**Bridge Data**

<table>
<thead>
<tr>
<th>Category</th>
<th>Details aspect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Span</td>
<td>80 ft. (Total Length = 81 ft.)</td>
</tr>
<tr>
<td>Year Built</td>
<td>1985</td>
</tr>
<tr>
<td>Materials</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>$f'_c = 4.0$ ksi (Deck)</td>
</tr>
<tr>
<td></td>
<td>$f'_c = 5$ ksi (P/S Beam)</td>
</tr>
<tr>
<td></td>
<td>$f'_c = 4$ ksi (P/S Beam at transfer)</td>
</tr>
<tr>
<td>Prestressing Steel</td>
<td>1/2 in. diameter, 270 ksi, Low-Relaxation Strands</td>
</tr>
<tr>
<td></td>
<td>$A_{ps} = 0.153$ in$^2$ per strand</td>
</tr>
<tr>
<td>Stirrups</td>
<td>#4 at 9 in. over end 20 ft.</td>
</tr>
<tr>
<td></td>
<td>#3 at 12 in. over center 40 ft.</td>
</tr>
<tr>
<td>Compression Steel</td>
<td>six #6 Grade 60</td>
</tr>
<tr>
<td>Condition</td>
<td>No Deterioration, NBI Item 59 Code = 6</td>
</tr>
<tr>
<td>Riding Surface</td>
<td>Minor surface deviations (Field verified and documented)</td>
</tr>
<tr>
<td>ADTT (one direction)</td>
<td>5000</td>
</tr>
</tbody>
</table>
PS-Girder Bridge LRFR Rating

SINGLE SPAN P/S I-GIRDER BRIDGE

- 2 TRAFFIC LANES
- 2.5m concrete
- 0.8m slab
- 0.1m haunch
- 2.6m piers
- 3.6m of land at 0.6m=2.6m

Details:
- 6 #6 rebars
- 44 at 6" over and 20'
- 32 at 2" over center 20'
- 32 strands
- 1/2" diameter
- 10 strands debonded up to 12
- C.G. of 32 strands
- 3.75"
- 20" span
- 8 at 2"
Summary of Section Properties
Type 4 Girder

\[ h = 54 \text{ in.} \]
\[ A = 789 \text{ in.}^2 \]
\[ I = 260730 \text{ in.}^4 \]
\[ Y_h = 24.73 \text{ in.} \]
\[ S_b = 10543 \text{ in.}^3 \]
\[ S_l = 8908 \text{ in.}^3 \]

2) Composite Section
Effective Flange Width \( b_e = 102 \text{ in.} \)

Modular Ratio \( n = \frac{E_{\text{deck}}}{E_{\text{beam}}} = \frac{3.64 \times 10^3}{4.07 \times 10^3} = 0.89 \)

Transformed Width, \( b_{\text{trans}} = 102 \text{ in.} \times 0.89 = 90.8 \text{ in.} \)

Components and Attachments \( DC \)
a) Non-Composite Dead Loads \( DC_1 \)
Girder Self Weight: \( = 0.822 \text{ kip/ft.} \)
Diaphragms: \( = 0.150 \text{ kip/ft.} \)
Slab + haunch:
\[
\frac{8.5 \text{ in.} \times 8.5 \text{ ft.} + 1 \text{ in.} \times 20 \text{ in.}}{12 \text{ in./ft.} \times 144 \text{ in.}^2 / \text{ft.}^2} \times 0.15 \text{ kcf} = 0.925 \text{ kip/ft.}
\]
Total per Girder \( DC_1 \)
\[
V_{DC_1} = 1.90 \text{ kip/ft.} \times \frac{80 \text{ ft.}}{2} = 76 \text{ kip}
\]
\[
M_{DC_1} = \frac{1}{8} \times 1.90 \text{ kip/ft.} \times (80 \text{ ft.})^2 = 1520 \text{ kip-ft.}
\]
a) Distribution Factor for Moment $g_m$
One Lane Loaded:

$$g_{m1} = 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left( \frac{K_g}{12.0Lt_s^3} \right)^{0.1}$$

$$= 0.06 + \left( \frac{8.5}{14} \right)^{0.4} \left( \frac{8.5}{80} \right)^{0.3} (2.28)^{0.1}$$

$$= 0.514$$

Two or More Lanes Loaded:

$$g_{m2} = 0.075 + \left( \frac{S}{9.5} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \left( \frac{K_g}{12.0Lt_s^3} \right)^{0.1}$$

$$= 0.075 + \left( \frac{8.5}{9.5} \right)^{0.6} \left( \frac{8.5}{80} \right)^{0.2} (2.28)^{0.1}$$

$$= 0.724 > 0.514$$

use $g_m = 0.724$

b) Distribution Factor for Shear $g_v$
One Lane Loaded:

$$g_{v1} = 0.36 + \frac{S}{25}$$

$$= 0.36 + \frac{8.5}{25}$$

$$= 0.70$$

Two or More Lanes Loaded:

$$g_{v2} = 0.2 + \left( \frac{S}{12} \right) - \left( \frac{S}{35} \right)^2$$

$$= 0.2 + \left( \frac{8.5}{12} \right) - \left( \frac{8.5}{35} \right)^2$$

$$= 0.849 > 0.70$$

use $g_v = 0.849$
Compute Maximum Live Load Effects

a) Maximum Design Live Load (HL-93)

\[ IM = 33\% \]

\[ M_{LL+IM} = 512 + 1160 \times 1.33 \]

\[ = 2054.8 \text{ kip-ft.} \]

Distributed Live Load Moment at Midspan

\[ M_{LL+IM} = 2054.8 \times g_m \]

\[ = 2054.8 \times 0.724 \]

\[ = 1487.7 \text{ kip-ft.} \]

Compute Nominal Flexural Resistance at Midspan

\[ f_{pu} = f_{pu} \left( 1 - k \frac{c}{d_p} \right) \]

\[ k = 0.28 \text{ for low-relaxation strands} \]

\[ f_{pu} = 270 \text{ ksi} \]

\[ f_{pu} = 270 \left( 1 - 0.28 \times \frac{4.39}{59.75} \right) \]

\[ = 264.4 \text{ ksi} \]

Nominal Flexural Resistance (Midspan):

\[ M_a = A_p f_{pu} \left( d_p \frac{a}{2} \right) \]

\[ = 4.896 \times 264.4 \left( 59.75 - \frac{3.73}{2} \right) \frac{1}{12} \]

\[ = 6244.4 \text{ kip-ft.} \]
Maximum Reinforcement

φ factor of compression controlled sections shall be reduced in accordance with LRFD Article 5.5.4.2.1.

The net tensile strain, $\varepsilon_t$, is the tensile strain at nominal strength and determined by strain compatibility.

Given an allowable concrete strain of 0.003 and depth to neutral axis $c = 4.39$ in. $d_p = 59.75$ in.

$$\frac{\varepsilon_t}{c} = \frac{\varepsilon_i}{d - c}$$

$$\frac{0.003}{4.39} = \frac{\varepsilon_i}{59.75 - 4.39}$$

$$\varepsilon_i = 0.0378$$

For $\varepsilon_i = 0.0378 > 0.005$, the section is tension controlled and Resistance Factor $\phi$ shall be taken as 1.0.

Minimum Reinforcement

Amount of reinforcement must be sufficient to develop $M_r$ equal to the lesser of:

1.2 $M_{cr}$ or 1.33 $M_u$

$M_u = \phi M_u = (1.0) (6244.4) = 6244.4 \text{ kip-ft.}$

1) 1.33 $M_u = 1.33 [1.75 (1487.7) + 1.25 (1520 + 200) + 1.5 (162)]$

$$= 6645.3 \text{ kip-ft.} > 6244.4 \text{ kip-ft.}$$

2) $M_{cr} = S_t \left( f_t + f_{cr} \right) - M_{cr} \left( \frac{S}{S_c} - 1 \right) \geq S_t f_t$

$$1.2 \times M_{cr} = 1.2 \times 3492.4 \text{ kip-ft} = 4190.9 \text{ kip-ft.}$$

1.33 $M_u = 6645.3 \text{ kip-ft.} \text{ (previously calculated)}$

1.2 $M_{cr} < 1.33 \times M_u \therefore \text{ resistance, } 1.2 \times M_{cr} \text{ governs}$

$M_r = 6244.4 \text{ kip-ft.} \text{ (previously calculated)}$

$M_r = 6244.4 \text{ kip-ft.} > 4190.9 \text{ kip-ft. OK}$

The minimum reinforcement check is satisfied.
Distance from centerline of bearing to critical shear section:
= 58.4 in. + 6 in.
= 64.4 in.
= 5.37 ft.

**Maximum Shear at Critical Section Near Supports**

Total Shear \( V_{LANE} + V_{TRUCK} \times 1.33 \) = 100.5 kips

Distributed \( V_{L+D} = 100.5 \text{ kips} \times 0.849 \) = 85.3 kips

Dead Load Shears:

\( DC_1 = 1.90 \text{ kip/ft.} \) and \( DC_2 = 0.25 \text{ kip/ft.} \)

\( DW = 0.203 \text{ kip/ft.} \)

\( V_{DC} = (1.90 \text{ klf} + 0.25 \text{ klf})(0.5 \times 80 \text{ ft.} - 5.37 \text{ ft.}) = 74.5 \text{ kips} \)

\( V_{DW} = (0.203 \text{ klf})(0.5 \times 80 \text{ ft.} - 5.37 \text{ ft.}) = 7.03 \text{ kips} \)

**Compute Nominal Shear Resistance**

The nominal shear resistance \( V_n \), shall be the lesser of:

\[ V_n = V_v + V_r + V_p \]

\[ V_r = 0.25 f'_c b_c d_v + V_p \]

\[ V_p = 0.0 \] as straight tendons are provided

**MCFT (Sectional Design Model)**

Shear stress on the concrete

\[ \psi = \frac{V_v - qV_p}{\phi b_c d_v} \]

\[ = \frac{252.8}{(0.9)(8)(58.4)} = 0.601 \text{ ksi} \]

\[ \frac{V}{f'_c} = \frac{0.601}{5.0} = 0.12 < 0.25 \]
At First Critical Section for Shear (64.4 in. from c.l. of bearing)

\[ g_m \times M_{LL, M} = 0.724 \times 539.3 = 390.5 \text{kip-ft.} \]

Dead Load Moments at First Critical Section for Shear:

<table>
<thead>
<tr>
<th>Load</th>
<th>Load Factor ( \gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>1.25</td>
</tr>
<tr>
<td>DW</td>
<td>1.50</td>
</tr>
<tr>
<td>LL</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Factored Moment:

\[ M_u = (1.75) (390.5) + (1.25) (430.8) + (1.50) (40.7) \]

= 1282.9 kip-ft.

Transfer Length 60 strand diameters = 30 in. < 64.4 in.
As the section is outside the transfer length, the full value of \( f_{pu} \) is used in resistance.

\[ \frac{V}{f'_c} = 0.12 \quad (\leq 0.125, \text{row 3 of LRFD Table 5.8.3.4.2-1}) \]

Assume \( \varepsilon_x \leq -0.10 \times 10^{-3} \) \( (\varepsilon_x \times 1000 \leq -0.10) \)

From LRFD Table 5.8.3.4.2-1: (row 3, column 2) \( \theta = 21.9^\circ \) \( \beta = 2.99 \)

If \( \varepsilon_x \) is negative, it must be recalculated including concrete stiffness.

\[ A_c = \text{Area below } h/2 \]

\[ = (8)(26) + 1/2 (8 + 26)(9) + (10)(8) = 441 \text{in.}^2 = 441 \text{in} \]

\[ \varepsilon_c = \frac{M_{ud} + 0.5V_u - V'_p \cot \theta - A_{pu} f_{pu}}{d_c} \]

\[ = \frac{12 \times 1282.9 + 0.5(252.8)(\cot 21.9^\circ) - (3.366)(189)}{58.4} \]

\[ = -0.016 \times 10^{-3} > \text{assumed } \varepsilon_x \leq -0.10 \times 10^{-3} \]
Assume $\epsilon_s \leq 0$

From LRFD Table 5.8.3.4.2-1: (row 3, column 4)  $\theta=23.7^\circ$  $\beta=2.87$

\[ V_s = 0.0316 \beta \sqrt{f_y b d_y} \]
\[ = (0.0316)(2.87)\sqrt{5}(8)(58.4) \]
\[ = 94.75 \text{ kips} \]

\[ V_s = \frac{A_f f_y d_y \cot \theta}{s} \]
\[ = \frac{(0.39)(60)(58.4)(\cot 23.7^\circ)}{9} \]
\[ = 345.9 \text{ kips} \]

\[ V_a = V_s + V_y \]
\[ = 94.75 + 345.9 = 440.7 \text{ kips} < 584 \text{ Kips} \]

\[ \phi V_a = 0.9 \times 440.7 = 396.6 \text{ kips} \]

---

### Summary of Moments and Shears

<table>
<thead>
<tr>
<th>location</th>
<th>support</th>
<th>critical shear change</th>
<th>stirrup change</th>
<th>midspan</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x/L$</td>
<td>0.0</td>
<td>0.067</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>X (ft.)</td>
<td>0.0</td>
<td>5.37</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>$V_{DC1}$ (kips)</td>
<td>76</td>
<td>65.8</td>
<td>38</td>
<td>-</td>
</tr>
<tr>
<td>$V_{DC2}$ (kips)</td>
<td>10</td>
<td>8.7</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>$V_{DW}$ (kips)</td>
<td>8.12</td>
<td>7.03</td>
<td>4.1</td>
<td>-</td>
</tr>
<tr>
<td>$g_mV_{LL+IM}$ (kips)</td>
<td>-</td>
<td>85.3</td>
<td>63.7</td>
<td>-</td>
</tr>
<tr>
<td>$V_a$ (kips) simplified</td>
<td>-</td>
<td>221.7</td>
<td>129.1</td>
<td>-</td>
</tr>
<tr>
<td>$V_a$ (kips) MCFT</td>
<td>-</td>
<td>440.7</td>
<td>227</td>
<td>-</td>
</tr>
<tr>
<td>$M_{DC1}$ (kip-ft.)</td>
<td>-</td>
<td>380.7</td>
<td>1140</td>
<td>1520</td>
</tr>
<tr>
<td>$M_{DC2}$ (kip-ft.)</td>
<td>-</td>
<td>50.1</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>$M_{DW}$ (kip-ft.)</td>
<td>-</td>
<td>40.7</td>
<td>121.8</td>
<td>162</td>
</tr>
<tr>
<td>$g_mM_{LL+IM}$ (kip-ft.)</td>
<td>-</td>
<td>390.5</td>
<td>1087</td>
<td>1487.7</td>
</tr>
<tr>
<td>$M_a$ (kip-ft.)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6244.4</td>
</tr>
</tbody>
</table>
General Load Rating Equation

\[ RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_{P})(P)}{(\gamma_{L})(LL + IM)} \]

Evaluation Factors (for Strength Limit State)

a) Resistance Factor \( \phi \)
   \[ \phi = 1.0 \text{ for flexure (tension controlled section)} \]
   \[ \phi = 0.9 \text{ for shear} \]

b) Condition Factor \( \phi_c \)
   \[ \phi_c = 1.0 \text{ No member deterioration, NBI Item 59 Code = 6} \]

c) System Factor \( \phi_s \)
   \[ \phi_s = 1.0 \text{ 4-girder bridge with spacing > 4 ft.} \]

Design Load Rating HL-93

A) Strength I Limit State
   a) Inventory Level

<table>
<thead>
<tr>
<th>LOAD</th>
<th>LOAD FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>1.25</td>
</tr>
<tr>
<td>DW</td>
<td>1.50</td>
</tr>
<tr>
<td>LL</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Overlay thickness was not field measured.

Flexure at Midspan

\[ RF = \frac{(1.0)(1.0)(6244.4) - [(1.25)(1520 + 200) + (1.5)(162)]}{(1.75)(1487.7)} \]
\[ = 1.48 \]

Shear at Critical Section

\[ RF = \frac{(1.0)(1.0)(440.7) - [(1.25)(65.8 + 8.7) + (1.50)(7.03)]}{(1.75)(85.3)} \]
\[ = 1.96 \]
B) Service III Limit State (Inventory Level)

$$RF = \frac{f_R - (\gamma_D)(f_{fb})}{(\gamma_L)(f_{LL+IM})}$$

Flexural Resistance $f_R = f_{pb} + $ Allowable tensile stress

$f_{pb} = \text{Compressive stress due to effective prestress}$

$= 2.548 \text{ Ksi}$

Allowable Tensile Stress $= 0.19 \sqrt{f_c'}$

$= 0.19 \times 5$

$= 0.425 \text{ ksi}$

$f_R = 2.548 + 0.425$

$= 2.973 \text{ ksi}$

Determine Dead Load Stresses At Midspan:

$M_{DC1} = 1520 \text{ kip-ft.}$ and $M_{DC2} = 200 \text{ kip-ft.}$

$M_{DW} = 162 \text{ kip-ft}$

$S_{h(ce)} = 10542 \text{ in}^3, S_{h(comp)} = 17471 \text{ in}^3$

$f_{DC} = \frac{1520 \times 12}{10542} + \frac{200 \times 12}{17471} = 1.87 \text{ ksi}$

$f_{DW} = \frac{162 \times 12}{17471} = 0.11 \text{ ksi}$

Total $f_D = 1.98 \text{ ksi}$

Live Load Stress At Midspan:

$M_{LL+IM} = 1487.7 \text{ kip-ft}$

$S_{h(comp)} = 17471 \text{ in}^3$

$f_{LL+IM} = \frac{1487.7 \times 12}{17471} = 1.02 \text{ ksi}$

$$RF = \frac{2.973 - (1.0)(1.98)}{(0.8)(1.02)}$$

$= 1.22$
Legal Load Rating

Inventory Design Load Rating RF > 1.0, therefore the legal load ratings do not need to be performed and no posting is required.

Permit Load Rating

Permit Type: Special, Single-Trip, Mix with traffic, No escort
Permit Weight: 220 kips
ADTT (one direction): 5000
Undistributed Maximum $M_{LL} = 2950.5$ kip-ft.
Undistributed Maximum $V_{LL} = 157.9$ kips

Use One-Lane Distribution Factor and divide out the 1.2 multiple presence factor.

$g_{m1} = 0.514 \times \frac{1}{1.2} = 0.428$
$g_{v1} = 0.70 \times \frac{1}{1.2} = 0.583$

$IM = 20\%$ (Minor Surface Deviations)

Maximum Live Load Effect:

$M_{LL-IM} = (2950.5)(0.428)(1.20) = 1515.4$ kip-ft. at Midspan
$V_{LL-IM} = (157.9)(0.583)(1.20) = 110.5$ kips

a) Flexure:

$RF = \frac{(1.0)(1.00)(1.0)(6244.4) - [(1.25)(1520+200)+(1.5)(162)]}{(1.5)(1515.4)}$

$= 1.69 > 1.0$  OK

b) Shear (Using MCFT):

$RF = \frac{(1.0)(1.0)(0.9)(440.7) - [(1.25)(72.0)+(1.50)(6.7)]}{(1.5)(110.5)}$

$= 1.79 > 1.0$  OK
### Summary of Rating Factors

<table>
<thead>
<tr>
<th>Limit State</th>
<th>Design Load Rating (HL-93)</th>
<th>Permit Load Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inventory</td>
<td>Operating</td>
</tr>
<tr>
<td><strong>Strength I</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexure (@ midspan)</td>
<td>1.48</td>
<td>1.92</td>
</tr>
<tr>
<td>Shear (@ 64 in)</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>Shear (@ 20 ft)</td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td><strong>Strength II</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexure (@ midspan)</td>
<td></td>
<td>1.69</td>
</tr>
<tr>
<td>Shear</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Service III</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexure (@ midspan)</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td><strong>Service I</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>