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**Design, Construction, and Quality Control
Guidelines for Stress Laminated Timber Bridge Decks**

West Virginia Univ., Morgantown

Prepared for:

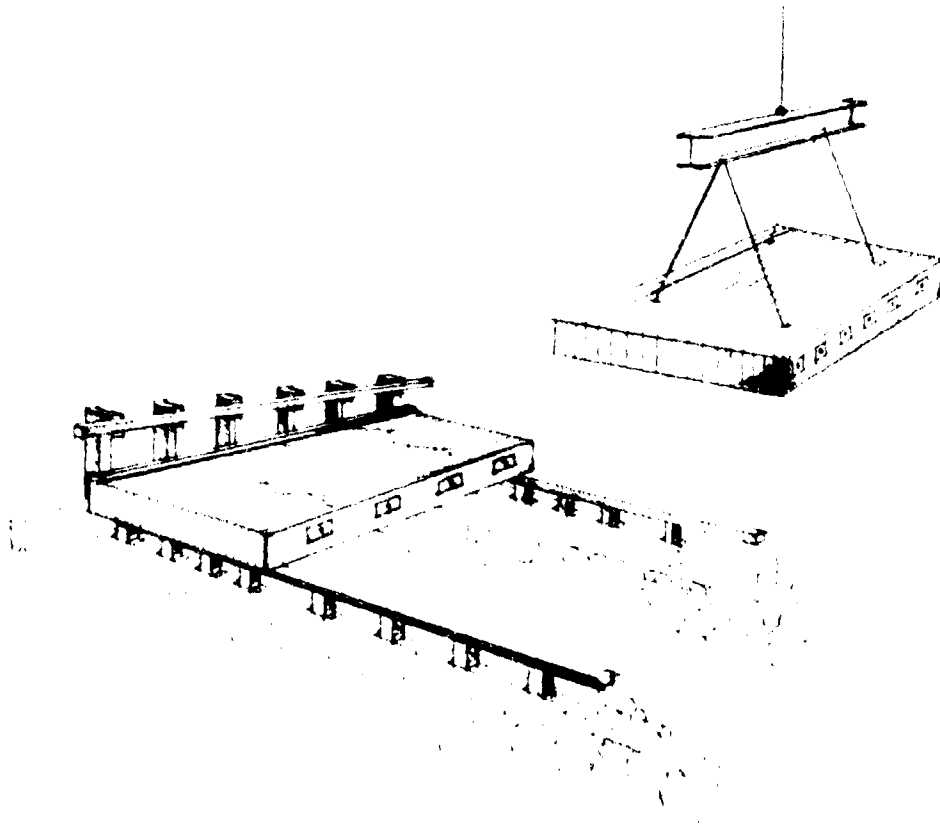
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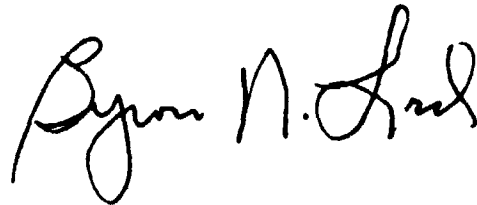
US Department of Transportation
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Research and Development
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McLean, Virginia 22101-2296

FOREWORD

This study is part of a research effort on low-cost timber bridge technology conducted by the Constructed Facilities Center at West Virginia University in cooperation with the Federal Highway Administration.

This publication discusses most aspects of the behavior of stress-laminated timber bridge decks. It offers specific guidelines on quality control of timber and steel bridge materials and step-by-step design procedures based on AASHTO specifications. It also presents general guidelines for construction, field-monitoring, inspection, and maintenance procedures. This booklet is written primarily for design engineers and inspectors concerned with timber bridges. Two other similar booklets dealing with corrosion of steel hardware and timber substructures are also being produced under the CFC-FHWA Timber Bridge Research Program.




Byron N. Lord
Acting Director, Office of Engineering and
Highway Operations Research and
Development

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16. Abstract

Under the U.S. National Timber Bridge Initiative Program, sponsored by Congress in 1989 and administered by the United States Department of Agriculture, Forest Service, approximately 130 modern timber bridges are currently in service in 41 participating States. Most of these bridges use stress-laminating technology. Considerable research on stress-laminating technology has been completed in the USA and has provided design, construction, and inspection guidelines for timber bridge decks. Guidelines for the design of stress-laminated timber decks have been published by AASHTO, but they do not provide comprehensive information on materials, construction, and inspection. Therefore, this document presents: (1) background information on timber bridge materials and their quality control; (2) a comprehensive step-by-step design procedure based on the 1991 AASHTO Guide Specification; and (3) guidelines for construction, field monitoring, inspection, and maintenance procedures. Potential fabrication problems are discussed, and an inspection checklist is included. This publication is part of a collection of three booklets of the study "Education and Technology Transfer," under the Timber Bridge Research Program. The other two booklets are:

FHWA-RD-92-044 COFROSION PROTECTION OF STEEL HARDWARE USED IN MODERN TIMBER BRIDGES

FHWA-RD-93-024 TIMBER SUBSTRUCTURES FOR BRIDGE APPLICATIONS

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PREFACE
TIMBER BRIDGE RESEARCH PROGRAM

Congress, in its fiscal year 1990 Appropriations Act, directed the Federal Highway Administration to cooperate with the Constructed Facilities Center in the planning and expenditure of \$500,000 for low-cost bridge technology involving wood.

This program was guided by the Timber Bridge Research Council (TBRC) formed by the Federal Highway Administration (FHWA), which includes the following representatives from the Federal, State, and county governments and industry:

Federal Highway Administration

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David H. Densmore
Donald Miller
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USDA Forest Service

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**American Association of State Highway
and Transportation Officials**

Donald J. Flemming, P.E.

American Wood Systems

Thomas G. Williamson

The TBRC at a joint meeting with the National Forest Products Association (NFPA) developed and prioritized a list of research topics to be conducted by the FHWA. The following three studies were conducted under this program:

<u>Priority</u>	<u>Description</u>
1.	Timber Bridge Rail Testing and Evaluation
2.	Education and Technology Transfer
3.	Design Optimization of T, Bulb-T, and Box-Stressed Timber Bridges

These topics were endorsed by the AASHTO Technical Committee on Timber Structures. This booklet is part of the second study "Education and Technology Transfer." It highlights the materials, design, construction, transportation, installation, inspection, and monitoring of stress-laminated timber decks. Other booklets are on timber substructures and the corrosion protection of steel hardware used on timber bridges.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH					LENGTH				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
AREA					AREA				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	square meters	1.195	square yards	ac
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	square kilometers	0.386	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	l	l	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	cubic meters	35.71	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	cubic meters	1.307	cubic yards	yd ³
NOTE: Volumes greater than 1000 l shall be shown in m ³ .									
MASS					MASS				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION					ILLUMINATION				
lc	foot-candles	10.76	lux	l	lx	lux	0.0929	foot-candles	lc
ftl	foot Lamberts	3.426	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.2919	foot Lamberts	ftl
FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS				
lbf	pound-force	4.45	newtons	N	N	newtons	0.225	pound-force	lbf
psi	pound-force per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	pound-force per square inch	psi

111

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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CHAPTER 1. INTRODUCTION

PURPOSE AND SCOPE

Stress-laminated timber decks were first designed in Canada in the mid-1970's as a method of rehabilitating existing nail-laminated bridges. The success of this method for rehabilitation led to further investigation of stress-laminated decks. Based on research contributing to the development of stress-laminated decks, the 1983 Ontario Highway Bridge Design Code incorporated design procedures for stress-laminated timber bridges.⁽¹⁾

Under the *U.S. National Timber Bridge Initiative Program*, sponsored by Congress in 1989 and administered by the United States Department of Agriculture, Forest Service, 130 modern timber bridges will be in service by 1992 in 41 participating States. Most of these bridges will use stress-laminating technology.

Stress-laminated timber bridge decks consist of sandwiched lumber boards transversely post-tensioned by high-strength steel bars that pass through holes predrilled on the wide-face of the boards. The threaded steel bars are tensioned using a hydraulic jack and are anchored against steel-bearing plates resting over the outer timber laminae (figure 1). The compression within the timber lamination and the frictional resistance to sliding between laminae are the mechanisms that permit the lumber components to act as an integrated plate.^(2,3) The compression exerted by the high-strength steel threaded bars allows the use of lumber components with end-to-end butt joints to span the length of the bridge. The maximum practical span of an economical stress-laminated deck is approximately 30 ft (9 m). To allow for larger spans or larger loads, designs of T-sections [up to 60 ft (18 m)] and box-section [up to 110 ft (34 m)] have been developed.^(4,5)

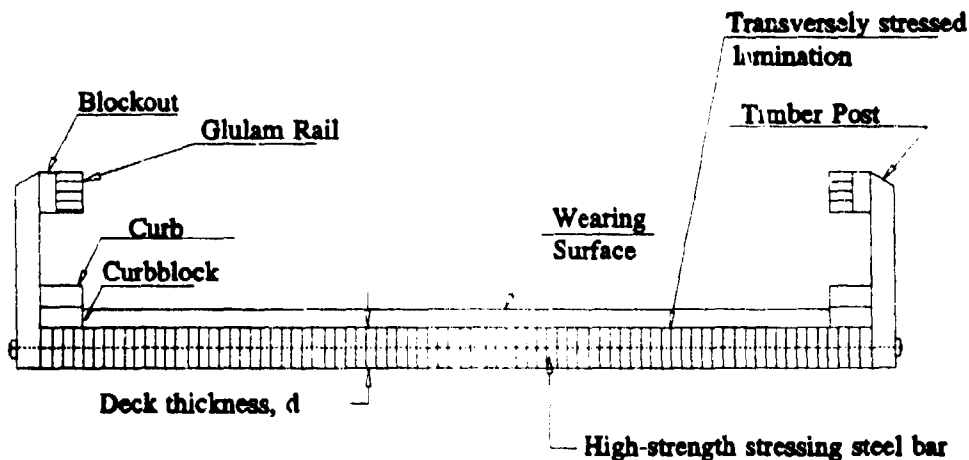


Figure 1. Schematic of stress-laminated deck.

Considerable research completed in the United States has provided design, construction, and inspection guidelines for stress-laminated deck bridges. Three recently published guidelines are Timber Bridges Design, Construction, Inspection, and Maintenance; Guide Specifications for the Design of Stress-Laminated Wood Decks; and Quality Assurance and Inspection Manual for Timber Bridges. (6,7,9)

The objectives of this booklet are: (1) to present background information on timber bridge materials and their quality control; (2) to present a comprehensive step-by-step design procedure based on the 1991 AASHTO guide specifications; and (3) to recommend guidelines for construction, field monitoring, inspection, and maintenance procedures.

Information on decking material, curb and rail, steel components, and treatment of wood and steel is presented in chapter 2. The design methodology and a design example are given in chapter 3. Important considerations in the construction of stress-laminated timber decks are discussed in chapter 4, which also includes potential fabrication problems and field monitoring guidelines. Inspection and quality control guidelines, followed by a checklist are given in chapter 5.

CHAPTER 2. MATERIALS

INTRODUCTION

Longitudinal stress-laminated timber deck superstructures consist of assemblies of lumber laminae placed edgewise and compressed transversely with high-strength steel bars. Vertical slippage of adjacent lumber laminae is prevented by maintaining an adequate amount of transverse compressive prestress between the laminae. This section provides an overview of timber and steel materials and includes steel corrosion protection and wood preservative treatment. For more detailed information on these issues see references 1, 5, 6, 7, 8, and 9 listed at the end of this manual.

DECKING MATERIAL

Longitudinal stress-laminated decks are constructed from visually graded or machine stress rated lumber in the *Joists and Planks* size classification [nominal 2 to 4 in (51 to 102 mm) thick, 5 or more in (127 mm) wide]. Although decks could theoretically be constructed from any lumber thickness, the 2- to 4-in (51- to 102-mm) thickness range has proved to be efficient and economical. The lumber may be dressed or rough-sawn. However, rough-sawn material must be surfaced to a uniform thickness to ensure full contact and uniform bearing between the laminae. Stress-laminated decks can generally be built from any lumber species, provided the lumber species meets design requirements for strength and stiffness and is treatable with preservatives. Each of the individual boards must be cut to length and all machining must be done prior to preservative treatment. In addition, the lumber boards must be free of excess preservative.

CURB AND RAIL

Guiderail posts, curbs, curb blocks, and guiderails can generally be built from any lumber species in the *Beams and Stringers* category or the *Post and Timber* category, provided the lumber species meets design requirements for strength and is treatable with preservatives. Currently two types of AASHTO-approved guiderail systems are in use, one made entirely of timber and the other made of galvanized steel guiderail on either timber or steel posts.

STEEL COMPONENTS

The prestressing system provides the required compressive force to ensure adequate performance of a stress-laminated deck. The prestressing elements include high-strength steel bars, anchor plates, bearing plates or channels, and fasteners. The steel bars are placed through the timber lamination and secured against anchorage plates with high-strength steel nuts.

Steel Bars

The high-strength steel threaded bars used in stress-laminated timber bridges transmit the required compressive force to the assembly of timber components and allow the system to act as a plate (see figure 2). Threaded bars for stress-laminated timber bridges must meet strength and corrosion protection requirements and should be able to fit into the hollow-core jack used for stressing operations. The ultimate strength of these bars is between 120,000 lb/in² (827 MPa) to 150,000 lb/in² (1033.5 MPa) and they are available in nominal diameters of 5/8 in (15.8 mm) to 1-3/8 in (35 mm). High-strength steel bars are manufactured in conformance with ASTM A 722-82 and ASTM A 615-82.^(10,11)

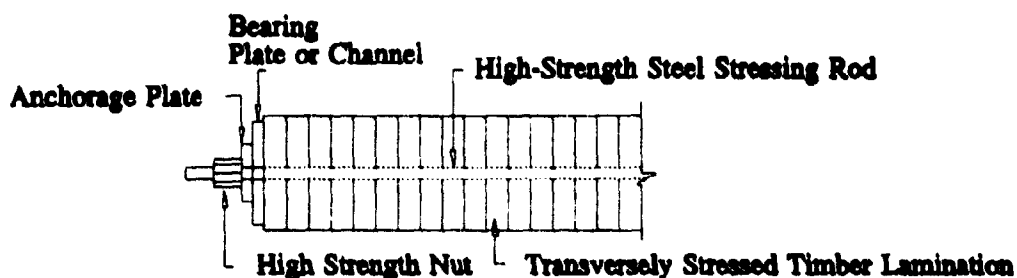


Figure 2. Steel stressing system for stress-laminated timber.

Anchorage Plates

The purpose of the anchor plates used in stress-laminated timber bridges is to allow proper seating of the stressing nuts and to distribute the bar-force over the bearing plate or channel (figure 2). Any type of steel plate that can support the applied loading and can be protected against corrosion is acceptable, but generally ASTM A36 steel is specified.⁽¹²⁾

Bearing Plates or Channels (Bulkheads)

The loads transmitted by the anchor plates are distributed over the timber assembly by the bulkheads (figure 2). Due to the large compressive force exerted by the bars, the area of the bulkhead in contact with the timber deck must be sufficiently large to prevent crushing of the outer lumber laminae. Bulkheads can be fabricated from various rolled steel shapes such as channels and plates. They can be continuous over the length of the bridge or they can extend only over a portion of the bridge, depending upon the design. ASTM A36 steel is typically used, but any steel that can be protected against corrosion and can carry the loads transmitted by the anchor plates is acceptable.

Steel Fasteners

Steel fasteners used in timber bridge construction include common and high-strength bolts, lag bolts, spikes, drift bolts and pins, shear plates, split rings, and special connectors. All of these fasteners must be protected against corrosion, and the plans and specifications for each project should be checked to insure that the proper fasteners are used.

TREATMENT OF WOOD/STEEL

This section describes the methods recommended to protect the steel components against corrosion and the preservative treatment needed to inhibit timber decay.

Corrosion Protection of Steel

High-strength steel bars and anchorage elements are susceptible to corrosion. Thus, to ensure the longevity of the superstructure, it is necessary to provide adequate corrosion protection for the steel stressing components. The most significant corrosion protection techniques include metallic coatings, non-metallic coatings, and sheathing and grouting.

- **Metallic coatings.** Coating a metal with another metal having different properties can provide corrosion protection in two different ways. The coating can act as a physical barrier from the corrosive environment; conversely, a coating with a more negative galvanic potential than the base metal will protect the base metal by acting sacrificially as an anode in an electro-chemical corrosion process.

The ability of the Zinc coating to protect the steel galvanically accounts for its application in corrosion protection.⁽¹³⁾ There are various types of zinc coatings available for corrosion protection depending on the application. The most commonly used for timber bridges is hot dip galvanizing.

Hot dip galvanizing is the process of coating fabricated steel material with a thin layer of zinc metal. This process is performed by immersing the steel material into a molten bath of zinc. The galvanizing process consists of two basic steps: (1) surface preparation, and (2) galvanizing.⁽¹⁴⁾

- (1) **Surface Preparation.** Surface cleaning for hot dip galvanized steel consists of: chemical cleaning, acid pickling, rinsing, and fluxing; or sand (or metal shot) blasting and fluxing.

Chemical cleaning. The chemical cleaning requires the use of a hot alkali solution to remove organic compounds such as dirt, paint, markings, grease, and oil.

Acid pickling. This process removes mill scale and rust from the steel surface by pickling in a dilute solution of hot acid or hydrochloric acid at ambient temperature. Acid pickling by double dipping a section of steel article can cause hydrogen embrittlement of the steel; which can lead to sudden fracture of components subjected to tension (e.g., stressing bars). Therefore, acid pickling of high-strength steel bars is not recommended.

Alternate method of surface preparation. Steel can also be prepared by using abrasive cleaning as an alternative to or in conjunction with chemical cleaning. Abrasive cleaning uses air blasting with sand or metal shot propelled against the steel. If this method is used, generally the acid pickling process is avoided. This method is highly recommended for critical steel items used in timber bridges (e.g., elements subjected to high tensile stress).

Rinsing. If the chemical cleaning method is used for surface preparation, the component must be rinsed immediately to prevent hydrogen embrittlement. This embrittlement occurs when the steel is exposed to an acid solution and rinsing is not performed within an adequate period of time. To avoid this problem, an abrasive cleaning method (sand blasting) can be used.

Fluxing. The fluxing process is the last step in surface preparation for galvanizing. Fluxing allows the removal of oxides, prevents the further formation of oxides on the steel surface, and helps zinc bond to the steel surface.

- (2) **Galvanizing.** The steel components are immersed into a molten bath of zinc at 850 °F (454 °C). Hot dip galvanizing forms a coating that thoroughly covers the material, including edges, seams, and welds. The size of the material to be galvanized by the conventional pot method is limited to the size of the galvanizing tank. Items up to 60 ft (18 m) long may be treated by dipping first one end and then the other.

The minimum thickness of the zinc coating of hot dip galvanizing, meeting ASTM specifications, is influenced by: the chemical composition of the base metal, surface condition, bath immersion time, and bath withdrawal rate. Excess zinc metal should be removed from the threads of nuts and couplings, but the zinc coating on threads should not be subjected to any finishing tool operations. However, nuts may be tapped after galvanization. Under adverse environmental conditions, a service-life of approximately 10 to 20 years, defined as the time of first-maintenance (5 percent rusting of the steel surface), can be expected from galvanized products with a coating thickness of approximately 4 mils [0.004 in (0.025 mm)].⁽¹⁵⁾

- **Non-Metallic Coatings.** In the control of corrosion by protective coatings, non-metallic barrier coatings are currently used. The barrier coating provides protection by shielding the steel from the surrounding environments and, in some instances, by containing reactive materials (usually pigments) that react to inhibit corrosion. Protective barrier coatings include organic (epoxy) and inorganic coatings. For the corrosion protection of the steel components used for timber bridges, only epoxy coatings are specified, and therefore, this is the only non-metallic protective barrier discussed in this manual.

The process of epoxy coating a steel component is quite simple and efficient. The steel elements are placed through shot mills to remove mill scale, rust, grease, and other contaminants. The cleaned components then go through a heating process to bring the steel temperature to 450 °F (232 °C), which is required to melt the powder epoxy resin that is electro-statically applied to the steel components. This application occurs in a chamber where the charged resin particles are attracted to the steel. During this period, the melted epoxy cures on the steel. The coated article is then cooled in a water quench and checked for holidays with a volt holiday detection device that locates cracks in the coating. Any defects are repaired with a cold epoxy mix that is compatible with the electro-statically applied epoxy. Epoxy coatings must conform to ASTM D3963-82 and AASHTO M284.^(15,16)

- **Sheathing and Grouting.** In addition to metallic and non-metallic protective coatings, a PE (Polyethylene) plastic tube conforming to ASTM 1248 and filled with grease can be placed over the stressing bars used in stress-laminated timber bridges. The holes in the bridge deck must be large enough to allow the bearing plate tube and the PE tube to overlap (see figure 3). To fit the bearing plate tube into the deck, holes of adequate diameter must be cut in the outer deck boards. After the bearing plates are pushed over the PE sleeve, the bearing plate tube is filled with grease. Once the stressing is completed, a PE cap is placed over the end of the stressing bar. For more specific information on corrosion protection of steel components used in stress-laminated bridges, see references 9 and 17.

Potential Problems

Potential problems associated with galvanizing and epoxy coatings include hydrogen embrittlement and cracks in the epoxy, as discussed next.

- **Hydrogen embrittlement.** If chemicals are used to clean the steel surface prior to galvanizing and if any part of the steel product is dipped two times in the acid pickling tank; or if the acid is not rinsed off the steel quickly enough, a potential problem exists due to the addition of hydrogen into the steel product. This phenomenon is known as hydrogen embrittlement and is particularly damaging to high-strength steel bars. To avoid hydrogen embrittlement, sand blasting is the recommended method of cleaning the steel product.
- **Cracks in the epoxy coating.** As long as the epoxy coating is continuous, the

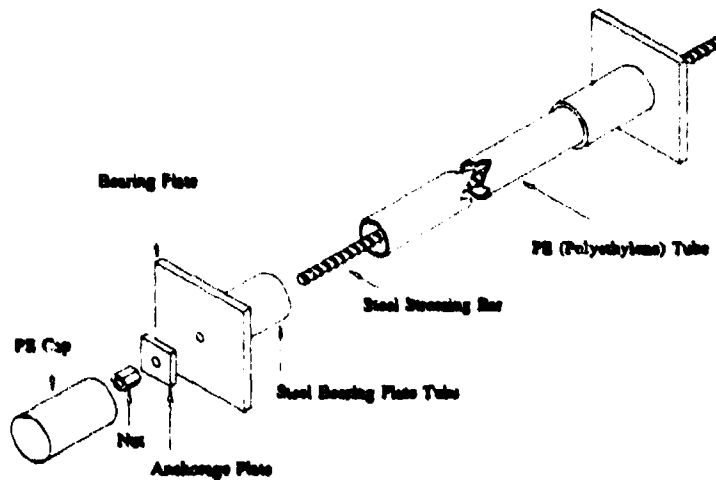


Figure 3. Typical PE-covered, grease-filled system.

protection is excellent. However, inevitable tears due to handling or threading operations can initiate corrosive activity which can intensify with time. The damage must be repaired with the same material used for patching of epoxy-coated steel products.

Wood Protection

Timber deterioration can be caused by fungi, bacteria, insects, and marine borers. The resistance of timber to the many agents of destruction can be increased by the injection of toxic preservative chemicals into the wood cells.

Wood preservatives are classified as either water-borne or oil-borne preservatives. This classification is based on the pesticide's carrier employed in treatment. In general, oil-borne preservatives, such as creosote, are more effective in wet conditions because they help to shed liquid water, but the treated wood is difficult to paint or glue.⁽⁹⁾ Because most oil-borne preservatives can cause skin irritations, they should not be used for applications that require repeated human or animal contact. On the other hand, water-borne preservatives, such as chromated copper arsenate (CCA), are safe and easy to handle but readily absorb liquid water which may cause checking after successive wetting and drying. The use of wood treated by these preservatives is not restricted but must be accompanied by a consumer information sheet which describes proper handling and storage. Creosote is the most commonly used preservative chemical for stress-laminated timber bridges. For more specific information on preservative chemicals and their application, refer to the American Wood Preserver's Association (AWPA) standards.⁽¹⁸⁾

The depth of the preservative injected into a wood member called penetration, and the quantity of the preservative retained in the treated wood called retention, determine the effectiveness of the preservative.⁽¹⁹⁾ Based on acceptable retention and penetration levels of preservative treatment, the AASHTO guide specification recommends the following species as suitable for timber bridge decks:⁽⁷⁾ douglas-fir, hem-fir, red pine, eastern white pine, and southern pine. Information for treatment of other species is provided by the AWWA and, as an example, levels of retention of creosote for red oak and southern pine are summarized in table 1. Additional information for other species including red maple and red oak is given in references 6 and 20. It should be noted that penetration and retention are not directly related and should be specified separately. Only penetration can be visually inspected, retention must be certified by the treater.

Table 1. Minimum retention of creosote for red oak and southern pine in lb/ft³ (kN/m³) (AWPA Standard C2-89)

Red Oak			
Preservative	Thickness	Above ground	Soil and fresh water use
Creosote	< 5 in	6	7
Creosote	5 in and thicker	5	6
Creosote Coal-Tar	< 5 in	6	7
Creosote Coal-Tar	5 in and thicker	5	6
Creosote Petroleum	< 5 in	6	7
Creosote Petroleum	5 in and thicker	5	6
Southern Pine			
Preservative	Above ground	Soil and fresh water use	
Creosote	8	10	
Creosote Coal-Tar	8	10	
Creosote Petroleum	8	10	

Note: 1 in = 25.4 mm
 1 lb/ft³ = 0.157 kN/m³

The most effective method of impregnating a toxic preservative into a wood member is to apply pressure treatment. The Boulton process, in which creosote is forced into the wood at very high temperatures is recommended. Through this process, lumber can be

effectively dried and treated simultaneously if appropriate quality assurance guidelines are observed. The American Wood Preservers Association's (AWPA) standard M2-89 for inspection of treated timber products must be used for the quality control and the inspection of preservative-treated timber before, during, and after treatment.⁽¹⁹⁾

Bleeding

Creosote-treated wood has a tendency to bleed or exude excess preservative, which can be harmful and can cause skin burns. To avoid bleeding, steaming of the treated wood following AWPA standard C2-89 is recommended.⁽¹⁸⁾ However, strict quality control and inspection of the material before, during, and after treatment can efficiently avoid this problem.

CHAPTER 3. DESIGN METHODOLOGY

OVERVIEW

The method presented in this manual for the design of stress-laminated timber bridge decks follows primarily the guidelines published by AASHTO.⁽⁷⁾

CONSIDERATIONS IN THE DESIGN OF LONGITUDINAL STRESS-LAMINATED TIMBER BRIDGE DECKS

As mentioned in chapter 2, stress laminating permits the creation of a timber deck that is held together by prestress compressive forces applied through the steel prestressing elements. To carry out a structural design of a stressed timber deck under vehicle loading, a portion of the deck under a line of wheel loads is analyzed as a beam. Important considerations in the design of stress-laminated decks include: allowable longitudinal bending strength, butt joint configuration and adjustment factors, moisture content, camber, diameter of holes for stressing bars, diameter of stressing steel bars, deflection limits, and loads. A general discussion of these issues is presented first, followed by specific design details and examples.

Longitudinal Bending Strength

When lumber boards are transversely prestressed, the effects of the strength-reducing characteristics (e.g. knots, cross grain, cracks, etc.) of the lumber components are reduced, and a very efficient load-sharing mechanism is accomplished by the side-by-side contact of the deck planks. Therefore, the design-bending strength values, F_b , given for *single member use* in the National Design Specification for Wood Construction (NDS) can be increased by an appropriate factor.⁽²¹⁾ A bending strength value of $1.3F_b$ for select structural is recommended; and a value of $1.5F_b$ for No. 1 and No. 2 grades can be used.^(6,22)

Butt Joints

Transverse load transfer in the deck is accomplished through friction between the side faces of the boards and the transverse force applied by the stressing bars. A compressive stress of approximately 25 lb/in^2 (172.2 kPa) is sufficient to prevent laminae slippage.^(2,3) The lumber boards need not be continuous over the bridge span; rather, longitudinal butt joints are provided at regular increments along the bridge span. Use of more than one butt joint in a group of four or five adjacent laminae is not recommended. The butt joints must be spaced at least 4 ft (1.2 m) apart along the bridge span (figure 4).⁽⁶⁾

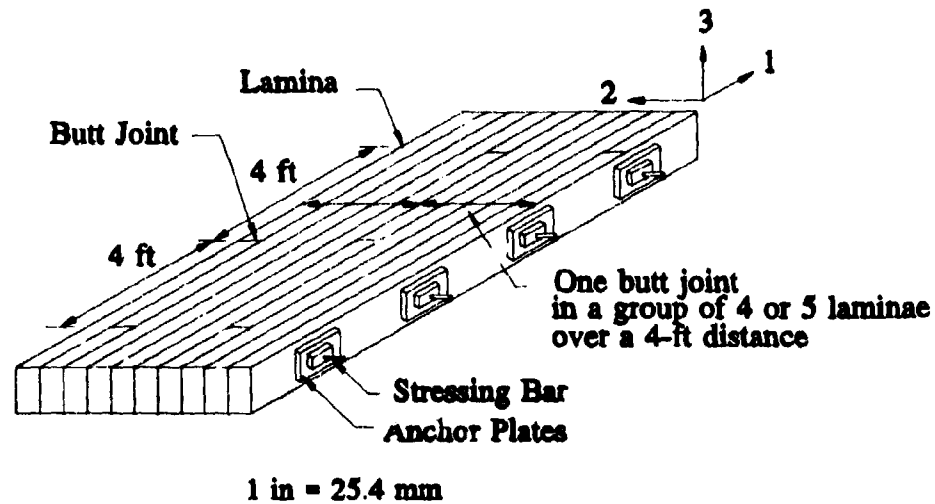


Figure 4. Butt joint pattern.

Moisture Content

Moisture content is important in bridge performance because it influences the strength and stiffness properties of timber. The stiffness and strength properties of wood decrease as the moisture content increases; in addition, fluctuations in timber moisture content affects the compressive force holding the timber boards together. The moisture content of the timber after treatment and prior to assembly should not be higher than 19 percent. However, a moisture content factor should be included in design to account for anticipated increases in moisture content during service.

Camber

Camber is usually built into the deck to compensate for immediate and long-term dead load deflection. Since long-term dead load deflection is usually significant, a camber equal to two or three times the immediate dead load deflection is specified.

Hole Diameter

Holes for stressing bars should be centered and large enough to allow a bar or a coupler, if used, to be easily removed from the stressed deck, but the hole diameter should not exceed 20 percent of the depth of the board.

Stressing Bars

High-strength stressing steel bars must conform to ASTM A722 and ASTM A 615-89. The bars are placed through the lamination and are attached to anchorage steel plates with high-strength nuts. All prestressing steel components and hardware must be protected against corrosion. The preferred method of corrosion protection is hot dip galvanizing.

Limits on Performance

The maximum allowable live load deflection used in the design is $\text{Span}/500$ in which impact is not included.⁽⁷⁾ Maximum bridge skew angle is 15 degrees. Decks with skewed ends can exhibit different load-carrying behavior than rectangular decks. If the skew is 15 degrees or less then the variation is small and can be neglected.⁽⁷⁾

Loads

Loads are based on AASHTO loading requirements for HS-20 or HS-25 truck loading.⁽²³⁾

DESIGN PROCEDURES

The basic step-by-step design procedures are outlined in this section. Initially, a thickness for the deck is assumed on the basis of bending strength, then the deflection limits are checked. In many instances, deflection requirement controls the design rather than the allowable bending stresses. The design steps are as follows:⁽⁶⁾

1. Define deck geometry and loading.
 - The effective deck span is the distance measured center-to-center of bearings. Deck width is the roadway width plus the width required for curb and railing.
 - Identify design vehicle loads according to AASHTO HS-20 or HS-25 loading.
2. Select a species and grade of lumber for the deck and determine the allowable design values given in NDS.⁽²¹⁾

Stress-laminated decks are usually constructed from lumber in the *Joists and Planks* size classification [2 to 4 in (51 to 102 mm) thick, 5 in (127 mm) and wider] and the values for single member use are utilized. Select a species and grade of lumber from NDS, Table 4A. Generally, grade No. 1 material is selected, and the following allowable design values are computed:⁽²¹⁾

Bending strength	:	$F_b' = F_b C_m (C_{LS})$	(1)
Elastic modulus	:	$E_L' = E_L C_m$	(2)
Compression Perpendicular to grain	:	$F_{cp}' = F_{cp} C_m$	(3)

Where,

C_m = Moisture content factor for each design property from NDS
 C_{LS} = Bending strength factor for stress-laminated decks: 1.5 for No. 1 and 2 grades, and 1.3 for select structural.

3. Estimate a deck thickness and determine the wheel load distribution width, D.

An initial deck thickness estimate may be used from table 2:

Table 2. Deck thickness.

Bridge Span	Deck Thickness
Spans less than 10 ft	10 in
Spans of 10 ft to 20 ft	12 in
Spans of 20 ft to 30 ft	14 in
Spans over 30 ft	16 in

Note: 1 ft = 0.305 m , 1 in = 25.4 mm

The wheel load distribution width, D, can be taken as the wheel width or tire contact plus twice the estimated deck thickness modified by a butt joint factor (figure 5).

$$D = [b_f + (2 \times d)] \times C_b \quad [\text{Article 3.25.5, Ref.7}] \quad (4)$$

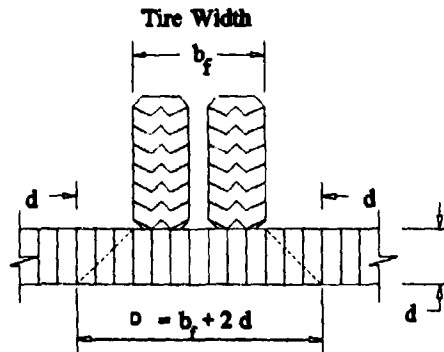


Figure 5. Wheel load distribution width.

Where,

D = Transverse wheel load distribution width, in (mm)

b_f = Truck tire width perpendicular to traffic

$$= \sqrt{0.025 P_w} \text{ in (mm)}^{(23)} \text{ [Article 3.30, Ref. 23]}$$

P_w = Wheel load, lb (N)

d = Deck thickness, in (mm)

C_b = Butt joint factor defined as:

$$C_b = \frac{j}{j+1} \quad (5)$$

Where,

j = Number of lanes between two successive butt joints

4. Compute live load and dead load moments.

The dead load is computed based on the estimated deck thickness. Additional dead loads from the guiderail, wearing surface, curbs, posts, and steel hardware are computed and distributed over the entire deck width. The dead load moment over the wheel load distribution width, D , assuming a simple span with uniform load is:

$$M_{dl} = \frac{W_{dl} \times L^2}{8} \quad (6)$$

where,

M_{dl} = Dead load moment

W_{dl} = Uniform dead load over the wheel load distribution width, D

L = Effective deck span

The maximum live load moment due to a single wheel line may be obtained from AASHTO (appendix A).⁽²³⁾

5. Determine the required deck thickness.

The required deck thickness is found using the flexural stress formula with the allowable bending stress and the effective distribution width, D .

$$F'_b = \frac{M_{ll+dl}}{S} \quad (7)$$

Where,

F'_b = Allowable bending strength, lb/in² (kPa) from step # 2

M_{ll+dl} = The sum of the maximum dead load moment and the live load moment from one wheel line of the design vehicle, in-lb (kN-m)

S = Effective deck section modulus, in³ (mm³)

$$= \frac{D d^2}{6}$$

Where,

D = Distribution width from step # 3

d = Required deck thickness, in (mm)

6. Check live load deflection.

The live load deflection due a wheel line acting over a distribution width, D , modified by a factor of 1.15 (Article 3.25.5.3, Ref. 7) is *assumed* to be computed as follows:

$$\Delta_{ll} = \frac{M_{ll} \times L^2}{12 \times E'_L \times I} \quad (8)$$

Where,

M_{ll} = Maximum live load moment from step # 4

L = Span length, in (mm)

E'_L = Longitudinal modulus of elasticity from step # 2

I = Moment of inertia, in⁴ (mm⁴)

$$= \frac{1.15 \times D \times d^3}{12}$$

The live load deflection must be compared to a live load deflection limit of $\text{Span}/500$. If the deflection limit is exceeded, a larger deck thickness is required.⁽⁷⁾

7. Revise thickness if necessary.

If the deck thickness computed in steps 5 and 6, is significantly different from the initial estimate, step # 3, then a new thickness should be taken and the previous calculations revised.

8. Calculate dead load deflection and camber.

Dead load deflection is *assumed* to be calculated as follows:

$$\Delta_d = \frac{5 \times W_{DL} \times L^4}{384 \times E I} \quad (9)$$

Substituting for $W_{dl} = 8 M_{dl}/L^2$ from eqn (6), Δ_d becomes:

$$\Delta_d = \frac{5 \times M_{dl} \times L^2}{48 E_L' I} \quad (10)$$

where,

- M_{dl} = Dead load moment, lb-in (kN-m) step # 4
 L = Span length, in (mm)
 E_L' = Longitudinal modulus of elasticity from step # 2
 I = Moment of inertia, in⁴ (mm⁴)

$$= \frac{D \times d^3}{12}$$

Camber = 3 (Δ_d)

9. Determine the required prestress level

The required prestress shall be the larger value of the following:
 [Article 13.11.1, Ref. 7]

- Transverse bending

$$P = \frac{6 M_T}{d^2} \quad (11)$$

where,

P = Prestress level lb/in² (kPa)

d = deck thickness, in (mm)

the moment, M_T shall be taken as:

For one-lane bridges

$$M_T = \frac{1.54 M_l}{1000 (C_b)^{1/4}} \left[\frac{b}{L} \right] \quad (12)$$

For two-lane bridges with spans less than 50 ft (15.25 m)

$$M_T = \frac{0.79 M_l}{1000} \left[\frac{b}{L} \right]^{1/2} \quad (13)$$

Where,

M_T = Transverse moment, in-lb/in (kN-m/m)

M_l = Live load moment due to a single wheel line from step # 4

b = Half the deck width, in (mm)

L = Span length, in (mm)

C_b = Butt joint factor from step # 3

- Transverse shear

$$P = \frac{1.5 V_T}{\mu d} \quad (14)$$

Where,

P = Prestress level, lb/in² (kPa)

d = Deck thickness, in (m)

μ = 0.35 for surfaced wood

μ = 0.45 for rough sawn wood

V_T is taken as:

$$V_T = \frac{P_w}{1000} \left(10.4 - \frac{b}{L} \right) \quad (15)$$

where,

V_T = Transverse shear, lb/in (kN/m)

P_w = Maximum single wheel load, lb (N)

To compensate for loss of prestress with time due to creep, the initial prestress, P_i , is calculated using the larger value of P as:

$$P_i = 2.5 \times P \quad (16)$$

10. Select a spacing for the prestressing elements.

The spacing, s , must not exceed 60 in (1,524 mm) [Article 3.11.2.2, Ref. 7]

11. Prestress element sizing.

The minimum area of the prestressing element is:

$$A_s = \frac{P_i s d}{f_s} \quad (17)$$

where,

- A_s = Required minimum area of prestressing, in² (mm²)
- P_i = Initial prestress from step # 9
- s = Prestressing elements spacing, in (mm)
- d = Deck thickness, in (mm)
- f_s = Maximum allowable stress in prestressing elements, lb/in. (kPa)

But to control loss of prestress between the laminae caused by creep, the steel area, A_s , must not exceed: [Article 13.11.2.3, Ref. 7]

$$A_s \leq 0.0016 s \times d \quad (18)$$

12. Size the bearing plates

The minimum area of the bearing plates is:⁽⁷⁾

$$A_{pt} = \frac{P_i \times s \times d}{F_{cp}'} \quad (19)$$

where,

- A_{pt} = Required bearing area in² (mm²)
- P_i = Initial prestress level from step # 9
- s = Prestress element spacing in (mm)
- d = Deck thickness in (mm)
- F_{cp}' = Allowable compression perpendicular to grain from step # 2

The minimum plate thickness is calculated from:

$$t_p = \left[\frac{3 F_{bp} K^2}{f_s} \right]^{0.5} \quad (20)$$

where,

- t_p = Plate thickness in (mm)
- F_{bp} = Actual bearing stress under the plate lb/in² (kPa)
- f_s = Allowable bending stress in steel plate lb/in² (kPa)
= 0.55 F_y
- F_y = Specified minimum yield point for the steel plate lb/in² (kPa), from AASHTO Table 10.32.1A

The factor K depends on the shape of the bearing plate and anchorage plate, and is taken as the greater of $(W_p - W_A)/2$ or $(L_p - L_A)/2$ as shown in figure 6.

where,

- W_p = Bearing plate width in (mm)
- L_p = Bearing plate length in (mm)
- W_A = Anchorage plate width in (mm)
- L_A = Anchorage plate length in (mm)

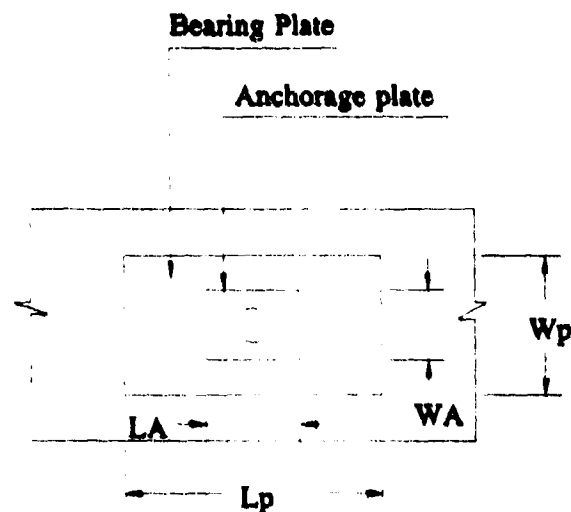


Figure 6. Bulkhead system.

DESIGN EXAMPLE

1. Deck Geometry and Loading

Center-of-bearing to center-of-bearing span	20 ft (6.1 m)
Clear width out-to-out	24 ft (7.3 m)
Loading	HS-20

2. Material Properties

The guide specifications are intended for use with douglas fir-larch, hem-fir (North), red pine, eastern white pine, or southern pine. According to article C13.11 of the AASTHO Guide Specifications,⁽⁷⁾ other species can be used only if the stress laminating technology has been proven for the species. Generally grade #1 material is used. However, other species can be used (see chapter two, wood protection). The example bridge deck is designed using northern red oak.

Decking :	northern red oak, Grade #2 J&P ⁽²¹⁾
F_b'	$= 975 \times 0.86 \times 1.5$ $= 1,257.75 \text{ lb/in}^2 \text{ (8.66 MPa)}$
F_{cp}'	$= 885 \times 0.67$ $= 593 \text{ lb/in}^2 \text{ (4 MPa)}$
E_t'	$= 1.3E06 \times 0.97$ $= 1.261E06 \text{ lb/in}^2 \text{ (8,688 MPa)}$
Specific weight	$= 50 \text{ lb/ft}^3 \text{ (7.85 kN/m}^3\text{)}$
Creosote retention	$= 8 \text{ lb/ft}^3 \text{ (1.25 kN/m}^3\text{)}$

3. Deck Thickness

An initial deck thickness of 14 in (356 mm) can be estimated for a 20-ft (6.1-m) span. The wheel load distribution width, D , is taken as the tire contact width plus twice the estimated deck thickness modified by a butt joint factor. This value of D is an effective width for a single wheel line.

Assume deck thickness: 14 in (356 mm)

The distribution width, D is:

$$D = [b_f + (2 \times d)] \times C_b \quad (21)$$

Where,

D = Transverse wheel load distribution width in (mm).

- P_w = Wheel load
 = 16,000 lb (71.2 kN)
 b_t = Truck tire width perpendicular to traffic
 = $\sqrt{0.025 P_w}$ in (mm).⁽²³⁾
 = $(0.0025 P_w)^{0.5} = (0.025 \times 16,000)^{0.5} = 20$ in (508 mm)
 d = Deck thickness = 14 in (356 mm)
 C_b = Butt joint factor

Butt joint pattern: 1 in 5

$$C_b = \frac{1}{j+1} \quad (22)$$

Where,

- j = Number of laminae between two successive butt joints
 C_b = $4/5 = 0.8$
 D = $(20 + 28) \times 0.8 = 38.4$ in (975 mm)

4. Dead Load Calculations

Deck weight:

Assume 14 in (356 mm) deck

Volume = 20 ft x 24 ft x (14/12) ft = 560 ft³ (15.7 m³)

$W_{DL,deck}$ = 560 ft³ x 58 lb/ft³ = 32,480 lb (144.5 kN)

Weight of guiderail system including posts, curbs, curbblock, and steel rail is at 75 lb/ft:⁽⁸⁾

$W_{DL,guiderail}$ = 75 lb/ft x 40 ft = 3,000 lb (13.35 kN)

Weight of steel stressing system:

¾-in bars @ 1.5 lb/ft (21.9 N/m)

bar spacing *assumed* to be equal to 24 inches (61 cm)

$$\text{No. of bars} = \frac{20 \text{ ft} \times 12 \text{ in/ft}}{24 \text{ in}} = 10 \text{ bars}$$

Total bar length = (24 ft + 1 ft) x (10 bars) = 250 ft (71 m)

$W_{DL,bar}$ = 250 ft x 1.5 lb/ft = 375 lb (1,669 N)

Plates (assumed):

20 plates at 10 in by 8 in by 1 in (254 mm by 203 mm by 25.4 mm)

$$W_{Dl,plates} = [10 \times 8 \times (1/12^3)] \text{ ft}^3 \times (20 \text{ plates}) \times 490 \text{ lb/ft}^3 = 454 \text{ lb (2020 N)}$$

$$W_{Dl,steel} = 375 \text{ lb} + 454 \text{ lb} = 829 \text{ lb (3,689 N)}$$

Weight of asphalt: (assuming 2 in (50.8 mm) thick):

$$W_{Dl,asph.} = 20 \text{ ft} \times 24 \text{ ft} \times (2/12) \text{ ft} \times 150 \text{ lb/ft}^3 = 12,000 \text{ lb (53.4 kN)}$$

Total dead load:

$$\begin{aligned} W_{Dl,total} &= 32,480 \text{ lb} + 3,000 \text{ lb} + 829 \text{ lb} + 12,000 \text{ lb} \\ &= 48,309 \text{ lb (214 kN)} \end{aligned}$$

Dead load moment: [(in-lb)/in (kN-m/m)]

$$M_{Dl} = \frac{W_{Dl} \times L^2}{8} \quad (23)$$

where, using $D = 38.4$ in (975 mm) from step # 3:

$$W_{Dl} = \frac{48,309 \text{ lb}}{(20 \text{ ft} \times 24 \text{ ft})} \times \frac{38.4}{12} = 322 \text{ lb/ft (4.7 kN/m)} \quad (24)$$

$$M_{Dl} = \frac{322 \times (20 \text{ ft})^2}{8} = 16,100 \text{ ft} \cdot \text{lb (21.7 kN-m)} \quad (25)$$

5. Live Load Moment

$$M_{ll} = 80,000 \text{ ft-lb (109 kN-m)} \quad (\text{AASHTO appendix A})$$

$$M_{ll+d1} = 16,100 + 80,000$$

$$= 96,100 \text{ ft-lb (131.5 kN-m)}$$

6. Required Deck Thickness

The required deck thickness is found using the flexural stress formula with the allowable bending stress and the effective distribution width, D :

$$F_b = \frac{M_{u-d}}{S} \quad (26)$$

$$S = \frac{M_{u-d}}{F_b} = \frac{96,100 \times 12 \text{ in}}{1257.75} = 917 \text{ in}^3 (0.015 \text{ m}^3) \quad (27)$$

The required deck thickness is computed as

$$d = \sqrt{\frac{S \times 6}{D}} = \sqrt{\frac{917 \times 6}{38.4}} = 12 \text{ in (305 mm)} \quad (28)$$

The required deck thickness = 12 in < 14 in (assumed), OK

7. Live Load Deflection

The live load deflection for an effective width, D , is *assumed* to be calculated as follows:

$$\Delta_H = \frac{M_H \times L^2}{12 E_L I} \quad (29)$$

$$I = \frac{1.15 \times D \times d^3}{12} = \frac{1.15 \times 38.4 \times 14^3}{12} = 10,097 \text{ in}^4 (0.0042 \text{ m}^4) \quad (30)$$

$$\Delta_H = \frac{80,000 \times 12 \times (20 \text{ ft} \times 12)^2}{12 \times 1.261 \times 10^6 \times 10,097} = 0.36 \text{ in (9.2 mm)} \quad (31)$$

The maximum allowable deflection is $\text{Span}/500 = 240/500 = 0.48 \text{ in (12 mm)}$

$$\Delta_{all} > \Delta_H \quad \text{OK}$$

8. Dead Load Deflection

The dead load deflection is again *assumed* to be calculated as follows:

$$\Delta_d = \frac{5 \times 16,100 \times 12 \text{ in} \times (240 \text{ in})^2}{48 \times 1.261 \times 10^6 \times 8,780} = 0.1 \text{ in (2.54 mm)} \quad (32)$$

$$\text{Camber} = 3 \times 0.1 = 0.3 \text{ in (7 mm)}$$

For practical purposes, specify ½ in (12.7 mm) to 1 in (25.4 mm) camber.

9. Required Prestress Level, P

Take the largest of the following:

- Transverse bending

$$M_T = \frac{0.79 M_f \left(\frac{b}{L}\right)^{1/2}}{1,000} = \frac{0.79 \times 80,000 \times 12 \text{ in} \left(\frac{144}{240}\right)^{1/2}}{1,000} = 587.4 \text{ lb-in/in} \quad (33)$$

$$P = \frac{6 M_T}{d^2} = \frac{6 \times 587.4}{14^2} = 18 \text{ lb/in}^2 \text{ (124 kPa)} \quad (34)$$

- Transverse shear

$$V_T = \frac{P_w}{1,000} \left(10.4 - \frac{b}{L}\right) = \frac{16,000}{1,000} \left(10.4 - \frac{144}{240}\right) = 156.8 \text{ lb/in} \quad (35)$$

$$P = \frac{1.5 V_T}{\mu d} = \frac{1.5 \times 156.8}{0.35 \times 14} = 48 \text{ lb/in}^2 \text{ (330 kPa)} \quad (36)$$

Take $P = 48 \text{ lb/in}^2$, and the initial prestress $P_i = 2.5 (48) = 120 \text{ lb/in}^2 \text{ (827 kPa)}$

10. Select Prestress Element Spacing

Assume spacing, $s = 24 \text{ in (610 mm)}$

11. Element Sizing

The minimum area of prestressing element is: [Article 13.11.2.3, Ref. 7]

$$A_s = \frac{P_i s d}{f_s} = \frac{120 \times 24 \times 14}{0.7 \times 150,000} = 0.38 \text{ in}^2 (236 \text{ mm}^2) \quad (37)$$

$A_{st} = 0.42 \text{ in}^2 (270 \text{ mm}^2)$ for a $\frac{3}{4}$ -in (19 mm) bar⁽¹⁰⁾

$A_{st \text{ actual}} > A_{st \text{ min}}$ OK

But to control loss of prestress between the laminae caused by creep, the steel area must not exceed:

$$A_s \leq [(0.0016 s \times d) - 0.537] ; 0.42 \text{ in}^2 (270 \text{ mm}^2) \leq 0.537 \text{ in}^2 (346 \text{ mm}^2) \text{ OK} \quad (38)$$

12. Bearing Plates

The minimum area of bearing plates shall be: [Article 13.11.2.4, Ref. 7]

$$A_{pl} = \frac{P_i s d}{F'_c} = \frac{120 \times 24 \times 14}{593} = 68 \text{ in}^2 (43,874 \text{ mm}^2) \quad (39)$$

Use 8.5 in by 8.5 in (216 mm by 216 mm) Bearing plate

Use 4 in by 4 in (102 mm by 102 mm) Anchorage plate

Bar force at jacking = 24 in x 14 in x 120 lb/in² = 40,320 lb (179 kN)

The actual bearing stress under the plate can be computed as:

$$F_{bp} = \frac{40,320 \text{ lb}}{8.5 \text{ in} \times 8.5 \text{ in}} = 558 \text{ lb/in}^2 (3.8 \text{ MPa}) \quad (40)$$

Bearing plate thickness can be found from:

$$t_p = \left[\frac{3 F_{bp} K^2}{f_s} \right]^{0.5} = \left[\frac{3 \times 558 \times 2.25^2}{20,000} \right]^{0.5} = 0.65 \text{ in} (16.5 \text{ mm}) \quad (41)$$

Where,

$$K = \frac{(W_p - W_A)}{2} = \frac{(8.5 - 4)}{2} = 2.25 \text{ in} (57.15 \text{ mm})$$

$$f_s = 0.55 F_y = 0.55 (36,000 \text{ lb/in}^2) = 20,000 \text{ lb/in}^2 (137 \text{ MPa})$$

$$F_{bp} = 558 \text{ lb/in}^2 (3.8 \text{ MPa})$$

Use 3/4-in (19-mm) thick plate

COMPARISONS

In addition to the AASHTO guide specifications, design methods for stress-laminated timber decks have been included in other design codes and also proposed by various researchers.^(1,6,8) Table 3 compares the response predictions by the AASHTO method, Ritter's method, and the WVU method.^(7,6,8) The material used to design the bridges in table 3 is northern red oak grade No. 2.

Table 3. Comparative response predictions.

Bridge	Span (ft)	Width (ft)	Deck depth (in)	Deflections (in)			Bending Stresses (lb/in ²)		
				WVU	AASHTO	Ritter	WVU	AASHTO	Ritter
1	15	15	12	0.22	0.26	0.17	738	966	780
2	20	24	14	0.47	0.36	0.28	931	919	878
3	25	24	16	0.53	0.45	0.44	967	903	902
4	30	24	18	0.74	0.58	0.59	1013	947	965

Note: 1 in = 25.4 mm
 1 ft = 0.305 m
 1 lb/in² = 6890 Pa

CHAPTER 4. FABRICATION, INSTALLATION, AND MONITORING

INTRODUCTION

This section provides an overview of the fabrication procedures and techniques for stress-laminated timber bridges. The topics include bridge fabrication, assembly, handling, transportation, installation, and monitoring. For more detailed information, see references 4, 5, 6, 8, 9, 20, and 24 listed at the end of this manual.

FABRICATION AND ASSEMBLY

It is essential that all machining, cutting, and drilling of lumber boards be completed before treatment with preservative. The presence of butt joints allows the use of boards that are shorter than the span length of the bridge. The designer must supply the fabricator with the intended butt joint layout including the spacing of butt joints along the span of the bridge and the number of boards between successive butt joints.

Stress-laminated timber bridges can be fabricated on-site or at a remote fabrication shop and transported to the bridge site for assembly. On-site fabrication can be accomplished by prefabricating panels on a level surface or on falsework near the bridge. Remote fabrication requires transportation of assembled panels and is similar to on-site fabrication.

On-site assembly of a bridge deck on falsework requires a work platform and one or more temporary supports. The temporary supports must be the correct height to provide the correct amount of camber in the bridge. If full-length bulkhead steel channels or plates are included in the bridge design, the fabrication is started by lifting the first steel bulkhead into position on the temporary supports. Timber laminac are then placed, according to the specified butt joint pattern, and secured to the bulkhead plate. Care must be taken to maintain alignment of the pre-drilled holes in the lumber. The holes are usually oversized, but size irregularities and warping of boards can lead to misalignment of the holes.

The stressing bars can be inserted through the holes after a portion of the bridge deck is stable. The fabrication process is continued by installing rows of lumber and by sliding the bars through the holes until the required laminae are in place. Placement of the second bulkhead completes the construction process.

As for remote construction, a level surface is prepared and sleeper blocks are positioned to support the structure and provide the necessary camber. Assembly is started by placing the first lumber row on the sleeper blocks and nailing the second lumber row to the first. The assembly process continues for the on-site construction, except that partial-width panels are built rather than a full-width structure.

Assembly Quality Control

Some fabrication problems that arise during the construction of stress-laminated decks and suggested solutions are presented next.

- The number of laminae needed

Fabricators often encounter difficulties estimating the number of timber boards needed to construct a bridge of certain width. Timber boards usually shrink during drying and swell during preservative treatment. These changes affect the original dimensions of boards, and the total width of the bridge will usually be greater than the sum of the original individual board widths. To give the fabricator a better estimate of the number of timber boards required, 0.1 in (2.54 mm) is added to the expected board width. For example, to fabricate a bridge designed to be 24 ft (7.32 m) wide using boards of 1.5 in (38 mm), the required number of boards is estimated as:

Width of bridge = 24 ft = 288 in (7.32 m)

Width of boards = 1.5 in (38 mm) + 0.1 in (2.54 mm) = 1.6 in (40.54 mm)

Number of boards required = 288 in / 1.6 in = 180 boards

- Tolerances in profile grade between adjacent laminae

Stress-laminated bridge decks will usually have uneven top and bottom surfaces, because of the lifting of the boards to create the required camber. Large height differences between boards must be prevented to avoid difficulties in placing an asphaltic wearing surface. A reasonable maximum limit of 3/4 in (19 mm) difference between any two adjacent laminae is acceptable.

STRESSING OPERATIONS

Stress-laminated bridge decks must be stressed a minimum of three stressing cycles. The bridge can be open to traffic after the first stressing cycle is completed. The second stressing cycle should be done about one week after the first; the third stressing cycle is applied about six weeks later. Each stressing cycle requires several passes. The bridge engineer specifies a tension level, a stressing sequence, and a stressing schedule. A hollow core hydraulic jacking system is needed to tension the bars. This system consists of one or more hollow core jacks, hoses, a hydraulic pump, and a pressure gauge.

Stressing Guidelines

A stressing cycle consists of the following steps: (1) using a single jack, tension is applied to the first specified bar to squeeze the lumber deck boards transversely. Initially, 50 percent of the final load should be applied to each of the bars. This first stressing pass

will close most of the gaps between the laminae, and (2) on the second stressing pass, each of the bars can be tensioned to 100 percent of the specified load, and (3) to ensure a uniform compressive stress in the lamination, a third stressing pass, again to 100 percent of the specified load, is required.

After the third stressing pass, the first three bars are checked for tension level. If the three bars have 90 percent or more of the specified load, then the first stressing cycle is completed. However, if any of the three bars tested indicate less than 90 percent of the specified load, the bars must be retensioned in the specified order to achieve 90 percent of the required load level. A bridge constructed off-site in half-width panels and joined with couplers is often stressed twice at the fabrication shop and stressed once to a 100 percent of the specified load at the bridge site. The bars are stressed as discussed above.

Stressing Quality Control

Some of the problems encountered while stressing a stress-laminated bridge deck are discussed next.

- **Irregular bridge shapes**

A common problem of stress-laminated bridge decks is an irregular shape after stressing. The possible causes include incorrect stressing sequence, unequal board width, or laminae swollen from preservative treatment. This situation can be avoided or minimized by following the stressing guidelines during the first and second stressing cycles.

- **Wood crushing at bearing plates**

Wood crushing at bearing plates is an indication that the force applied is higher than that specified by the design or that the bearing plates are improperly designed. If wood crushing occurs, the inspector should check the hydraulic jack calibration. For an uncalibrated jack, a rough estimate of the force applied can be found by multiplying the hydraulic pressure by the area of the jack's ram.

- **Broken stressing bar**

Possible causes of broken bars include over-stressing, eccentric loading, defective steel in bars, incorrect galvanization procedures, or physical damage to the bars. If a bar breaks some time after stressing, the most likely cause is hydrogen embrittlement resulting from incorrect galvanization. If this is the case, all of the bars in the bridge that came from the same batch should be replaced.

TRANSPORTATION

Pre-assembled bridge panels need to be transported to the job site. The size of the panels depend on permissible transportation limits, location of the bridge site, and capacity of the lifting crane. A bridge panel must be stressed with temporary bars before lifting. The preferred method of lifting a bridge panel is to use a system of lifting hooks and spreader beams. With this system available at the bridge site, the only piece of equipment needed for loading and off-loading the deck is a mobile crane of sufficient capacity. After the removal of the lifting hooks, treated wood dowels are used to plug the holes (figure 7).⁽⁹⁾

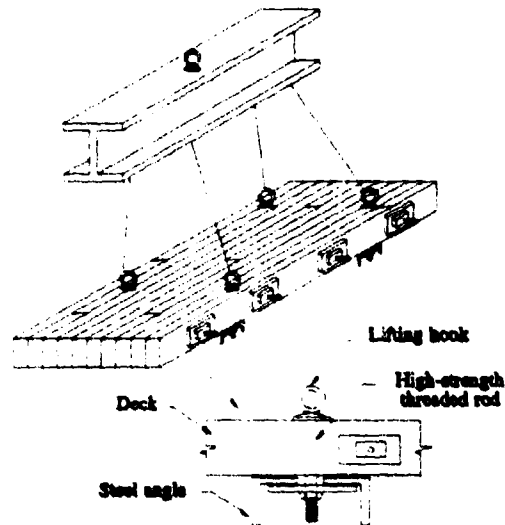


Figure 7. Typical lifting hooks.

INSTALLATION

Once the required bearing pads are in position, the bridge deck or panel is lifted off the truck bed and placed on the abutments as shown in the bridge plans. If the design uses modular panels, these are placed side by side until the required width of the bridge is completed. As each successive panel is placed in position, the temporary threaded bars are removed and the permanent bars are inserted. After the entire bridge is in position and stressed for the first time, the anchor nuts of the abutment anchor bolts are tightened, and the bolts are covered with the grout material called for in the plans and/or specifications.

After the guiderail system is installed, the excess preservative is removed from the deck surface, and a specialized paving geotextile mat can be placed over the deck; the wearing surface is then compacted on top of the mat. The geotextile mat can permit a better bonding of the wearing surface, provide a moisture barrier, and help alleviate surface cracking. For more information on wearing surface materials and geotextile fabrics see references 6 and 9.

MONITORING

To monitor and evaluate the performance of stress-laminated timber bridges, several responses can be measured. These responses include moisture content, deflections, and bar tension levels. For more information on monitoring, see references 9 and 25.

Moisture Content

Variations in the timber deck moisture content due to ambient conditions can affect the strength, stiffness, and dimensional stability. A gain in moisture content leads to an increase in bar force levels, while a loss in moisture content will result in a bar force level decrease. Variations in moisture content of the deck are measured at 6 to 12 locations using an electrical resistance moisture meter with insulated probes. The moisture content assumed in the design is usually 19 percent.

Deflections

Bridge behavior can be assessed by measuring the deck's deflection pattern under self weight and vehicular loading.

Deflections due to self weight. Deflections due to the self weight (dead load) of the structure can be significant. To offset the dead load deflection and additional creep deformations, camber (an upward profile) can be built in the structure by forcing small rotations of the butt joints. Elevations are measured on the underside of the deck at mid-span using a survey rod and level. The measured elevations are compared to the original elevation of the deck measured shortly after installation.

Live load deflections. To assess the bridge performance and evaluate proposed design procedures under vehicular loading, the bridge is tested under a simulated AASHTO truck loading and the deflections are measured.

Bar Tension Levels

Adequate compressive stress must be maintained between the lumber lamination to ensure good performance. The compressive stress in the lamination can be monitored by measuring the level of forces in the stressing bars. The force in the bars can fluctuate due to transverse creep and moisture content variations. To monitor changes in bar forces, a few bars are instrumented with load cells. A load cell is installed between the bulkhead and the anchor plate. The bar is tensioned and an anchor nut is secured against the anchor plate. The bar force can be measured directly from the load cell by reading the strain from a strain indicator and converting the reading into lb (kN).

CHAPTER 5. INSPECTION AND MAINTENANCE

INTRODUCTION

The effective life of timber bridges is often shortened by decay of the timber components or failure of the timber connections. This chapter describes procedures for periodic inspections of components prior to construction and inspection procedures of stress-laminated decks after assembly. In addition, recommended quality control guidelines designed to identify potential problems are presented, followed by inspection checklists. Also discussed are guidelines for maintenance of stress-laminated decks. For more detailed information on inspection and maintenance, see references 6, 9, 26, and 27.

INSPECTION OF BRIDGE COMPONENTS PRIOR TO CONSTRUCTION

This section discusses the inspection and quality control of lumber laminae and steel components used in stress-laminated decks. Relevant ASTM and AASHTO specifications are presented for preservative treatment of wood and galvanizing and epoxy coating of steel. For more information on inspection of timber and steel components used in modern timber bridges, see reference 9.

Lumber Lamination

The lumber laminae provide the required strength and stiffness for adequate bridge performance. To guarantee the quality of timber components, the inspection procedures include checking timber grades, machining, moisture content, preservative treatment, and handling and storage.

Grading. The lumber laminae for stress-laminated decks fall in the *Joists and Planks* size classification with a specified width of 2 to 4 in (51 to 102 mm) thick. A certified lumber grader should supply the bridge inspector with the grade and species of lumber.

Machining. All machining, surfacing, drilling, and cutting should be done prior to preservative treatment. If machining is required after treatment, the component must be protected against decay by applying an AWPAs approved brush-on preservative. Also, the inspector should check the board lengths, widths, and size and hole location.

Moisture Content. The moisture content should be measured with an electric moisture meter following ASTM D4444-84.⁽²⁸⁾ AWPAs standard M2-89 specifies that individual pieces of lumber exceeding the specified moisture content (usually 19 percent) by 20 percent or more should be rejected.⁽¹⁸⁾

Preservative Treatments. AWWA standard M2-89 should be used to inspect preservative treated lumber before, during, and after treatment. The moisture content of treated lumber can only be measured accurately using extraction assay methods outlined in AWWA standard A6-89.⁽¹⁸⁾ Creosote treated lumber will exude excessive creosote after treatment which may be harmful. To avoid bleeding, AWWA standard C2-89 provides guidelines for acceptable retention levels and steaming after treatment.

Handling and Storage. Treated lumber components should be handled with care to avoid damaging the preservative envelope protecting the members. Throwing, dropping, or gouging lumber components may damage the treated wood. Treated lumber should be stacked in such a manner to allow air circulation. Direct contact with the ground or wet surfaces should be avoided. To avoid health hazards, treated lumber should be handled following the consumer information sheet provided by the treater.

Steel Components

The prestressing system provides the required compressive force to ensure adequate performance of a stress-laminated deck. The prestressing elements include high-strength steel bars, steel anchorage plates, and hardware. It is necessary to provide adequate corrosion protection for the steel stressing components. Two common ways of protecting the steel components are galvanizing and epoxy coating. In addition, grease-filled PE tubes placed over the prestressing bars are currently used.

Galvanizing. Inspection of galvanized steel articles should be carried out by a third party at the galvanizer's plant and should conform to ASTM A 123, ASTM A 153, and ASTM 722-88 as applicable.^(10,29,30) The galvanized surface should be continuous, smooth, and free of surface imperfections. If adherence or thickness need to be checked, the inspector can follow tests outlined in ASTM A 153 and ASTM E 376 respectively.⁽³¹⁾ Damaged areas due to flame cutting, welding, handling, and transportation should be repaired with a cold galvanizing compound conforming to ASTM A 780-88.⁽³²⁾ For specific information on inspection of galvanized articles see reference 33.

Epoxy Coating. Epoxy coated steel articles should be inspected by a third party to insure that the coating conforms to ASTM D 3963 and AASHTO M284. Non-destructive coating thickness measurements can be performed following ASTM G12.⁽³⁴⁾ The coating must be free of holes, cracks, or missed coated spots. The coating should be checked for missed coated spots following ASTM A 775/ A 775M.⁽³⁵⁾

Handling and Storage. Galvanized articles should be stacked in such a way to allow air circulation and continuous drainage of water. Galvanized steel articles should not

be placed on cinder blocks or stored on wet or decaying vegetation.⁽³⁶⁾ The galvanized article should be handled carefully so as to minimize damage to the coating.

INSPECTION OF STRESS-LAMINATED TIMBER DECKS

Stress-laminated bridge decks not covered by a wearing surface are inspected visually from above for surface wear, physical damage, evidence of decay, and tightness of connections. Visual inspection from below should reveal additional evidence of loose or missing connectors and physical damage of boards. Loose or missing connectors must be noted. Crushing around connectors and bearing surfaces must also be noted. In bridges covered by a wearing surface, drainage areas and the asphalt cover must be inspected. Potholes and cracks in the wearing surface may allow moisture to reach the timber and cause decay. Loss of camber, excessive or unusual deck deformation, and/or signs of board slippage are usually indications of failure of the stressing system, and the inspector must immediately notify the bridge engineer. For more information on inspection of modern timber bridges, see references 6, 9, and 19.

Moisture Content

Timber moisture content influences the strength and stiffness of the material, and therefore, it affects the performance of a bridge. Moisture content levels should be monitored to ensure they remain below the design specifications. Since a moisture content greater than 20 percent is necessary for decay, high moisture areas should alert the inspector to a potential decay situation. Visual indicators of liquid water include water marks on and below the deck. The moisture content of stress-laminated decks should be periodically measured with an electrical-resistance type moisture meter with insulated probes. Insulated probes can be driven to different depths to detect moisture gradients. If the moisture gradient is not significant (less than 8 percent moisture content difference), the reading taken from the inner portion of the timber can be used to obtain an average moisture content value. Inspections should take place in dry weather when liquid water is not present. The moisture content should be measured at several sampling locations to compute an average moisture content condition. Care should be taken not to use past sampling holes because of possible moisture intrusion in these areas.⁽⁹⁾

INSPECTION OF TIMBER COMPONENTS

Wood members should be thoroughly inspected regularly for decay and failures. Checking (cracking) commonly occurs in wood members from drying stresses. Small checks [less than 3 inches (76.2 mm) in length] are generally insignificant. However, large checks and splits should be noted and monitored for growth. Indications of progressive failure in wood members are: excessive member deflection, fastener penetration into a member, and cracks that extend perpendicularly to the grain direction of a member.

Wood members are typically not treated with a preservative throughout the member. Rather, an envelope of preservative treatment surrounds a core of untreated wood. When exposed to the environment, the untreated wood can suffer serious decay damage. Despite preservative treatments, timber bridges must be inspected regularly for evidence of decay. Decay can occur on the external faces of a member or in the interior. Advanced external decay is relatively easy to detect visually; however, internal decay may go undetected through advanced stages without any external evidence. Typically, color changes of the wood are one of the earliest signs of evidence of external decay. In addition, external surfaces will often shrink abnormally, creating a sunken appearance of a localized depression.⁽¹⁹⁾ Periodic visual inspection of the bridge deck to detect external evidence of decay and presence of liquid water is necessary to avoid or minimize detecting internal decay.

INSPECTION OF STEEL COMPONENTS

This section discusses the inspection of steel components used in stressed decks, which include the stressing system and the various fasteners used to connect the components.

Fasteners

The portions of the fasteners that are visible should be checked for corrosion, and the area of the timber in contact with fasteners should be checked for decay. The tightness of connections should be checked. If a fastener is found to be defective, it must be replaced.

Stressing System

To ensure adequate performance of a stress-laminated deck, the pre-stressing system must be thoroughly inspected for bar tension levels, corrosion of bars, and corrosion of anchor system.

- **Bar Tension Level**

Several methods are currently used to test the tension level in the stressing bars. The following procedure can be used to accurately determine the force level in a stressing bar:

Set up the bar jacking system in the same manner as when performing the initial stressing operation. While one person operates the hydraulic pump and monitors the hydraulic pressure gauge, a second person attempts to loosen the stressing anchor nut with a wrench or the ratchet mechanism of the stressing jack. Care must be taken not to exceed the bar force limit of the original design. As soon as the nut is free to turn, the pump operator notes the hydraulic pressure level. The hydraulic pressure can then be converted to pounds of force in the bar and to compressive stress within the lamination.

Compressive stress levels within the lamination must be at least 50 lb/in² (345 kPa). If the compressive stress levels are below 50 lb/in² (345 kPa), the bridge should be immediately restressed. To calculate the transverse stress level applied to the boards, multiply the hydraulic pressure level by the area of the jack (or use a calibration chart for the jack), and then divide that value by the area of timber compressed by one bar. This area is simply the center-to-center spacing of the bars multiplied by the depth of the lamination.

Example: The stressing anchor nut comes loose at 4,200 lb/in² (29 MPa). The jack used has a ram area of 9 in² (5,806 mm²) ; the stress bars are on 36 in (914 mm) centers, and the deck is 12 in (305 mm) deep. The compressive stress within the lamination equals:

$$\frac{4,200 \text{ lb/in}^2 \times 9 \text{ in}^2}{36 \text{ in} \times 12 \text{ in}} = 87.5 \text{ lb/in}^2 \text{ (603 kPa)}$$

- **Corrosion of Bars**

Stressing bars without a permanent protective tube filled with grease should be inspected visually for evidence of corrosion. One bar at a time may be loosened (using the same procedure for tension level testing) and removed from the bridge. Heavy truck loads must be prevented during such an operation. However, light traffic may be maintained. Ten to twenty years is the estimated time for first-maintenance, defined as 5 percent rusting of the steel surface, of galvanized steel products.⁽¹⁵⁾ Therefore, stressing bars installed in a bridge without greased-filled tubes or other grouting systems must be inspected completely after 10 years of service and every 6 years thereafter. Bars with a permanent protective tube filled with grease are designed for long-term protection and do not allow inspection of the bar itself (see figure 4).

- **Corrosion of Anchor System**

Anchorage components are very susceptible to corrosion because of the extensive exposure to weather and road salts. Some of the bridges built include a protective cover (such as a grease-filled cap similar to that used in the bar protection system) that must be inspected visually for damage. Systems without a protective cover must also be inspected visually for any corrosive activity.

INSPECTION GUIDELINES: WHAT TO LOOK FOR

Specific comments about assembly, stressing operations, and recommended treatments for wood and steel are presented followed by inspection checklists. The purpose of this section is to provide the practitioner with quality control do's and don'ts.

Assembly

- ***Uneven deck surface.*** Building the required camber can sometimes create differences in profile grade between adjacent laminae. Also, uneven deck surfaces can be caused by misalignment of boards or bowed boards.

Recommendation. A maximum limit of 3/4 in (19 mm) difference between two adjacent laminae can be allowed.

Stressing Operations

- ***Irregular bridge shapes.*** Irregular bridge shapes do not affect the overall bridge performance. However, width adjustments by cutting and shimming of posts can reduce the capacity of the guiderail system.

Recommendation. Monitor the magnitude and sequence of the applied force during stressing operations and simultaneously measure the width of the bridge at the bar locations to obtain a consistent bridge width.

- ***Wood crushing at bearing plate.*** This is an indication that either the force applied is higher than the specified level or that the bearing plate is under designed.

Recommendation. Stop the bar stressing and check the jack calibration.

Preservative treatment

- ***Destruction of preservative envelope.*** Breaking of the preservative envelope can be the result of mishandling, machining, cutting, or drilling of timber components after treatment.

Recommendation. An approved AWPAs preservative compound should be applied to the unprotected area.

- ***Bleeding.*** Creosote-treated wood will usually shed excess creosote, which can cause environmental hazards and skin irritations.

Recommendation. Consult AWPAs standard C2-89 for acceptable retention levels and steaming after treatment.

Galvanizing

- ***Hydrogen embrittlement.*** If chemicals are used to clean the steel, the acid pickling tank must be of sufficient length to immerse the entire steel component at one time in the acid solution. Acid pickling by double dipping is prohibited. Rinsing with plain water should immediately follow the acid pickling.

Recommendation. Use blast cleaning for steel surface preparation.

- ***Touch-up and repair.*** Any damaged area exceeding 3/16 in (4.7 mm) in width should be repaired by using a cold galvanizing compound.
- ***Machining and Welding.*** Galvanized hardware subjected to machining and welding should be repaired with a cold galvanizing compound.

Caution: Galvanized high-strength steel bars and other steel components to be used under tension should not be welded or exposed to a torch flame.

Epoxy coating

- ***Holidays.*** Holidays should be checked using a 67.5 V holiday detector in accordance with ASTM D 3963.
- ***Damaged Coating.*** Damaged areas should not exceed 2 percent of the surface area. The total surface area covered by patching material should not exceed 5 percent.
- ***Connections.*** After installation of mechanical connections and threading of high-strength nuts, all parts of the connections, including high-strength bars, bolts, and nuts should be coated with the same material used for the repair of damaged coating.
- ***Machining and welding.*** If epoxy-coated steel articles are subjected to cutting and drilling in the field, patching material should be applied to the cut ends.

Caution: Epoxy-coated high-strength steel bars and other steel components to be used under tension should not be welded or exposed to a torch flame.

Handling and Storage

- *Handling.* To minimize damage during handling and job-site placing, handling equipment should have protected contact areas. Epoxy-coated and galvanized bars should not be dropped or dragged.
- *Storage.* Galvanized steel articles should be stacked to allow air circulation and should never be stored on wet soil or decaying vegetation. Epoxy-coated components should not be stored in direct sunlight or in a humid environment.

QUALITY CONTROL CHECK LIST

What to Request or Check

WOOD COMPONENTS

- | | |
|--|---|
| <input type="checkbox"/> Grade and Species | Request a certificate for the grade and species of lumber from a licensed grader and record the grading agency. |
| <input type="checkbox"/> Machining | Check size and location of holes. |
| <input type="checkbox"/> Moisture Content | Record moisture content prior to and after preservative treatment. |
| <input type="checkbox"/> Preservative Treatment | |
| • Effectiveness | Record penetration and retention levels as certified by the applicator in conformance with AWPA standards. |
| • Bleeding | Check that treater is following AWPA standards for retention levels and steaming after treatment. |
| • Handling | Check the integrity of the preservative envelope and request a consumer information sheet (CIS) from the treater. All personnel in contact with treated lumber must be given a copy of the CIS. |
| <input type="checkbox"/> Lumber Distortion | Reject lumber components that are excessively warped, cupped, or bent. |

STEEL COMPONENTS

Mill Certificate

The coating applicator should furnish a written certificate in compliance with ASTM standards.

Galvanized Articles

- Surface preparation

If chemicals are used, check the length of the acid pickling tank. Dipping the steel component twice into the acid solution is prohibited. Rinsing after acid pickling should be done immediately.

- Fit of nuts

Nuts may be tapped after galvanizing.

Epoxy-Coated Articles

- Repair of damage

Damaged area should not exceed 2 percent of the total surface area. Use an appropriate coating material for patching.

Handling and Storage

Handle with care to minimize damage to coating. Check suitable stacking methods to allow for air circulation and avoid placing galvanized components on cinder blocks or decaying vegetation.

Sheathing and Grouting

Check plastic tubing for conformance with ASTM D 1248; check that tubing is filled with grease; and check that end-caps are tightly secured.

CONSTRUCTION

Deck Assembly

- Butt joint pattern

Check correct placement of butt joints.

- Profile tolerances

Check that the height differences between adjacent laminae are within limits.

- Stressing sequence

Check stressing guidelines to avoid irregular bridge shapes. Measure the width of the bridge above each bar to ensure that the bridge width is consistent.

- **Camber**

Check that camber is properly built. Measure height of temporary supports.

- **Record Information**

Note stressing sequence, bar forces, and deck dimensions. Also, note camber measurements.

REQUIRED FIELD INSPECTION TOOLS

Some of the tools required for the inspection of stress-laminated timber bridge decks include a flashlight, an increment borer, a string line, feeler gauges, wood picks, a moisture meter, a spirit level, plum bob, hammer and nails, and a measuring tape. Inspection guidelines and checklists are provided in reference 9, which should be consulted for more detailed inspection information.

MAINTENANCE

Good maintenance practices should extend the life expectancy of a bridge. To ensure adequate bridge service and performance, the following maintenance activities can be implemented:

1. **Moisture content control**

As discussed previously, exposure to high moisture levels accelerates the decay of timber. Moisture levels should be monitored to plan and provide protective measures for timber components with moisture contents above 20 to 25 percent. In particular, because the deck wearing surface plays an important role in moisture protection, the protection effectiveness of the wearing surface is increased when a geotextile membrane is used.⁽⁶⁾ Any joint between timber members is a water trap and should be inspected regularly.

2. **Wearing surface**

Asphalt pavement and asphalt chip seal are the only acceptable wearing surfaces for timber bridges on paved roads. The wearing surface should be inspected and maintained regularly. Potholes and cracks that allow moisture to reach the timber can promote decay. If the crack or hole is large enough to allow access to the timber, the surrounding area should be investigated for decay. For more information on wearing surfaces, see references 6 and 9.

3. **Debris retains moisture and must be removed from the bridge deck, particularly from drain openings which are exposed to high moisture levels.**

4. **Timber curbs, curb blocks, and posts should be inspected for splits, checks, and vehicular damage. Retreatment of these components by a liquid wood preservative is often necessary. Members damaged by vehicle impact must be repaired or replaced.**
5. **The bolts on the guiderails and curbs should be tightened periodically.**
6. **An operational prestress level of 50 lb/in² (344.5 kPa) should be maintained.**
7. **Breaking of the preservative envelope of timber components should not be allowed. If cutting or drilling is necessary (or when accidental damage occurs), retreatment of the exposed surface is required. In most cases, a surface treatment is sufficient, but there may be instances when a complete member retreatment is required.**

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