LOAD DISTRIBUTION
This section illustrates how load will transmit from the deck to the stringers.

Determining the fraction of load carried by a loaded member and the remainder distributed to other members is the focus of this discussion.
How Loads Are Distributed

✓ A wide variety of parameters which range from the structure’s geometry to element material properties influence exactly how loads are distributed.

✓ The influencing parameters are a function of the bridge superstructure cross-sectional properties.

✓ The following parameters determine how loads are distributed in a bridge superstructure.
  - Type and depth of deck
  - Span length
  - Spacing between stringers
  - Spacing of secondary members
  - Stiffness of primary members
  - Stiffness of secondary members
  - Type of bracing employed (if any)
  - Size and position of loads
AASHTO Standard
How Loads Are Distributed (AASHTO Standard)

- In order to simplify the computation of load distribution, AASHTO Standard Specifications choose to utilize a **distribution factor (DF)** based on only two of the above referenced criteria:
  - Type of floor.
  - Stringer spacing.
- Load distribution factor (DF) is computed and applied to live load bending moments and shear forces.
- It is important to note that these factors are applied to **wheel loads** *(multiply by 1/2 if using axle value or lane load)*.
The following Table 3.6 shows the AASHTO Standard Specifications wheel load distribution factors in longitudinal Beam for various floor type and spacing configurations. \( S = \text{Average Stringer Spacing in feet} \)

<table>
<thead>
<tr>
<th>TYPE OF FLOOR</th>
<th>BRIDGE TRAFFIC LANE</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CONCRETE FLOOR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On Steel I-Beam Stringers and Prestressed Concrete Girders</td>
<td>( S = \frac{7.0}{6.0} ) if ( S ) exceeds 10 ft, see note this row. ( S = \frac{5.5}{6.0} ) if ( S ) exceeds 14 ft, see note this row.</td>
<td>Assume the flooring between stringers acts as a simple beam with the load on each stringer being the wheel load reaction.</td>
</tr>
<tr>
<td>On Concrete T-Beams</td>
<td>( S = \frac{6.5}{6.0} ) if ( S ) exceeds 6 ft, see note this row. ( S = \frac{6.0}{6.0} ) if ( S ) exceeds 10 ft, see note this row.</td>
<td>Assume the flooring between stringers acts as a simple beam with the load on each stringer being the wheel load reaction.</td>
</tr>
<tr>
<td>On Timber Stringers</td>
<td>( S = \frac{6.0}{6.0} ) if ( S ) exceeds 6 ft, see note this row. ( S = \frac{5.0}{6.0} ) if ( S ) exceeds 10 ft, see note this row.</td>
<td>Assume the flooring between stringers acts as a simple beam with the load on each stringer being the wheel load reaction.</td>
</tr>
<tr>
<td>Concrete Box Girders</td>
<td>( S = \frac{8.0}{7.0} ) if ( S ) exceeds 12 ft, see note this row. ( S = \frac{7.0}{7.0} ) if ( S ) exceeds 16 ft, see note this row.</td>
<td>Assume the flooring between stringers acts as a simple beam...as above. Omit sidewalk live load for interior and exterior girders designed with this criteria.</td>
</tr>
<tr>
<td>On Steel Box Girders</td>
<td>Find live load bending moment for each girder using: ( \text{FRACTION OF WHEEL LOAD} = 0.1 + 1.7R + 0.85/NW )</td>
<td>( R = \text{NW} / \text{Number of Box Girders} (0.5 \leq R \leq 1.5) ) ( NW = WC / 12 ) reduced to the nearest whole number ( WC = \text{Curb to curb or barrier to barrier width (feet)} )</td>
</tr>
<tr>
<td>On Prestressed Concrete Spread Box Beams</td>
<td>Find interior girder live load bending moment using: ( \text{FRACTION OF WHEEL LOAD} = (2NL/NB) + k(S/L) ) For exterior girder assume flooring between stringers acts as a simple beam...as above, but not less than ( 2NL/NB ).</td>
<td>( NL = \text{Number of Design Traffic Lanes} ) ( NB = \text{Number of Beams} (4 &lt; NB &lt; 10) ) ( S = \text{Beam Spacing} (0.57 \leq S \leq 11.00) ) (feet) ( L = \text{Span Length (feet)} ) ( W = \text{Curb to Curb Width (feet)} ) ( k = 0.1W - NL(0.10NL - 0.26) - 0.20WB - 0.12 )</td>
</tr>
</tbody>
</table>
Load Distribution Factor (AASHTO Standard)

DF for Bending Moment

yect computing the bending moment due to live load, for example, a fraction of both the front and rear wheel loads is taken to act on a given interior stringer.

- This value would be multiplied by half the weight of the design truck (wheel load)
DF for Bending Moment

- The total weight of an H20-44 truck is 8,000 lb (front axle) + 32,000 lb (rear axle)
- one set of front and rear wheels would be half this
  \[= \frac{1}{2}(8,000+32,000) = 20,000 \text{ lb or 20 kips.}\]
  - Distributed Load =DF ×One set of Wheels
  - Distributed Load =1.27 ×20 kips =25.4 kips
- This means that 25.4 kips of the 40 kip H20-44 design truck acts on any given interior stringer and the remaining 14.6 kips are distributed amongst the other stringers.
- If the spacing between stringers had been greater than 14ft, the concrete deck between the two adjacent interior stringers would be assumed to act as a simple beam.
Load Distribution Factor (AASHTO Standard)

**DF for Shear**

- If the axle load is not at the support, the live load distribution factor for an interior stringer shear is the same as that for an interior stringer moment.

- If the axle load is at support, we should calculate the distribution factor for shear assuming the deck is simply supported by the stringers. This procedure is called “Level Rule”

- **Level Rule** should only be applied to the axle load at the support. The normal live load distribution factor (as in Table 3.6) shall be applied to the rest axle loads.
Load Distribution Factor (AASHTO Standard)

DF for Exterior Longitudinal Members

- Depending on the girder arrangement, outside girders are often subjected to heavier loads than interior girders.
- Superimposed dead loads such as curbs, sidewalks, railings, barriers, etc., which are placed on an exterior girder after the deck has cured, can be distributed equally among all primary members.
- For a slab-on-stringer bridge with four or more stringers, the following distribution

  \[ DF = \frac{S}{5.5} \quad (S \leq 6\text{ft}) \quad \text{or} \quad DF = \frac{S}{4 + 0.25S} \quad (6 \leq S \leq 12\text{ft}) \]

  \[ S = \text{distance between exterior and adjacent interior stringer} \]
Load Distribution Factor (AASHTO Standard)

DF for Transverse Members

✓ The AASHTO specifications do not allow for any lateral distribution of loads for transverse members (e.g., floor beams).

✓ When there are no longitudinal members present and the deck is supported entirely by floor beams, the distribution factors can be calculated as follows:

  ✓ For concrete deck bridges, the distribution factors for both moment and shear is $S/6$, where $S$ is the spacing of the transverse beams.

  ✓ If $S$ exceeds 6 feet (1.8 m), the distribution factor can be calculated by positioning the live load to obtain the maximum reaction at the floor beam, assuming the deck is simply supported by the floor beams.

✓ The distribution factors for both AASHTO Standards and AASHTO LRFD Specifications are similar for transverse members.
AASHTO LRFD
How Loads Are Distributed (AASHTO LRFD)

- It is very important to remember that AASHTO LRFD uses **axle load and lane load**, instead of **wheel load**.
- Provides a more accurate formula to calculate the live load distribution factors.
- The live load distribution factors in LRFD method is approximately half of these in the standard specifications.
Load Distribution Factor (AASHTO LRFD)

✓ Distribution factor for Moment in interior stringers are:

1. One design lane loaded:

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

- \( S \) = spacing of stringers (ft)
- \( L \) = span length (ft)
- \( K_g \) = longitudinal stiffness parameter of the stringer (in^6)
- \( t_s \) = depth of concrete slab (in)

2. Two or more design lanes loaded:

\[
0.075 + \left( \frac{S}{9.5} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \left( \frac{K_g}{12.0L^3} \right)^{0.1}
\]
Load Distribution Factor (AASHTO LRFD)

- Distribution factor for Shear in interior stringers are:

1. One design lane loaded:
   \[ 0.36 + \frac{S}{25.0} \]

2. Two or more design lanes loaded:
   \[ 0.2 + \frac{S}{12} \left( \frac{S}{35} \right)^{2.0} \]

To apply these equations, the bridge has to meet the following conditions:

- \[ 3.5 \leq S \leq 16.0 \]
- \[ 4.5 \leq t_s \leq 12.0 \]
- \[ 20 \leq L \leq 240 \]
- \[ 10000 \leq K_z \leq 7000000 \]

The minimum number of stringers is 4.

- \( S \) = spacing of stringers (ft)
- \( L \) = span length (ft)
- \( K_z \) = longitudinal stiffness parameter of the stringer (in^4)
- \( t_s \) = depth of concrete slab (in)
Load Distribution Factor (AASHTO LRFD)

\[ K_g = n \left( I + Ae_g^2 \right) \]

\( n \) = ratio of modulus of elasticity between stringer material and concrete deck  
\( I \) = moment of inertia of the stringer (in\(^4\))  
\( A \) = section area of the stringer (in\(^2\))  
\( e_g \) = distance between the centers of gravity of the stringer and the deck (in)
Load Distribution Factor (AASHTO LRFD)

DF for Exterior Longitudinal Members.

1. One design lane loaded:
The load distribution factors for moment and shear can be obtained by positioning the truck wheel loads 2 feet from the parapet, and calculating the reaction from the exterior girder, assuming the deck is simply supported by the girders in the transverse direction.
Load Distribution Factor (AASHTO LRFD )

DF for Exterior Longitudinal Members

2. Two or more lanes are loaded:
   - live load distribution factor for **moment** can be obtained as for (Interior Stringer) and modified by a factor:
     \[ 0.77 + \frac{d_e}{9.1} \]
   - live load distribution factor for **shear** can be obtained as for (Interior Stringer), and modified by a factor:
     \[ 0.6 + \frac{d_e}{10} \]
   - where \( d_e \) = distance between the exterior web of exterior girder to the face of traffic barrier (ft.) \((-1 \leq d \leq 5.5)\)
   - If an exterior girder is under a sidewalk, the girder should be designed for truck load on the sidewalk.
Concrete Deck Slabs
1. Effective Span Length

✓ We begin with the deck because the nature of the design process generally follows a top-down approach.

✓ To simplify the design, a segment of the assumed slab-beam is taken and analyzed as a simple span. The length of this segment is called the effective span length.

✓ The size of the effective span length is dependent on
  – Whether the slab is continuous over more than two supports
  – The type of supports (e.g., steel or concrete stringers)
  – How the slab is integrated with the supports
<table>
<thead>
<tr>
<th>SLAB CONFIGURATION</th>
<th>EFFECTIVE SPAN LENGTH</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slab on two supports.</td>
<td>( S = \text{The distance center to center of supports} )</td>
<td><img src="example1.png" alt="Example" /></td>
</tr>
<tr>
<td></td>
<td>( S \leq \text{Clear Span + Slab Thickness} )</td>
<td><img src="example2.png" alt="Example" /></td>
</tr>
<tr>
<td><strong>SIMPLE SPAN</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab monolithic with beams.</td>
<td>( S = \text{Clear Span} )</td>
<td><img src="example3.png" alt="Example" /></td>
</tr>
<tr>
<td></td>
<td>(Clear distance between faces of supports)</td>
<td><img src="example4.png" alt="Example" /></td>
</tr>
<tr>
<td>Slab monolithic with walls without haunches.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rigid top flange prestressed beams with top flange width to minimum thickness ratio less than 4.0.</td>
<td><img src="example5.png" alt="Example" /></td>
</tr>
<tr>
<td><strong>CONTINUOUS OVER MORE THAN TWO SUPPORTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab supported on steel stringers.</td>
<td>( S = \text{Distance Between Edges of Top Flange + } \frac{1}{2} \text{ Top Flange Width} )</td>
<td><img src="example6.png" alt="Example" /></td>
</tr>
<tr>
<td>Slab supported on thin top flange prestressed beams with top flange width to minimum thickness ratio greater than or equal to 4.0.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slab supported on timber stringers.</td>
<td>( S = \text{Clear Span + } \frac{1}{2} \text{ Thickness of Stringer} )</td>
<td><img src="example7.png" alt="Example" /></td>
</tr>
</tbody>
</table>

*Table 3.7: AASHTO Effective Span Length Criteria for Concrete Slabs*
**EXAMPLE 3.1**  
**DESIGN OF REINFORCED CONCRETE DECK SLAB—LFD METHOD**  

| DET | 1/5 |

**PROBLEM:** Design the transversely reinforced concrete deck slab shown in the cross section detail below.

![Diagram of reinforced concrete deck slab](image)

**GIVEN:**
- Bridge to carry two traffic lanes.
- Bridge loading specified to be HS20-44.
- Concrete strength $f'_c = 4.5$ ksi.
- Grade 60 reinforcement $f_y = 60$ ksi.
- Account for 25 psf future wearing surface.
- Assume stringers are W36x150.
- Deck has integrated wearing surface.

**STEP 1:** Compute the Effective Span Length

From Table 3.7 we see that, for a slab supported on steel stringers and continuous over more than two longitudinal supports:

$S = \text{Distance Between Flanges} + \frac{1}{2} \text{Top Flange Width}$

Top Flange Width = 12" for W36 $\times$ 150 (from AISC) = 1.0 ft

Distance Between Flanges = 8.0 ft $- 2(1\ ft \ / 2) = 7.0$ ft

$S = 7.0\ ft + (0.5)(1.0\ ft)$

$\Rightarrow S = 7.5\ ft$
2. Calculation of Bending Moment

- As mentioned the design of a concrete deck slab is performed on a per foot width of slab basis.
- The live load bending moment criteria vary depending on whether the main reinforcement is perpendicular or parallel to the direction of traffic.
- Keep in mind that the AASHTO bending moment equations do not include impact.
- If the designer so wishes, a more exact analysis can be performed using the AASHTO specified tire contact area.
2.1 Main Reinforcement Perpendicular to Traffic

✓ Occurs in structures where the concrete deck slab rests on a set of longitudinally oriented primary members. The most common example of this is a slab-on-stringer bridge.

For slab spans simply supported: 

\[ M_{LL} = \left( \frac{S + 2}{32} \right) P \]

For slab is continuous over more than two supports: 

\[ M_{LL} = 0.8 \left( \frac{S + 2}{32} \right) P \]

– where \( M_{LL} \) = live load moment per foot-width of slab, ft-lb
– \( S \) = effective span length, ft
– \( P \) = live load
  
  = 16 kips for H20 and HS20 loading or
  
  = 20 kips for H25 and HS25 loading

✓ We will always use an impact factor of \( 1.30 \) in calculating the effects of live load on a concrete slab.
2.2 Main Reinforcement Parallel to Traffic

- Occurs in structures where the slab resists major flexural forces or floor beams are present.
- AASHTO specifies that the slab be analyzed as a beam having an effective width $E$, a length $S$.

$$E = 4 + 0.06S$$

$E =$ effective width of slab, ft

$S =$ effective span length, ft

- The effective width cannot be greater than 7.0 ft (2.13 m). This value is given for truck wheel loading.
- If lane loading governs, though, a width of $2E$ is to be used.
2.2 Main Reinforcement Parallel to Traffic

If the slab is simply supported, AASHTO specifies approximate maximum live load moments based on the loading conditions for HS20 loading.

1. For slab spans simply supported

\[
M_{LL} = 900S \quad \text{for } S \leq 50
\]

\[
M_{LL} = 1000(1.3S - 20) \quad \text{for } 50 < S < 100
\]

2. For slab is continuous over more than two supports, truck or lane loads should be positioned so as to cause maximum positive and negative moment.
2.3 Dead Load Moments

1. For slab spans simply supported

\[ M_{DL} = \frac{wS^2}{8} \]

2. For slab is continuous over more than two supports

\[ M_{DL} = \frac{wS^2}{10} \]

3. The load factors for dead load and live load are 1.30 and 2.17 respectively.
**STEP 2:** Compute Moment Due to Dead Load  
Dead load includes slab and future wearing surface, so that the total dead load on the slab is

\[ DL = (\text{Thickness of Slab})(\text{Weight of Concrete}) + \text{Future WS} = [(8 \text{ in})(1 \text{ ft/12 in})(0.15 \text{ K/ft}^3) + (0.025 \text{ K/ft}^3)](1 \text{ ft Strip}) \]

\[ \Rightarrow DL = 0.125 \text{ K/ft} \]

\[ M_{DL} = \frac{wS^2}{10} = \frac{DL \cdot S^2}{10} = \frac{(0.125 \text{ k/ft})(7.5 \text{ ft})^2}{10} \]

\[ \Rightarrow M_{DL} = 0.70 \text{ ft-kips} \]

The load factors are (see Table 3.2):

\[ DL = 1.3 \]

\[ LL = 1.3 \times 1.67 = 2.17 \]

**STEP 3:** Compute Moment Due to Live Load + Impact  
Live load is computed as per Equation 3.29

\[ M_{LL} = 0.8 \left( \frac{S + 2}{32} \right) P = 0.8 \left( \frac{7.5 \text{ ft} + 2}{32} \right) \times 16 \text{ kips} \]

\[ \Rightarrow M_{LL} = 3.80 \text{ ft-kips} \]

Impact for spans between 2 ft and 24 ft will always be 30%, so use an impact factor of 1.30 to obtain

\[ M_{LL+I} = (3.80 \text{ ft-kips})(1.30) \]

\[ \Rightarrow M_{LL+I} = 4.94 \text{ ft-kips} \]

**STEP 4:** Compute Total Factored Bending Moment  

\[ M_u = 1.3M_{DL} + 2.17M_{LL+I} = (1.30)(0.70 \text{ ft-kips}) + (2.17)(4.94 \text{ ft-kips}) \]

\[ \Rightarrow M_u = 11.63 \text{ ft-kips} \]
STEP 5: Compute Effective Depth of Slab

Slab depth = 8.0 in
Sacrificial surface = 0.5 in
Concrete cover at bottom of slab = 1.0 in
#5 reinforcing steel bar diameter = 0.625 in

The effective depth of slab (from center of bottom reinforcement to the deck top surface):
\[ d = 8.0 - 0.5 - 1.0 - 0.625/2 \]
\[ \Rightarrow d = 6.19 \text{ in} \]

\[ \phi M_n = \phi A_s f_y \left( d - \frac{a}{2} \right) \]

\[ \phi M_n = (0.9)(0.62)(60)
\left( 6.19 - \frac{0.81}{2} \right)
\left( \frac{1}{12} \right) \]

\[ \phi M_n = 16.14 \text{ K \cdot FT} > M_u = 11.63 \text{ K \cdot FT} \]

Since the reinforcement assumed is more than what is required, the designer can reduce the amount of reinforcing steel by increasing the rebar spacing to:

\[ (6.0 \text{ in}) \left( \frac{\phi \cdot M_n}{M_u} \right) = (6.0) \left( \frac{16.14}{11.63} \right) = 8.3 \text{ in} \]

STEP 6: Compute Required Main Reinforcement

First, try to use #5 @ 6"

\[ A_s = (0.31)(12/6) = 0.62 \text{ in}^2 \]

\[ a = \frac{A_s \cdot f_y}{0.85 f_c b} \]

\[ a = \frac{(0.62 \text{ in}^2)(60 \text{ ksi})}{0.85(4.5 \text{ ksi})(12 \text{ in})} = 0.81 \text{ in} \]

Now, use #5 @ 8" reinforcement

\[ A_s = 0.31 \cdot \frac{12}{8} = 0.465 \text{ in}^2 \]

\[ a = \frac{A_s \cdot f_y}{0.85 f_c b} \]

\[ a = \frac{(0.465 \text{ in}^2)(60 \text{ ksi})}{0.85(4.5 \text{ ksi})(12 \text{ in})} = 0.61 \text{ in} \]
STEP 6: Compute Required Main Reinforcement (Continued)

\[ \phi M_n = \phi A_s f_y \left( d - \frac{a}{2} \right) \]

\[ \phi M_n = (0.9)(0.465)(60) \left( 6.19 - \frac{0.61}{2} \right) \left( \frac{1}{12} \right) \]

\[ \phi M_n = 12.31 \text{ K·FT} > M_u = 11.63 \text{ K·FT} \]

Note that the same reinforcement should be used for both top and bottom of the slab.
3. Distribution Reinforcement

- Whether or not the main reinforcement is parallel or perpendicular to the direction of traffic, distribution reinforcement will be required.
- Distribution reinforcement is used to account for the lateral distribution of live loads.
- By lateral we imply a direction transverse to the main reinforcement.
- Distribution reinforcement is located in the bottom of the deck slab.
- To determine the amount of distribution steel required, the amount of main reinforcement needed is multiplied by a specified percentage.

1. Main reinforcement perpendicular

   \[
   \text{Percent of Main} = \frac{220}{\sqrt{S}} \leq 67\% 
   \]

2. Main reinforcement is parallel

   \[
   \text{Percent of Main} = \frac{100}{\sqrt{S}} \leq 50\% 
   \]
**STEP 7:** Compute Distribution Steel in Bottom of Slab

\[
D = \frac{220}{\sqrt{7.5\text{ ft}}} = \frac{220}{\sqrt{7.5}} = 80\% > 67\% \text{ so use } 67\%
\]

Distribution Steel = \( (A_y)(67\%) = (0.465 \text{ in}^2/\text{ft})(0.67) = 0.31 \text{ in}^2/\text{ft} \)

#5 Bars @ 12 in Spacing ✔
4. Minimum Slab Thickness

- In AASHTO Standard Specifications for deck slab whose main reinforcement is parallel to the direction of traffic.
  1. For slabs which are simply supported

\[ t_{\text{min}} = \frac{1.2(S + 10)}{30} \]

2. when the slab is continuous over more than two supports

\[ t_{\text{min}} = \frac{(S + 10)}{30} \geq 0.542 \]

- In AASHTO LRFD Specifications, the minimum depth of a concrete deck is **7.0 inch** (**178 mm**), in addition to surface grooving and sacrificial wearing surface.
5. Railing Loads

• The portion of slab which resists loads induced by railing posts varies depending on whether a parapet is present or not

• When parapet is not present, the effective length of slab resisting the post loads is given as

\[ E = 0.8X + 3.75 \]
5. Railing Loads

- When a parapet is provided, the effective length of slab is defined by the following:

\[ E = 0.8X + 5.0 \]

\( E \) = effective length of slab resisting railing load, ft  
\( X \) = distance from center of a post to point of analysis, ft

- Note: Railing loads are not to be applied simultaneously with wheel loads.
Concrete Slab Design using AASHTO LRFD

✓ AASHTO LRFD allows designers to use one of the following two approaches for the concrete deck slab design:

1. **Analytical Method:**
   This method is almost identical to the method used in the Standard Specifications. The design truck wheel load \( P = 16 \) kips should be to obtain live load bending moment.

   \[
   M_{LL} = \left( \frac{S + 2}{32} \right) P \quad \text{and} \quad M_{LL} = 0.8 \left( \frac{S + 2}{32} \right) P
   \]

2. **Empirical Design Method:**
   - Minimum depth of the deck should not be less than 7.0 in (178 mm)
   - The effective span length of the deck should not exceed 13.5 ft (4.1 m)
   - The ratio of effective span length to deck depth is between 6.0 and 18.0.
Concrete Slab Design using AASHTO LRFD

2 Empirical Design Method:
The slab must be:

• Minimum depth of the deck should not be less than 7.0 in (178 mm)
• The effective span length of the deck should not exceed 13.5 ft (4.1 m)
• The ratio of effective span length to deck depth is between 6.0 and 18.0
• The minimum amount of reinforcement for each bottom layer to be 0.27in²/ft (572 mm² /m)
• The minimum amount of reinforcement for each top layer to be 0.18 in²/ft (381 mm² /m)
• All reinforcement shall be straight bars except for hooks where required, and the maximum spacing is 18 in (457 mm).
7. Slab Reinforcement Details

1. Minimum cover:
   The cover requirement for slabs with an integrated wearing surface is based on epoxy-coated bars being used in the top mat.
   • Top of Slab
     With separate Wearing Surface use 1.5 in (4 cm)
     With integrated Wearing Surface 2.5 in (6.5 cm)
   • Bottom of Slab 1 in (2.5 cm)

2. Spacing between parallel:
   The clear distance $D$ between parallel bars is defined by the following criteria:
   
   $D < 24$ in (0.61 m)
   
   $D > 1.5 \times$ Nominal diameter of bars
   
   $D > 1.5 \times$ Max size of coarse aggregate
   
   $D > 1.5$ in (38 mm)
Example 1

- Design the interior stringer for the bridge cross section given
- Bridge to carry two traffic lanes.
- Bridge loading specified to be HS20-44.
- Concrete strength $f_c = 4.5$ ksi.
- Grade 60 reinforcement $f_y = 60$ ksi.
- Account for 25 psf future wearing surface.
- Assume stringers are W36x150.
- Deck has integrated wearing surface
**STEP 1:** Compute the Effective Flange Width

The effective flange width is defined as:

\[ b_{eff} = \frac{1}{4} \times \text{Span Length} = \frac{1}{4} \times (0.25)(45.00) = 11.25 \text{ ft} \]

\[ \text{Center-to-Center Between Stringers} = 8.00 \text{ ft} \]

\[ 12 \times \text{Min. Slab Thickness} = (12)(7.5 \text{ in})(1 \text{ ft/12 in}) = 7.50 \text{ ft} \]

\[ \Rightarrow b_{eff} = 7.5 \text{ ft} \]

**STEP 2:** Compute the Dead Load on Stringer

The dead load is composed of the following items:

\[ \text{DL}_{\text{slab}} = (b)(\text{slab thickness})(w_{\text{conc}}) \]
\[ = (8.0 \text{ ft})(8.0 \text{ in})(1 \text{ ft/12 in})(0.150 \text{ k/ft}^3) = 0.800 \text{ k/ft} \]

\[ \text{DL}_{\text{haunch}} = (\text{haunch width})(\text{haunch thickness})(w_{\text{conc}}) \]
\[ = (1.0 \text{ ft})(2.0 \text{ in})(1 \text{ ft/12 in})(0.150 \text{ k/ft}^3) = 0.025 \text{ k/ft} \]

\[ \text{DL}_{\text{steel}} = (\text{assumed stringer weight}) + (\text{misc. steel}) \]
\[ = (0.100 \text{ k/ft}) + (5\%)(0.100 \text{ k/ft}) = 0.105 \text{ k/ft} \]

\[ \Rightarrow \text{DL} = 0.930 \text{ k/ft} \]

**STEP 3:** Compute the Superimposed Dead Load on Stringer

Account for future wearing surface:

\[ \text{SDL}_{\text{ws}} = \frac{(\text{width of roadway})(\text{future wearing surface})}{\text{number of stringers}} \]

\[ = \frac{(44 \text{ ft})(0.025 \text{ k/ft}^2)}{6 \text{ Stringers}} = 0.183 \text{ k/ft} \]
**STEP 3:** Compute the Superimposed Dead Load (Continued):

Calculate weight of parapet by first computing the area of its cross section:

- \( A_1 = (7 \text{ in})(21 \text{ in}) = 147.00 \text{ in}^2 \)
- \( A_2 = \frac{1}{2}(2.25 \text{ in})(21 \text{ in}) = 23.63 \text{ in}^2 \)
- \( A_3 = (9.25 \text{ in})(10 \text{ in}) = 92.50 \text{ in}^2 \)
- \( A_4 = \frac{1}{2}(6 \text{ in})(10 \text{ in}) = 30.00 \text{ in}^2 \)
- \( A_5 = (15.25 \text{ in})(3 \text{ in}) = 45.75 \text{ in}^2 \)

\[ A_p = 338.88 \text{ in}^2 \]

\[ w_p = \frac{(338.88 \text{ in}^2)(1 \text{ ft}^2/144 \text{ in}^2)(0.150 \text{ k/ft}^3)}{} = 0.353 \text{ k/ft} \]

There are two parapets on the bridge which are distributed over all six stringers:

\[ \text{SDL}_p = 2 \text{ Parapets} \times \frac{w_p}{6 \text{ Stringers}} = 2 \times \frac{0.353 \text{ k/ft}}{6} = 0.118 \text{ k/ft} \]

\[ \text{SDL} = \text{SDL}_{ws} + \text{SDL}_p = 0.183 \text{ k/ft} + 0.118 \text{ k/ft} \]

\[ \Rightarrow \text{SDL} = 0.301 \text{ k/ft} \]

**STEP 4:** Compute Dead Load Moments and Shears

\[ M_{DL} = \frac{wL^2}{8} = \frac{(0.930)(45.0^2)}{8} = 235.41 \text{ k} \cdot \text{ft} \]

\[ \Rightarrow M_{DL} = 235.41 \text{ k-ft} \]

\[ V_{DL} = \frac{wL}{2} = \frac{(0.930)(45.0)}{2} = 20.93 \text{ k} \]

\[ \Rightarrow V_{DL} = 20.93 \text{ k} \]

**STEP 4:** Compute Dead Load Moments and Shears (Continued):

\[ M_{SDL} = \frac{wL^2}{8} = \frac{(0.301)(45.0)^2}{8} = 76.19 \text{ k-ft} \]

\[ \Rightarrow M_{SDL} = 76.19 \text{ k-ft} \]

\[ V_{SDL} = \frac{wL}{2} = \frac{(0.301)(45.0)}{2} = 6.77 \text{ k} \]

\[ \Rightarrow V_{SDL} = 6.77 \text{ k} \]
STEP 5: Compute Live Load Moment and Shear:

We must first compute the wheel load distribution factor and impact factor. Referring to Table 3.6, for:

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The live load distribution factor for moment, and shear when axle load is not acting at support, can be calculated:

\[ DF = \frac{S}{5.5} = \frac{8.0 \text{ ft}}{5.5} = 1.45 \]
\[ \Rightarrow DF = 1.45 \]

For the rear axle at support, the live load distribution for shear when axle is acting at support can be calculated assuming deck is simply supported by the stringers (See the sketch on Sheet 5):

\[ DF_R = \text{Left Support} \cdot DF + \text{Center Support} \cdot DF + \text{Right Support} \cdot DF \]
\[ DF_R = \frac{4.0 \text{ ft}}{8.0 \text{ ft}} + 1 + \frac{2.0 \text{ ft}}{8.0 \text{ ft}} \]
\[ \Rightarrow DF_R = 1.75 \]

Impact is computed by Equation 3.15:

\[ I = \frac{50}{L + 125} = \frac{50}{45 \text{ ft} + 125} = 0.29 \]
\[ \Rightarrow \text{Use } I = 0.29 \]

To obtain the maximum moment, we locate the HS20-44 truck (See Figure 3.32) as shown below:
STEP 5: Compute Live Load Moment and Shear (Continued):

First, solve for the reactions by summing moments about Point A:

\[ \sum M_A = 0: \]
\[
(4k \cdot 6.167 \text{ ft}) + (16k \cdot 20.167 \text{ ft}) + (16k \cdot 34.167 \text{ ft}) - (R_b \cdot 45 \text{ ft}) = 0
\]

\[ R_b = \frac{894 \text{ ft} \cdot k}{45 \text{ ft}} = 19.867 \text{ k} \quad \text{so,} \quad R_A = 36 \text{ k} - 19.867\text{ k} = 16.133 \text{ k} \]

Now, compute the maximum live load moment:

\[ M_{LL} = M_{MAX} = (R_A \cdot 20.167 \text{ ft}) - (4k \cdot 14 \text{ ft}) = 269.35 \text{ k} \cdot \text{ft} \]

The maximum shear is at support when the 16 k axle is at the support:

\[ V_{LL} = 16 + \frac{(16)(31) + (4)(17)}{45} = 16 + 12.53 = 28.53 \text{ k} \]

Check maximum lane load moment and shear:

\[ M_{LL} = \frac{PL}{4} + \frac{wL^2}{8} = \frac{(9)(45)}{4} + \frac{(0.32)(45.0^2)}{8} = 182.25 \text{ k} \cdot \text{ft} \]

\[ V_{LL} = P + \frac{wL}{2} = 13 + \frac{(0.32)(45.0)}{2} = 20.20 \text{ k} \]

\[ M_{LL} = 269.35 \text{ k} \cdot \text{ft} \]

\[ V_{LL} = 28.53 \text{ k} \]

To obtain the maximum moment, we locate the HS20-44 truck (See Figure 3.32) as shown below:
**STEP 5:** Compute Live Load Moment and Shear (Continued):
The live load and impact forces acting on an interior stringer is:

\[ M_{LL+1} = M_{LL} \cdot DF \cdot (I + 1) = (269.35)(1.45)(1 + 0.29) \]
\[ V_{LL+1} = V_{LL} \cdot DF \cdot (I + 1) = (16.0)(1.75)(1 + 0.29) + (12.53)(1.45)(1 + 0.29) \]

\[ \Rightarrow M_{LL+1} = 503.82 \text{ k-ft} \]
\[ \Rightarrow V_{LL+1} = 59.56 \text{ k} \]

**STEP 6:** Compute Factored Moment and Shear:

\[ M_u = 1.3[M_{DL} + M_{SDL} + 1.67(M_{LL} + I)] \]
\[ = 1.3[(235.41 + 76.19 + (1.67)(503.82))] \]

\[ \Rightarrow M_u = 1498.9 \text{ k-ft} \]

\[ V_u = 1.3[V_{DL} + V_{SDL} + 1.67(V_{LL} + I)] \]
\[ = 1.3[(20.93 + 6.77 + (1.67)(59.56))] \]

\[ \Rightarrow V_u = 165.3 \text{ k} \]
AASHTO Standard Specifications values for \( \gamma \) and \( \beta \) based on load factor (limit state) design method.

| GROUP | \( \gamma \) | \( \beta_D \) | \( (L+I)_a \) | \( (L+I)_e \) | CF | E | B | SF | W | WL | LF | R+S+T | EQ | ICE | % |
|-------|-------------|------------|------------|------------|---|---|---|---|---|---|---|---|---|---|---|---|
| I     | 1.3         | \( 1.67^* \) | 0          | 1.0        | \( \beta_E \) | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IA    | 1.3         | \( 2.20 \)  | 0          | 0          | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IB    | 1.3         | \( 0 \)     | 1          | 1.0        | \( \beta_E \) | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| II    | 1.3         | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| III   | 1.3         | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 0.3 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| IV    | 1.3         | \( 0 \)     | 1          | 1          | \( \beta_E \) | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| V     | 1.25        | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| VI    | 1.25        | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 0.3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| VII   | 1.3         | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| VIII  | 1.3         | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| IX    | 1.20        | \( 0 \)     | 0          | 0          | \( \beta_E \) | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| X     | 1.30        | \( 1.67 \)  | 0          | 0          | \( \beta_E \) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0