Pacific Timber Engineering Conference
Gold Coast Australia
July 11 - July 15, 1994.

DURABILITY IN STRESS LAMINATED TIMBER BRIDGES

R. Taylor, * R. J. Taylor Consulting P/L, Australia
M. Ritter, * USDA, Forest Service, USA.

SUMMARY

With the development of the stress laminated timber (SLT) bridge concept we now have the means of designing and constructing strong and durable timber bridges. while there are dozens of successful applications around the world there exists only limited design support information. The available specifications still provide the designer with considerable latitude in some areas. This paper discusses some of the important areas that the designer should consider in order to produce a more durable SLT bridge. The paper does not provide any detailed information on the design process. It does, however, review the basis for some of the design requirements. In this way the designer can better understand some of the key elements necessary to ensure a durable design.

INTRODUCTION

The concept of Stress Laminated Timber (SLT) bridges was developed in Ontario, Canada in the late 1970's (csagoly and Taylor 1980). Basically the system consists of a series of timber planks placed on edge and stressed together using high strength steel bars as shown in figure 1. The lateral pressure provides enough friction between the planks to prevent slippage under load and so forms a continuous structural timber slab.

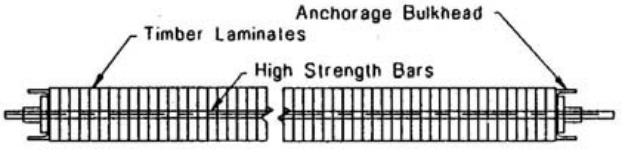

Figure 1 Stress Laminated Timber Deck

This new SLT design has proven to be very durable and far superior to many previous timber bridge systems. since its inception in Canada in 1976 (Taylor & csagoly 1978) it has now been used successfully around the world. Some additional discussion on the development and current use of the SLT can be found in an accompanying paper in these prcoeedings (Taylor & Keith 1994).

Both of the authors have been involved in the research and development of the SLT concept. In addition, they have played a primary role in the derivation of design specifications (AASHTO 1991 & OHBDC, 1991) as well as being directly involved in the design and construction of many of the existing field applications. Through this work they have observed numerous different design applications which have resulted in varied degrees of success.

while there are some existing design specifications for SLT bridges, as will be discussed later, there remains a great deal of latitude for the designer. This paper briefly presents and discusses a range of design considerations of which the designer should be aware. In each case, it presents some insight into the potential problem area, as well as discussing some of the design alternatives that can be considered.

It is not the intent of this paper to cover the details of any of the design processes. In fact, in order to cover the subject matter, we must assume that the reader has some familiarity with the SLT system.

GENERAL DESIGN FEATURES

We can begin by discussing the overall design of the SLT deck for strength and serviceability. It is the authors

opinion that this probably constitutes the simplest part of the design process.

For the most part, the available design specifications, as will be discussed in the next section, provide the designer with all the necessary information.

Design Specifications

Currently there is only one formal design specification for SLT decks. This is contained in the Ontario Highway Bridge Design Code (OHBDC 1991) and is fully supported by a recent text publication (Taylor & Keenan 1991). In addition, there are several interim documents (AASHTO 1991 and Crews 1991) providing guidance in the USA and Australia respectively.

It is recommended that the designer follow the design guide which was prepared for that particular country. It is also recommended that, except in Ontario, the designer should contact the main transportation authority (ie: State Roads Authority or equivalent) prior to implementing an SLT design.

Serviceability

As far as the subject of this paper is concerned, we begin by noting that, for the most part, serviceability will govern the design of an SLT deck. This results from the fact that the new SLT system provides a considerable increase in the strength of the SLT deck when compared to similar previous timber deck designs (Taylor et al 1983). In fact, some SLT designs may only be utilising up to 60% of the available design strength.

We hi-light this point because some agencies have elected to waive or violate the suggested or specified limitations for serviceability (ie: allow for lower stiffness or increased deflection). This has been done in an attempt to utilise more of the available strength.

This reduced stiffness can cause the deck to undergo significant permanent deflection due to long term creep under dead loads. This is displayed dramatically by the Trout Rd bridge in state College Pennsylvania, as shown in figure 2. This bridge, along with several others, have permanent sags of 75 mm and more. While such sags may not be detrimental to the strength of the bridge, they can seriously affect drainage and can increase the dynamic effect (impact) of vehicular loading.

Through recent work (Ritter et al 1994) it is now believed that the most significant factor affecting this long term creep is the magnitude of the maximum bending stress under dead load. However, there are no current design provisions aimed at limiting this stress. It would appear that creep has not posed a problem for bridges that were designed to satisfy a limiting deflection under service loads.

In the USA and Canada, where bridges have been designed to satisfy deflection limits of L/360 to L/400 (under specified service loadings) they have exhibited no signs of significant long term creep (Ritter et al 1994, Taylor 1986).

In this regard, it is strongly recommended that the designer satisfy a comparable deflection limit under service loading.

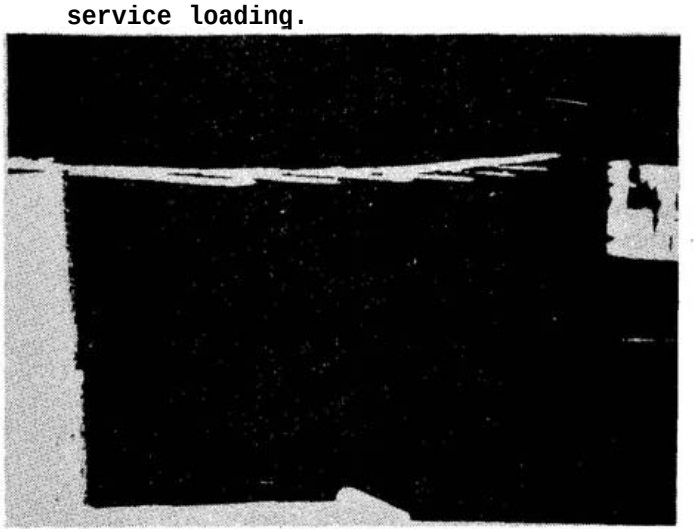

Figure 2 Trout Road Bridge, Penn, USA

Timber species

To-date, in North America, a number of species of timber have been used in the construction of SLT bridges. However, for the most part, these have been structural softwoods and primarily Douglas Fir. Regardless, there does not appear to be any significant difference in performance between species in the softwoods (Taylor et al 1983).

In the USA and Australia, only a limited number of hardwood species have been

used in SLT bridges. However, even in this limited application, it would appear that, if anything, these timbers may provide even better performance characteristics (Taylor et al 1994).

Moisture Content

One of the most important factors which can affect the performance of an SLT deck is the moisture content (MC). Timber will swell and shrink with changes in the MC, which can affect the level of force in the prestressing steel bars (Taylor et al 1983). In this regard we must consider two important aspects.

The first is the initial moisture content at which the timber is installed in the bridge. We should attempt to match the equilibrium MC at which the timber would finally stabilise in the environment to which it is exposed. This assumes, of course, that it will remain stable at some value and we will discuss methods of protection later. If anything, we should assure the timber is drier than required. otherwise, additional drying will result in shrinkage, causing additional losses of the prestressing forces. On the other hand a slight increase in the overall MC will have a positive effect by offsetting the potential losses.

currently the recommended MC of the timber at the time of installation varies depending upon the location (country). Generally, for SLT decks in North America, the timber is dried to between 14% to 19%. In Australia, (specifically in NSW) the timber (hardwood included) is dried to a maximum MC of 15% prior to installation. Regardless, the designer must investigate this requirement and make sure it is *clearly* indicated on the drawings and/or specifications.

DESIGN OF THE PRESTRESSING SYSTEM

In general the prestressing system must be capable of applying and maintaining a lateral pressure on the timber which will prevent slippage of the laminates under loading. Each of the design specifications provide guidance in this regard.

Prestress Pressure and Long Term Losses

It is possible to design a variety of systems which could apply the necessary lateral pressure to the timber. However, the most important consideration is the long term maintenance of this pressure with time. under the influence of this permanent pressure, the timber will creep perpendicular to the laminates, which will reduce the forces being applied. Basically, it is necessary to provide a prestressing system which is elastic enough to offset the effects of creep in the timber.

We should first note that the existing design specifications were derived primarily from work performed on structural softwoods. In this regard, the following discussion relates specifically to softwood timber. However, we will follow up with some commentary on the use of hardwoods as are being used in some parts of the USA and Australia.

By following the existing design specifications, one will discover that it is necessary to utilise high strength post tensioning steel bars of at least 1000 Mpa strength. At the same time, these bars will be stressed to their maximum levels (65% to 70% of ultimate). This introduces maximum elongation in the bars so that, as the wood creeps, the strain potential in the bars helps to offset the potential stress losses. coupled with this, the specifications require that the bars be re-stressed several times during, and shortly after, construction. This further aids in reducing the long term bar force losses.

We hi-light this subject to ensure the designer understands the basis for the use of the high strength prestressing system. Using a lower strength material will provide a stiffer system which will result in higher bar force losses. In the long term this may lead to slip of the laminates under loading.

currently, the same design specifications are being applied to SLT bridges using hardwoods. However, it is becoming apparent, particularly in Australia, that some changes may be forthcoming. Monitoring of bridges built using Australian hardwoods (Taylor et al 1994), has indicated that the effects of creep is far less significant than for softwoods. While we anticipate some changes in the design of the prestressing systems for hardwood bridges, the designer should not vary from the current specifications at this time.

Anchorage Bulkheads

The anchorage bulkheads provide for the attachment of the post tensioning bars at their ends and the subsequent distribution of the high forces to the timber. considering the very high concentrated forces (200 to 400 kN) that must be transferred, it is important to provide a properly designed anchorage bulkhead.

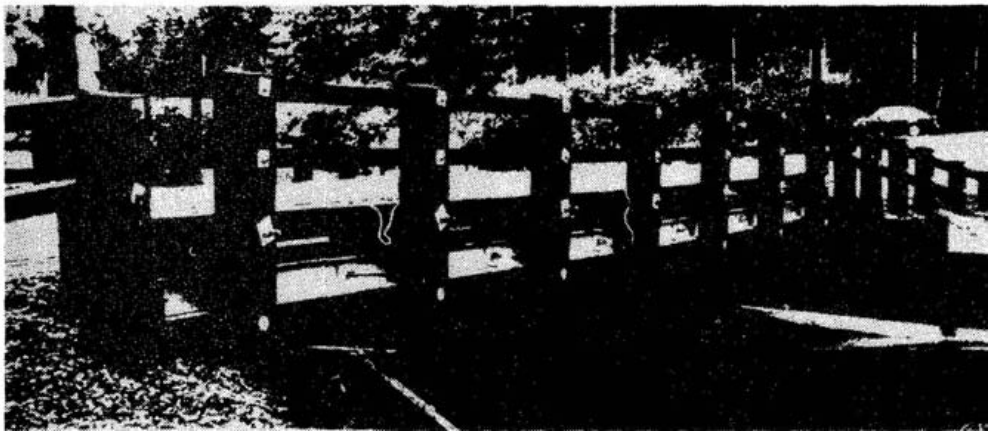

Figure 3 Steel Channel Anchorage Bulkhead

The current specifications were derived for decks built of softwood timber and consequently their use for hardwoods has not presented any problems to date. Therefore, we note that the following discussion pertains specifically to the use of softwood timber.

There are two basic arrangements that are currently considered for use in SLT bridges and these are displayed in figures 3 and 4.

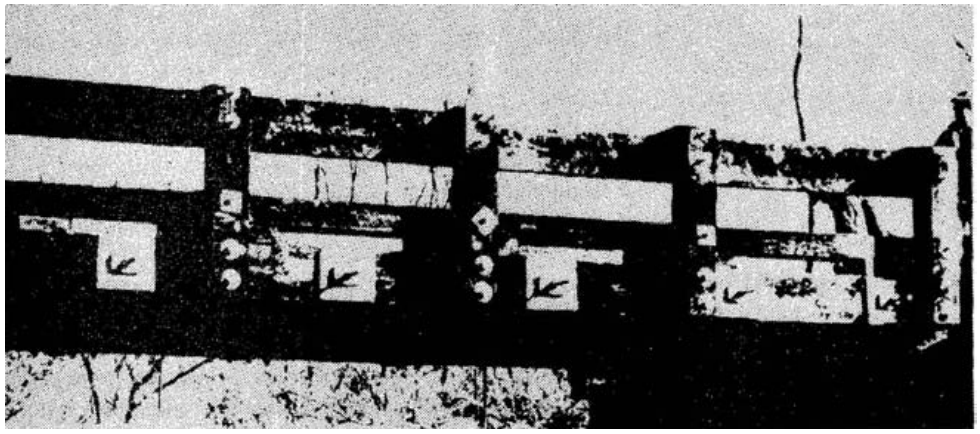

Figure 4 Steel Plate Anchorage Bulkhead

In Ontario, Canada, where the SLT was developed, the most effective form of bulkhead has become the continuous steel channel (figure 3) . This channel, which runs along the full length of the deck, is supplemented by heavy steel plates at the bar locations. This system has not demonstrated any problems in performance (Taylor 1986).

In the USA, while the steel channel has been used, the less expensive discrete plates (figure 4) have been used extensively. However, it has demonstrated varied performance and is losing favour with some designers. While the design bearing stresses on the timber, under the plates, may satisfy the specifications, many of these systems have suffered some crushing of the timber beneath the steel plate.

it is believed that the effects of cyclic moisture lowers the resistance of the timber to bearing perpendicular to the grain. Even where a bridge does not display any signs of distress initially, with time the plates can begin to crush softwood timber. In the USA, due to the cost savings over steel channel systems, the current specifications commonly utilise the discrete plate anchorages. In doing so the us designers accept a slight crushing (3 to 6 mm) of the timber with time (Ritter et al 1994). To prevent crushing on softwood it is necessary to either use the steel channel, increase the plate sizes significantly or alternately utilise several hardwood laminates on the outsides of hte deck.

we should note that, while the crushing damages the aesthetic appearance, it can also significantly affect the bar forces. Consider for example, that for an averate two lane bridge, with the bars stressed to 70% of ultimate (700 Mpa), the bar is elongated only about 30 mm. Therefore, if the timber crushes even 3 mm on each side of the deck, this represents 20% of the bar elongation.

The designer should seriously consider using a steel channel bulkhead or several hardwood outer laminates, particularly in high moisture environments.

DESIGN DETAILING

There are two objectives in detailing all timber bridges. One is to keep the timber dry and the other is to maintain structural integrity. By the latter we mean to ensure that the bridge performs as an integral system and not as a loose assemblage of components. Both of these areas have commonly been the source of failure (in terms of durability and/or maintenance) for many timber bridges in the past.

STRUCTURAL DETAILING

we will begin by discussing some of the structural detailing which can affect the long term performance of the SLT bridge.

Laminate Layout and Butt Joints

It is necessary to introduce butt joints into a laminated deck in order to accommodate the limited lengths of timber available on the market. The effects of these butt joints, or so-called *discontinuity's,* on the strength and stiffness of an SLT deck, is in itself worthy of a formal paper. suffice it to say that the butt joints, depending on the number and frequency, can seriously affect both the strength and stiffness of the deck (Crews et al 1994, Jaeger & Bakht 1990).

The present specifications have proven adequate and the designer should not vary from them.

Nailing

only the Ontario specifications specifically require that the laminates in SLT bridges be nailed during construction. However, some agencies in both the USA and Australia have adopted this policy. Basically this nailing facilitates construction. It also provides a limited assurance of performance should a major failure occur in the prestressing system in the future.

The designer should be specific about nailing and prevent over-nailing of an SLT deck. Too many nails can initially resist the compression of the laminates as the deck is stressed together. subsequently, this resistance is overcome with time, and only then does the timber begin to properly undergo creep. This belated creep can occur after the period of re-stressing cycles mentioned earlier, which are specifically designed to offset the creep effects. The result can be an increase in the long term losses of the prestressing force.

Deck Tie-Downs

It is important to note that the deck can undergo considerable lateral movement (narrowing) during the initial prestressing. Therefore, in general, the deck should not be tied down to the supports until after it has been fully stressed.

The designer should note that the final restressing of an SLT deck will generally occur after the deck has been completed and installed. Therefore, the tie downs, particularly those near the outsides of the deck, should be able to accommodate some movement (usually only a few millimetres). coupled with this is the need to ensure the tie downs can be accessed to re-tighten them in the future.

Expansion Joints

Joints in bridge decks have always been a source of maintenance problems with all bridge types. In the past, most timber bridges have received very little attention in the area of expansion joints, even at the abutments. This has resulted from the fact that previous timber bridges represented a somewhat loose assemblage of members. As such, any expansion and contraction of the components was easily absorbed by the inherent spaces between them. The new SLT decks are continuous slabs and it is important that some attention be given to the effects of temperature.

In North America most SLT decks are not provided with expansion joints. The wearing surface is usually continuous over the transition between the deck and the approach. Generally, it is accepted that the bitumen will crack at the abutment to relieve temperature stresses. This has not proven to be a maintenance problem as the surface does not appear to deteriorate (Ritter et al 1994).

In Australia, as discussed earlier, improved moisture protection is necessary. As such, we must provide a more sophisticated approach to prevent or minimise the effects of moisture penetrating at the abutments. To-date three forms of joints have been specified for SLT decks in NSW:

- compression seals
- Therma joints
- Open joints

Any one of these approaches can be used successfully, however is important that proper air circulation is provided beneath any sealed joint to prevent moisture build up. If a joint is not 100% effective, it can allow moisture to penetrate and then restrict subsequent drying. A sample joint detail for a compression seal is shown in figure 5. Here the end gap between the deck and the abutment sill is kept to at least 40 mm wide.

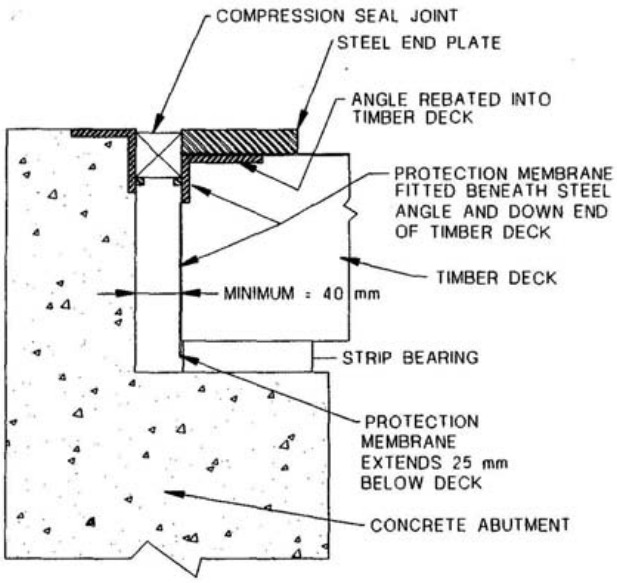

Figure 5 Compression Seal Deck Joint

Guard Rail Post Attachment

The SLT deck provides a much stiffer and stronger medium, than previous timber decks, for the attachment of guard rail posts. A number of acceptable details have been used (Taylor and Keenan 1992) some of which have been supported by crash testing in the USA.

Regardless of the basic design, it is strongly recommended that no attachments be made directly to the steel anchorage bulkheads on an SLT deck. Unless they are detailed to break away from the anchorage bulkhead under impact, collision loads can seriously damage the prestressing bars.

DRAINAGE AND MOISTURE PROTECTION

Proper drainage and moisture protection of the timber deck go hand in hand. It is important that a bridge deck shed water as quickly and efficiently as possible. At the same time, the timber itself should be protected against direct moisture penetration.

Drainage

It must be recognised that, unlike previous timber decks which usually consisted of individual planks, the SLT deck does not allow water to drain through the deck itself. Also, unlike a concrete deck, we cannot shape the SLT deck to provide a two way cross fall for drainage. The SLT deck must remain planar or the high prestressing forces will introduce lateral component forces. This would impart loads on the tie downs as well as causing the deck to distort.

Generally we can form a two way cross fall using the bitumen surface, by varying the depth from the centreline to the shoulders. It is also possible to form a one way cross fall (either transverse or longitudinal) by sloping the timber deck itself. Regardless, some form of cross fall should be provided to shed the majority of water during rain.

In addition to cross fall, it is essential to provide access for the water to exit the bridge. Typically in the past we have used raised kerbs to allow the water to run off the sides of the bridge (figures 3 & 4). However, this usually sheds the water directly onto other components and, in the case of SLT decks, onto the steel anchorage bulkheads.

Since the SLT deck forms a continuous timber slab, it is possible to install drains through the deck as shown in figure 6. Typically these drains would be round, and the holes would be drilled after the deck has been constructed. The drain pipe can be extended as far below the deck as necessary to protect any other components from the discharge.

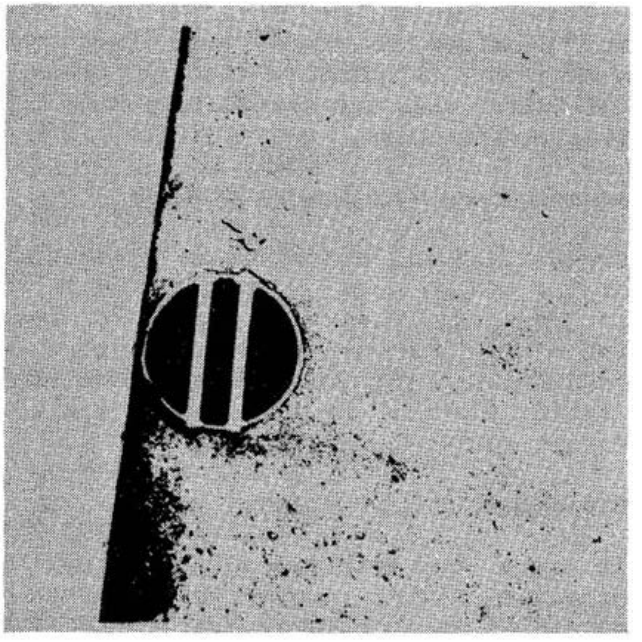

Figure 6 Through Drain in an SLT Deck

Water Proofing the Deck

Even with proper drainage, water will still penetrate the bitumen surface. It is essential that we protect the timber from moisture.

In North America the majority of SLT bridges utilise timber which is treated with heavy oil-borne preservatives. In most cases the only (top) surface treatment is a tack coat spray followed by a bitumen wearing surface. The impregnated oil in the timber, coupled with a bitumen surface, appears to provide a reasonable moisture barrier (Ritter et al 1994).

In Australia most hardwood SLT bridges are not preservative treated, and the softwood decks are not treated with heavy oils. Therefore, it is necessary to provide some specific protection against moisture penetration on the top of the SLT decks.

Water Proof Membranes in NSW

Basically three types of water proofing membranes have been applied in New south Wales: rubberised bitumen, sprayed Polyurethane Elastomer and sheet type (wolfin) membranes.

The rubberised bitumen has successfully been applied with no problems. It is assumed that it provides a good protection against moisture penetration.

The sprayed polyurethane elastomer coating has been used several times on SLT decks (Taylor et al 1994). To-date, it has proven to be durable and appears to provide adequate adhesion for the bitumen surface. However, care must be taken to assure strict control during application as the constituents are mixed on site.

The wolfin sheet membrane is only now being evaluated for SLT bridges. It is a tough membrane which has been used successfully on concrete bridges in Europe. However, both the membrane and the adhesive, can react to the heat of hot asphalt. In one respect this is advantageous, as it allows the membrane to form to any uneven areas on the timber. However, in order to protect against movement of the membrane during paving, it is necessary to initially apply a thin (insulating) sand asphalt coating prior to paving (Taylor 1994).

MATERIALS AND CONSTRUCTION

We have already covered a lot of points which directly relate to the materials and construction of SLT decks. Like some of the other topics, the subject of construction could easily become a paper in itself. Therefore, we will only hi-light some of the areas which we feel could have ramifications on the long term durability of an SLT deck.

Materials

We have noted a number of areas relating to the timber that must be considered, particularly the initial moisture content of the timber. The species, preservative treatment (when required) and the grade of the timber is also important.

Protection of the steel components is also required. While most of the steel will be hot dipped galvanised, the high strength prestressing steel may require alternate treatment such as epoxy coating. It should be noted that these materials usually receive considerable handling during the construction of an SLT deck. As such, the protective coatings can become damaged and must be repaired in order to ensure long term durability.

It is essential that some method of quality assurance be used to enforce the material requirements.

Deck Assembly

The assembly of an SLT deck can be performed either in situ (on the permanent supports) or by prefabrication. In either case, it is important that the deck be constructed such that it remains planar and properly aligned. In the case of a prefabricated deck the temporary supports must be level and square.

Prestressing the Deck

During the initial assembly of a deck, even with the nailing as discussed earlier, it is not possible to achieve full contact between the sides of the laminates. The inherent warps and twists contained in the laminates can introduce spaces between them that can total as much as 5% of the overall deck width.

With all these spaces it is essential that the deck be compressed together evenly to prevent distortion. Applying the full design forces in only a few bars at a time, can seriously distort the deck out of square. The resulting internal stresses can also cause the deck to distort out of plane.

Theoretically, we should use as many hydraulic jacks as possible to ensure uniform compression. However, caution is advised when using multiple jacking systems. Even when connected to a common hydraulic manifold, identical jacks can display different rates of movement at low pressures. We note this because most of the lateral movement in the deck will occur before any significant pressure is achieved.

In the USA, experience has shown that distortion can be minimised by gradually stressing the deck in three of four stages (Ritter et al 1994). This allows the spaces between the laminates to close evenly.

It is also possible to remove some of the spaces between the laminates prior to applying any hydraulic jacks. This can also be achieved in stages by sequentially tightening the nuts (by hand) an equal amount on each bar along the bridge (Taylor 1993 & 1994). The process is repeated until reasonable resistance is reached at each anchorage. care should be taken not to over tighten the anchorage nuts, as they are not specifically designed for this purpose.

Regardless of the approach taken, it is essential that the geometry of the deck be monitored and recorded during the process.

Bearing on the Supports

It is very important to obtain uniform bearing of the SLT deck on the supports. Otherwise the deck may move under loading and this can be reflected in the wearing surface.

Generally, minor variations in bearing contact can be corrected using a thixotropic paste between the deck and the support. using the tie downs to correct local distortions can require high forces and is not recommended unless they have been designed for that purpose.

Experience in Australia has shown that the hardwood decks are much stiffer than the softwoods. In this regard it is more difficult to correct uneven bearing. One successful method of correction is to partially de-stress the deck, and then tap the high laminates down until they contact the bearing (Taylor 1993).

Attachments

Except for holes that may be required to lift or launch a prefabricated deck, no other holes should be drilled, or attachments installed, until after the deck has been completed. Otherwise the alignment of these holes will be affected during stressing. In addition, the movements during stressing can seriously affect any pre-installed bolted connections.

CONCLUSIONS AND RECOMMENDATIONS

While there is some degree of latitude for the designer, it is essential that he or she understand the basis and importance for some of the design specifications. We can summarise the more important areas as follows:

1. While it is important to ensure adequate strength, it is just as important to satisfy a minimum serviceability requirement. It is suggested that the deck be designed to satisfy a maximum vertical deflection of not greater than L/350 under the applicable service loading for that jurisdiction.
2. The requirements for the timber must be clearly specified and a quality

assurance program applied to enforce them. A maximum moisture content, as outlined previously, should be required for the timber.

3. The prestressing system must be designed to provide the proper elastic response to offset creep. The current specifications should be followed.
4. The anchorage bulkheads should be detailed to prevent or minimise crushing of the timber. The current specifications should be followed.
5. The current empirical requirements for the detailing of the prestressing system and laminate layout are based upon successful field applications. The designer should not vary from these requirements without some supportive test data.
6. Attention should be given to the detailing of expansion joints and tie downs to ensure long term performance. Both should be accessible for future repair and/or re-tightening.
7. Proper drainage should be provided, as well as additional surface protection for timber that has not been treated with heavy oils.
8. Care should be taken during the assembly and stressing of an SLT. The geometry should be monitored continuously to ensure it remains plane and square.
9. No attachments should be installed, or holes pre-drilled, until after the deck has been fully stressed.

REFERENCES

-AASHTO Supplement, 1991, ``Guide Specifications for the Design of Stress Laminated Wood Decks'', Washington, D.C.

-Csagoly, P. & Taylor, R., 1980. ``A Structural Wood System for Highway Bridges'', International Association for Bridge and Structural Engineering, Vienna, Periodica 4/1980, pp 157-183

-Crews, K., 1991, ``Guideline Design Procedures for Douglas Fir Longitudinal Stress-Laminated Timber Bridge Decks'', Western Wood Products Association, Sydney

-Crews, K., Carter, D. & Taylor, R., 1994, ``Ultimate Load Behaviour of Stress Laminated Timber Plates and Cellular Decks: Implications for Design'', Proceedings: 1994 AUSTROADS Bridges Conference, Melbourne

-Jaeger, L. & Bakht, B., 1990, ``Effects of Butt Joints on the Flexural Stiffness of Laminated Timber Bridges'', Canadian Journal of Civil Engineering, vol 17, no. 5, pp 859-864

-OHBDC, 1991, ``Ontario Highway Bridge Design Code'', Ontario Ministry of Transportation, Ontario, 3rd edition.

-Ritter, M., Wacker, J. & Duwadi, S., 1994, ``Field Performance of Stress Laminated Timber Bridges on Low Volume Roads'', Draft Paper for the 6th International Conference on Low Volume Roads (June 1995), Madison, Wisc.

-Taylor, R., 1986, ``Applications in Prestressed Wood'', 2nd International Conference on Short and Medium Span Bridges, Ottawa, CSCE, vol. 1, pp. 31-41

-Taylor, R., 1993, ``The Construction and Launching of a Stress Laminated Timber Bridge Deck at Molong, NSW'', R. J. Taylor Consulting P/L, Report to the RTA, 93008RPT, Sydney

-Taylor, R., 1994, ``Construction and Installation of a Stress Laminated LVL Deck at McGraths Hill'', R.J. Taylor Consulting P/L, Report to the RTA, 93702D-R, Sydney

-Taylor, R., Batchelor, B. & Van Dalen, K. 1983, ``Prestressed Wood Bridges'', International Conference on Short and Medium Span Bridge Proceedings, Toronto, Canadian Society for Civil Engineering, vol 2, pp 203-218

-Taylor, R., Carter, D. & Crews, K., 1994, ``Field Applications of Stress Laminated Timber Decks in NSW'', Proceedings: 1994 AUSTROADS Bridges Conference, Melbourne.

-Taylor, R. & Csagoly, P., 1978, ``Transverse Post Tensioning of Longitudinally Laminated Timber Bridge Decks'', Transportation Research Record 665, Bridge Engineering vol. 2, pp 236-244

-Taylor, R. & Keenan, F., 1992, ``Wood Highway Bridges'', Canadian Wood Council, Text Series No.2, Ottawa

-Taylor, R. & Keith, J., 1994, ``The Past, Present and Future of Stress Laminated Timber Bridges'', Pacific Timber Engineering Conference, Gold Coast, Australia.

PRINTED WITH SOY INK on recycled paper

In: PTEC 94 Timber shaping the future: Proceedings of Pacific timber engineering conference; 1994 July 11–15, Gold Coast, Australia. Fortitude Valley MAC, Queensland, Australia: Timber Research and Development Advisory Council: 686–694. Vol. 1.