LRFD Provisions for Wood Bridges

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Abstract

A project to develop a load and resistance factor design (LRFD) edition of the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges is complete. A part of this effort involved the development of LRFD provisions for wood bridges. These new specifications include numerous changes and several significant departures from current allowable stress design practices for wood bridges.

Introduction

The development of a load and resistance factor design (LRFD) specification for wood bridges presented several unique opportunities and challenges. Overall, this project was a rare opportunity to completely revise and update American Association of State Highway and Transportation Officials (AASHTO) wood bridge design requirements, which have traditionally lagged behind state-of-the-art wood design methodologies. The primary challenge for wood bridges was to develop basic design requirements and procedures for LRFD. Unlike concrete and steel, which have had an LRFD procedure available for several years, LRFD specifications for wood are in the developmental stages (Goodman 1990, Murphy 1988). This paper briefly summarizes selected provisions of the new AASHTO LRFD specification as they relate to the design of wood bridges. These provisions include topics related to general design features, loads and load distribution, and wood design.

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General Design Features

The AASHTO LRFD specification is based on a limit states design approach. As defined in the specification, a limit state represents a condition beyond which the bridge or component ceases to satisfy the provisions for which it was designed. For general bridge design, four limit states are defined; strength, service, extreme events, and fatigue and fracture. For wood bridge design, the most applicable of these limit states are the Strength Limit State, which is intended to ensure that the structure will provide the required strength and stability over the design life, and the Service Limit State, which restricts stress and deformation under regular service conditions. The Extreme Event Limit States, which is intended to ensure structural survival in major earthquakes, floods and vehicle collisions, will generally not control the design of most wood bridges. The Fatigue and Fracture Limit State, which applies primarily to steel bridges, is not applicable to the design of wood components under current design practices.

In the LRFD specification, each component must satisfy the following equation for each limit state:

\[ \eta \sum (\gamma_i, Q_i) \leq \phi R_s \]  

Where \( \eta \) = load modifier for ductility, redundancy, and operational importance, \( \gamma_i \) = load factor, \( Q_i \) = force effect, \( \phi \) = resistance factor, and \( R_s \) = nominal resistance.

Within the general provisions of the LRFD specification, two provisions that affect wood design are noteworthy. In the past, wood structures have not been subject to impact factor adjustments that increase vehicle live load to account for dynamic effects. In the LRFD specification, general requirements for a dynamic load allowance require that the static truck loads be increased 75% for the design of deck joints and 33% for the design of all other components. For wood design, these values may be reduced by one-half. Another area that has not been addressed for wood bridges in previous allowable stress design (ASD) specifications is live load deflection. The LRFD specification presents a deflection limit for wood bridges equal to the bridge span divided by 425. This deflection limit, which is based on the vehicle live load including the dynamic allowance, is considered an optional requirement and is left to designer judgment.

Loads and Load Distribution

The LRFD specification presents load combinations in tabular format with the specified load factors for each type of applied loading. There are a total of 11 load combinations; 5 for the Strength Limit State, 2 for the Extreme Events Limit State,
3 for the Service Limit State and 1 for the Fatigue and Fracture Limit State. Of these, 2 strength load combinations and 1 service load combination will most commonly control design for wood bridges.

Requirements for structural analysis and evaluation in the LRFD specification include guidelines for sophisticated bridge analysis and simplified approximate methods of analysis, which have traditionally been used. In general, the requirements for approximate load distribution for wood bridges are the same as those currently presented in the AASHTO ASD specification. An exception is the load distribution criteria for the design of slab-type superstructures. Rather than the traditional criteria based on a longitudinal distribution width as a function of tire width and deck thickness, the following equations are given for an equivalent longitudinal distribution width per lane and are applicable both to wood and concrete superstructures.

With one lane loaded,

\[ E = 1.00 + 0.50 \sqrt{L_1 W_1} \]  

(2)

With more than one lane loaded,

\[ E = 7.00 + 0.12 \sqrt{L_1 W_1} \leq \frac{W}{N} \]  

(3)

Where \( E \) = equivalent distribution width per lane (ft) (1 ft = 0.305 m), 
\( L_1 \) = modified span equal to the lesser of the actual span or 60 ft (18 m), 
\( W_1 \) = modified width equal to the lesser of actual width or 60 ft (18 m), 
\( W \) = physical edge-to-edge bridge width (ft), 
\( L \) = physical bridge length (ft), and 
\( N \) = number of design lanes.

Wood Design

Provisions for the LRFD design of wood components are presented in one chapter and include requirements for materials, limit states, component design, bracing, and camber. From a design perspective, the most significant departures from the ASD method involve provisions for base and nominal resistance values for wood materials, resistance factors and the relationship of these factors to limit states and load combinations, and component design requirements.

Base Resistance

One key wood design requirement for the AASHTO LRFD specification was the development of a procedure for obtaining base resistance values for various
engineered wood products. Given the large number of wood species, products and 
grades used in bridge applications, AASHTO ASD specifications have traditionally 
included design values for only a limited number of the species and grades of sawn 
lumber, glued laminated timber, and timber piles. These values have been obtained 
directly from national standards, primarily the National Design Specification for 
Wood (NDS) (NFPA 1991) for sawn lumber and timber piles and AITC 117-Design 
(AITC 1987) for glued laminated timber. This approach has provided consistency 
between the design values used for bridges and those used for buildings and other 
structures. In addition, this approach provides the most expedient reference to 
current design values when industry changes are made. Based on these 
considerations, a procedure for determining base resistance values for wood products 
was developed that directly incorporates industry standards presented in the NDS and 
AITC 117-Design.

The LRFD specification includes tables of base resistance values for selected wood 
species and grades of sawn lumber, glued laminated timber, and timber piles that are 
commonly used for wood bridge design. The values are based on wet-use conditions 
and a 2-month load duration, which corresponds to the most common design 
conditions. Within these tables, base resistance values are given for flexure ($F_{bo}$), 
tension parallel to grain ($F_{to}$), shear parallel to grain ($F_{vo}$), compression perpendicular 
to grain ($F_{cpo}$), compression parallel to grain ($F_{co}$), and modulus of elasticity ($E_o$). 
To obtain values for species and grades not included in the tables, a direct 
conversion of ASD values in the NDS or AITC 117-Design is specified using the 
following conversion factors (Table 1).

<table>
<thead>
<tr>
<th>Material</th>
<th>$F_{bo}$</th>
<th>$F_{to}$</th>
<th>$F_{vo}$</th>
<th>$F_{cpo}$</th>
<th>$F_{co}$</th>
<th>$E_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension Lumber</td>
<td>2.35</td>
<td>2.95</td>
<td>3.05</td>
<td>1.75</td>
<td>1.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Beams and Stringers</td>
<td>2.80</td>
<td>2.95</td>
<td>3.15</td>
<td>1.75</td>
<td>2.40</td>
<td>1.00</td>
</tr>
<tr>
<td>and Posts and Timbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glued laminated timber</td>
<td>2.20</td>
<td>2.35</td>
<td>2.75</td>
<td>1.35</td>
<td>1.90</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Nominal Resistance

Base LRFD resistance values obtained from the specification tables, or through 
adjustment of ASD values, are based on specific conditions and are intended to serve 
as a starting point for determining the nominal resistance values used for design. 
To determine nominal resistance values, base resistance values must be adjusted by 
factors that compensate for (1) differences between the assumptions used to establish 
the base resistance values and the actual use conditions, (2) variations in wood 
behavior related to the type of stress or member orientation, and (3) differences 
between the physical and mechanical behavior of wood and that of an ideal material
assumed in most equations of engineering mechanics. General adjustments that are common to the design of most components are presented in the LRFD specification as follows:

\[ F = F_o C_F C_M C_D \]  \hspace{1cm} (4)

\[ E = E_o C_M \]  \hspace{1cm} (5)

Where

- \( F \) = applicable nominal resistance \( F_b, F_c, F_v, F_{cp}, \) or \( F_c \),
- \( F_o \) = applicable base resistance \( F_{bo}, F_{co}, F_{vo}, \) or \( F_{co} \),
- \( C_F \) = size effect factor based on the member size or volume,
- \( C_M \) = moisture content factor for adjustment to dry use conditions,
- \( C_D \) = deck factor applicable to the design of some deck types,
- \( E \) = nominal modulus of elasticity, and
- \( E_o \) = base modulus of elasticity.

Additional adjustments that are related only to the design of specific components are included in the component design subsections of the wood design section.

**Resistance Factors**

As previously presented in the general LRFD design equation, the nominal resistance of a component is multiplied by a resistance factor \( \phi \). For wood design, the resistance factors for all wood products, species, and grades are as follows:

- Flexure \( \phi = 0.85 \)
- Shear \( \phi = 0.75 \)
- Compression parallel to grain \( \phi = 0.90 \)
- Compression perpendicular to grain \( \phi = 0.90 \)
- Tension parallel to grain \( \phi = 0.80 \)

For Strength Load Combination IV, corresponding to the case governed by permanent loads, the resistance factors are multiplied by 0.75 to compensate for the load duration effect on wood properties when components are subjected to the long-term loading.

**Component Design Requirements**

Within the LRFD wood design section, subsections are provided for component design for members in flexure, shear, compression, tension parallel to grain, and combined flexure, and axial loading. These subsections include specific provisions related to design, including additional adjustment factors that are applied to the
nominal resistance. An example equation for nominal resistance in flexure follows:

\[ M_n = F_b S C_s C_r \]  

(6)

Where \( M_n \) = nominal resistance in flexure,
\( F_b \) = specified resistance in flexure from Equation (2),
\( S \) = section modulus,
\( C_s \) = stability factor, and
\( C_r \) = repetitive member factor.

Within the LRFD specification, values for specific factors such as \( C_s \) and \( C_r \) are determined from equations or tables presented in the component design subsection.

Summary

The new AASHTO LRFD specification presents a new approach to bridge design that differs from traditional ASD methodology. From the perspective of wood bridge design, significant provisions of the LRFD specification include (1) the use of load and resistance factors, (2) inclusion of a dynamic load allowance for static truck loads, (3) new live load deflection criterion, (4) revised load combinations and live load distribution requirements, and (5) new values for material strength (base resistance).

References


