Introduction to LRFD, Loads and Loads Distribution

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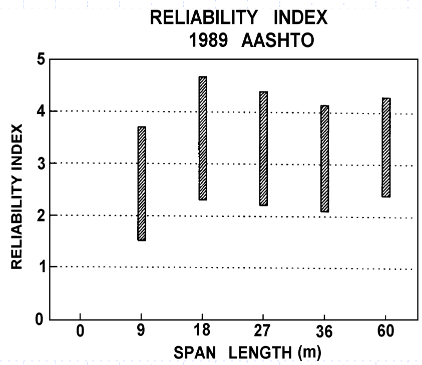
Evolution of Design Methodologies

- **SLD Methodology:**
  $(f_t)_D + (f_t)_L \leq 0.55F_y$, or
  $1.82(f_t)_D + 1.82(f_t)_L \leq F_y$
- **LFD Methodology:**
  $1.3[1.0(f_t)_D + 5/3(f_t)_L] \leq \phi F_y$, or
  $1.3(f_t)_D + 2.17(f_t)_L \leq \phi F_y$ (ϕ by judgment)
- **LRFD Methodology:**
  $1.25(f_t)_D + 1.75(f_t)_L \leq \phi F_y$ (ϕ by calibration)
  (new live-load model)

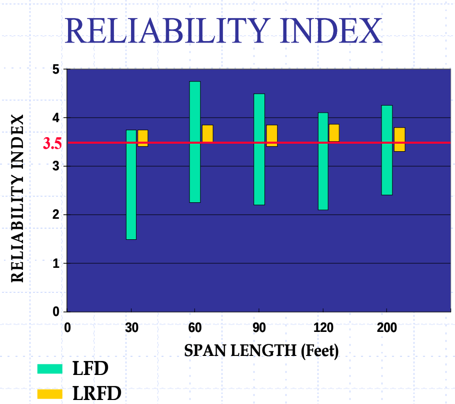
Evolution of Design Methodologies (cont'd)

- SLD does not recognize that some types of loads are more variable than others.
- LFD provides recognition that types of loads are different.
- LRFD provides a probability-based mechanism to select load & resistance factors.



Evolution of Design Methodologies (cont'd)

- As a result, LRFD achieves considerable improvement in the clustering of reliability indices versus the AASHTO Standard Specifications.



Basic LRFD Design Equation

$$\Sigma\ \eta_i \gamma_i Q_i \leq \phi R_n = R_r$$ Eq. (1.3.2.1-1)

where:

η_i = $\eta_D\ \eta_R\ \eta_I$

- $\eta_i \geq 0.95$ for maximum γ's
- $\eta_i = \dfrac{1}{\eta_D \eta_R \eta_I} \leq 1.00$ for minimum γ's

γ_i = Load factor

ϕ = Resistance factor

Q_i = Nominal force effect

R_n = Nominal resistance

R_r = Factored resistance = ϕR_n

LRFD Limit States

- The LRFD Specifications require examination of several load combinations corresponding to the following limit states:
  - **SERVICE LIMIT STATE**
    relating to stress, deformation, and cracking
  - **FATIGUE & FRACTURE LIMIT STATE** relating to stress range and crack growth under repetitive loads, and material toughness
  - **STRENGTH LIMIT STATE**
    relating to strength and stability
    - (CONSTRUCTIBILITY)
  - **EXTREME EVENT LIMIT STATE**
    relating to events such as earthquakes, ice load, and vehicle and vessel collision

3.3.2 Load and Load Designation

STRENGTH I :	without wind.
STRENGTH II :	owner design / permit vehicles without wind.
STRENGTH III :	wind exceeding 55 mph.
STRENGTH IV :	very high dead-to-live load ratios.
STRENGTH V :	vehicular use with 55 mph wind.
SERVICE I :	normal operational use of the bridge with a 55 mph wind and nominal loads. Also control cracking of reinforced concrete structures.
SERVICE II :	control yielding of steel structures and slip of connections
SERVICE III :	control cracking of prestressed concrete superstructures.
SERVICE IV :	control cracking of prestressed concrete substructures.
FATIGUE :	repetitive vehicular live load and dynamic responses under a single truck.

3.3.2 Load and Load Designation

DD	=	downdrag
DC	=	dead load of structural components and nonstructural attachments
DW	=	dead load of wearing surfaces and utilities
EH	=	horizontal earth pressure
EL	=	accumulated locked-in force effects resulting from the construction process, including the secondary forces from post-tensioning
ES	=	earth surcharge load
EV	=	earth fill vertical pressure
BR	=	braking force
CE	=	centrifugal force
CR	=	creep
CT	=	vehicular collision force
CV	=	vessel collision force
EQ	=	earthquake
FR	=	friction
IC	=	ice load
IM	=	dynamic load allowance
LL	=	live load
LS	=	live load surcharge
PL	=	pedestrian live load
SE	=	settlement
SH	=	shrinkage
TG	=	temperature gradient
TU	=	uniform temperature
WA	=	water load and stream pressure
WL	=	wind on live load
WS	=	wind load on structure

Permanent Loads (Article 3.5)

- **Dead Load (Article 3.5.1):**

DC - Dead load, except wearing surfaces & utilities

DC_1 - placed prior to deck hardening and acting on the noncomposite section

DC_2 - placed after deck hardening and acting on the long-term composite section

DW - Wearing surfaces & utilities acting on the long-term composite section

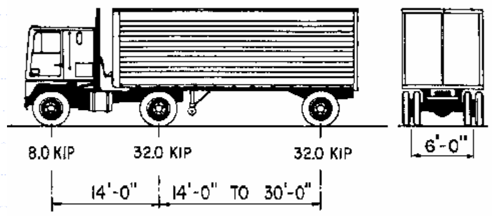
Load Factors for Permanent Loads, γ_p

Type of Load	Load Factor Maximum	Load Factor Minimum
DC: Component and Attachments	1.25	0.90
DD: Downdrag	1.80	0.45
DW: Wearing Surfaces and Utilities	1.50	0.65
EH: Horizontal Earth Pressure		
• Active	1.50	0.90
• At-Rest	1.35	0.90
EV: Vertical Earth Pressure		
• Overall Stability	1.35	N/A
• Retaining Structure	1.35 1.30	1.00 0.90
• Rigid Buried Structure	1.35	0.90
• Rigid Frames	1.95	0.90

Basic LRFD Design Live Load

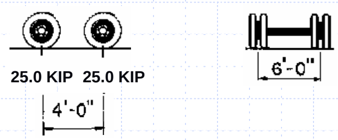
HL-93 -- (Article 3.6.1.2.1)

- **Design Truck:** ⇒



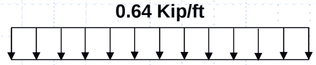
or **or**

- **Design Tandem:**
  Pair of 25.0 KIP axles spaced 4.0 FT apart



superimposed on **+**

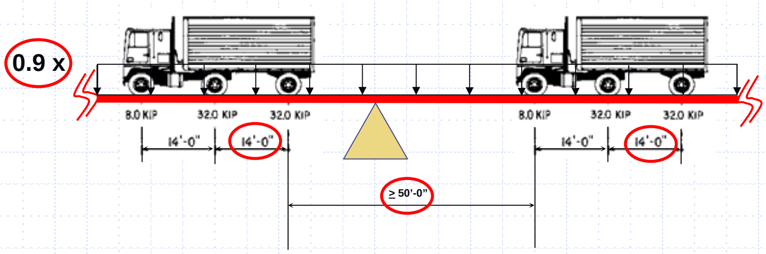
- **Design Lane Load 0.64 KLF uniformly distributed load**



LRFD Negative Moment Loading

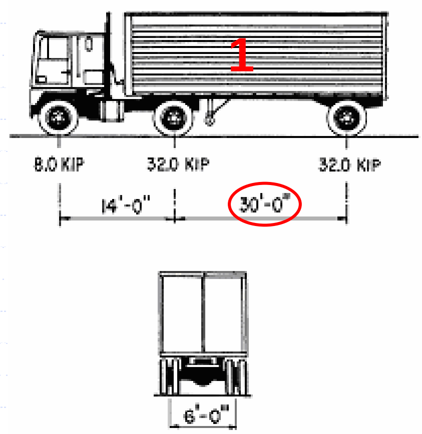
(Article 3.6.1.3.1)

- **For negative moment (between points of permanent-load contraflexure) & interior-pier reactions, check an additional load case:**



LRFD Fatigue Load
(Article 3.6.1.4.1)

- **Design Truck only =>**
  - **w/ fixed 30-ft rear-axle spacing**
  - **Placed in a single lane**



Load Combinations and Load Factors

Load Combination / Limit State	DC DD DW EH EV ES	LL IM CE BR PL LS	WA	WS	WL	FR	TU CR SH	TG	SE	Use One of These at a Time: EQ	IC	CT	CV
STRENGTH-I	γ_p	1.75	1.00	-	-	1.00	0.50/1.20	γ_{TG}	γ_{SE}	-	-	-	-
STRENGTH-II	γ_p	1.35	1.00	-	-	1.00	0.50/1.20	γ_{TG}	γ_{SE}	-	-	-	-
STRENGTH-III	γ_p	-	1.00	1.40	-	1.00	0.50/1.20	γ_{TG}	γ_{SE}	-	-	-	-
STRENGTH-IV EH, EV, ES, DW DC ONLY	γ_p 1.5	-	1.00	-	-	1.00	0.50/1.20	-	-	-	-	-	-
STRENGTH-V	γ_p	1.35	1.00	0.40	1.00	1.00	0.50/1.20	γ_{TG}	γ_{SE}	-	-	-	-
EXTREME-I	γ_p	γ_{EQ}	1.00	-	-	1.00	-	-	-	1.00	-	-	-
EXTREME-II	γ_p	0.50	1.00	-	-	1.00	-	-	-	-	1.00	1.00	1.00
SERVICE-I	1.00	1.00	1.00	0.30	0.30	1.00	1.00/1.20	γ_{TG}	γ_{SE}	-	-	-	-
SERVICE-II	1.00	1.30	1.00	-	-	1.00	1.00/1.20	-	-	-	-	-	-
SERVICE-III	1.00	0.80	1.00	-	-	1.00	1.00/1.20	γ_{TG}	γ_{SE}	-	-	-	-
FATIGUE-LL, IM & CE ONLY	-	0.75	-	-	-	-	-	-	-	-	-	-	-

Resistance Factors
(Article 6.5.4.2)

Resistance factors, ϕ, for the strength limit state shall be taken as follows:

- For flexure $\phi_f = 1.00$
- For shear $\phi_v = 1.00$
- For axial compression, steel only $\phi_c = 0.90$
- For axial compression, composite $\phi_c = 0.90$
- For tension, fracture in net section $\phi_u = 0.80$
- For tension, yielding in gross section $\phi_y = 0.95$
- For bolts bearing on material $\phi_{bb} = 0.80$
- For shear connectors $\phi_{sc} = 0.85$
- For A 325 and A 490 bolts in shear $\phi_s = 0.80$
- For block shear $\phi_{bs} = 0.80$
- For web crippling $\phi_w = 0.80$
- For weld metal in fillet welds:
  - tension or compression parallel to axis of the weld same as base metal
  - shear in throat of weld metal $\phi_{e2} = 0.80$

Resistance Factors
(Article 5.5.4.2)

Resistance factor ϕ shall be taken as:

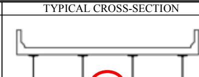
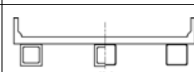
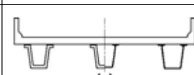
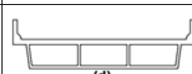
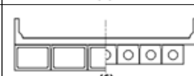
- For flexure and tension of reinforced concrete………………………………. 0.90
- For flexure and tension of prestressed concrete………………………………. 1.00
- For shear and torsion:
  - normal weight concrete……………… 0.90
  - lightweight concrete………………… 0.70
- For axial compression with spirals or ties, except as specified in Article 5.10.11.4.1b for Seismic Zones 3 and 4 at the extreme event limit state……………………………. 0.75
- For bearing on concrete………….. 0.70
- For compression in strut-and-tie models… 0.70
- For compression in anchorage zones:
  - normal weight concrete……………… 0.80
  - lightweight concrete………………… 0.65
- For tension in steel in anchorage zones….. 1.00
- For resistance during pile driving…………. 1.00

Structural Analysis & Evaluation
(Article 4)

- **Static Analysis (Article 4.6)**
  - Approximate Methods of Analysis (Article 4.6.2)
  - Beam-Slab Bridges (Article 4.6.2.2)

Live-Load Lateral Distribution Factors

TABLE 4.6.2.2.1-1 COMMON DECK SUPERSTRUCTURES COVERED IN ARTICLES 4.6.2.2.2 AND 4.6.2.2.3.

SUPPORTING COMPONENTS	TYPE OF DECK	TYPICAL CROSS-SECTION
Steel Beam	Cast-in-place concrete slab, precast concrete slab, steel grid, glued/spiked panels, stressed wood	 (a)
Closed Steel or Precast Concrete Boxes	Cast-in-place concrete slab	 (b)
Open Steel or Precast Concrete Boxes	Cast-in-place concrete slab, precast concrete deck slab	 (c)
Cast-in-Place Concrete Multicell Box	Monolithic concrete	 (d)
Cast-in-Place Concrete Tee Beam	Monolithic concrete	 (e)
Precast Solid, Voided or Cellular Concrete Boxes with Shear Keys	Cast-in-place concrete overlay	 (f)
Precast Solid, Voided, or Cellular Concrete Box with Shear Keys and with or without Transverse Posttensioning	Integral concrete	 (g)

Live-Load Distribution Factors
For Moments – Interior Beams

Table 4.6.2.2.2b-1 Distribution of Live Loads Per Lane for Moment in Interior Beams.

Type of Beams	Applicable Cross-Section from Table 4.6.2.2.1-1	Distribution Factors	Range of Applicability
Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-Beams, T- and Double T-Sections	a, e, k and also i, j if sufficiently connected to act as a unit	One Design Lane Loaded: $0.06+\left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12.0Lt_s^3}\right)^{0.1}$ Two or More Design Lanes Loaded: $0.075+\left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12.0\,Lt_s^3}\right)^{0.1}$	$3.5 \le S \le 16.0$ $20 \le L \le 240$ $4.5 \le t_s \le 12.0$ $N_b \ge 4$ $10{,}000 \le K_g \le 7{,}000{,}000$
		use lesser of the values obtained from the equation above with $N_b = 3$ or the lever rule	$N_b = 3$

Notes: 1) Units are in LANES and not WHEELS!

2) No multiple presence factor

Interior I Girder—Strength Limit State

$$K_g = n\left(I + Ae_g^2\right) \qquad (4.6.2.2.1\text{–}1)$$

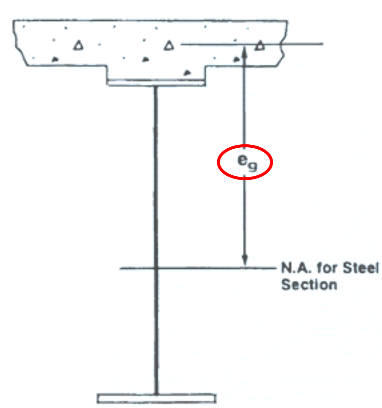
n = modular ratio

I = moment of inertia of steel girder

A = area of steel girder

e_g = distance between centers of gravity of steel girder and concrete deck

$\left(\frac{K_g}{Lt_s^3}\right)$ term may be taken as 1.0 for preliminary design



Live-Load Distribution Factors
For Shear – Interior Beams

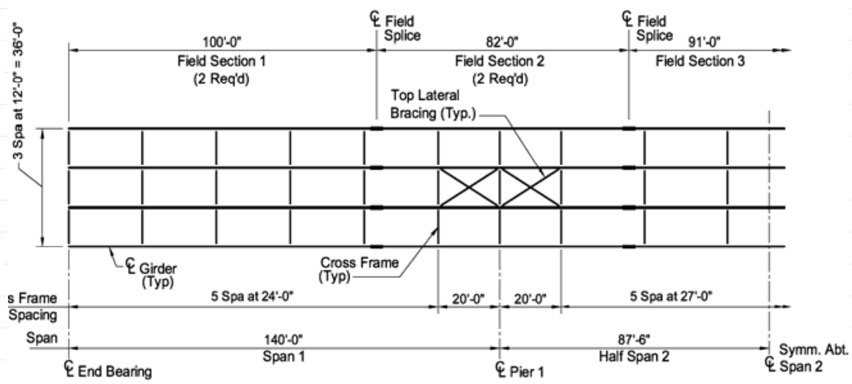
Table 4.6.2.2.3a-1 Distribution of Live Load per Lane for Shear in Interior Beams.

Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	One Design Lane Loaded	Two or More Design Lanes Loaded	Range of Applicability
Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-Beams, T-and Double T-Sections	a, e, k and also i, j if sufficiently connected to act as a unit	$0.36+\frac{S}{25.0}$	$0.2+\frac{S}{12}-\left(\frac{S}{35}\right)^{2.0}$	$3.5 \le S \le 16.0$ $20 \le L \le 240$ $4.5 \le t_s \le 12.0$ $N_b \ge 4$
		Lever Rule	Lever Rule	$N_b = 3$

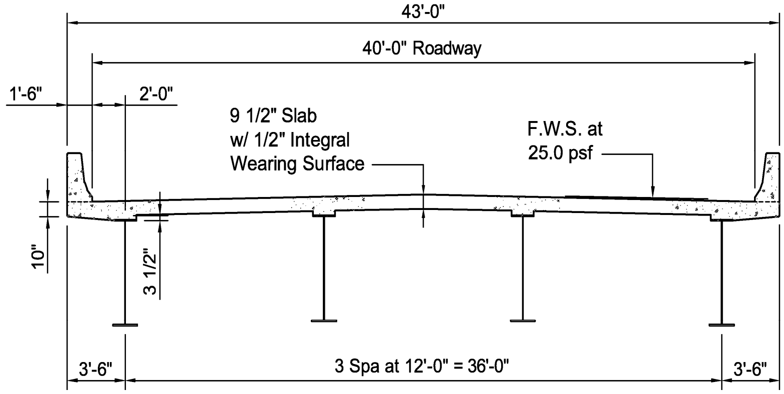
Notes: 1) Units are in LANES and not WHEELS!

2) No multiple presence factor

Live-Load Distribution Factors
Design Example

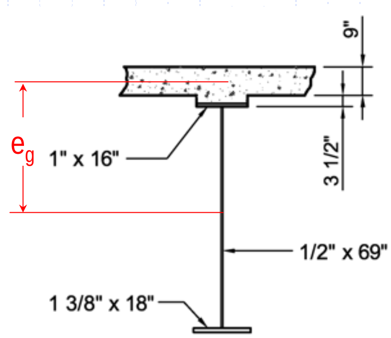


Live-Load Distribution Factors Example



POSITIVE FLEXURE (END SPAN)

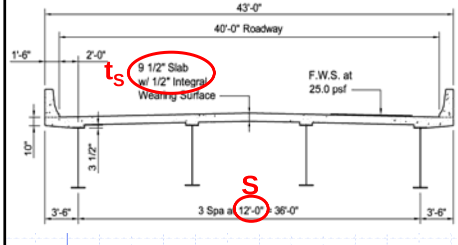
- **Calculate Kg:**
  - n = 8
  - N.A. is 39.63 in. from the top of the steel.

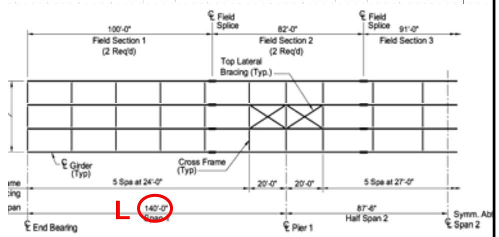


$$e_g = \frac{9.0}{2} + 3.5 + 39.63 - 1.0 = 46.63\,\text{in.}$$

$$K_g = n\left(I + Ae_g^2\right) = 8\left(62{,}658 + 75.25(46.63)^2\right) = 1.81 \times 10^6\ \text{in.}^4$$

Live-Load Distribution Factors
M+ , Interior Girder





Article 4.6.2.2.2b:

***One lane loaded*:**

$$0.06+\left(\frac{S}{14}\right)^{0.4}\left(\frac{S}{L}\right)^{0.3}\left(\frac{K_g}{12.0Lt_S^3}\right)^{0.1}$$

***Two or more lanes loaded*:**

$$0.075+\left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12.0Lt_S^3}\right)^{0.1}$$

Live-Load Distribution Factors
M+ , Interior Girder - (cont'd)

***One lane loaded*:**

$$0.06+\left(\frac{12.0}{14}\right)^{0.4}\left(\frac{12.0}{140.0}\right)^{0.3}\left(\frac{1.81\times 10^6}{12.0(140.0)(9.0)^3}\right)^{0.1}=0.528\text{ lanes}$$

***Two or more lanes loaded*:**

$$0.075+\left(\frac{12.0}{9.5}\right)^{0.6}\left(\frac{12.0}{140.0}\right)^{0.2}\left(\frac{1.81\times 10^6}{12.0(140.0)(9.0)^3}\right)^{0.1}=0.807\text{ lanes (governs)}$$

Live-Load Distribution Factors
V , Interior Girder

Table 4.6.2.2.3a-1

***One lane loaded*:**

$$0.36 + \frac{S}{25.0}$$

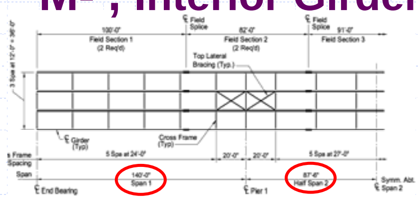
$$0.36 + \frac{12.0}{25.0} = 0.840 \text{ lanes}$$

***Two or more lanes loaded*:**

$$0.2 + \frac{S}{12} - \left(\frac{S}{35}\right)^2$$

$$0.2 + \frac{12.0}{12} - \left(\frac{12.0}{35}\right)^2 = 1.082 \text{ lanes (governs)}$$

Live-Load Distribution Factors
M- , Interior Girder



L = 0.5(140+175)
= 157.5 ft.

***One lane loaded*:**

$$0.06 + \left(\frac{12.0}{14}\right)^{0.4}\left(\frac{12.0}{157.5}\right)^{0.3}\left(\frac{2.65 \times 10^6}{12.0(157.5)(9.0)^3}\right)^{0.1} = 0.524 \text{ lanes}$$

***Two or more lanes loaded*:**

$$0.075 + \left(\frac{12.0}{9.5}\right)^{0.6}\left(\frac{12.0}{157.5}\right)^{0.2}\left(\frac{2.65 \times 10^6}{12.0(157.5)(9.0)^3}\right)^{0.1} = 0.809 \text{ lanes (governs)}$$

.

Live-Load Distribution Factors

Moments – Exterior Beams

Table 4.6.2.2.2d-1 Distribution of Live Loads Per Lane for Moment in Exterior Longitudinal Beams.

Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	One Design Lane Loaded	Two or More Design Lanes Loaded	Range of Applicability
Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-Beams, T- and Double T- Sections	a, e, k and also i, j if sufficiently connected to act as a unit	Lever Rule	$g = e\, g_{interior}$ $e = 0.77 + \frac{d_e}{9.1}$	$-1.0 \le d_e \le 5.5$
			use lesser of the values obtained from the equation above with $N_b = 3$ or the lever rule	$N_b = 3$

Notes: In beam-slab bridges with diaphragms or cross-frames, the distribution factor for the exterior beam shall not be taken to be less than that which would be obtained by assuming that the cross-section deflects and rotates as a rigid cross-section.

$$R = \frac{N_L}{N_b} + \frac{X_{ext} \sum^{N_L} e}{\sum^{N_b} x^2}$$

Live-Load Distribution Factors

Shear – Exterior Beams

Table 4.6.2.2.3b-1 Distribution of Live Load per Lane for Shear in Exterior Beams.

Type of Superstructure	Applicable Cross-Section from Table 4.6.2.2.1-1	One Design Lane Loaded	Two or More Design Lanes Loaded	Range of Applicability
Concrete Deck, Filled Grid, Partially Filled Grid, or Unfilled Grid Deck Composite with Reinforced Concrete Slab on Steel or Concrete Beams; Concrete T-	a, e, k and also i, j if sufficiently connected to act as a unit	Lever Rule	$g = e\, g_{interior}$ $e = 0.6 + \frac{d_e}{10}$	$-1.0 \le d_e \le 5.5$
			Lever Rule	$N_b = 3$

Notes: In beam-slab bridges with diaphragms or cross-frames, the distribution factor for the exterior beam shall not be taken to be less than that which would be obtained by assuming that the cross-section deflects and rotates as a rigid cross-section.

$$R = \frac{N_L}{N_b} + \frac{X_{ext} \sum^{N_L} e}{\sum^{N_b} x^2}$$

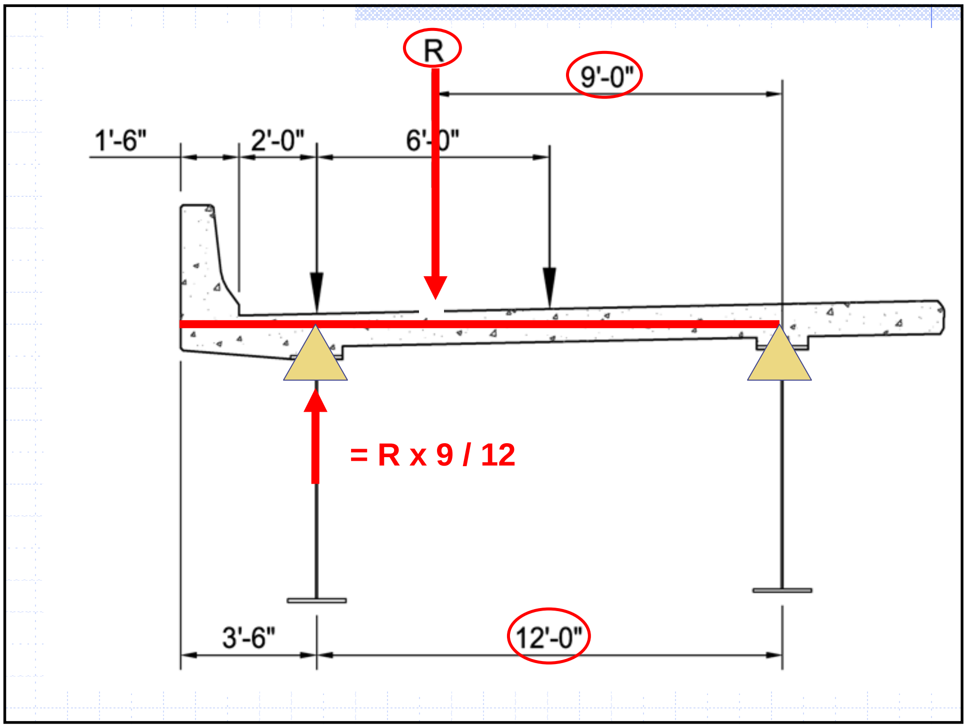
Live-Load Distribution Factors
M, Exterior Girder

- **For bending moment (Article 4.6.2.2.2d):**

  One lane loaded: **Use the lever rule**

- **Consider multiple presence factors when:**
  - **# of lanes of traffic on the deck must be considered in the analysis (Art. 3.6.1.1.2)**

Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
> 3	0.65



Live-Load Distribution Factors
M, Exterior Girder - (cont'd)

One lane loaded: Using the lever rule

$$\frac{9.0}{12.0} = 0.750$$

Multiple presence factor $m = 1.2$ (Table 3.6.1.1.2 - 1)

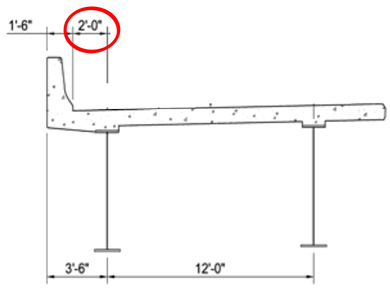
$$1.2(0.750) = 0.900 \text{ lanes}$$

Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
> 3	0.65

Live-Load Distribution Factors
M, Exterior Girder - (cont'd)

Two or more lanes loaded:

Modify interior-girder factor by e



$$e = 0.77 + \frac{d_e}{9.1}$$ (Table 4.6.2.2.2d-1)

$$e = 0.77 + \frac{2.0}{9.1} = 0.990$$

$$0.990(0.807) = 0.799 \text{ lanes}$$

Note: 1) The multiple presence factor is not applied.

Live-Load Distribution Factors
M, Exterior Girder - (cont'd)

Special Analysis: for beam-slab bridges with diaphragms or cross frames

Assuming the entire cross-section rotates as a rigid body about the longitudinal centerline of the bridge, distribution factors for one, two and three lanes loaded are computed using the following formula:

$$R = \frac{N_L}{N_b} + \frac{X_{ext} \sum^{N_L} e}{\sum^{N_b} x^2} \qquad \text{Eq. (C4.6.2.2.2d-1)}$$

Live-Load Distribution Factors
M, Exterior Girder - (cont'd)

Special Analysis:

$$R = \frac{N_L}{N_b} + \frac{X_{ext} \sum^{N_L} e}{\sum^{N_b} x^2} \qquad \text{Eq. (C4.6.2.2.2d-1)}$$

- R = reaction on exterior beam in terms of lanes
- N_L = number of loaded lanes under consideration
- e = eccentricity of a lane from the center of gravity of the pattern of girders (ft)
- x = horizontal distance from the center of gravity of the pattern of girders to each girder (ft)
- X_{ext} = horizontal distance from the center of gravity of the pattern of girders to the exterior girder (ft)
- N_b = number of beams or girders

Live-Load Distribution Factors

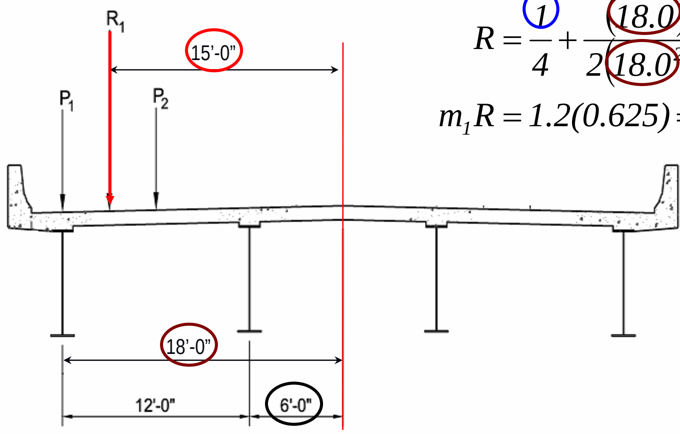
M, Exterior Girder - (cont'd)

One lane loaded:

$$R = \frac{N_L}{N_b} + \frac{X_{ext}\sum^{N_L} e}{\sum^{N_b} x^2}$$

$$R = \frac{1}{4} + \frac{(18.0)(15.0)}{2\left(18.0^2 + 6.0^2\right)} = 0.625$$

$$m_1 R = 1.2(0.625) = 0.750\ lanes$$



Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
> 3	0.65

Live-Load Distribution Factors

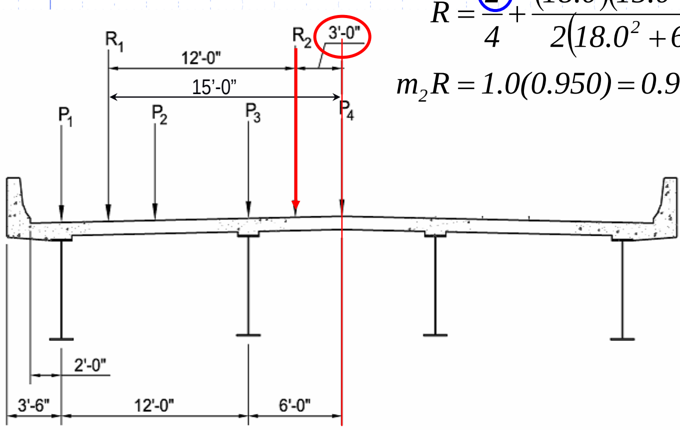
M, Exterior Girder - (cont'd)

Two lanes loaded:

$$R = \frac{N_L}{N_b} + \frac{X_{ext}\sum^{N_L} e}{\sum^{N_b} x^2}$$

$$R = \frac{2}{4} + \frac{(18.0)(15.0 + 3.0)}{2\left(18.0^2 + 6.0^2\right)} = 0.950$$

$$m_2 R = 1.0(0.950) = 0.950\ lanes\ (governs)$$



Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
> 3	0.65

Live-Load Distribution Factors

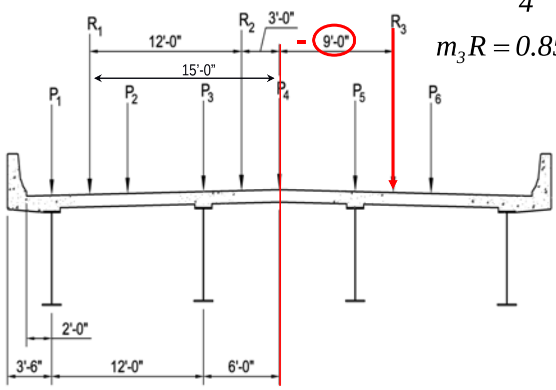
M, Exterior Girder - (cont'd)

Three lanes loaded:

$$R = \frac{N_L}{N_b} + \frac{X_{ext} \sum^{N_L} e}{\sum^{N_b} x^2}$$

$$R = \frac{3}{4} + \frac{(18.0)(15.0 + 3.0 - 9.0)}{2(18.0^2 + 6.0^2)} = 0.975$$

$$m_3 R = 0.85(0.975) = 0.829 \text{ lanes}$$



Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
> 3	0.65

Live-Load Distribution Factors

V, Exterior Girder - (cont'd)

- **For shear (Article 4.6.2.2.3b):**

One lane loaded: **Use the lever rule**

0.970 lanes

Two or more lanes loaded:

Modify interior-girder factor by e

$$e = 0.6 + \frac{d_e}{10} \quad \text{(Table 4.6.2.2.3b-1)}$$

$$e = 0.6 + \frac{2.0}{10} = 0.80$$

$$0.80(1.082) = 0.866 \text{ lanes}$$

Live-Load Distribution Factors
V, Exterior Girder - (cont'd)

Special Analysis:

The factors used for bending moment are also used for shear:

One lane loaded: **0.750 lanes**

Two lanes loaded: **0.950 lanes (governs)**

Three lanes loaded: **0.829 lanes**

- All factors used for both pos. & neg. flexure.

SUMMARY
Live-Load Distribution Factors
Strength Limit State

- AASHTO LRFD - Positive Flexure:

	Interior Girder	Exterior Girder
Bending Moment	0.807 lanes	0.950 lanes
Shear	1.082 lanes	0.950 lanes

- AASHTO LRFD - Negative Flexure:

	Interior Girder	Exterior Girder
Bending Moment	0.809 lanes	0.950 lanes
Shear	1.082 lanes	0.950 lanes

Live-Load Distribution Factors
Fatigue Limit State

- The fatigue load is placed in a single lane. Therefore, the distribution factors for one-lane loaded are used. (see Article 3.6.1.4.3b)
- Multiple presence factors are not to be applied for fatigue. Thus, the distribution factors for one-lane loaded must be modified by dividing out the multiple presence factor of ***1.2*** specified for one-lane loaded. (see Article 3.6.1.1.2)

SUMMARY
Live-Load Distribution Factors
Fatigue Limit State - Design Example

- AASHTO LRFD - Positive Flexure:

	Interior Girder	Exterior Girder
Bending Moment	0.440 lanes	0.750 lanes
Shear	0.700 lanes	0.750 lanes

- AASHTO LRFD - Negative Flexure:

	Interior Girder	Exterior Girder
Bending Moment	0.437 lanes	0.750 lanes
Shear	0.700 lanes	0.750 lanes

Live-Load Distribution Factors
Skew Correction Factors

For bending moment (Article 4.6.2.2.2e):

The skew correction factor for bending moment reduces the live-load distribution factor. For skew angles less than 30°, the correction factor is equal to 1.0. For skew angles greater than 60°, the correction factor is computed using an angle of 60°. The difference in skew angle between two adjacent lines of supports cannot exceed 10°. Dead-load moments are currently not modified for the effects of skew.

$$c_1 = 0.25\left(\frac{K_g}{Lt_s^3}\right)^{0.25}\left(\frac{S}{L}\right)^{0.5}$$ (Table 4.6.2.2.2e-1)

$$\text{Correction factor} = 1 - c_1(\tan\theta)^{1.5}$$

Live-Load Distribution Factors
Skew Correction Factors – (cont.)

For shear (Article 4.6.2.2.3c):

The skew correction factor increases the live-load distribution factor for shear in the exterior girder at the obtuse corner of the bridge. The correction factor is valid for skew angles less than or equal to 60°. The factor may be conservatively applied to all end shears. Dead-load shears are currently not modified for the effects of skew.

$$\text{Correction factor} = 1.0 + 0.20\left(\frac{Lt_s^3}{K_g}\right)^{0.3}\tan\theta$$

(Table 4.6.2.2.3c-1)

Load for Optional Live-Load Deflection Evaluation (Article 3.6.1.3.2)

- The larger of:
  - The design truck, or
  - 25% of the design truck + 100% of the design lane load.

Live-Load Deflection (Article 2.5.2.6.2)

- Use the SERVICE I load combination & multiple presence factors where appropriate.
- For straight-girder systems, all lanes should be loaded and all supporting components should be assumed to deflect equally.
- For composite design, the stiffness used for calculation of the deflection should include the entire width of the roadway, and may include the structurally continuous portions of the railings, sidewalks and barriers.

Distribution Factor for Live-Load Deflection

- For the design example:

$$DF = m_3\left(\frac{N_L}{N_b}\right)$$

$$= 0.85\left(\frac{3}{4}\right) = 0.638 \text{ lanes}$$

Number of Loaded Lanes	Multiple Presence Factors "m"
1	1.20
2	1.00
3	0.85
> 3	0.65

Dynamic Load Allowance (Impact - IM) – (Article 3.6.2.1)

- IM = 33% (for *truck or tandem only; not* for lane).

- Exceptions are:

Deck joints:	IM = 75%
Fatigue limit state:	IM = 15%

QUESTIONS?

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