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23.1 Introduction

23.1.1 General

This chapter covers the design of spike “laminated deck” superstructures made of timber. This type of structure has a laminated wood deck, where a series of laminations are placed edgewise and oriented in the direction of the span of the bridge. They are spiked together on their wide face with deformed spikes to create a laminated deck panel. These deck panels are prefabricated at a plant in panels less than 7'-6" wide, so they can be easily shipped to the bridge site. At the bridge site the panels are joined together by driving spikes through the ship-lap joint. To assist in spreading applied loads transversely across the deck, stiffener beams are provided. These beams are attached to the underside of each deck panel near its edges and at intermediate points. The timber deck members are treated with a preservative prior to shipping. This will protect the timber against decay and insects, and it will also retard weathering and checking. A bituminous overlay or wearing surface is placed on top of the deck to provide a good riding surface and to protect the deck.

Other types of timber bridges not discussed in this chapter include timber trusses, arches, box culverts, girders, glu-laminated girders and parallel chord timber bridges.

The spike “laminated deck” is one of the least complex bridge types to construct. It is composed of simple spans between each support. It has a superstructure composed of a single material which is easy to fabricate and install. Its limitation lies in the practical range of span lengths for its application.

Timber bridges are aesthetically pleasing and blend well in natural surroundings. These bridges can be constructed in any weather, including cold and wet conditions, without detrimental effects. They are resistant to the effects of deicing agents. The lighter weight of timber allows for easier fabrication and construction since smaller equipment can be used to lift the members into place. Timber bridges tend to deteriorate faster if subjected to high repetitions of heavy loads. Their cost effectiveness should also be evaluated for each site.

23.1.2 Limitations

Timber bridges are not recommended over streams where the 100 year (Q_{100}) frequency flood discharge provides a freeboard less than 24 inches.

They are also not recommended on highways where the Average Daily Traffic (ADT) is greater than 400 vehicles per day The Average Daily Truck Traffic (ADTT) should be significantly less than 100 trucks per day before these timber bridges are allowed **LRFD [9.9.6.1]**.

23.2 Specifications, Material Properties and Deck Thickness

23.2.1 Specifications

Reference may be made to the design and construction related material as presented in the following specifications:

- *State of Wisconsin, Department of Transportation Standard Specifications for Highway and Structure Construction*

  Section 507 Timber Structures

- Other Specifications as referenced in Chapter 3
- *National Design Specifications for Wood Construction (NDS)*
- *American Institute of Timber Construction (Manual) - (AITC)*

23.2.2 Material Properties

23.2.2.1 Reference Design Values

The reference design values for timber members used in laminated deck panels are defined as follows:

Douglas Fir – Larch (No. 1 & Better) – Visually Graded Sawn Lumber **LRFD [Table 8.4.1.1.4-1]**

F_{bo} = 1.20 ksi = reference design value in bending (flexure)

F_{vo} = 0.180 ksi = reference design value in shear

F_{cpo} = 0.625 ksi = reference design value in compression perpendicular to grain

E_o = 1800 ksi = reference modulus of elasticity

Reference design values are based on dry-use conditions, with the wood moisture content not exceeding 19 percent for sawn lumber **LRFD [C8.4.1]**. Reference design values also apply to material treated with preservatives in accordance with *AASHTO Standard Specifications for Transportation Materials* M133 **LRFD [8.4.1]**.

23.2.2.2 Adjusted Design Values

Adjusted design values shall be obtained by multiplying the reference design values by applicable adjustment factors in accordance with **LRFD [8.4.4]** and shown below. All units are in ksi.

$F_b = F_{bo}\ C_{KF}\ C_M\ (\ C_F \text{ or } C_v\ )\ C_{fu}\ C_i\ C_d\ C_\lambda$ = adjusted design value in bending (flexure)

$F_v = F_{vo} C_{KF} C_M C_i C_\lambda$ = adjusted design value in shear

$F_{cp} = F_{cpo} C_{KF} C_M C_i C_\lambda$ = adjusted design value in compression perpendicular to grain

$E = E_o C_M C_i$ = adjusted modulus of elasticity

Where:

C_{KF}	=	Format conversion factor specified in **LRFD [8.4.4.2]**
C_M	=	Wet service factor specified in **LRFD [8.4.4.3]**
C_F	=	Size factor for visually graded dimension lumber and sawn timbers specified in **LRFD [8.4.4.4]**
C_v	=	Volume factor for structural glued laminated timber specified in **LRFD [8.4.4.5]**
C_{fu}	=	Flat use factor specified in **LRFD [8.4.4.6]**
C_i	=	Incising factor specified in **LRFD [8.4.4.7]**
C_d	=	Deck factor specified in **LRFD [8.4.4.8]**
C_λ	=	Time effect factor specified in **LRFD [8.4.4.9]**

23.2.2.2.1 Format Conversion Factor, C_{KF}

The reference design value is multiplied by the format conversion factor, C_{KF} , to go from a value that is used in allowable stress design to a value that is used with load and resistance factor design **LRFD [8.4.4.2]**. Use a C_{KF} value of $2.5/\phi$, except for compression perpendicular to the grain which shall use a value of $2.1/\phi$. The resistance factors, ϕ , are provided in **LRFD [8.5.2.2]**.

23.2.2.2.2 Wet Service Factor, C_M

The reference design value is based on dry use resistance and shall be modified for moisture content using the wet service factor, C_M. For sawn lumber with an in-service moisture content of 19% or less, use a C_M value of 1.0. Otherwise, see **LRFD [8.4.4.3]**.

23.2.2.2.3 Size Factor for Sawn Lumber, C_F

The size factor, C_F , shall have a value of 1.0, unless otherwise specified by **LRFD [Table 8.4.4.4-1]**.

23.2.2.2.4 Volume Factor, C_v , (Glulam)

The volume factor, C_v , doesn't apply to laminated deck structures, but to horizontally laminated glulam members **LRFD [8.4.4.5]**.

23.2.2.2.5 Flat Use Factor, C_{fu}

The flat use factor, C_{fu} , doesn't apply to laminated deck structures, but to specific grades of planks with load applied to the wide face and vertically laminated glulam with loads applied parallel to the wide face of laminations **LRFD [8.4.4.6]**.

23.2.2.2.6 Incising Factor, C_i

The reference design values for dimension lumber shall be multiplied by the incising factor specified in **LRFD [Table 8.4.4.7-1]** when members are incised parallel to the grain a maximum depth of 0.4 inches, a maximum length of 3/8 inches, and a density of incisions up to 1100/ft^2.

23.2.2.2.7 Deck Factor, C_d

For spike "laminated decks" constructed of solid sawn lumber 2 to 4 inches thick, F_{bo} may be adjusted by multiplying it by C_d as specified in **LRFD [Table 8.4.4.8-1]**. Laminated decks exhibit an increased resistance in bending. The value for C_d in this table is 1.15.

23.2.2.2.8 Time Effect Factor, C_λ

The time effect factor, C_λ , shall be chosen to respond to the appropriate strength limit state as specified in **LRFD [Table 8.4.4.9-1]**. For Strength I Limit State the value for C_λ is 0.8.

23.2.3 Deck Thickness

Deck Thickness (inches)	Effective Span (L) [1] (feet)
10	L = 17
12	17 < L ≤ 25
14	25 < L ≤ 30
16	30 < L ≤ 36

Table 23.2-1
Deck Thickness vs. Effective Span

[1] The effective span shall be taken as the clear distance between supports plus one half the width of one support, but not to exceed the clear span plus the deck thickness.

23.3 Limit States Design Method

23.3.1 Design and Rating Requirements

All new laminated deck structures are to meet design requirements as stated in 17.1.1 and rating requirements as stated in 17.1.2.

23.3.2 LRFD Requirements

23.3.2.1 General

For laminated deck design, the deck dimensions, length of bearing at support and the spacing of spikes at the ship-lap joint shall be selected to satisfy the equation below for all appropriate Limit States: **LRFD [1.3.2.1]**

$$Q = \sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r$$ (Limit States Equation) **LRFD [1.3.2.1, 3.4.1]**

Where:

η_i	=	Load modifier (a function of η_D , η_R and η_I) **LRFD [1.3.2.1, 1.3.3, 1.3.4, 1.3.5]**
γ_i	=	Load factor
Q_i	=	Force effect; moment, shear or deformation caused by applied loads
Q	=	Total factored force effect
ϕ	=	Resistance factor
R_n	=	Nominal resistance; resistance of a component to force effects
R_r	=	Factored resistance = ϕR_n

The Limit States used for laminated deck design are:

- Strength I Limit State
- Service I Limit State

23.3.2.2 Statewide Policy

Current Bureau of Structures policy is :

- Set value of load modifier, η_i , and its factors (η_D , η_R , η_I) all equal to 1.00 for laminated deck design.

- Ignore any influence of ADTT on multiple presence factor, m, in **LRFD [Table 3.6.1.1.2-1]** that would reduce force effects, Q_i , for laminated deck bridges.

- Ignore reduction factor, r, for skewed laminated deck bridges in **LRFD [4.6.2.3]** that would reduce longitudinal force effects, Q_i .

23.3.3 Strength Limit State

Strength I Limit State shall be applied to ensure that strength and stability are provided to resist the significant load combinations that a bridge is expected to experience during its design life **LRFD [1.3.2.4]**. The total factored force effect, Q, must not exceed the factored resistance, R_r , as shown in the equation in 23.3.2.1.

Strength I Limit State **LRFD [3.4.1]** will be used for:

- Designing laminated deck for bending (flexure)

- Checking horizontal shear in laminated deck near the supports

- Checking compression perpendicular to grain in laminated deck at the supports

- Checking spacing of drive spikes at ship-lap joint

23.3.3.1 Factored Loads

The value of the load modifier, η_i , is 1.00, as stated in 23.3.2.2.

Strength I Limit State will be used to design the structure for force effects, Q_i , due to applied dead loads, DC and DW (including future wearing surface), defined in 23.4.3 and appropriate (HL-93) live loads, LL and IM, defined in 23.4.4.1. When sidewalks are present, include force effects of pedestrian live load, PL, defined in 23.4.4.2.

The load factor, γ_i , is used to adjust force effects on a structural element. This factor accounts for variability of loads, lack of accuracy in analysis, and the probability of simultaneous occurrence of different loads.

For Strength I Limit State, the values of γ_i for each applied load, are found in **LRFD [Tables 3.4.1-1 and 3.4.1-2]** and their values are: γ_{DC} = 1.25/0.90, γ_{DW} = 1.50/0.65, γ_{LL+IM} = γ_{PL} = 1.75. The values for γ_{DC} and γ_{DW} have a maximum and minimum value.

Therefore, for Strength I Limit State:

$$Q = 1.0 [1.25(DC) + 1.50(DW) + 1.75((LL + IM) + PL)]$$

Where DC, DW, LL, IM, and PL represent force effects due to these applied loads. The load factors shown for DC and DW are maximum values. Use maximum or minimum values as shown in **LRFD [Table 3.4.1-2]** to calculate the critical force effect.

23.3.3.2 Factored Resistance

The resistance factor, ϕ, is used to reduce the computed nominal resistance of a structural element. This factor accounts for variability of material properties, structural dimensions and workmanship, and uncertainty in prediction of resistance.

The resistance factors, ϕ, for Strength Limit State **LRFD [8.5.2.2]** are:

- ϕ = 0.85 for flexure
- ϕ = 0.75 for shear
- ϕ = 0.90 for compression perpendicular to grain
- ϕ = 0.65 for connections

The factored resistance, R_r (M_r , V_r , P_r), associated with the list of items to be designed/checked using Strength I Limit State in 23.3.3, are described in the following sections.

23.3.3.2.1 Moment Capacity

For rectangular sections, the nominal moment resistance, M_n , equals: **LRFD [8.6.2]**

$$M_n = F_b\ S\ C_L$$

Where:

F_b	=	Adjusted design value in bending (flexure) specified in **LRFD [8.4.4.1]** (ksi)
S	=	Section modulus = $b\ d^2 / 6$ (in^3)
b	=	Net width, as specified in **LRFD [8.4.1.1.2]** (in)
d	=	Net depth, as specified in **LRFD [8.4.1.1.2]** (in)
C_L	=	Beam stability factor

The factored resistance, M_r , or moment capacity, shall be taken as: **LRFD [8.6.1]**

$$M_r = \phi\ M_n = \phi\ F_b\ S\ C_L$$

For timber members in flexure, the resistance factor, ϕ, is 0.85 and for spike “laminated decks” the value for C_L is 1.0, therefore:

$$M_r = (0.85)\ F_b\ S$$

23.3.3.2.2 Shear Capacity

The nominal shear resistance, V_n , shall be determined as: **LRFD [8.7]**

$$V_n = F_v \, b \, d / 1.5 \quad \text{(kips)}$$

Where:

F_v = Adjusted design value in shear, specified in **LRFD [8.4.4.1]** (ksi)

b = Net width, as specified in **LRFD [8.4.1.1.2]** (in)

d = Net depth, as specified in **LRFD [8.4.1.1.2]** (in)

The factored resistance, V_r , or shear capacity of a component of rectangular cross-section, shall be taken as: **LRFD [8.7]**

$$V_r = \phi \, V_n = \phi \, F_v \, b \, d / 1.5$$

The resistance factor for shear, ϕ, is 0.75, therefore:

$$V_r = (0.75) \, F_v \, b \, d / 1.5$$

23.3.3.2.3 Compression Perpendicular to Grain Capacity

The nominal resistance, P_n , of a member in compression perpendicular to grain shall be taken as: **LRFD[8.8.3]**

$$P_n = F_{cp} \, A_b \, C_b$$

Where:

F_{cp} = Adjusted design value in compression perpendicular to grain as specified in **LRFD [8.4.4.1]** (ksi)

A_b = Bearing area (in^2)

C_b = Bearing adjustment factor as specified in **LRFD [Table 8.8.3-1]**

When the bearing area is in a location of high flexural stress or is closer than 3 inches from the end of the component, C_b , shall be taken as 1.0. In all other cases, C_b , shall be as specified in **LRFD [Table 8.8.3-1]**.

The factored resistance, P_r , or compression capacity, shall be taken as: **LRFD [8.8.1]**

$$P_r = \phi \, P_n = \phi \, F_{cp} \, A_b \, C_b$$

For compression perpendicular to grain, the resistance factor, ϕ, is 0.90, therefore:

$P_r = (0.9)\ F_{cp}\ A_b\ C_b$

23.3.4 Service Limit State

Service I Limit State shall be applied as a restriction on deformation under regular service conditions **LRFD [1.3.2.2]**. The total factored force effect, Q, must not exceed the factored resistance, R_r , as shown in the equation in 23.3.2.1.

Service I Limit State **LRFD [3.4.1]** will be used for:

- Checking live load deflection criteria

23.3.4.1 Factored Loads

The value of the load modifier, η_i , is 1.00, as stated in 23.3.2.2.

Service I Limit State will be used to analyze the structure for force effects, Q_i , due to appropriate (HL-93) live loads, LL and IM, defined in 23.4.4.1.

For Service I Limit State, the value of γ_i for applied live load, is found in **LRFD [Table 3.4.1-1]** and its value is: $\gamma_{LL+IM} = 1.0$

Therefore, for Service I Limit State:

$$Q = 1.0\ [\ 1.0(LL + IM)\ ]$$

Where LL and IM represent force effects due to these applied loads.

23.3.4.2 Factored Resistance

The resistance factor, ϕ, for Service Limit State, is found in **LRFD [1.3.2.1]** and its value is 1.00.

The factored resistance, R_r , associated with the checking of live load deflection using Service I Limit State is described below.

23.3.4.2.1 Live Load Deflection Criteria

All spike "laminated deck" structures shall be designed to meet live load deflection limits. Large deflections in wood components can cause fasteners to loosen and wearing surfaces to deteriorate. The limit for live load deflections for laminated deck structures is L/425 for vehicular and pedestrian loads **LRFD [2.5.2.6.2]**. The deflections are based on entire deck width acting as a unit and net-section moment of inertia, I_{net} .

The nominal resistance, R_n , or deflection limit, is:

$$R_n = L/425$$

Where:

L = Span length

The factored resistance, R_r , is:

$R_r = \phi R_n = \phi (L/425)$

The resistance factor, ϕ, is 1.00, therefore:

$R_r = (1.0) R_n = (L/425)$

23.3.5 Fatigue Limit State

Fatigue need not be investigated for wood decks (laminated decks) as described in **LRFD [9.5.3, 9.9]**

23.4 Laminated Deck Design Procedure

23.4.1 Trial Deck Depth

Prepare preliminary structure data, looking at the type of structure, span lengths, skew, roadway width, etc.. Knowing the span lengths, a trial deck depth can be obtained from Table 23.2-1.

NOTE: With preliminary structure sizing complete, check to see if structure exceeds limitations in 23.1.2.

23.4.2 Dimensions

Structural calculations shall be based on the actual net dimensions for the anticipated use conditions. These net dimensions depend on the type of surfacing used on the timber member. See **LRFD [8.4.1.1.2]** for a description of dimensions to use.

23.4.3 Dead Loads (DC, DW)

Dead loads (permanent loads) are defined in **LRFD [3.3.2]**. Timber dead load is computed by using a unit weight of 50 pcf **LRFD [3.5.1]**. This value includes the weight of mandatory preservatives used to treat the wood. The bituminous wearing surface load is computed by using a unit weight of 150 pcf.

DC	=	dead load of structural components and any nonstructural attachments
DW	=	dead load of bituminous wearing surface, future wearing surface (F.W.S.) and utilities

The laminated deck dead load, DC_{deck} , and the bituminous wearing surface load, DW_{bitws} , are included in the design. A post dead load, DW_{FWS} , of 20 psf, for possible future wearing surface (F.W.S.), is required in the design by the Bureau of Structures.

Dead loads, DC, from railings, curbs and scupper blocks are uniformly distributed across the full width of the deck when designing an interior strip. For the design of exterior strips, any of these dead loads, DC, that are located directly over the exterior strip width shall be applied to the exterior strip. For both interior and exterior strips, the future wearing surface, DW_{FWS} , and bituminous wearing surface, DW_{bitws} , located directly over the strip width shall be applied to it.

23.4.4 Live Loads

23.4.4.1 Vehicular Live Load (LL) and Dynamic Load Allowance (IM)

The *AASHTO LRFD Specifications* contain several live load components (see 17.2.4.2) that are combined and scaled to create live load combinations that apply to different Limit States **LRFD [3.6.1]**. Where the equivalent strip method is used as described in 23.4.6, and the span exceeds 15 feet, all of the live loads specified in **LRFD [3.6.1.2]** shall be applied **LRFD**

[3.6.1.3.3]. Live load combinations (LL#3 and LL#4) as shown in 17.2.4.2.6, do not apply because all spans in laminated deck structures are simple spans and the Fatigue Limit State does not apply to laminated decks.

The live load combinations used for design are:

LL#1:	Design Tandem (+ IM) + Design Lane Load	**LRFD [3.6.1.3.1]**
LL#2:	Design Truck (+ IM) + Design Lane Load	**LRFD [3.6.1.3.1]**
LL#5:	Design Truck (+ IM)	**LRFD [3.6.1.3.2]**
LL#6:	25% [Design Truck (+ IM)] + Design Lane Load	**LRFD [3.6.1.3.2]**

Table 23.4-1
Live Load Combinations

The dynamic load allowance, IM, **LRFD [3.6.2.3]** need not be applied to wood components. Wood structures are known to experience reduced dynamic wheel load effects due to internal friction between the components and the damping characteristics of wood. Additionally, wood is stronger for short duration loads, as compared to longer duration loads. This increase in strength is greater than the increase in force effects resulting from the dynamic load allowance.

The live load combinations are applied to the Limit States as shown in Table 23.4-2.

The live load force effect, Q_i , shall be taken as the largest from the live loads shown in Table 23.4-2 for that Limit State.

Strength I Limit State: [1]	LL#1 , LL#2	IM = 0%
Service I Limit State: (for LL deflection criteria)	LL#5 , LL#6	IM = 0%

Table 23.4-2
Live Loads for Limit States

[1] Load combinations shown are used for design of interior strips and exterior strips.

23.4.4.2 Pedestrian Live Load (PL)

For bridges designed for both vehicular and pedestrian live load, a pedestrian live load, PL, of 75 psf is used. However, for bridges designed exclusively for pedestrian and/or bicycle traffic, a live load of 85 psf is used **LRFD [3.6.1.6]**. The dynamic load allowance, IM, is not applied to pedestrian live loads **LRFD [3.6.2]**.

Pedestrian loads are not applied to an interior strip for its design. For the design of exterior strips, any pedestrian loads that are located directly over the exterior strip width shall be applied to the exterior strip.

23.4.5 Minimum Deck Thickness Criteria

Check adequacy of chosen deck thickness by looking at live load deflection criteria, using Service I Limit State.

23.4.5.1 Live Load Deflection Criteria

All laminated deck structures shall be designed to meet live load deflection limits **LRFD [2.5.2.6.2, 9.9.3.3]**. Live load deflections for laminated deck structures are limited to L/425. The live load deflection, Δ_{LL+IM} , shall be calculated using factored loads described in 23.3.4.1 and 23.4.4.1 for Service I Limit State.

Place live loads in each design lane **LRFD [3.6.1.1.1]** and apply a multiple presence factor **LRFD [3.6.1.1.2]**. Use net-section moment of inertia, I_{net} , based on entire deck width acting as a unit. Use adjusted modulus of elasticity, E as described in 23.2.2.2. The factored resistance, R_r , is described in 23.3.4.2.1.

Then check that, $\Delta_{LL+IM} \leq R_r$ is satisfied.

23.4.6 Live Load Distribution

Live loads are distributed over an equivalent width, E, as calculated below. The equivalent distribution width applies for both live load moment and shear.

23.4.6.1 Interior Strip

Equivalent interior strip widths for laminated deck bridges are covered in **LRFD [4.6.2.1.2, 4.6.2.3]** for spans more than 15 feet.

The live loads to be placed on these widths are axle loads (i.e., two lines of wheels) and the full lane load.

Single-Lane Loading: $E = 10.0 + 5.0\,(L_1 W_1)^{1/2}$

Multi-Lane Loading: $E = 84.0 + 1.44(L_1 W_1)^{1/2} \leq 12.0(W)/N_L$

Where:

E = Equivalent distribution width (in)

L_1 = Modified span length taken equal to the lesser of the actual span or 60.0 ft (ft)

W_1 = Modified edge to edge width of bridge taken to be equal to the lesser of the actual width or 60.0 ft for multi-lane loading, or 30.0 ft for single-lane loading (ft)

W = Physical edge to edge width of bridge (ft)

N_L = Number of design lanes as specified in **LRFD [3.6.1.1.1]**

23.4.6.1.1 Strength Limit State

Use the smaller equivalent width (single-lane or multi-lane), when (HL-93) live load is to be distributed for Strength I Limit State.

The distribution factor, DF, is computed for a design deck width equal to one foot.

$$DF = \frac{1}{E}$$

Where:

E = Equivalent distribution width (ft)

The multiple presence factor, m, has been included in the equations for distribution width, E, and therefore aren't used to adjust the distribution factor, DF, **LRFD [3.6.1.1.2]**.

23.4.6.2 Exterior Strip

Equivalent exterior strip widths for laminated deck bridges are covered in **LRFD [4.6.2.1.4]**.

The exterior strip width, E, is assumed to carry one wheel line and a tributary portion of design lane load (located directly over the strip width).

E equals the distance between the edge of the deck and the inside face of the barrier, plus 12 inches, plus ¼ of the full strip width specified in **LRFD [4.6.2.3]**.

The exterior strip width, E, shall not exceed either ½ the full strip width or 72 inches.

Use the smaller equivalent width (single-lane or multi-lane), for full strip width, when (HL-93) live load is to be distributed for Strength I Limit State.

The multiple presence factor, m, has been included in the equations for full strip width and therefore aren't used to adjust the distribution factor **LRFD [3.6.1.1.2]**.

23.4.6.2.1 Strength Limit State

The distribution factor, DF, is computed for a design deck width equal to one foot.

Compute the distribution factor associated with one truck wheel line, to be applied to axle loads:

$$DF = \frac{(1 \text{ wheel line})}{(2 \text{ wheel lines/lane})(E)}$$

Where:

E = Equivalent distribution width (ft)

Compute the distribution factor associated with tributary portion of design lane load, to be applied to full lane load: **LRFD [3.6.1.2.4]**

$$DF = \frac{\left[\frac{(SWL)}{(10 \text{ ft lane load width})}\right]}{(E)}$$

Where:

E = Equivalent distribution width (ft)

SWL = Deck width loaded (ft)

= E – (distance from edge of deck to inside face of barrier or curb) (ft)

23.4.7 Design Deck for Strength in Bending

The total factored moment, M_u , shall be calculated using factored loads described in 23.3.3.1 for Strength I Limit State.

The factored resistance, M_r , or moment capacity, shall be calculated as in 23.3.3.2.1.

Then check that, $M_u \leq M_r$ is satisfied.

The laminated deck should also be checked for moment capacity (factored resistance), to make sure it can handle factored moments due to applied dead load (including future wearing surface) and the Wisconsin Standard Permit Vehicle (Wis-SPV) (with a minimum gross vehicle load of 190 kips) on an interior strip. This requirement is stated in 17.1.2.1.

23.4.8 Check for Shear

Shear shall be investigated at a distance away from the face of support equal to the depth of the component. When calculating the maximum design shear, the live load shall be placed so as to produce the maximum shear at a distance from the support equal to the lesser of either three times the depth, d , of the component or one-quarter of the span L.

The critical section is between one and three depths from the support.

The critical shear in flexural components is horizontal shear acting parallel to the grain of the component. The resistance of bending components in shear perpendicular to grain need not be investigated.

The factored shear, V_u , shall be calculated using factored loads described in 23.3.3.1 for Strength I Limit State.

The factored resistance, V_r , or shear capacity, shall be calculated as in 23.3.3.2.2.

Then check that, $V_u \le V_r$ is satisfied.

The laminated deck should have the shear capacity to handle the dead loads and Permit Vehicle as discussed in 23.4.7.

23.4.9 Check Compression Perpendicular to Grain

The factored compression perpendicular to the grain, P_u , shall be calculated using factored loads described in 23.3.3.1 for Strength I Limit State.

The factored resistance, P_r , or compression capacity, shall be calculated as in 23.3.3.2.3.

Then check that, $P_u \le P_r$ is satisfied.

The laminated deck should have the compression capacity to handle the dead loads and Permit Vehicle as discussed in 23.4.7.

23.4.10 Check Spacing of Drive Spikes at Ship-Lap Joint

Check the spacing of drive spikes at the ship-lap joint to make sure it is adequate to provide sufficient capacity to resist the factored horizontal shear forces along the length of the span.

23.4.11 Fabrication of Deck Panels

The laminations in deck panels are spiked together on their wide faces with deformed spikes of sufficient length to fully penetrate four laminations. The spikes shall be placed in lead holes that are bored through pairs of laminations at each end and at intervals not greater than 12 inches in an alternating pattern near the top and bottom of the laminations, as shown in **LRFD [9.9.6]**. Laminations shall not be butt spliced within their unsupported length. The typical thickness of the laminations is 4 inches. The deck panels are prefabricated at a plant in panel widths less than 7'-6" wide, so it can easily be shipped to the bridge site. The specified design details for lamination arrangement and spiking are based upon current practice. It is important that the spike lead holes provide a tight fit to ensure proper load transfer between laminations and to minimize mechanical movements. See **LRFD [9.9.6]** for spike layout for spike "laminated decks."

23.4.12 Thermal Expansion

Thermal expansion may be neglected in spike "laminated decks". Generally, thermal expansion has not presented problems in wood deck systems. Most wood decks inherently contain gaps at the butt joints that can absorb thermal movements **LRFD [9.9.3.4]**.

23.4.13 Wearing Surfaces

Laminated decks shall be provided with a wearing surface conforming to the provisions of **LRFD [9.9.8]**. Experience has shown that unprotected wood deck surfaces are vulnerable to wear and abrasion and/or may become slippery when wet.

23.4.14 Deck Tie-Downs

Where deck panels are attached to wood supports, the tie-downs shall consist of metal brackets that are bolted through the deck and attached to the sides of the supporting component. Lag screws or deformed shank spikes may be used to tie panels down to the wood support **LRFD [9.9.4.2]**.

23.4.15 Transverse Stiffener Beam

Interconnection of panels should be made with transverse stiffener beams attached to the underside of the deck. The distance between stiffener beams shall not exceed 8 feet, and the rigidity, EI, of each stiffener beam shall not be less than 80,000 kip-in^2. The beams shall be attached to each deck panel near the panel edges and at intervals not exceeding 15 inches **LRFD [9.9.4.3.1]**.

23.4.16 Metal Fasteners and Hardware

Attachments and fasteners used in wood construction shall be of stainless steel , malleable iron, aluminum or steel that is galvanized, cadmium plated, or otherwise coated to provide durability **LRFD [2.5.2.1.1]**. Material property requirements for metal fasteners and hardware are covered in **LRFD [8.4.2]**. The design of fasteners and connections is covered in **LRFD [8.13]**.

23.4.17 Preservative Treatment

All wood used for permanent applications shall be pressure impregnated with wood preservatives in accordance with the requirements of *AASHTO Standard Specifications for Transportation Materials* M133. Insofar as is practicable, all wood components shall be designed and detailed to be cut, drilled, and otherwise fabricated prior to pressure treatment with wood preservatives. When cutting, boring or other fabrication is necessary after preservative treatment, exposed, untreated wood shall be specified to be treated in accordance with the requirements of *AASHTO* M133. See **LRFD [8.4.3]** for other preservative treatment requirements.

23.4.18 Timber Rail System

Use approved crash-tested rail systems only.

23.4.19 Rating of Superstructure

Refer to *AASHTO Manual for Bridge Evaluation (MBE)* and also the example that follows.

23.5 References

1. Wipf, T. J., "Load *Distribution Criteria for Glued Laminated Longitudinal Timber Deck Highway Bridges*", Engineering Research Institute, Iowa State University. 1985.

2. Transportation Research Board, "*Timber Bridges*", (Transportation Research Record #1053). 1989.

3. Forest Products Laboratory, "Design*, Fabrication, Testing, and Installation of a Press-Lam Bridges*", (Research Paper FPL-332) 1979.

4. AITC, "*Modern Timber Highway Bridges, A State of the Art Report*", (American Institute of Timber Construction, July 1, 1973).

5. Bohannan, Bill, "*FLP Timber Bridge Deck Research*," Journal of the Structural Division, ASCE, Vol. 98 No. ST3, Proc. Paper 8779, March, 1972, pp. 729-740.

6. Forest Products Laboratory, "*Procedure for Design of Glued-Laminated Orthotropic Bridge Decks*", (Research Paper FPL-210) 1973.

7. Forest Products Laboratory, "*Erection Procedure for Glued-Laminated Timber Bridge Decks with Dowel Connectors*", (Research Paper FPL-263) 1970.

8. Ou, Fong L., Ph.D., P.E., "*An Overview of Timber Bridges*", Engineering Staff Forest Service. (Transportation Research Board Paper-65th Annual Meeting) 1986.

23.6 Design Example

E23-1 Two-Span Timber Bridge, 14 inch Deck, LRFD

(This Design Example will be added in the future)