Introduction to LRFD
Loads and Loads Distribution

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**AASHTO Load and Resistance Factor Design (LRFD)**

- **Goal:** develop more comprehensive specifications to:
  - Eliminate any gaps & inconsistencies in the AASHTO Standard Specifications,
  - Incorporate the latest in bridge research,
  - Achieve more uniform margins of safety or reliability across a wide variety of structures,
  - Take variability of the behavior of structural elements into account, but present the results in a format readily usable by bridge designers.

**AASHTO Load and Resistance Factor Design (LRFD)**

- 1993 - adopted by AASHTO
  - published First Edition of Construction Specifications
Areas of Major Change

- A new philosophy of safety
- Load and resistance factors based on calibration
- Identification of limit states
- Constructibility criteria
- New load models
- Chapter on structural analysis
- Simplified fatigue design provisions

Areas of Major Change - (cont’d)

- Revised seismic design provisions
- Isotropic reinforced concrete deck design
- Unified approach for concrete design
- Improved Geotechnical Provisions
- Incorporates other AASHTO documents
- Parallel commentary

Evolution of Design Methodologies

- SLD Methodology:
  \( f_{t0} + f_{tL} \leq 0.55F_y \), or
  \( 1.82(f_{t0}) + 1.82(f_{tL}) \leq F_y \)
- LFD Methodology:
  \( 1.3[1.0(f_{t0}) + 5/3(f_{tL})] \leq \phi F_y \), or
  \( 1.3(f_{t0}) + 2.17(f_{tL}) \leq \phi F_y \) (\( \phi \) by judgment)
- LRFD Methodology:
  \( 1.25(f_{t0}) + 1.75(f_{tL}) \leq \phi F_y \) (\( \phi \) 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.

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

LRFD Limit States

- The LRFD Specifications require examination of several load combinations corresponding to the following limit states:
  - SERVICE LIMIT STATE
  - FATIGUE & FRACTURE LIMIT STATE
  - STRENGTH LIMIT STATE
    - (CONSTRUCTIBILITY)
  - EXTREME EVENT LIMIT STATE
### Basic LRFD Design Equation

$$\Sigma \eta_i \gamma_i Q_i \leq \phi R_n = R_i \quad \text{Eq. (1.3.2.1-1)}$$

Where:
- $\eta_i$ = factored loads
- $\eta = \eta_0 \eta_1 \eta_2$
- $\eta_0 \geq 0.95$ for maximum $\gamma_i$'s
- $\eta_1 \leq 1.00$ for minimum $\gamma_i$'s
- $\eta_i = \eta_1 \eta_2$
- $\gamma_i$ = load factor
- $\phi$ = resistance factor
- $Q_i$ = nominal force effect
- $R_n$ = nominal resistance
- $R_i$ = factored resistance $= \phi R_n$

### 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 track.
### 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 bonus 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** = vehicle collision force
- **EQ** = earthquake
- **HC** = live load
- **IC** = ice load
- **IM** = dynamic load allowance
- **LL** = live load
- **LS** = live load surcharge
- **PL** = pedestrian live load
- **SH** = settlement
- **TG** = temperature gradient
- **TU** = uniform temperature
- **WA** = water load and stream pressure
- **WS** = wind load on structure
- **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	extsubscript{1}** - placed prior to deck hardening and acting on the noncomposite section
  - **DC	extsubscript{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

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>Load Factor</th>
<th>Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC: Component and Attachments</td>
<td>1.25</td>
<td>0.90</td>
</tr>
<tr>
<td>DD: Downdrag</td>
<td>1.80</td>
<td>0.45</td>
</tr>
<tr>
<td>DW: Wearing Surfaces and Utilities</td>
<td>1.50</td>
<td>0.65</td>
</tr>
<tr>
<td>EH: Horizontal Earth Pressure</td>
<td>1.35</td>
<td>0.90</td>
</tr>
<tr>
<td>SV: Vertical Earth Pressure</td>
<td>1.35</td>
<td>0.90</td>
</tr>
</tbody>
</table>

#### Notes:
- **N/A** indicates not applicable.
Basic LRFD Design Live Load
HL-93 -- (Article 3.6.1.2.1)

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

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

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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:

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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

Use One of These at a Time

Limit State
Load Combination
DC
DD
DW
EH
EV
ES
LL
IM
CE
BR
PL
LS
WA
WS
WL
FR
TU
CR
SH
TG
SE
EQ
IC
CT
CV
STRENGTH-I
γ
p
1.75
1.00
-
-
1.00
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
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### 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

### Live-Load Distribution Factors For Moments – Interior Beams

<table>
<thead>
<tr>
<th>Type of Beams</th>
<th>Applicable Cross Section From Table 4.6.2.1-1 Distribution Factors</th>
<th>Range of Applicability</th>
<th>Distribution Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Deck, Filled Grid, Partially Filled Grid, Unfilled Grid</td>
<td></td>
<td></td>
<td>One Design Lane Loaded:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.5 ≤ Kg ≤ 16.0</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>4.5 ≤ Kg ≤ 14.0</td>
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<tr>
<td></td>
<td></td>
<td>10,000 ≤ Kg ≤ 3,700,000</td>
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<td></td>
<td>N ≥ 4</td>
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<td>12,500 ≤ Kg ≤ 7,900,000</td>
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<td>N &gt; 4</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1) Units are in LANES and not WHEELS!
2) No multiple presence factor
Table 4.6.2.2.3a-1 Distribution of Live Load per Lane for Shear in Interior Beams.

<table>
<thead>
<tr>
<th>Type of Superstructure</th>
<th>Applicable Cross-Section from Table 4.6.2.1-1</th>
<th>One Design Lane Loaded</th>
<th>Two or More Design Lanes Loaded</th>
<th>Range of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Deck, Filled Grid, Partly Filled Grid, or Unfilled Grid Deck; Composite with Reinforced Concrete Slab or Steel or Concrete Beams; Concrete T-Beams, T-and Double T-Sections</td>
<td>a, b, and e, s, f, k and also i, j if sufficiently connected to act as a unit</td>
<td>a = 3.5</td>
<td>b = 2, f = 20</td>
<td>( n_b \leq n_t \leq n_t \leq 4 )</td>
</tr>
</tbody>
</table>

**Notes:**
1) Units are in LANES and not WHEELS!
2) No multiple presence factor

Live-Load Distribution Factors
For Shear – Interior Beams

Live-Load Distribution Factors
Design Example
Live-Load Distribution Factors
Example

\[ n = 8 \]

N.A. is 39.63 in. from the top of the steel.

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

\[ K_g = (1 + A e_g) = \frac{862,658 + 75.25(46.63)^2}{4622 \times 81.163} = 1.81 \times 10^4 \text{ in.}^4 \]

POSITIVE FLEXURE (END SPAN)

Live-Load Distribution Factors
M+, Interior Girder

Article 4.6.2.2.2b:
One lane loaded:
\[ 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left( \frac{K_g}{12.0(1.0)^{0.1}} \right) \]

Two or more lanes loaded:
\[ 0.075 + \left( \frac{S}{9.5} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left( \frac{K_g}{12.0(1.0)^{0.1}} \right) \]
Live-Load Distribution Factors

M+, Interior Girder - (cont’d)

One lane loaded:

\[
0.06 + \left( \frac{12.0}{14} \right) \left( \frac{12.0}{140.0} \right) \left( 1.81 \times 10^5 \right) = 0.528 \text{ lanes}
\]

Two or more lanes loaded:

\[
0.075 + \left( \frac{12.0}{3.5} \right) \left( \frac{12.0}{140.0} \right) \left( 1.81 \times 10^5 \right) = 0.807 \text{ lanes (governs)}
\]

Live-Load Distribution Factors

V, Interior Girder

Table 4.6.2.2.3a-1

One lane loaded:

\[
0.36 + \frac{S}{25.0} \\
0.36 + \frac{S}{12.0} = 0.840 \text{ lanes}
\]

Two or more lanes loaded:

\[
0.2 + \frac{S}{12} - \frac{S}{35} \\
0.2 + \frac{12.0}{12} - \frac{12.0}{35} = 1.082 \text{ lanes (governs)}
\]

Live-Load Distribution Factors

M+, Interior Girder

One lane loaded:

\[
0.06 + \left( \frac{12.0}{14} \right) \left( \frac{12.0}{157.5} \right) \left( 2.65 \times 10^5 \right) = 0.524 \text{ lanes}
\]

Two or more lanes loaded:

\[
0.075 + \left( \frac{12.0}{3.5} \right) \left( \frac{12.0}{157.5} \right) \left( 2.65 \times 10^5 \right) = 0.809 \text{ lanes (governs)}
\]
### Live-Load Distribution Factors

#### Moments – Exterior Beams

<table>
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<tr>
<th>Type of Superstructure</th>
<th>Applicable Cross-Section from Table 4.6.2.2.1</th>
<th>One Design Lane Loaded</th>
<th>Two or More Design Lanes Loaded</th>
<th>Range of Applicability</th>
</tr>
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<tr>
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</tbody>
</table>

**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.

\[
R = \frac{N_i}{N_j} \times \frac{X_{ib} \times X_j}{X_{ib} + X_j}
\]

---

#### Shear – Exterior Beams

<table>
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<tr>
<th>Type of Superstructure</th>
<th>Applicable Cross-Section from Table 4.6.2.2.1</th>
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**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.

\[
R = \frac{N_i}{N_j} \times \frac{X_{ib} \times X_j}{X_{ib} + X_j}
\]

---

#### 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)

<table>
<thead>
<tr>
<th>Number of Loaded Lanes</th>
<th>Multiple Presence Factors “m”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>0.85</td>
</tr>
<tr>
<td>&gt; 3</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Live-Load Distribution Factors M, Exterior Girder - (cont'd)

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

\[
\frac{9.0}{12.6} = 0.750
\]

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

\[
1.2(0.750) = 0.900 \text{ lanes}
\]

<table>
<thead>
<tr>
<th>Number of Loaded Lanes</th>
<th>Multiple Presence Factors “m”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25</td>
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<td>2</td>
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</tr>
<tr>
<td>3</td>
<td>0.85</td>
</tr>
<tr>
<td>&gt; 3</td>
<td>0.65</td>
</tr>
</tbody>
</table>

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

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

**Two or more lanes loaded:** Modify interior-girder factor by \( e \)

\[
e = 0.77 + \frac{d}{9.1} \quad \text{(Table 4.6.2.2d-1)}
\]

\[
e = 0.77 + \frac{2.0}{9.1} = 0.990
\]

\[
0.990 (0.807) = 0.799 \text{ lanes}
\]
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:

\[ R = \frac{\sum N_i X_i e}{\sum N_i x_i} \]

Eq. (C4.6.2.2d-1)

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

   \[ R = \frac{N_i X_i}{N_b} \sum e \]

   Eq. (C4.6.2.2d-1)

   - \( R \) = reaction on exterior beam in terms of lanes
   - \( N_i \) = 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

2. **One lane loaded**

   \[ R = \frac{N_i X_i}{N_b} \sum e \]

   \[ R = \frac{18(0.625)}{4(0.750)} = 0.625 \]

   \[ m_i R = 1.2(0.625) = 0.750 \text{ lanes} \]

3. **Multiple Presence Factors**

   \[
   \begin{array}{c|c|c}
   \text{Number of Loaded Lanes} & \text{Multiple Presence Factors } m^n & \\
   \hline
   1 & 1.00 & \\
   2 & 0.90 & \\
   3 & 0.83 & \\
   + 3 & 0.75 & \\
   \end{array}
   \]
### Live-Load Distribution Factors

#### M, Exterior Girder - (cont'd)

For shear (Article 4.6.2.2.3b):

1. **One lane loaded:** Use the lever rule
   - 0.970 lanes

2. **Two or more lanes loaded:**
   - Modify interior-girder factor by \( e \)
   - \( e = 0.6 + \frac{d}{10} \) (Table 4.6.2.2.3b-1)
   - \( e = 0.6 + \frac{2.0}{10} = 0.80 \)
   - \( 0.80(1.082) = 0.866 \) lanes

#### Two lanes loaded:

\[
R = \frac{N_1}{N_0} \sum_{i=1}^{n} x_i
\]

\[
R = \frac{18.0(15.0 + 6.0)}{2(18.0 + 6.0)} = 0.950
\]

\[m, R = 1.0(0.950) = 0.950 \text{ lanes (governs)}\]

### Table: Number of Loaded Lanes vs. Multiple Presence Factors \( m^* \)

<table>
<thead>
<tr>
<th>Number of Loaded Lanes</th>
<th>Multiple Presence Factors ( m^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.90</td>
</tr>
<tr>
<td>3</td>
<td>0.95</td>
</tr>
<tr>
<td>+ 2</td>
<td>0.85</td>
</tr>
</tbody>
</table>

#### Three lanes loaded:

\[
R = \frac{N_1}{N_0} \sum_{i=1}^{n} x_i
\]

\[
R = \frac{18.0(15.0 + 3.0)}{2(18.0 + 6.0)} = 0.975
\]

\[m, R = 0.85(0.975) = 0.829 \text{ lanes}\]
**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:**
  
<table>
<thead>
<tr>
<th>Interior Girder</th>
<th>Exterior Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Moment</td>
<td>0.807 lanes</td>
</tr>
<tr>
<td>Shear</td>
<td>1.082 lanes</td>
</tr>
</tbody>
</table>

- **AASHTO LRFD - Negative Flexure:**

<table>
<thead>
<tr>
<th>Interior Girder</th>
<th>Exterior Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Moment</td>
<td>0.807 lanes</td>
</tr>
<tr>
<td>Shear</td>
<td>1.082 lanes</td>
</tr>
</tbody>
</table>

---

**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:

<table>
<thead>
<tr>
<th></th>
<th>Interior Girder</th>
<th>Exterior Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Moment</td>
<td>0.440 lanes</td>
<td>0.150 lanes</td>
</tr>
<tr>
<td>Shear</td>
<td>0.750 lanes</td>
<td>0.750 lanes</td>
</tr>
</tbody>
</table>

AASHTO LRFD - Negative Flexure:

<table>
<thead>
<tr>
<th></th>
<th>Interior Girder</th>
<th>Exterior Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Moment</td>
<td>0.437 lanes</td>
<td>0.150 lanes</td>
</tr>
<tr>
<td>Shear</td>
<td>0.750 lanes</td>
<td>0.750 lanes</td>
</tr>
</tbody>
</table>

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

In the LRFD Specification, live-load deflection is taken as that resulting from the larger of:

- The design truck by itself, or
- 25% of the design truck together with 100% of the design lane load.

Live-Load Deflection (Article 2.5.2.6.2)

- Evaluation is optional.
- 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:

\[ DF = m_1 \left( \frac{N_L}{N_K} \right) \]

\[ = 0.85 \left( \frac{3}{2} \right) = 0.638 \text{ lanes} \]

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%

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.

\[ c_1 = 0.25 \left( \frac{K_s}{L^2} \right) \left( \frac{S}{L} \right)^{0.5} \] (Table 4.6.2.2e-1)

Correction factor = \[ 1 - c_1 (\tan \theta)^{1.5} \]
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.

\[
\text{Correction factor} = 1.0 + 0.20 \left( \frac{L}{K} \right)^{0.3} \tan \theta
\]

(Table 4.6.2.2.3c-1)

QUESTIONS?