Lecture 3C – Key Messages

- Mean load method for load rating discussed.
- The concept of capacity verification of a bridge by load testing is discussed.
- AASHTO Manual for Bridge Evaluation is introduced and parallels between Canadian and American approaches highlighted.

[Photo: IS-Beton]

Clause 14.15.2.3 – Mean Load Method

The mean load method is an another approach for calculating the live load capacity factor, which uses bias factors instead of load and resistance factors.

It is more complicated, but can lead to higher live load capacity factors, according to [Au et al. 2005].

$$F = \frac{\overline{R}\exp\left[-\beta\left(V_R^2 + V_S^2\right)^{0.5}\right] - \Sigma\overline{D}}{\overline{L}}$$

where

$$\overline{R} = \delta_R R$$

$$V_S = \frac{\left(S_D^2 + S_L^2\right)^{0.5}}{\left(\Sigma\overline{D} + \overline{L}\right)}$$

where

$$S_D = \left[\sum\left[\left(V_D^2 + V_{AD}^2\right)\left(\delta_D \delta_{AD} D\right)^2\right]\right]^{0.5}$$

$$S_L = \left[V_{AL}^2 + V_L^2 + \left(V_I \delta_I I\right)^2 / \left(1 + \delta_I I\right)^2\right]^{0.5}\left[\delta_L \delta_{AL} L\left(1 + \delta_I I\right)\right]$$

$$\Sigma\overline{D} = \Sigma\delta_D \delta_{AD} D$$

$$\overline{L} = \delta_L \delta_{AL} L\left(1 + \delta_I I\right)$$

Table C14.1
Statistical parameters for various dead loads

(See Clause C14.8.2.1.)

Dead load type	δ_D	V_D
D1	1.03	0.08
D2	1.05	0.10
D3	1.03	0.30

[CSA S6]

Table C14.2
Statistical parameters for traffic loads

(See Clause C14.9.)

Load type	Span	δ_L	V_L	Source
Normal traffic (CL-W)	short spans	1.35	0.035	—
	other spans	1.35	0.035	—
Normal traffic (Alternative Loading)	short spans	1.76	0.035	—
	other spans	1.35	0.035	—
Permit annual (PA)	short spans	1.35	0.017	—
	other spans	1.25	0.017	—
Permit bulk (PB)	short spans	1.09	0.0088	Kennedy (1992)
	other spans	1.06	0.0094	Kennedy (1992)
Permit controlled (PC)	short spans	1.077	0.04	—
	other spans	1.002	0.039	Kennedy (1992)
Permit single trip (PS)	short spans	1.26	0.041	Kennedy (1992)
	other spans	1.17	0.030	Kennedy (1992)

[CSA S6]

Table C14.3
Statistical parameters for dynamic load allowance
(See Clause C14.9.3.)

Span	δ_I	V_I
Short	0.67	0.60
Other — 1 lane loaded	0.60	0.80
— 2 or more lanes loaded	0.40	0.80

[CSA S6]

Table C14.6
δ_R and V_R values
(See Clause C14.14.2.)

Resistance category	δ_R	V_R	Source
Structural steel			
Plastic moment	1.13	0.10	Kennedy & Baker (1984)
Yield moment	1.22	0.10	Kennedy & Baker (1984)
Inelastic buckling moment*	1.16	0.08	Kennedy & Baker (1984)
Elastic buckling moment*	1.09	0.09	Kennedy & Baker (1984)
Compression	1.05	0.08	Kennedy & Baker (1984)
Shear (stocky web)	1.10	0.07	Kennedy (1996)
Shear (tension field)	1.18	0.10	Kennedy (1996)
Bolts (tension)	1.12	0.09	Fisher *et al.* (1978)
Bolts (shear)	1.16	0.10	Fisher *et al.* (1978)
Welds (not base metal)	1.32	0.17	Fisher *et al.* (1978)
Rivets	1.50	0.11	CAN/CSA-S6-88 Supplement No. 1
Composite — Slab-on-steel girder			
Bending moment*	1.10	0.10	Kennedy & Baker (1984)
Reinforced concrete			
Bending moment			
$\rho \le 0.4\ \rho_b$	1.04	0.08	Mirza & MacGregor (1982)
$0.4\ \rho_b \le \rho \le 0.7\ \rho_b$	1.03	0.12	Mirza & MacGregor (1982)
Axial compression plus bending (no slenderness)	1.02	0.11	Mirza & MacGregor (1982)
Shear (> minimum stirrups)	1.15	0.14	Mirza & MacGregor (1982)
Prestressed concrete			
Prestressed beams in bending			
$\omega_p \le 0.15$	1.06	0.05	Mirza & MacGregor (1982)
$0.15 \le \omega_p \le 0.30$	1.06	0.09	Mirza & MacGregor (1982)

**Includes stiffened plate girder*

[CSA S6]

Clause 14.16 – Load Testing

<u>Load testing of structures and elements:</u>

Load tests are used to check proposed maximum loading and to ensure elements in structure are able to take the design working load safely. Examples of loading mediums:

- Certified steel weights (for small tests)
- Water (suitable for providing uniform load up to 1 t/m^2)
- Bagged sand
- Kentledge: steel, iron, or concrete used where large test loads are demanded.
- Hydraulic jack (offer the possibility of gradual application of the load in "displacement control")

Clause 14.16 – Load Testing

<u>Load testing of structures and elements:</u>

Safety precautions:

1) Safety supports should be placed underneath the structure if the load is to be applied vertically.
2) Load should applied and removed in increments (minimum 6 increments each).
3) If creep of the structure under maximum load is an important consideration, the test load should be maintained for an agreed period of time in which the deflection is monitored at regular intervals.

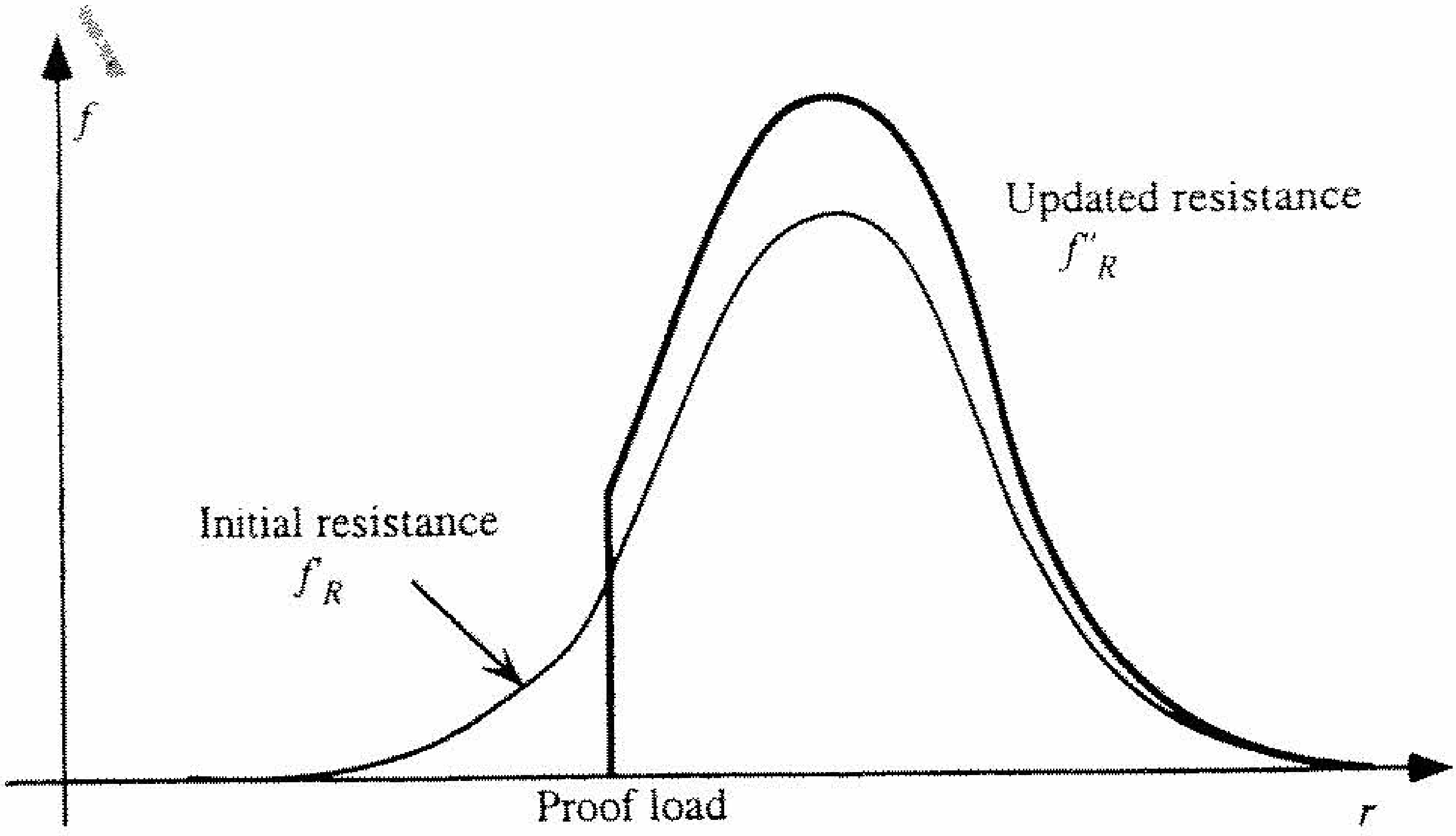
Clause 14.16 – Load Testing

<u>Load testing of structures and elements</u>:

The structure or member can be deemed to have passed the test by checking one of the following:

1) Comparison of the actual behaviour of the structure under load with the theoretically predicted performance (in case you have sufficient information regarding the construction material).
2) Comparison of recovery of the structure on completion of the load test with deflection under full load test (the acceptable percentage of recovery should be specified beforehand).

Load Testing



[Melchers 1999]

Load Testing

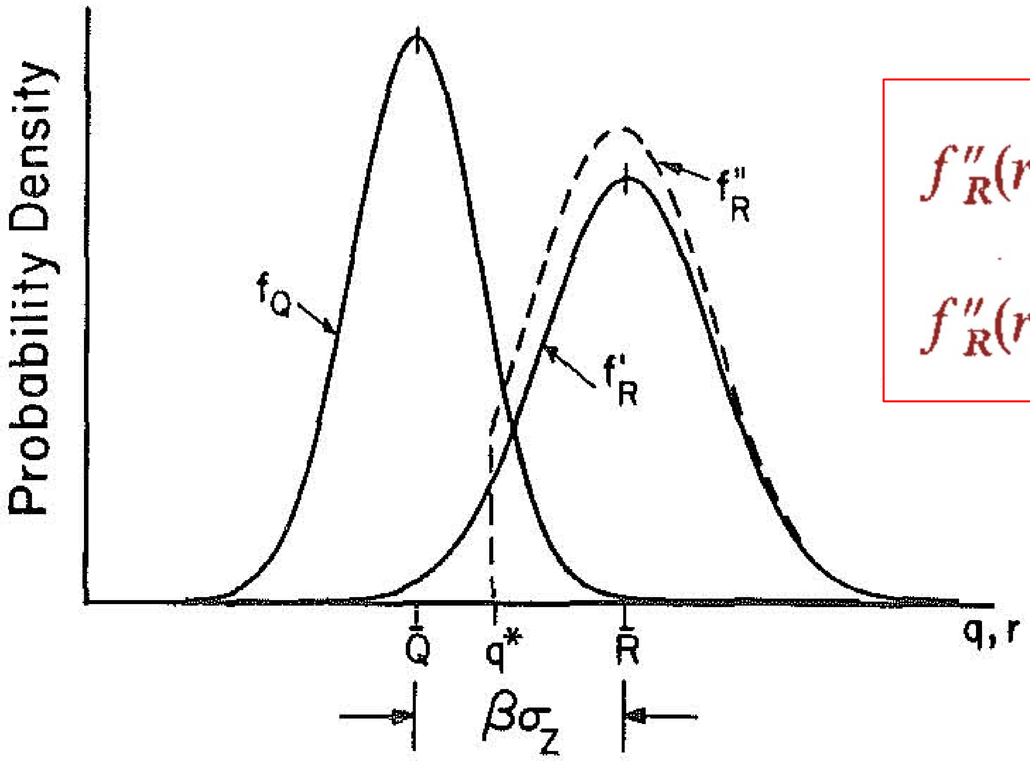


FIG. 1. Random Load Q versus Random Strength R before and after Proof Test at Load q^*

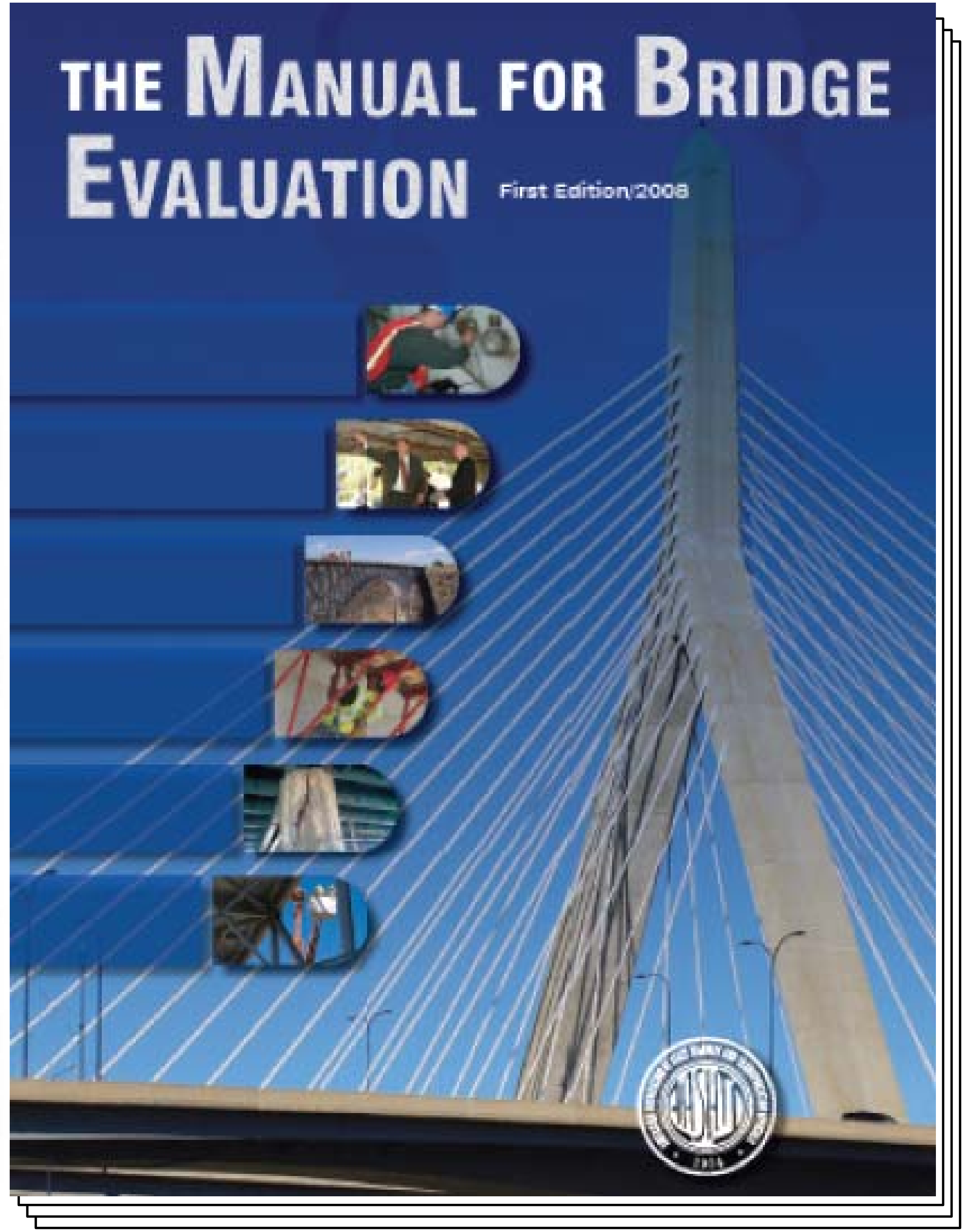
$$f''_R(r) = \frac{f'_R(r)}{1 - F'_R(q^*)}; \qquad r \geq q^*$$

$$f''_R(r) = 0; \qquad r \leq q^*$$

f', *F'* = original PDF, CDF
f'' = corrected PDF
q^* = load test level

[Hall 1988]

How do Canadian and American approaches compare?



[AASHTO MBE 2008]

AASHTO MBE – Material Strengths

Table 6A.5.2.1-1—Minimum Compressive Strength of Concrete by Year of Construction

Year of Construction	Compressive Strength, f'_c, ksi	
Prior to 1959	2.5	17.2 MPa
1959 and Later	3.0	20.7 MPa

Table 6A.5.2.2-1—Yield Strength of Reinforcing Steel

Type of Reinforcing Steel	Yield Strength, f_y, ksi	
Unknown steel constructed prior to 1954	33.0	228 MPa
Structural grade	36.0	248 MPa
Billet or intermediate grade, Grade 40, and unknown steel constructed during or after 1954	40.0	276 MPa
Rail or hard grade, Grade 50	50.0	345 MPa
Grade 60	60.0	414 MPa

[AASHTO MBE 2008]

AASHTO MBE – Material Strengths

Table 6A.6.2.1-1—Minimum Mechanical Properties of Structural Steel by Year of Construction

Year of Construction	Minimum Yield Point or Minimum Yield Strength, F_y, ksi	Minimum Tensile Strength, F_u, ksi
Prior to 1905	26 179 MPa	52 359 MPa
1905 to 1936	30 207 MPa	60 414 MPa
1936 to 1963	33 228 MPa	66 455 MPa
After 1963	36 248 MPa	66 455 MPa

For wrought iron: F_y = 26 ksi, F_u = 48 ksi

179 MPa 331 MPa

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

$$RF = \frac{C-(\gamma_{DC})(DC)-(\gamma_{DW})(DW)\pm(\gamma_P)(P)}{(\gamma_{LL})(LL+IM)}$$

For the Strength Limit States:

$C = \varphi_c \varphi_s \varphi_n$

Where the following lower limit shall apply:

$\varphi_c \varphi_s \geq 0.85$

For the Service Limit States:

$C = f_R$

RF = Rating factor

C = Capacity

f_R = Allowable stress specified in the LRFD code

R_n = Nominal member resistance (as inspected)

DC = Dead load effect due to structural components and attachments

DW = Dead load effect due to wearing surface and utilities

P = Permanent loads other than dead loads

LL = Live load effect

IM = Dynamic load allowance

γ_{DC} = LRFD load factor for structural components and attachments

γ_{DW} = LRFD load factor for wearing surfaces and utilities

γ_p = LRFD load factor for permanent loads other than dead loads = 1.0

γ_{LL} = Evaluation live load factor

φ_c = Condition factor

φ_s = System factor

φ = LRFD resistance factor

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table 6A.4.2.2-1—Limit States and Load Factors for Load Rating

Bridge Type	Limit State*	Dead Load γ_{DC}	Dead Load γ_{DW}	Design Load Inventory γ_{LL}	Design Load Operating γ_{LL}	Legal Load γ_{LL}	Permit Load γ_{LL}
Steel	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service II	1.00	1.00	1.30	1.00	1.30	1.00
	Fatigue	0.00	0.00	0.75	—	—	—
Reinforced Concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service I	1.00	1.00	—	—	—	1.00
Prestressed Concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service III	1.00	1.00	0.80	—	1.00	—
	Service I	1.00	1.00	—	—	—	1.00
Wood	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1

* Defined in the *AASHTO LRFD Bridge Design Specifications*.

Notes:

- Shaded cells of the table indicate optional checks.
- Service I is used to check the 0.9 F_y stress limit in reinforcing steel.
- Load factor for DW at the strength limit state may be taken as 1.25 where thickness has been field measured.
- Fatigue limit state is checked using the LRFD fatigue truck (see Article 6A.6.4.1).

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table 6A.4.2.3-1—Condition Factor: φ_c

Structural Condition of Member	φ_c
Good or Satisfactory	1.00
Fair	0.95
Poor	0.85

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table 6A.4.2.4-1—System Factor: φ_s for Flexural and Axial Effects

Superstructure Type	φ_s
Welded Members in Two-Girder/Truss/Arch Bridges	0.85
Riveted Members in Two-Girder/Truss/Arch Bridges	0.90
Multiple Eyebar Members in Truss Bridges	0.90
Three-Girder Bridges with Girder Spacing 6 ft	0.85
Four-Girder Bridges with Girder Spacing ≤4 ft	0.95
All Other Girder Bridges and Slab Bridges	1.00
Floorbeams with Spacing >12 ft and Noncontinuous Stringers	0.85
Redundant Stringer Subsystems between Floorbeams	1.00

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table 6A.4.4.2.3a-1—Generalized Live Load Factors, γ_L for Routine Commercial Traffic

Traffic Volume (One direction)	Load Factor for Type 3, Type 3S2, Type 3-3 and Lane Loads
Unknown	1.80
$ADTT \geq 5000$	1.80
$ADTT = 1000$	1.65
$ADTT \leq 100$	1.40

Linear interpolation is permitted for other *ADTT*.

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table 6A.4.4.2.3b-1—Generalized Live Load Factors, γ_L for Specialized Hauling Vehicles

Traffic Volume (One direction)	Load Factor for NRL, SU4, SU5, SU6, and SU7
Unknown	1.60
ADTT ≥ 5000	1.60
ADTT = 1000	1.40
ADTT ≤ 100	1.15

Linear interpolation is permitted for other *ADTT*.

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table C6A.4.4.3-1—Dynamic Load Allowance: *IM*

Riding Surface Conditions	*IM*
Smooth riding surface at approaches, bridge deck, and expansion joints	10%
Minor surface deviations or depressions	20%

[AASHTO MBE 2008]

AASHTO MBE – Load Rating

Table 6A.4.5.4.2a-1—Permit Load Factors: γ_L

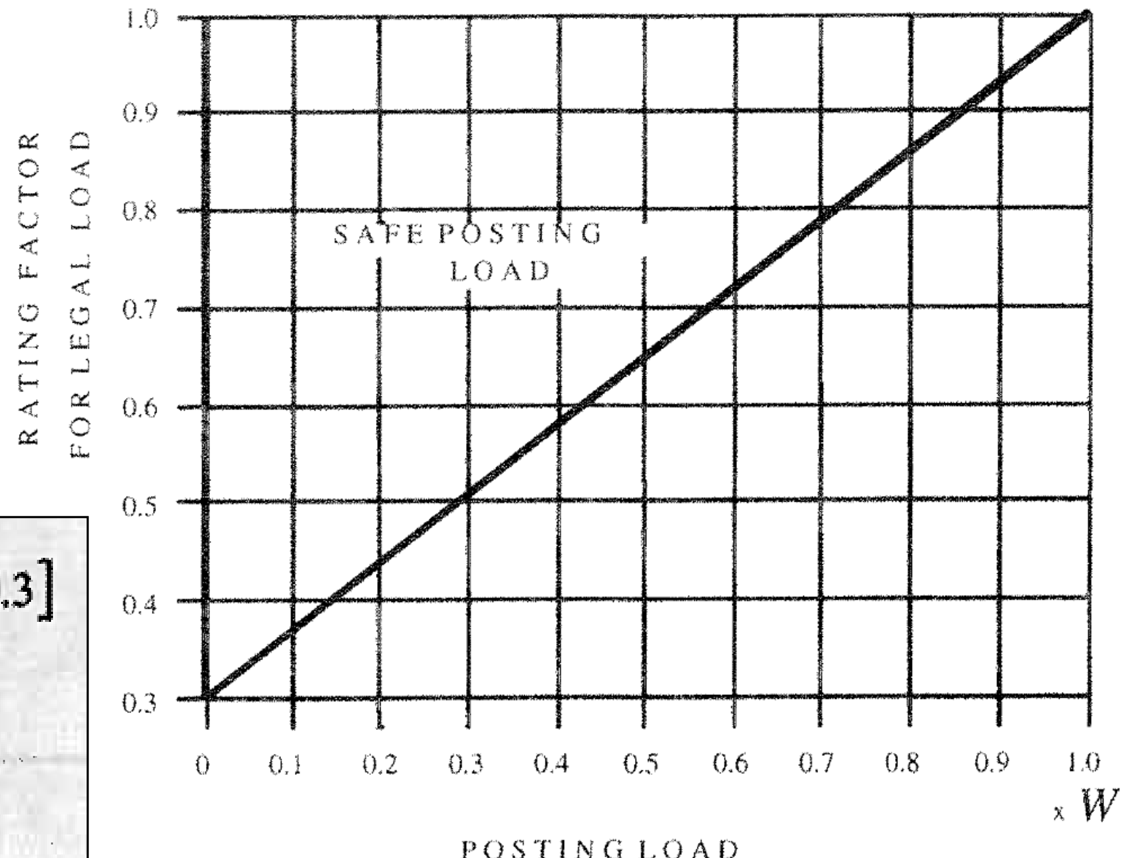
Permit Type	Frequency	Loading Condition	DF[a]	$ADTT$ (one direction)	Load Factor by Permit Weight[b] Up to 100 kips	Load Factor by Permit Weight[b] ≥150 kips
Routine or Annual	Unlimited Crossings	Mix with traffic (other vehicles may be on the bridge)	Two or more lanes	>5000	1.80	1.30
				=1000	1.60	1.20
				<100	1.40	1.10
					All Weights	
Special or Limited Crossing	Single-Trip	Escorted with no other vehicles on the bridge	One lane	N/A	1.15	
	Single-Trip	Mix with traffic (other vehicles may be on the bridge)	One lane	>5000	1.50	
				=1000	1.40	
				<100	1.35	
	Multiple-Trips (less than 100 crossings	Mix with traffic (other vehicles may be on the bridge)	One lane	>5000	1.85	
				=1000	1.75	
				<100	1.55	

[a] DF = LRFD distribution factor. When one-lane distribution factor is used, the built-in multiple presence factor should be divided out.

[b] For routine permits between 100 kips and 150 kips, interpolate the load factor by weight and $ADTT$ value. Use only axle weights on the bridge.

[AASHTO MBE 2008]

AASHTO MBE – Load Rating



$$\text{Safe Posting Load} = \frac{W}{0.7}\left[(RF) - 0.3\right]$$

where:

RF = Legal load rating factor

W = Weight of rating vehicle

[AASHTO MBE 2008]

AASHTO MBE – Load Testing

The following conditions could render a bridge an unsuitable candidate for load testing:

- The cost of testing reaches or exceeds the cost of bridge strengthening.
- Pretest evaluation shows that the load test is unlikely to show the prospect of improvement in load-carrying capacity.
- According to calculations, the bridge cannot sustain even the lowest level of load.
- There is a possibility of sudden failure (shear or fracture).
- Load tests may be impractical because of access difficulties or site traffic conditions.

[AASHTO MBE 2008]