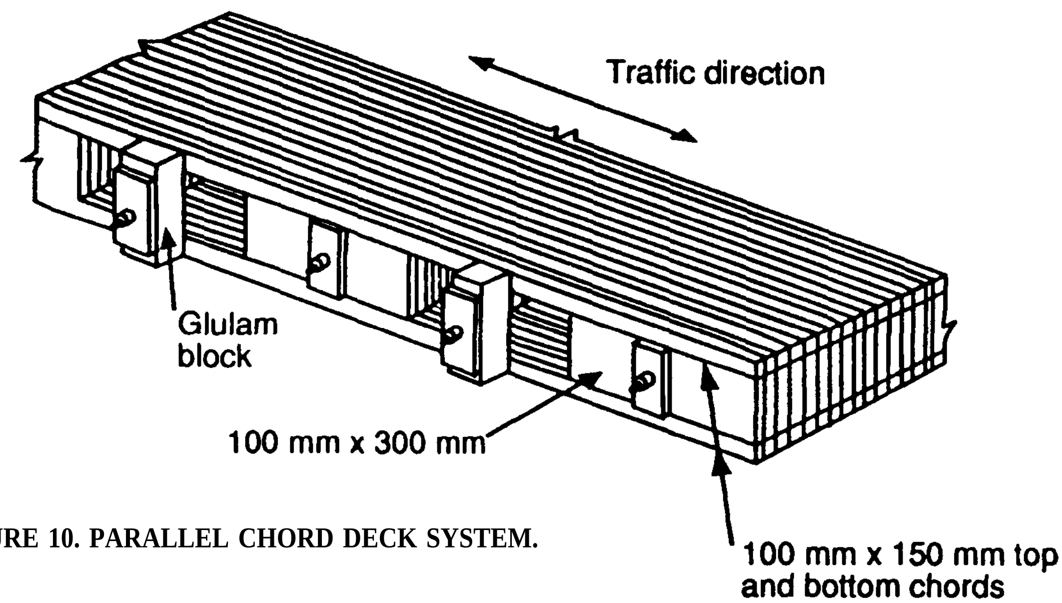
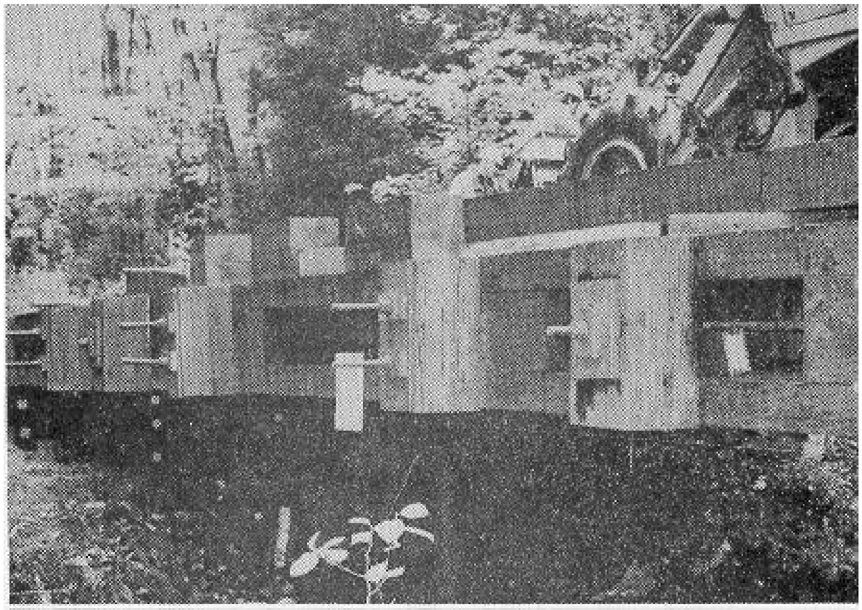


FIGURE 10. PARALLEL CHORD DECK SYSTEM.

FIGURE 11. PARALLEL CHORD PROTOTYPE, HIAWATHA NATIONAL FOREST.



T-Beam. The first stressed T-Beam, as shown in figure 12, was introduced in West Virginia in 1988 (Dickson and Gangarao 1989 a & b). The West Virginia University (WVU) performed laboratory testing and constructed a 22.3 m span prototype near Charleston WV.. The bridge, shown in figure 13, utilizes 150 mm X 1140 mm LVL beams and 230 mm deep Oak decking. The use of the Oak represents part of the aim of the wood program in WV. which is to promote the use of local species.

Another T-beam bridge was constructed in 1989 over Mason Creek in Ada county Idaho (Meyer 1989). This structure used Douglas Fir LVL to construct the T sections which were prefabricated by Trus joist Corporation.

Both of these bridges have been load tested and have performed as composite sections up to the maximum legal loads. In addition, the West Virginia bridge is being monitored by the University, in cooperation with the FPL, to complement the information being collected on the many other stressed wood bridges around the US,

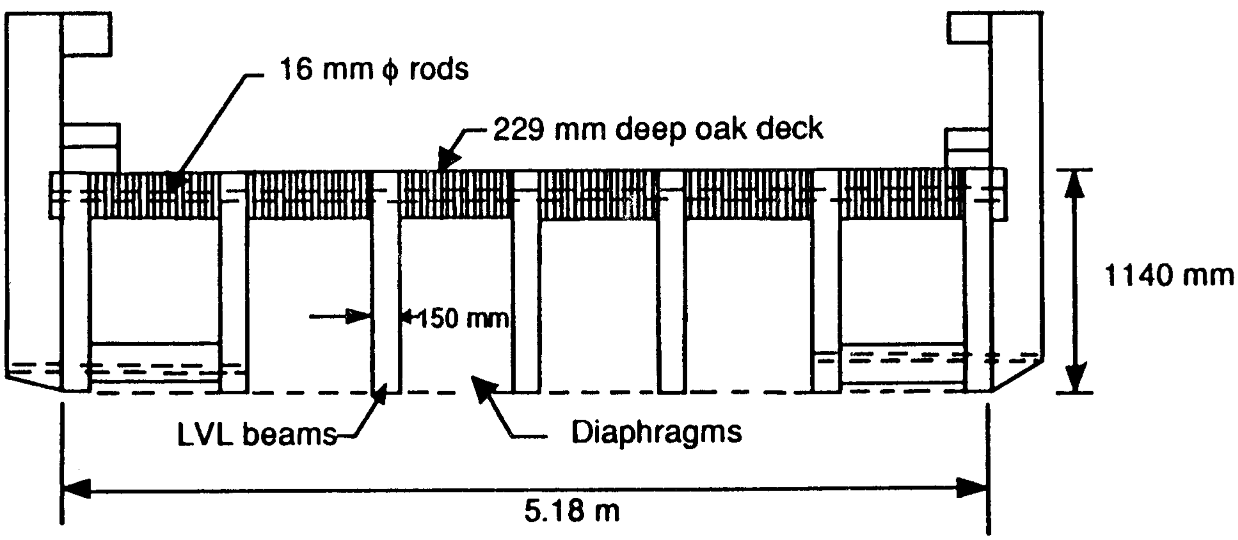
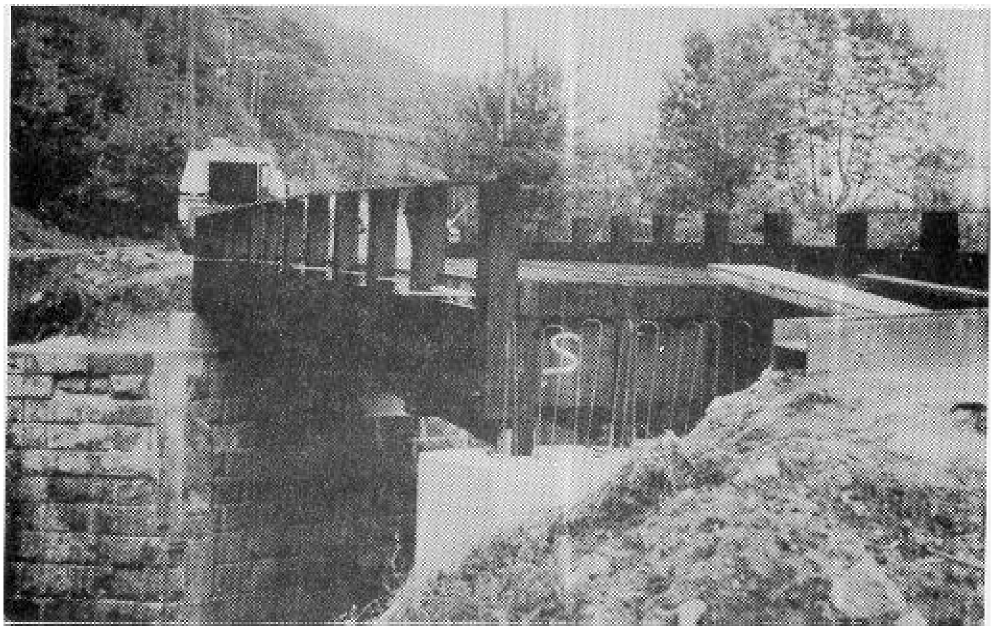


FIGURE 12. T-BEAM DECK SYSTEM.

FIGURE 13. T-BEAM PROTOTYPE. TWO-MILE CREEK. WEST VIRGINIA.



Cellular Deck. The truly cellular deck concept as portrayed in figure 9 has received some preliminary evaluation by MTO (Taylor 1988) and is also being investigated by the University of West Virginia in cooperation with the FPL. However, it appears the approach is slightly different in each case.

The original concept of the integrated or cellular deck by MTO was for spans up to and exceeding 60 m. The cells are expected to be closely spaced using thin webs for which an extensive understanding of the flexural and torsional properties of the materials will be necessary. Along these lines MTO will be conducting some large scale laboratory testing in 1990.

WVU is developing a lower profile box system using widely spaced thicker web members. Several prototype bridges are expected to be constructed this year as part of an extensive construction program involving 20 or more new wood bridges in West Virginia.

In both cases it is necessary to understand the torsional and flexural characteristics of these systems. Excessive deformations of these bridges, either overall or differently within the bridge, can lead to serious maintenance problems when it comes to wearing surfaces and fatigue of components. However, both applications are aimed at utilizing local wood species in the deck systems as much as possible.

SUMMARY

This brief review of the work being performed on wood bridges around North America hardly reflects the quantity of information that now exists on wood bridges using the SWS. Additional details can be obtained through the references which in turn identify other literature on the same subjects. There are no formal design specifications for composite SWS designs. Although there is considerable development work going on it will take some time to properly evaluate the performance of these composites through the monitoring and testing of the many prototype bridges that are being constructed.

The FPL and MTO are currently developing a cooperative program to evaluate and monitor the many existing SWS bridges as well as the R & D activities around North America. This program will not be aimed at controlling the development work but rather monitoring the activities in efforts to consolidate the work of the many groups interested in developing the SWS for longer span wood bridges.

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