

Designing Timber Bridge Superstructures: A Comparison of US and Canadian Bridge Codes

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INTRODUCTION

Several changes relating to timber bridges have been incorporated into the AASHTO-LRFD Bridge Design Specifications recently. In addition, the Federal Highway Administration is strongly encouraging an LRFD-based design approach for all new bridges in the United States. The Bridge Design Code in Canada was one of the first to adopt the limit states design philosophy, doing so many years ago. This paper presents an overview of the United States and Canadian bridge design codes, highlighting similarities and differences that relate to the design of timber bridges.

COMPARISON PARAMETERS

Our review used the latest edition of the bridge design codes from each country. For the United States, we used the American Association of State and Highway Transportation Officials (AASHTO) 4th Edition of the LRFD Bridge Design Specification [1]. For Canada, we used the 10th edition of the Canadian Highway Bridge Design Code CAN/CSA S6-06 [2]. The results of our study are presented in the following sections.

Design Philosophy

The United States (USA) and Canada (CAN) have developed separate design codes for highway bridges. However, both codes recently adopted the limit states design (LSD) approach. The USA version uses a calibration coefficient to convert from “tabulated strength properties” in allowable stress design (ASD) to “reference design values” in load resistance factor design (LRFD). Both codes use the same basic structural equations for flexure and shear, but they use different adjustment factors to modify reference design values or specified strength values. Both codes consider the ultimate limit states (ULS) and service limit states (SLS), but do not require fatigue limit states (FLS) to be considered for the design of timber bridges.

Organizational Format

Both countries have dedicated sections for each type of material (wood, steel, and concrete, including resistance values) and design factors (loads, load factors, and analysis methods). The Canadian code is the only one with a section dedicated to fiber-reinforced-plastic (FRP) materials. The AASHTO code includes companion versions in metric and English units, while

the Canadian code uses only metric units. The AASHTO code includes commentary in a side-by-side, two-column format, while Canada includes code commentary in a companion publication [3].

The Canadian code includes the evaluation (load rating) of bridges within their bridge design code, while this same topic is covered in a completely separate publication in the United States code. Currently, the *Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR)* [4] is being used by engineers to evaluate and load rate bridges in the United States.

Superstructure Types

Both codes include design specifications for a variety of bridge superstructures that use timber structural components. The longitudinal deck systems included in both codes are spike-laminated, glued-laminated, and stress-laminated superstructures. The transverse deck systems on beam girders included in both codes are planks, nail-laminated, glulam panels, and concrete slabs. Specific differences in the design of each superstructure systems in the two countries include:

- The USA and CAN code do not permit longitudinal (continuous) nail-laminated decks, but only the panelized spike-laminated deck.
- The Canadian code includes a composite nail-laminated concrete longitudinal deck system, and permits mechanically spliced butt-jointed deck laminations.
- The Canadian code permits the use of FRP prestressing strands for stress-laminated decks.

Loads

Sections 3 of both codes cover Loads (CAN) or Load and Load Factors (USA). These sections cover load combinations for ULS, SLS, and FLS. The load factors and load combinations for the Canadian Code are typically less than those for AASHTO. AASHTO has seven ULS load combinations, which it refers to as Strength I-V and Extreme I & II, while the Canadians have nine ULS load combinations. AASHTO has four SLS load combinations referred to as Service I-IV, while the Canadians only have two. Both codes have one FLS that does not have to be analyzed for timber bridges.

Both codes have tables for permanent load factors that give the maximum and minimum values used to produce the more critical combinations for design loads. Only one load combination will be discussed here, the main load combination for both codes, ULS Combination 1 (CAN) and Strength I (USA). The basic load combinations used for the normal design vehicle and a dead load without wind are:

$$Q = 1.2 * \text{Dead_Load} + 1.7 * \text{Live_Load} \quad (\text{CAN})$$

$$Q = 1.25 * \text{Dead_Load} + 1.75 * \text{Live_Load} \quad (\text{USA})$$

The design vehicle for each code has a different configuration. The AASHTO code uses a HL-93 Design Vehicle (figure 1) and the Canadian code uses the CL-625 Design Vehicle (figure 2) for national highway network bridges. At first glance, the two design vehicles look quite different because of their wheel spacing and axle loads. Despite these differences, they both yield about the same design moments and shear (figure 3). The Canadian Design Vehicle (CL-

625) has a gross weight of about 70 tons (625 kN). The AASHTO Design Vehicle (HL-93) plus its lane load for a 50-foot bridge has a combined weight of 52 tons (463 kN). Although the AASHTO design vehicle weighs less than the Canadian design vehicle, the variable wheel spacing of the AASHTO design truck develops more of a point load than does the Canadian design vehicle.

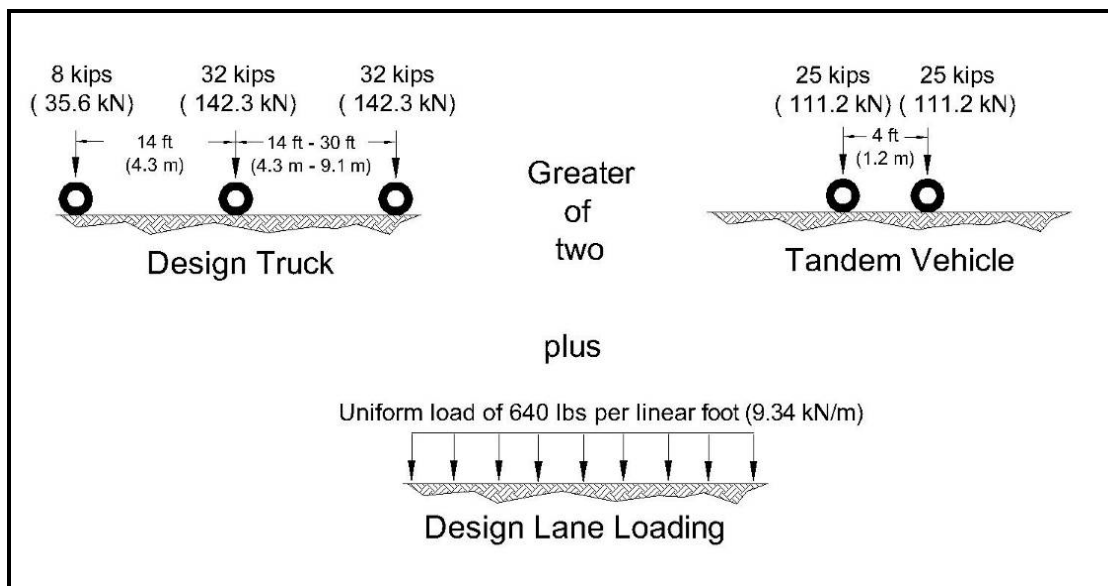


FIGURE 1 - TRUCK/LANE LOADING CONFIGURATION IN USA.

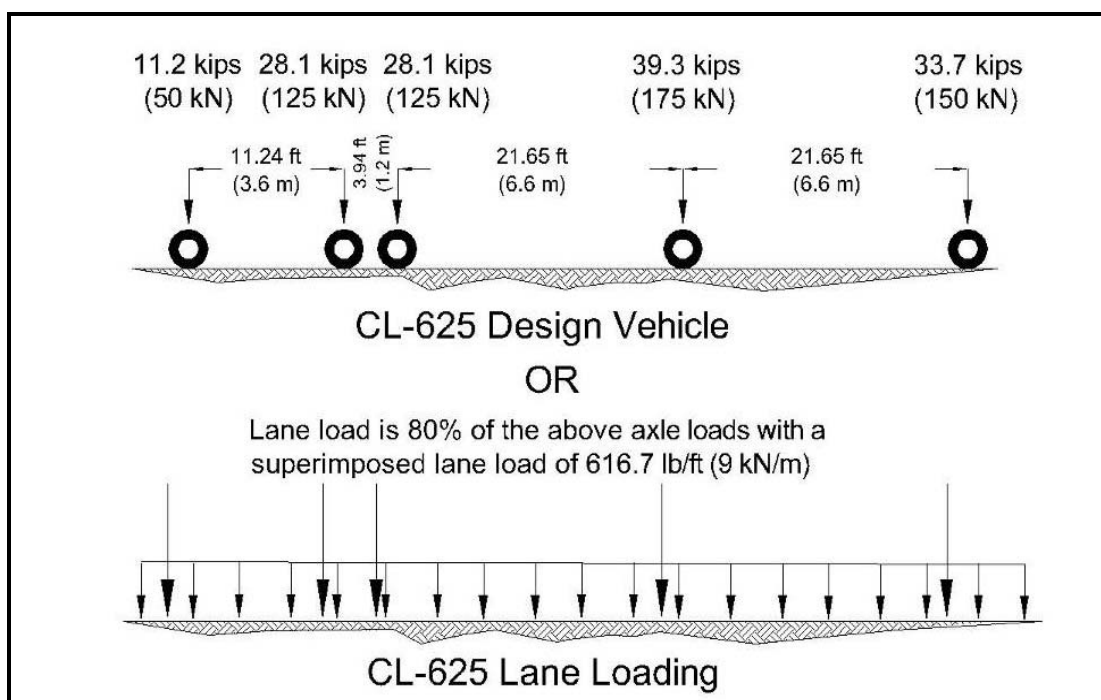
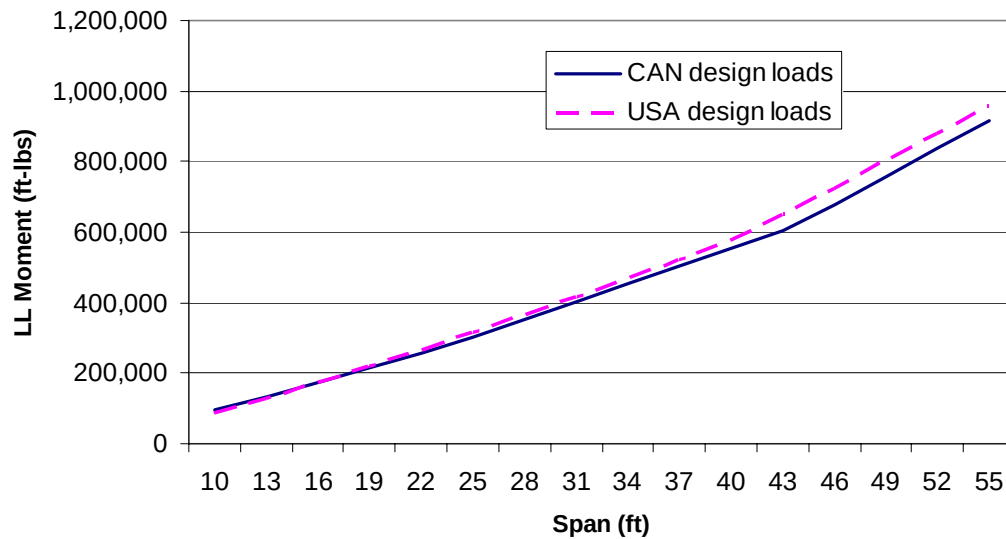
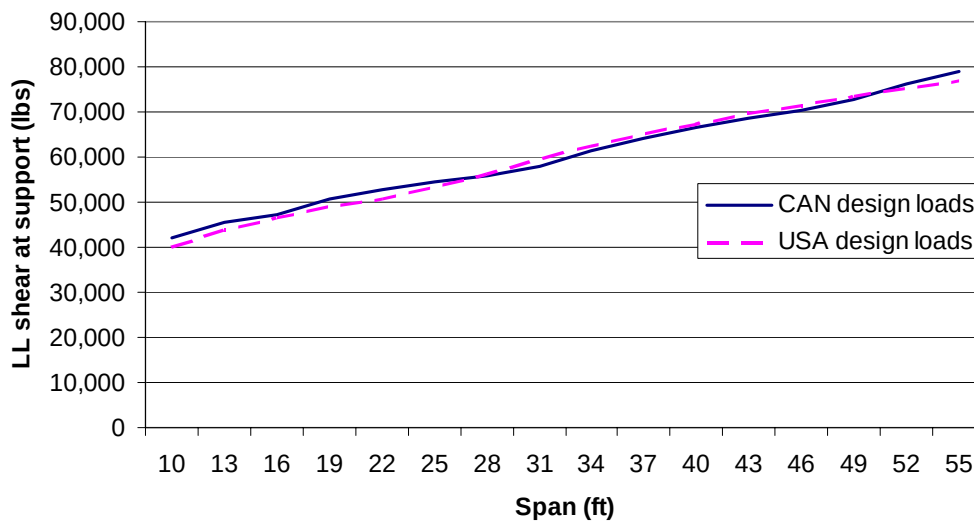


FIGURE 2 - TRUCK/LANE LOADING CONFIGURATION IN CANADA.



(A)



(B)

FIGURE 3 - COMPARISON OF (A) LIVE LOAD (LL) MOMENTS AND (B) LIVE LOAD SHEAR FOR DESIGN VEHICLES FROM THE UNITED STATES AND CANADA.

AASHTO does not require a dynamic load allowance for timber bridges, based on the assumption that wood is stronger for short-duration loads than it is for long-duration loads. This increase in strength cancels out the increase in force of dynamic loads. The Canadians require a dynamic load allowance for wood, but that allowance is only 70 percent of the allowance required for steel and concrete bridges.

The multiple presence factor (USA) and multi-lane loading (CAN) is included in the codes to account for the probability of having more than one lane loaded at a time (figure 4).

No. Lanes Loaded	USA Multiple Presence Factors	CAN Multi-Lane Loading Factors
1	1.2	1.0
2	1.0	0.9
3	.85	0.8
4	.65	0.7
5	.65	0.6
6 or more	.65	0.55

FIGURE 4 - COMPARISON OF MULTIPLE PRESENCE FACTOR (USA) AND MULTI-LANE LOADING (CAN).

For the United State code, the multiple presence factors are included in the approximate equations for distribution factors for bending and shear.

Materials

		USA Code	CAN Code	
Sawn lumber	Doug fir- Larch select structural beam / stringer	Bending Stress	1.60 ksi (11.03 MPa)	2.83 ksi (19.50 MPa)
		Shear Stress	0.17 ksi (1.17 MPa)	0.22 ksi (1.50 MPa)
	Hem-Fir select structural beam / stringer	Bending Stress	1.30 ksi (8.96 MPa)	2.10 ksi (14.50 MPa)
		Shear Stress	0.14 ksi (0.97 MPa)	0.17 ksi (1.20 MPa)
Glulam	Douglas fir 20f	Bending Stress	2.00 ksi (13.79 MPa)	3.34 ksi (23.00 MPa)
		Shear Stress	0.27 ksi (1.83 MPa)	0.20 ksi (1.40 MPa)
	Douglas fir 24f	Bending Stress	2.40 ksi (16.55 MPa)	3.99 ksi (27.5 MPa)
		Shear Stress	0.27 ksi (1.83 MPa)	0.20 ksi (1.40 MPa)

FIGURE 5 - COMPARISON OF WOOD MATERIAL REFERENCE DESIGN VALUES OR SPECIFIED STRENGTHS

The two codes base their strength and design values on other referenced codes. AASHTO uses National Design Standards (NDS) 2005 for sawn lumber reference design values and the American Institute of Timber Construction (AITC) 117-2004 Standard Specifications for Structural Glued Laminated Timber of Softwood Species for glued laminated timber reference design values. Both of these tables are in English units and are ASD values (figure 5). The Canadians use two standards developed by the Canadian Standards Association (CSA) for wood. Sawn lumber is covered by CAN/CSA-086 and glued-laminated timber is covered by CSA 0177. The Canadian code uses limit states design values and is in metric units. The Canadian code uses LSD values, wet-use condition, and a one-month load duration, while the AASHTO code uses ASD, dry-use condition, and a 10-year load duration.

The number of sawn lumber species covered by the codes varies from 11 in the AASHTO code to 8 species (4 species combination groups) in the Canadian code. Canadian code values are for visually graded lumber.

The Canadians use only Douglas-fir for glued-laminated timbers and have specified strength values for four combinations in bending, one combination in compression, and one combination in tension. AASHTO lists 5 species of trees and includes reference design values for 21 combinations for bending and 15 combinations for compression and tension. Canadian values are for visually graded lumber. The AASHTO code includes both visually graded and mechanically graded lumber.

Both codes include a limited number of reference values for piles. The AASHTO code lists four species and the Canadian code lists six species. Both tables of reference design values or specified strengths are wet-use condition values. Red pine and Douglas-fir are common to both tables; red oak and southern pine are included in AASHTO, while the Canadian code includes jack pine, western larch, lodgepole pine and ponderosa pine.

The Canadian code includes an additional section on structural composite lumber. The specifications are for laminated veneer lumber (LVL) and parallel strand lumber (PSL). There is only one structural composite wood discussed in the AASHTO code, glued-laminated timbers.

Design for Bending

The approach for both codes is very similar for bending strength design. They both use reference design or specified strength values and multiply them by adjustment factors to calculate an adjusted design value. This adjusted value is used to calculate a nominal flexural resistance value, which is modified by the resistance factor to yield the factored flexural resistance value. The factored flexural resistance value must be larger than the total factor load for the beam in bending.

The AASHTO code uses the following equations to determine factored flexural resistance:

$$F_b = F_{bo} * C_{kf} * C_M * (C_F \text{ or } C_V) * C_{fu} * C_i * C_d * C_\lambda \quad (\text{AASHTO 8.4.4.1-1})$$

$$M_n = F_b * S * C_L \quad (\text{AASHTO 8.6.2-1})$$

$$M_r = \phi * M_n \quad (\text{AASHTO 8.6.1-1})$$

The Canadian code uses a single equation to determine factored flexural resistance:

$$M = \phi * k_d * k_{ls} * k_m * k_{sb} * f_{bu} * S$$

The equations' terms for design values and adjustment factors are similar. The design values for AASHTO are F_{bo} for the reference design value and F_b for the adjusted design value. The reference design value can be compared to specified bending strength, f_{bu} , for the Canadian code. The resistance factor is ϕ for both codes, but AASHTO uses a resistance factor of 0.85 for flexure while the Canadians use a resistance factor of 0.9. The section modulus, S , is also common to both codes.

Four adjustment factors are common to both codes: beam stability factor, C_L & k_{ls} , time effect factor or load duration factor, C_λ & k_d , size effect factor for sawn lumber or volume factor, C_F or C_V & k_{sb} , and the deck factor or load sharing factor, C_d & k_m . AASHTO uses a few more adjustment factors such as C_{kf} for the format conversion factor to convert from ASD to LRFD, C_M for the wet-service factor, C_{fu} for the flat use factor and C_i for the incising factor.

The Canadians use a true limit states design, so they do not require a format conversion factor to convert from ASD to LRFD. The semi-wet condition and incising factor are already included in the Canadian code's specified strength tables.

The distribution of live load and dead load moments are covered by both codes in the section on analysis. The codes allow many different ways to calculate the distribution of moments for longitudinal beams, but both include a simplified method that may be used for timber bridges. The Canadian's simplified method is a little more complicated than the method used by AASHTO. The distribution factors vary based on deck type (plank, glulam, nail laminated, etc.) and beam type (sawn lumber, glulam, etc.).

Design for Shear

Both codes use a similar approach for shear strength design. Both use reference design or specified strength values and multiply them by adjustment factors to calculate an adjusted design value. This adjusted value is used to calculate a nominal shear resistance value, which is modified by the resistance factor to yield the factored shear resistance value. The factored shear resistance value must be larger than the total factor load for the beam in shear.

AASHTO uses the following equations to determine factored shear resistance:

$$F_v = F_{vo} * C_{kf} * C_M * C_i * C_\lambda \quad (\text{AASHTO 8.4.4.1-2})$$

$$V_n = F_v * \frac{b * d}{1.5} \quad (\text{AASHTO 8.7-2})$$

$$V_r = \phi * V_n \quad (\text{AASHTO 8.7-1})$$

The Canadian code uses a single equation to determine factored shear resistance:

$$V = \phi * k_d * k_m * k_{sv} * f_{vu} * \frac{A}{1.5}$$

The equations' terms for design values and adjustment factors are similar. The design values for AASHTO are F_{v0} for the reference design value and F_v for the adjusted design value. The AASHTO reference design value can be compared to specified shear strength, f_{vu} , for the Canadian code. The resistance factor is ϕ for both codes, but AASHTO uses a resistance factor of 0.75 for flexure while the Canadian code uses a resistance factor of 0.9. The area, A , is common to both codes, but is referred to as $b*d$ in AASHTO.

The time effect or load duration factor, C_λ & k_d , is the only adjustment factor for shear that is common to both codes. AASHTO has a few more adjustment factors, such as C_{kf} for the format conversion factor to convert from ASD to LRFD, C_M for the wet-service factor, C_{fu} for the flat use factor, and C_i for the incising factor.

The Canadian code uses a true limit states design, so it does not require a format conversion factor to convert from ASD to LRFD. The semi-wet condition and incising factor are already included in the Canadian code's specified strength tables. The last two adjustment factors k_m , modification for load sharing, and k_{sv} , modification for size effect for shear, are found only in the Canadian code.

The location where the design shear is calculated is the same for both codes and is the distance of a beam's depth from the support. AASHTO requires the live load to be placed to produce the maximum shear at a distance equal to the lesser of either three times the beam's depth or one-quarter of the bridge span. The Canadian code does not have this requirement.

The distribution of live load and dead load shear is covered by both codes in the section on analysis. The codes allow many different ways to calculate the distribution of shear for longitudinal beams, but they both include a simplified method that may be used for timber bridges. The Canadian code's simplified method is a little more complicated than that used by AASHTO. The distribution factors vary based on deck type (plank, glulam, nail laminated, etc.) and beam type (sawn lumber, glulam, etc.). The AASHTO code has another requirement when investigating shear parallel to grain. Live load shear is determined by the following equation:

$$V_{LL} = 0.5 * [(0.6 * V_{LU}) + V_{LD}] \quad (\text{AASHTO 4.6.2.2a-1})$$

Where V_{LL} is the distributed live load shear, V_{LU} is the maximum vertical shear at a distance three times the depth of the beam from the support or one-quarter the length of the bridge for undistributed wheel loads, and V_{LD} is the maximum vertical shear at a distance three times the depth of the beam from the support or one-quarter the length of the bridge for lateral distribution.

Deflection Criteria

Both codes set limits for the amount of deflection at the SLS with the allowable deflection varying from $L/400$ for the Canadian code to $L/425$ for the AASHTO code, where L equals the length of the bridge. AASHTO also requires that the maximum deflection between deck panels to be no more than 0.10 inches. There is no requirement for camber for sawn lumber bridges, but both codes have a camber requirement for glued laminated timber beams. The Canadian code requires a camber equal to the sum of $L/600$ plus twice the calculated deflection of the unfactored dead load and the AASHTO code requires a camber at least two times the dead load at the SLS.

Decks

The US code has a separate section for decks and the Canadian code includes decks in the wood section. The decks covered in both codes are glued laminated decks, stress-laminated decks, spike-laminated decks and plank decks. The Canadians also include wood-concrete composite decks in their specifications. Both codes include a short section on the wearing surfaces for timber bridges.

Durability

Both codes require timber used in bridges to be treated with preservatives applied by pressure treatment. AASHTO follows the AASHTO M 133 standard for allowable treatments and retentions. The Canadian code has a whole subsection on durability that lists allowable preservatives and follows the Canadian Standards Association (CSA) 080 series of standards. Both codes reference the American Wood Preservative Association (AWPA) standards. The allowable preservative treatments are similar. Both codes allowing preservatives ranging from creosote to chromate copper arsenate (CCA). Both codes require galvanized metal fasteners and hardware, conforming to either AASHTO M 232 or CAN/CSA-G164.

SUMMARY

The national bridge design codes in the US recently adopted the limit states design approach. While Canada was one of the first to adopt the limit states design philosophy for their bridge design code, doing so many years ago. Our study compared the key timber-bridge-related sections in both code specifications along with their commentaries. We discovered many similarities and some distinct differences. The design analyses for both are similar, but have slightly different equations and adjustment factors. The design vehicles have drastically different load configurations, but produce approximately the same bending moments and shears. Each code has unique base resistance values and the derivation of allowable design values is quite different. The code architecture is similar in format and organization with a few exceptions. The Canadian code includes a new section for Fiber-Reinforced-Polymer (FRP) materials for bridges. The Load rating and field evaluations are incorporated into a dedicated section of the Canadian code, while the same resides in a separate publication from the US code. Future work will include a comparative design of two bridges in close proximity to each other and straddling the US-CA border.

REFERENCES

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