Appendix XXII
Detailing Requirements of the Prestressed Concrete Girder Bridge

West Bound Bridge

1.a. Transverse Reinforcement in potential plastic hinge zones

\[ A_{bh} = \text{cross sectional area of the spiral reinforcement} = 0.11 \text{ in}^2 \quad (#3 \text{ rebar}) \]
\[ s = \text{center-to-center spacing of the spiral reinforcement} = 10.5 \text{ in.} \]
\[ D'' = \text{the out-to-out diameter of the spiral reinforcement in the circular section} \]
\[ = 36.625 \text{ in.} \]

\[ \rho_{v, provided} = \frac{2A_{bh}}{sD''} = \frac{2(0.11\text{in}^2)\left(\frac{25.4\text{mm}}{1\text{in.}}\right)^2}{(10.5\text{in.})(36.625\text{in.})} = 0.000572 \quad \text{[MCEER/ATC, 2002]} \]

\[ K_{\text{shape}} = \text{factor that depends on the shape of the section} = 0.32 \text{ for a circular section} \]
\[ \Lambda = \text{fixity factor} = 2 \text{ for fixed-fixed} \]
\[ \rho_t = \text{ratio of longitudinal reinforcement} \]
\[ = \frac{A_t}{A_g} \]
\[ = \frac{(20)(1.00\text{in}^2)}{1385.4\text{in}^2} \]
\[ = 0.0144 \]

\[ \phi = \text{resistance factor for seismic shear} = 0.85 \]
\[ f_{su} = \text{the ultimate tensile stress of the longitudinal reinforcement. If } f_{su} \text{ is not available from coupon tests, then it shall be assumed that } f_{su} = 1.5 f_y. \]
\[ A_g = \text{gross area of the column} = 0.25\pi(42\text{in.})^2 = 1385.4\text{in}^2. \]
\( A_{cc} = \text{area of column core concrete, measured to the centerline of the perimeter hoop} \)
\( \text{or spiral} = 0.25\pi(37\text{in.} - 0.375\text{in.})^2 = 1,053.5\text{in.}^2 \)

\( D' = \text{diameter of the column concrete core (center-to-center of the rebars)} \)
\( \begin{align*}
&= 42\text{ in.} - 2(3.5\text{in.}) \\
&= 35\text{ in.}
\end{align*} \)

\( L = \text{column length} = 221.77\text{ in.} \)

\[ \tan \alpha = \frac{D'}{L} = \frac{35\text{in.}}{221.77\text{in.}} = 0.158 \]

\( \rho_v = \text{provided} = 0.000572 \)

\( A_v = 0.8A_g \text{ for a circular column} \)

\[ \tan \theta = \left( \frac{1.6 \rho_v A_v}{A_{cc}} \right)^{0.25} = \left( \frac{1.6 \times 0.000572}{0.8} \right)^{0.25} = 0.399 \]

\[ \tan \theta > \tan \alpha \rightarrow O.K. \]

\[ \rho_v, \text{required} = K_{\text{shape}} \rho_v \frac{f_{su}}{\phi f_{yh}} A_{cc} \tan \alpha \tan \theta \]

\[ = (0.32)(2) \left( \frac{0.0144}{0.85} \right)(1.5) \left( \frac{1,385.4\text{in.}^2}{1053.5\text{in.}^2} \right) \left( \frac{35\text{in.}}{221.77\text{in.}} \right)(0.399) \]  
\[ = 0.00135 \]

\( \rho_v \text{ provided} < \rho_v \text{ required} \text{ (Not Good)} \)

1.b. Transverse Reinforcement outside the Plastic Hinge Zones

\( \rho_v^* = \text{transverse reinforcement ratio outside the plastic hinge zone} \)

\( \rho_v^* \text{ provided} = 0.000572 \)

\( \rho_v = \text{the steel provided in the potential plastic hinge zone} = \rho_v^* \text{ provided} = 0.000572 \)

\[ \rho_v^* \text{ required} = \rho_v - 0.17 \frac{f_c'}{f_{yh}} = 0.000572 - 0.17 \frac{\sqrt{20.685}}{275.8} = -0.00223 \]

\( \rho_v^* \text{ provided} > \rho_v^* \text{ required} \text{ (Good)} \)

[MCEER/ATC, 2002]
2.a. Transverse Reinforcement in potential plastic hinge zones using the explicit shear detailing approach.

\[ \phi V_s \geq V_u - \phi(V_p + V_c) \]

\[ V_p = \frac{A}{2} P_e \tan \alpha \]

\[ = \frac{2}{2} (376.95k) \left( \frac{35 \text{in.}}{221.77 \text{in.}} \right) \]

\[ = 59.5k \]

Inside the plastic hinge zone:

\[ V_c = 0.05 \sqrt{f_{c}^{*}A_v} \]

\[ = 0.05 \sqrt{20.685(0.8)(1385.4 \text{in}^2)} \left( \frac{25.4 \text{mm}}{\text{lin.}} \right)^2 \]

\[ = 162,604N \]

\[ = 36.6k \]

\[ A_{sh} = 0.11 \text{in}^2 \]

\[ S = 10.5 \text{in.} \]

\[ f_{sh} = 40 \text{ksi} \]

\[ D'' = 36.625 \text{in.} \]

\[ \tan \theta = \left( \frac{1.6(0.000572)(0.8)}{2(0.0144)} \right)^{0.25} = 0.399 \]

\[ \tan \alpha = \frac{35 \text{in.}}{221.77 \text{in.}} = 0.158 \]

\[ \tan \theta > \tan \alpha \]

\[ \theta = 21.767^\circ < 25^\circ \rightarrow \theta = 25^\circ \]

\[ V_s = \frac{\pi}{2} \frac{A_{hh}}{s} f_{sh} D'' \cot \theta \]

\[ = \frac{\pi}{2} \left( \frac{0.11 \text{in}^2}{10.5 \text{in.}} \right)(40 \text{ksi})(36.625 \text{in.}) \left( \frac{1}{\tan 25^\circ} \right) \]

\[ = 51.7k \]
Thus the transverse (shear) reinforcement is adequate (Good).

2.b. Transverse Reinforcement outside the plastic hinge zones using the explicit shear detailing approach.

\[ V_c = 0.17 \sqrt{f_c \cdot A_v} \]
\[ = 124.3k \]
\[ V_u - \phi (V_p + V_c) = 2.728k - 0.85(59.5k + 124.3k) = -153.5k \]
\[ \phi V_s > V_u - \phi (V_p + V_c) \]

[MCEER/ATC, 2002]

Thus the transverse (shear) reinforcement is adequate (Good).

3. Transverse Reinforcement for Confinement at Plastic Hinges

\( \rho_s = \) transverse reinforcement for confinement at plastic hinges
\( U_{st} = \) strain energy capacity (modulus of toughness) of the transverse reinforcement
\[ = 110 \text{ MPa} \]
\[ = 110 \text{ N/mm}^2 \]
\( P_e = \) factored axial load (N) including seismic effects
\[ = 376.95 \text{ kips (from Appendix XIX)} \]
4. Spiral Spacing for Longitudinal Bar Restraint at Plastic Hinges

\[ d_b = \text{diameter of longitudinal reinforcing bars} \]

Required Spacing \( s = 6d_b = 6(1.128 \text{ in.}) = 6.768 \text{ in.} \)

Provided Spacing \( s = 10.5 \text{ in.} \)

**Provided Spacing > Required Spacing (Not Good)**

[MCEER/ATC, 2002]

\[ \rho_s \text{ provided} < \rho_s \text{ required} (\text{Not Good}) \]

5. Transverse Spiral Reinforcement at the Moment Resisting Connection Between Members (Column/Beam and Column/Footing Joints)

\[ \rho_s \text{ provided} = 0.00114 \text{ (from 2.a.)} \]

\[ \tan \alpha = \frac{D}{H_c} \]

\( D = \text{diameter of the column framing into the joint} = 42 \text{ in.} \)

\( H_c = \text{the height of the cap beam / joint} = 48 \text{ in.} \)

\[ \rho_s \text{ required} = \text{transverse spiral reinforcement at the moment resisting connection between members (column/beam and column/footing joints)} \]

= the maximum of \( \rho_s \text{ required} \) obtained in 2.a. (\( \rho_s \text{ required} = 0.00297 \)) and the following formula:

\[
\rho_s, \text{provided} = \frac{4A_{ph}}{D^ns} = 2(0.000572) = 0.00114
\]

\[
\rho_s, \text{required} = 0.008 \frac{f_c}{U_{sf}} \left[ 12 \left( \frac{P_c}{f_c} + \rho_r \frac{f_y}{f_c} \right)^2 \left( \frac{A_g}{A_{cc}} \right)^2 - 1 \right]
\]

\[
= 0.008 \frac{20.685}{110} \left[ 12 \left( \frac{376.95}{(3)(1385.4)} + 0.0144 \frac{60}{3} \right)^2 \left( \frac{1385.4}{1053.5} \right)^2 - 1 \right]
\]

\[
= 0.00297
\]

[MCEER/ATC, 2002]
\[ \rho_{s, \text{required}} = 0.76 \frac{\rho_s}{\phi} \frac{f_{su}}{f_{y\rho}} \frac{A_{se}}{A_{cc}} \tan^2 \alpha \]

\[ = 0.76 \left( \frac{0.01444}{0.85} \right) (1.5) \left( \frac{1385.4 \text{in.}^2}{1053.5 \text{in.}^2} \right) \left( \frac{42 \text{in.}}{48 \text{in.}} \right)^2 \]

\[ = 0.01944 \]

Thus \( \rho_s \) required obtained using the above formula (\( \rho_s \) required = 0.01944) controls.

\( \rho_s \) provided = 0.00114 < \( \rho_s \) required = 0.01944 (Not Good).

[MCEER/ATC, 2002]

6. Minimum Required Horizontal Reinforcement

\( \rho_s = \) the volumetric ratio of transverse reinforcement in the form of spirals or circular hoops to be continued into the cap or footing to provide continuity of reinforcement at the intersection between the columns and pier cap beam

\( \rho_s, \text{provided} = 0.00114 \) (from 2.a)

\( \rho_s, \text{required} = \frac{0.29 \sqrt{f_{y\rho}}}{f_{y\rho}} = \frac{0.29 \sqrt{20.685}}{275.8} = 0.00478 \)

\( \rho_s \) provided = 0.00114 < \( \rho_s \) required = 0.00478 (Not Good).

[MCEER/ATC, 2002]

7. Stirrups in the Pier Cap Beam

Required stirrups \( A_{Js} = 0.16 A_{st} \), located within a distance 0.5D from the column face, where :

\( A_{Js} = \) total provided stirrups cross sectional area in the pier cap beam
\( A_{st} = \) total area of longitudinal steel in the column
\( D = \) diameter of the column.

0.5 D = 0.5 (42 in.) = 21 in.
0.16A_{st} = 0.16(20)(1.00in.^2) = 3.2in.^2

For the left and right columns, there are 24-#5 stirrups within 0.5D of the column. Therefore,
\[ A_{jv} = (24)(0.31in.^2) = 7.44in.^2 \]

For the center column, there are 16-#5 stirrups within 0.5D of the column. Therefore,
\[ A_{jv} = (16)(0.31in.^2) = 4.96in.^2 \]

[MCEER/ATC, 2002]

**Provided stirrups A_{jv} > Required stirrups = 0.16 A_{st} (Good)**

8. Lap splices are used at the bottom of the column, as shown in Figure XXII-1. That is not permitted (Not Good). [MCEER/ATC, 2002]

![Figure XXII-1](image)

Figure XXII-1. Lap splices that are used at the bottom of the columns of the West Bound Bridge [Brown, 1993].

9. Column Joint Spiral Reinforcement to be Carried into the Pier Cap Beam

\[ \rho_s = \text{the volumetric ratio of column joint hoop or spiral reinforcement to be carried into the cap or footing} \]

\[ \rho_{s,\text{required}} = \frac{0.4A_{st}}{l_{ac}^2} = \frac{0.4(20in.^2)}{(37in.)^2} = 0.00584 \]
\( \rho_s \) provided = 0, because the column spiral reinforcement is not continued into the pier cap beam.

\( \rho_s \) provided = 0 < \( \rho_s \) required = 0.00584 (Not Good).

[MCEER/ATC, 2002]

**East Bound Bridge**

1.a. Transverse Reinforcement in potential plastic hinge zones

\( A_{bh} \) = cross sectional area of the spiral reinforcement = 0.11 in\(^2\) (#3 rebar)

\( s \) = center-to-center spacing of the spiral reinforcement = 10.5 in.

\( D^* \) = the out-to-out diameter of the spiral reinforcement in the circular section = 36.625 in.

\[
\rho_{s,\text{provided}} = \frac{2A_{bh}}{sD^*} = \frac{2(0.11in^2)\left(\frac{25.4mm}{1in.}\right)^2}{(10.5in.)(36.625in.)} = 0.000572 \quad \text{[MCEER/ATC, 2002]}
\]

\( K_{\text{shape}} \) = factor that depends on the shape of the section = 0.32 for a circular section

\( \Lambda \) = fixity factor = 2 for fixed-fixed

\( \rho_l \) = ratio of longitudinal reinforcement

\[
= \frac{A_u}{A_g} = \frac{(22)(1.00in^2)}{1385.4in^2} = 0.0159
\]

\( \phi \) = resistance factor for seismic shear = 0.85

\( f_{su} \) = the ultimate tensile stress of the longitudinal reinforcement. If \( f_{su} \) is not available from coupon tests, then it shall be assumed that \( f_{su} = 1.5 f_y \).

\( A_g \) = gross area of the column = 0.25\( \pi (42in.)^2 \) = 1,385.4in\(^2\)
\( A_{cc} = \text{area of column core concrete, measured to the centerline of the perimeter hoop or spiral} = 0.25\pi(37\text{ in.} - 0.375\text{ in.})^2 = 1,053.5 \text{ in.}^2 \)

\( D' = \text{diameter of the column concrete core (center-to-center of the rebars)} = 42 \text{ in.} - 2(3.5 \text{ in.}) = 35 \text{ in.} \)

\( L = \text{column length} = 207.40 \text{ in.} \)

\[
\tan \alpha = \frac{D'}{L} = \frac{35\text{ in.}}{207.40 \text{ in.}} = 0.16876
\]

\( \rho_v = \text{provided} \rho_v = 0.000572 \)

\( A_v = 0.8A_g \text{ for a circular column} \)

\[
\tan \theta = \left( \frac{1.6 \rho_v A_v}{\Lambda \rho_i A_g} \right)^{0.25} = \left( \frac{1.6 \cdot 0.000572}{0.0159 \cdot 0.8} \right)^{0.25} = 0.390
\]

\( \tan \theta > \tan \alpha \rightarrow O.K. \)

\( \rho_v,\text{required} = K_{\text{shape}} \frac{\rho_i f_{su}}{f_{yh} A_{cc}} \tan \alpha \tan \theta \)

\[
= (0.32)(2) \left( \frac{0.0159}{0.85} \right)(1.5) \left( \frac{1,385.4 \text{ in.}^2}{1053.5 \text{ in.}^2} \right) \left( \frac{35 \text{ in.}}{207.40 \text{ in.}} \right)(0.390) \quad \text{[MCEER/ATC, 2002]}
\]

\[
= 0.00155
\]

\( \rho_v \text{ provided} < \rho_v \text{ required} \text{ (Not Good)} \)

1.b. Transverse Reinforcement outside the Plastic Hinge Zones

\( \rho_v^* = \text{transverse reinforcement ratio outside the plastic hinge zone} \)

\( \rho_v^* \text{ provided} = 0.000572 \)

\( \rho_v = \text{the steel provided in the potential plastic hinge zone} = \rho_v^* \text{ provided} = 0.000572 \)

\[
\rho_v^*,\text{required} = \rho_v - 0.17 \frac{f_c^*}{f_{yh}} = 0.000572 - 0.17 \frac{\sqrt{20.685}}{275.8} = -0.00223
\]

\( \rho_v^*,\text{provided} > \rho_v^*,\text{required} \text{ (Good)} \)

[\text{MCEER/ATC, 2002}]
2.a. Transverse Reinforcement in potential plastic hinge zones using the implicit shear detailing approach.

\[ \phi V_s \geq V_u - \phi (V_p + V_c) \]

\[ V_p = \frac{A}{2} P \tan \alpha \]

\[ = \frac{2}{323.77k} \left( - \frac{35\text{in.}}{207.40\text{in.}} \right) \]

\[ = 54.6k \]

Inside the plastic hinge zone:

\[ V_c = 0.05 \sqrt{f_y A_v} \]

\[ = 0.05 \sqrt{20.685(0.8)(1385.4\text{in}^2) \left( \frac{25.4\text{mm}}{\text{lin.}} \right)^2} \]

\[ = 162,604 N \]

\[ = 36.6k \]
\[ A_{th} = 0.11\text{in}^2 \]
\[ S = 10.5\text{in.} \]
\[ f_{yh} = 40\text{ksi} \]
\[ D'' = 36.625\text{in.} \]
\[ \tan \theta = \left( \frac{1.6(0.000572)(0.8)}{2(0.0159)} \right)^{0.25} = 0.390 \]
\[ \tan \alpha = \frac{35\text{in.}}{207.40\text{in.}} = 0.169 \]
\[ \tan \theta > \tan \alpha \]
\[ \theta = 21.283^\circ < 25^\circ \rightarrow \theta = 25^\circ \]
\[ V_s = \frac{\pi A_{th}}{2} f_{yh} D'' \cot \theta \]
\[ = \frac{\pi}{2} \left( 1.11\text{in}^2 \right) \left( 36.625\text{in.} \right) \left( \frac{1}{\tan 25^\circ} \right) \]
\[ = 51.7k \]
\[ V_u = 2.596k \]
\[ \phi V_s = 0.85(51.7k) = 43.9k \]
\[ V_u - \phi(V_p + V_c) = 2.596k - 0.85\left( 54.6k + 36.6k \right) = -74.9k \]
\[ \phi V_s > V_u - \phi(V_p + V_c) \]

Thus the transverse (shear) reinforcement is adequate (Good).

2.b. Transverse Reinforcement outside the plastic hinge zones using the explicit shear detailing approach.

\[ V_c = 0.17 \sqrt{f_c' A_r} \]
\[ = 124.3k \]
\[ V_u - \phi(V_p + V_c) = 2.596k - 0.85\left( 54.6k + 124.3k \right) = -149.5k \]
\[ \phi V_s > V_u - \phi(V_p + V_c) \]

Thus the transverse (shear) reinforcement is adequate (Good).
3. Transverse Reinforcement for Confinement at Plastic Hinges

\( \rho_s = \) transverse reinforcement for confinement at plastic hinges

\( U_{sf} = \) strain energy capacity (modulus of toughness) of the transverse reinforcement

\[ \begin{align*}
U_{sf} &= 110 \text{ MPa} \\
U_{sf} &= 110 \text{ N/mm}^2
\end{align*} \]

\( P_e = \) factored axial load (N) including seismic effects

\[ \begin{align*}
P_e &= 323.77 \text{ kips (from Appendix XIX)}
\end{align*} \]

\[ \rho_{s, provided} = \frac{4A_{ph}}{D^n s} = 2(0.000572) = 0.00114 \]

\[ \rho_{s, required} = 0.008 \frac{f_c' t}{U_{sf}} \left[ 12 \left( \frac{P_e}{f_c' A_g} + \rho_s \frac{f_y}{f_c'} \right)^2 \left( \frac{A_g}{A_{cc}} \right)^2 - 1 \right] \]

\[ \begin{align*}
= 0.008 \frac{20.685}{110} \left[ 12 \left( \frac{323.77}{(3)(1385.4)} + 0.0159 \frac{60}{1385.4} \right)^2 \left( \frac{1385.4}{1053.5} \right)^2 - 1 \right] \\
= 0.00339
\]

[MCEER/ATC, 2002]

\( \rho_s \text{ provided} < \rho_s \text{ required (Not Good)} \)

4. Spiral Spacing for Longitudinal Bar Restraint at Plastic Hinges

\( d_b = \) diameter of longitudinal reinforcing bars

Required Spacing \( s = 6d_b = 6(1.128 \text{ in.}) = 6.768 \text{ in.} \)

Provided Spacing \( s = 10.5 \text{ in.} \)

**Provided Spacing > Required Spacing (Not Good)**

[MCEER/ATC, 2002]

5. Transverse Spiral Reinforcement at the Moment Resisting Connection Between Members (Column/Beam and Column/Footing Joints)

\( \rho_s \text{ provided} = 0.00114 \) (from 2.a.)
\[
\tan \alpha = \frac{D}{H_c}
\]

D = diameter of the column framing into the joint = 42 in.

H_c = the height of the cap beam / joint = 48 in.

\( \rho_s \) required = transverse spiral reinforcement at the moment resisting connection between members (column/beam and column/footing joints) = the maximum of \( \rho_s \) required obtained in 2.a. (\( \rho_s \) required = 0.00339) and the following formula:

\[
\rho_{s,\text{required}} = 0.76 \frac{\rho_s f_{su}}{\phi f_{y,h} A_{cc}} \tan^2 \alpha
\]

\[
= 0.76 \left( \frac{0.0159}{0.85} \right) \left( 1.5 \right) \left( \frac{1385.4 \text{in.}^2}{1053.5 \text{in.}^2} \right) \left( \frac{42 \text{in.}}{48 \text{in.}} \right)^2
\]

= 0.0215

Thus \( \rho_s \) required obtained using the above formula (\( \rho_s \) required = 0.0215) controls.

\( \rho_s \) provided = 0.00114 < \( \rho_s \) required = 0.0215 (Not Good).

[MCEER/ATC, 2002]

6. Minimum Required Horizontal Reinforcement

\( \rho_s \) = the volumetric ratio of transverse reinforcement in the form of spirals or circular hoops to be continued into the cap or footing to provide continuity of reinforcement at the intersection between the columns and pier cap beam

\( \rho_{s,\text{provided}} = 0.00114 \) (from 2.a)

\( \rho_{s,\text{required}} = \frac{0.29 \sqrt{f_{c'}}}{f_{y,h}} = \frac{0.29 \sqrt{20.685}}{275.8} = 0.00478 \)

\( \rho_s \) provided = 0.00114 < \( \rho_s \) required = 0.00478 (Not Good).

[MCEER/ATC, 2002]
7. Stirrups in the Pier Cap Beam

Required stirrups \( A_{jv} = 0.16 \, A_{st} \), located within a distance 0.5D from the column face, where:

\( A_{jv} \) = total provided stirrups cross sectional area in the pier cap beam
\( A_{st} \) = total area of longitudinal steel in the column
D = diameter of the column.

0.5 \( D = 0.5 \times 42 \text{ in.} = 21 \text{ in.} \)

\[ 0.16A_{st} = 0.16(22)(1.00in.^2) = 3.52in.^2 \]

For all the columns, there are 24-#5 stirrups within 0.5D of the column. Therefore,

\[ A_{jv} = (24)(0.31in.^2) = 7.44in.^2 \]

[MCEER/ATC, 2002]

Provided stirrups \( A_{jv} > \) Required stirrups = 0.16\( A_{st} \) (Good)

8. Lap splices are used at the bottom of the column, as shown in Figure XXII-2.

That is not permitted (Not Good). [MCEER/ATC, 2002]

Figure XXII-2. Lap splices that are used at the bottom of the columns of the East Bound Bridge [Brown, 1993].
9. Column Joint Spiral Reinforcement to be Carried into the Pier Cap Beam

\( \rho_s \) = the volumetric ratio of column joint hoop or spiral reinforcement to be carried into the cap or footing

\[
\rho_{s, \text{required}} = \frac{0.4 A_{st}}{l_{ac}^2} = \frac{0.4 \left(22 \text{in.}^2\right)}{(37 \text{in.})^2} = 0.00643
\]

\( \rho_s \) provided = 0, because the column spiral reinforcement is not continued into the pier cap beam.

\( \rho_s \) provided = 0 < \( \rho_s \) required = 0.00584 (Not Good).

[MCEER/ATC, 2002]

The total construction cost for the two bridges is given in Table XXII-1. General conditions, overhead, profit and contingencies were not included in the total cost, because the estimate was only intended to be used to illustrate how much approximately the new LRFD Guidelines were going to impact the construction cost. The calculation to estimate the additional cost incurred in order to comply with the new LRFD Guidelines is as follows.

**Additional Spiral Reinforcing Steel Calculation**

**WEST BOUND BRIDGE**

The requirement for transverse spiral reinforcement at the moment resisting connection between members (column/beam and column/footing joints) controls, because its required spiral reinforcement ratio \( (\rho_s = 0.01944) \) is the highest. For practical reasons, that reinforcement ratio will be used for the whole length of the column instead of just at the connections between the columns, pier cap beam and footings. The spiral spacing will also be reduced from 10.5 in. to 6.5 in., as required for longitudinal bar restraint at plastic hinges. Thus now the minimum required cross sectional area of the spiral reinforcing bar can be found by using the formula for the provided \( \rho_s \):
\[ \rho_{provided} = \frac{4A_{bh}}{D'^{s}} \]

\[ 0.01944 = \frac{4A_{bh}}{(36.625 in.)(6.5 in.)} \]

\[ A_{bh} = \frac{(0.01944)(36.625 in.)(6.5 in.)}{4} \]

\[ A_{bh} = 1.16 in.^2 \]

The required cross sectional area is 1.16 in.\(^2\), and the smallest sufficient rebar size is rebar #10, which has a cross sectional area of 1.27 in.\(^2\)
Table XXII-1. The estimate for the construction cost of the two steel girder bridges. All prices are in US dollars. Virginia sales tax (4.5%) was applied to material price only. “From Means Heavy Construction Cost Data 2003. Copyright R.S. Means Co., Inc., Kingston, MA 781-585-7880; All rights reserved.”

<table>
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<tr>
<th>Item</th>
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<th>Labor Unit Price</th>
<th>Equipment Unit Price</th>
<th>Total Unit Price</th>
<th>Subtotal Cost</th>
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</thead>
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<td>70</td>
<td></td>
<td></td>
<td>73.15</td>
<td>37,482</td>
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<td>CY</td>
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<td>79.42</td>
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<td>20,098</td>
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<td>602</td>
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<td><strong>Total Cost</strong></td>
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</table>
Spiral Diameter = 37 in. – 0.375 in.
   = 36.625 in.

# 3 spiral rebars at spacing s = 10.5 in. (as written on the drawings)

Length covered by the spiral reinforcement = 18’-5 1/2”
   = 221.5 in.

The length of one full turn
\[
= \sqrt{(36.625\pi)^2 + 10.5^2}
\]
\[= 115.5\text{in.}\]

The number of turns
\[
= \frac{221.5}{10.5}
\]
\[= 21.1\]

Total length of the spiral reinforcing bar for one column
\[= 115.5\text{in.} \times 21.1\]
\[= 2437\text{in.}\]

Total volume of the spiral reinforcing bar for one column
\[
= \frac{1}{4} \pi (0.375\text{in.})^2 (2437\text{in.})
\]
\[= 269.2\text{in}^3\]

Total volume of the spiral reinforcing bar for the West Bound pier (three columns)
\[= 3 \times 269.2\text{in.}^3\]
\[= 807.6\text{in.}^3\]
\[\approx 0.467\text{ft.}^3\]
Total weight of the spiral reinforcing bar for the West Bound pier

\[ 807.6in. \times \frac{0.284lb}{in.} = 229lb. \]

#10 spiral rebars at spacing \( s = 6.5 \) in. (as required by the new LRFD Guidelines)

Required length covered by the spiral reinforcement = 18’-5 1/2” + 3’-0” + 2’-0”

\[ = 281.5 \text{ in.} \]

The length of one full turn

\[ = \sqrt{(36.625\pi)^2 + 6.5^2} \]

\[ = 115.2 \text{ in.} \]

The number of turns

\[ = \frac{281.5\text{ in.}}{6.5\text{ in.}} = 43.3 \]

Total length of the spiral reinforcing bar for one column

\[ = 115.2\text{ in.} \times 43.3 \]

\[ = 4988\text{ in.} \]

Total volume of the spiral reinforcing bar for one column

\[ = \frac{1}{4} \pi (1.27\text{ in.})^2 (4988\text{ in.}) \]

\[ = 6318\text{ in.}^3 \]

Total volume of the spiral reinforcing bar for the West Bound pier (three columns)

\[ = 3 \times 6318\text{ in.}^3 \]

\[ = 18954\text{ in.}^3 \]

\[ \approx 10.97 \text{ ft.}^3 \]

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Total weight of the spiral reinforcing bar for the West Bound pier
\[ = 18954in.³ \times 0.284 \frac{lb}{in.³} \]
\[ = 5383lb. \]

Additional rebar that has to be put in the West Bound pier
\[ = 5383lb. – 229lb \]
\[ = 5154lb \]

EAST BOUND BRIDGE

The requirement for transverse spiral reinforcement at the moment resisting connection between members (column/beam and column/footing joints) controls, because its required spiral reinforcement ratio \( \rho_s = 0.0215 \) is the highest. For practical reasons, that reinforcement ratio will be used for the whole length of the column instead of just at the connections between the columns, pier cap beam and footings. The spiral spacing will also be reduced from 10.5 in. to 6.5 in., as required for longitudinal bar restraint at plastic hinges. Thus now the minimum required cross sectional area of the spiral reinforcing bar can be found by using the formula for the provided \( \rho_s \):

\[
\rho_{s,\text{provided}} = \frac{4A_{bh}}{D''s} \\
0.0215 = \frac{4A_{bh}}{(36.625in.)(6.5in.)} \\
A_{bh} = \left(0.0215\right)(36.625in.)(6.5in.) \\
A_{bh} = 1.28in.²
\]

The required cross sectional area is 1.28 in.², and the smallest sufficient rebar size is rebar #11, which has a cross sectional area of 1.56 in.²

Spiral Diameter = 37 in. – 0.375 in.
\[ = 36.625 \text{ in.} \]
#3 rebars at spacing s = 10.5 in. (as written on the drawings)
Length covered by the spiral reinforcement = 17' - 4 5/8"
   = 208.625 in.

The length of one full turn
\[ = \sqrt{(36.625\pi)^2 + 10.5^2} \]
\[ = 115.5\text{in.} \]

The number of turns
\[ = \frac{208.625}{10.5} \]
\[ = 19.9 \]

Total length of the spiral reinforcing bar for one column
\[ = 115.5\text{in.} \times 19.9 \]
\[ = 2298\text{in.} \]

Total volume of the spiral reinforcing bar for one column
\[ = \frac{1}{4} \pi (0.375\text{in.})^2 (2298\text{in.}) \]
\[ = 253.8\text{in}^3 \]

Total volume of the spiral reinforcing bar for the East Bound pier (four columns)
\[ = 4 \times 253.8\text{in}^3 \]
\[ = 1015.2\text{in}^3 \]
\[ \approx 0.5875\text{ft}^3 \]

Total weight of the spiral reinforcing bar for the East Bound pier
\[ = 1015.2\text{in}^3 \times 0.284 \frac{lb}{\text{in}^3} \]
\[ = 288\text{lb.} \]
#11 rebars at spacing s = 6.5 in. (as required by the new LRFD Guidelines)

Length covered by the spiral reinforcement = 17’-4 5/8” + 3’-0” + 2’-0”

= 268.625 in.

The length of one full turn

\[
= \sqrt{(36.625\pi)^2 + 6.5^2}
\]

= 115.2 in.

The number of turns

\[
= \frac{268.625\text{in.}}{6.5\text{in.}}
\]

= 41.3

Total length of the spiral reinforcing bar for one column

= 115.2 in. \times 41.3

= 4758 in.

Total volume of the spiral reinforcing bar for one column

\[
= \frac{1}{4} \pi (1.56\text{in.})^2 (4758\text{in.})
\]

= 9094 in.\(^3\)

Total volume of the spiral reinforcing bar for the East Bound pier (four columns)

= 4 \times 9094 in.\(^3\)

= 36,376 in.\(^3\)

≈ 21.05 ft.\(^3\)

Total weight of the spiral reinforcing bar for the East Bound pier

\[
= 36,376\text{in.}^3 \times 0.284 \frac{lb}{\text{in.}^3}
\]

= 10,331 lb.
Additional rebar that has to be put in the East Bound pier

\[= 10,331 lb - 288 lb \]
\[= 10,043 lb \]

Thus, total additional rebar that has to be put in both piers = 5,154 lb + 10,043 lbs.

\[= 15,197 lb.\]

According to the construction drawings, all the rebars in the pier are epoxy-coated. Therefore according to Table XXII-1, the cost of placing 15197 lbs. additional rebar in the bridge pier is

\[
= 15,197 lbs. \times \frac{1 \text{ Ton}}{2,000 \text{ lbs.}} \times \frac{1315.64 \text{ dollars}}{1 \text{ Ton}}
\]

\[= 9,997 \text{ dollars} \]

The total construction cost was approximately $1,040,075. Thus the percentage of construction cost increase for compliance with the new LRFD Guidelines is

\[
= \frac{9,997 \text{ dollars}}{1,040,075 \text{ dollars}} \times 100\%
\]

\approx 1.0\%