Appendix XXII
Detailing Requirements of the Prestressed Concrete Girder Bridge

West 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.

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

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

Λ = fixity factor = 2 for fixed-fixed

ρ_t = ratio of longitudinal reinforcement

$$= \frac{A_{st}}{A_g}$$

$$= \frac{(20)\left(1.00in.^2\right)}{1385.4in.^2}$$

$$= 0.0144$$

ϕ = 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} = area of column core concrete, measured to the centerline of the perimeter hoop or spiral = $0.25\pi(37in. - 0.375in.)^2 = 1{,}053.5in.^2$

D’ = diameter of the column concrete core (center-to-center of the rebars)

= 42 in. – 2(3.5in.)

= 35 in.

L = column length = 221.77 in.

$$\tan\alpha = \frac{D'}{L} = \frac{35in.}{221.77in.} = 0.158$$

ρ_v = provided ρ_v = 0.000572

$A_v = 0.8A_g$ for a circular column

$$\tan\theta = \left(\frac{1.6}{\Lambda}\frac{\rho_v}{\rho_t}\frac{A_v}{A_g}\right)^{0.25} = \left(\frac{1.6}{2}\frac{0.000572}{0.0144}(0.8)\right)^{0.25} = 0.399$$

$$\tan\theta > \tan\alpha \rightarrow O.K.$$

$$\rho_v required = K_{shape}\Lambda\frac{\rho_t}{\phi}\frac{f_{su}}{f_{yh}}\frac{A_g}{A_{cc}}\tan\alpha\tan\theta$$

$$= (0.32)(2)\left(\frac{0.0144}{0.85}\right)(1.5)\left(\frac{1{,}385.4in.^2}{1053.5in.^2}\right)\left(\frac{35in.}{221.77in.}\right)(0.399)$$ [MCEER/ATC, 2002]

$$= 0.00135$$

ρ_v provided < ρ_v required (Not Good)

1.b. Transverse Reinforcement outside the Plastic Hinge Zones

ρ_v* = transverse reinforcement ratio outside the plastic hinge zone

ρ_v* provided = 0.000572

ρ_v = the steel provided in the potential plastic hinge zone = ρ_v* provided = 0.000572

$$\rho_v * required = \rho_v - 0.17\frac{\sqrt{f_c'}}{f_{yh}} = 0.000572 - 0.17\frac{\sqrt{20.685}}{275.8} = -0.00223$$

ρ_v* provided > ρ_v* required (Good)

[MCEER/ATC, 2002]

2.a. Transverse Reinforcement in potential plastic hinge zones using the explicit shear detailing approach.

$$\phi V_s \geq V_u - \phi\left(V_p + V_c\right)$$

$$V_p = \frac{\Lambda}{2} P_e \tan\alpha$$

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

$$= 59.5k$$

Inside the plastic hinge zone:

$$V_c = 0.05\sqrt{f_c'}A_v$$

$$= 0.05\sqrt{20.685}(0.8)(1385.4in^2)\left(\frac{25.4mm}{1in.}\right)^2$$

$$= 162{,}604N$$

$$= 36.6k$$

$$A_{bh} = 0.11in^2$$

$$S = 10.5in.$$

$$f_{yh} = 40ksi$$

$$D'' = 36.625in.$$

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

$$\tan\alpha = \frac{35in.}{221.77in.} = 0.158$$

$$\tan\theta > \tan\alpha$$

$$\theta = 21.767° < 25° \rightarrow \theta = 25°$$

$$V_s = \frac{\pi}{2}\frac{A_{bh}}{s} f_{yh} D'' \cot\theta$$

$$= \frac{\pi}{2}\left(\frac{0.11in^2}{10.5in.}\right)(40ksi)(36.625in.)\left(\frac{1}{\tan 25°}\right)$$

$$= 51.7k$$

$$V_u = 2.728k$$
$$\phi V_s = 0.85(51.7k) = 43.9k$$
$$V_u - \phi(V_p + V_c) = 2.728k - 0.85(59.5k + 36.6k) = -78.9k$$
$$\phi V_s > V_u - \phi(V_p + V_c)$$

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

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

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

[MCEER/ATC, 2002]

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

3. Transverse Reinforcement for Confinement at Plastic Hinges

ρ_s = transverse reinforcement for confinement at plastic hinges

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

= 110 MPa

= 110 N/mm^2

P_e = factored axial load (N) including seismic effects

= 376.95 kips (from Appendix XIX)

$$\rho_s provided = \frac{4A_{bh}}{D''s} = 2(0.000572) = 0.00114$$

$$\rho_s required = 0.008\frac{f_c'}{U_{sf}}\left[12\left(\frac{P_e}{f_c'A_g} + \rho_t\frac{f_y}{f_c'}\right)^2\left(\frac{A_g}{A_{cc}}\right)^2 - 1\right]$$

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

$$= 0.00297$$

[MCEER/ATC, 2002]

ρ_s provided < ρ_s 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 in.) = 6.768 in.

Provided Spacing s = 10.5 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)

ρ_s 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.

ρ_s required = transverse spiral reinforcement at the moment resisting connection between members (column/beam and column/footing joints)

= the maximum of ρ_s required obtained in 2.a. (ρ_s required = 0.00297) and the following formula:

$$\rho_s required = 0.76 \frac{\rho_t}{\phi} \frac{f_{su}}{f_{yh}} \frac{A_g}{A_{cc}} \tan^2 \alpha$$

$$= 0.76 \left(\frac{0.0144}{0.85} \right) (1.5) \left(\frac{1385.4 in.^2}{1053.5 in.^2} \right) \left(\frac{42 in.}{48 in.} \right)^2$$

$$= 0.01944$$

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

ρ_s provided = 0.00114 < ρ_s required = 0.01944 (Not Good).

[MCEER/ATC, 2002]

6. Minimum Required Horizontal Reinforcement

ρ_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

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

$$\rho_s required = \frac{0.29\sqrt{f_c'}}{f_{yh}} = \frac{0.29\sqrt{20.685}}{275.8} = 0.00478$$

ρ_s provided = 0.00114 < ρ_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 (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]

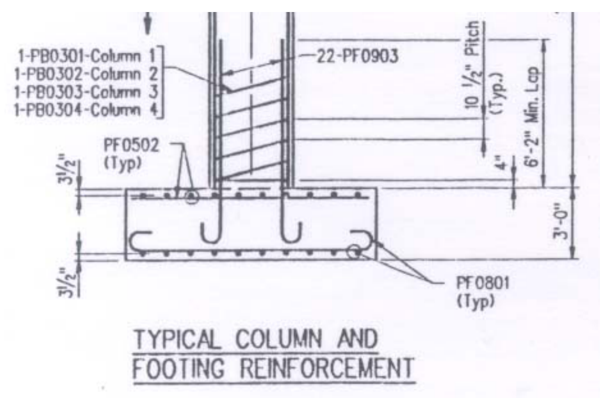

Figure XXII-1. Lap splices that are used at the bottom of the columns of the West Bound Bridge [Brown, 1993].

9. <u>Column Joint Spiral Reinforcement to be Carried into the Pier Cap Beam</u>

ρ_s = the volumetric ratio of column joint hoop or spiral reinforcement to be carried into the cap or footing

$$\rho_s required = \frac{0.4A_{st}}{l_{ac}^2} = \frac{0.4(20in.^2)}{(37in.)^2} = 0.00584$$

ρ_s provided = 0, because the column spiral reinforcement is not continued into the pier cap beam.

ρ_s provided = 0 < ρ_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.

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

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

Λ = fixity factor = 2 for fixed-fixed

ρ_t = ratio of longitudinal reinforcement

$$= \frac{A_{st}}{A_g}$$

$$= \frac{(22)\left(1.00in.^2\right)}{1385.4in.^2}$$

$$= 0.0159$$

ϕ = 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} = area of column core concrete, measured to the centerline of the perimeter hoop or spiral = $0.25\pi(37in. - 0.375in.)^2 = 1{,}053.5in.^2$

D' = diameter of the column concrete core (center-to-center of the rebars)

= 42 in. – 2(3.5in.)

= 35 in.

L = column length = 207.40 in.

$$\tan\alpha = \frac{D'}{L} = \frac{35in.}{207.40in.} = 0.16876$$

ρ_v = provided ρ_v = 0.000572

$A_v = 0.8A_g$ for a circular column

$$\tan\theta = \left(\frac{1.6}{\Lambda}\frac{\rho_v}{\rho_t}\frac{A_v}{A_g}\right)^{0.25} = \left(\frac{1.6}{2}\frac{0.000572}{0.0159}(0.8)\right)^{0.25} = 0.390$$

$$\tan\theta > \tan\alpha \rightarrow O.K.$$

$$\rho_v required = K_{shape}\Lambda\frac{\rho_t}{\phi}\frac{f_{su}}{f_{yh}}\frac{A_g}{A_{cc}}\tan\alpha\tan\theta$$

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

$$= 0.00155$$

ρ_v provided < ρ_v required (Not Good)

1.b. <u>Transverse Reinforcement outside the Plastic Hinge Zones</u>

ρ_v* = transverse reinforcement ratio outside the plastic hinge zone

ρ_v* provided = 0.000572

ρ_v = the steel provided in the potential plastic hinge zone = ρ_v* provided = 0.000572

$$\rho_v * required = \rho_v - 0.17\frac{\sqrt{f_c'}}{f_{yh}} = 0.000572 - 0.17\frac{\sqrt{20.685}}{275.8} = -0.00223$$

ρ_v* provided > ρ_v* required (Good)

[MCEER/ATC, 2002]

2.a. <u>Transverse Reinforcement in potential plastic hinge zones using the implicit shear detailing approach.</u>

$$\phi V_s \geq V_u - \phi\left(V_p + V_c\right)$$

$$V_p = \frac{\Lambda}{2} P_e \tan\alpha$$

$$= \frac{2}{2}\left(323.77k\right)\left(\frac{35in.}{207.40in.}\right)$$

$$= 54.6k$$

Inside the plastic hinge zone:

$$V_c = 0.05\sqrt{f_c{'}}A_v$$

$$= 0.05\sqrt{20.685}\left(0.8\right)\left(1385.4in^2\right)\left(\frac{25.4mm}{1in.}\right)^2$$

$$= 162{,}604N$$

$$= 36.6k$$

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

[MCEER/ATC, 2002]

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

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

$$V_c = 0.17\sqrt{f_c'}A_v$$
$$= 124.3k$$
$$V_u - \phi(V_p + V_c) = 2.596k - 0.85(54.6k + 124.3k) = -149.5k$$
$$\phi V_s > V_u - \phi(V_p + V_c)$$

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

3. <u>Transverse Reinforcement for Confinement at Plastic Hinges</u>

ρ_s = transverse reinforcement for confinement at plastic hinges

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

= 110 MPa

= 110 N/mm^2

P_e = factored axial load (N) including seismic effects

= 323.77 kips (from Appendix XIX)

$$\rho_s\, provided = \frac{4A_{bh}}{D''s} = 2(0.000572) = 0.00114$$

$$\rho_s required = 0.008\frac{f_c'}{U_{sf}}\left[12\left(\frac{P_e}{f_c' A_g} + \rho_t \frac{f_y}{f_c'}\right)^2\left(\frac{A_g}{A_{cc}}\right)^2 - 1\right]$$

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

$= 0.00339$

[MCEER/ATC, 2002]

ρ_s provided < ρ_s required (Not Good)

4. <u>Spiral Spacing for Longitudinal Bar Restraint at Plastic Hinges</u>

d_b = diameter of longitudinal reinforcing bars

Required Spacing s = $6d_b$ = 6(1.128 in.) = 6.768 in.

Provided Spacing s = 10.5 in.

Provided Spacing > Required Spacing (Not Good)

[MCEER/ATC, 2002]

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

ρ_s 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.

ρ_s required = transverse spiral reinforcement at the moment resisting connection between members (column/beam and column/footing joints)

= the maximum of ρ_s required obtained in 2.a. (ρ_s required = 0.00339) and the following formula:

$$\rho_s required = 0.76 \frac{\rho_t}{\phi} \frac{f_{su}}{f_{yh}} \frac{A_g}{A_{cc}} \tan^2\alpha$$

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

$$= 0.0215$$

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

ρ_s provided = 0.00114 < ρ_s required = 0.0215 (Not Good).

[MCEER/ATC, 2002]

6. <u>Minimum Required Horizontal Reinforcement</u>

ρ_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

$\rho_s provided = 0.00114$ (from 2.a)

$$\rho_s required = \frac{0.29\sqrt{f_c'}}{f_{yh}} = \frac{0.29\sqrt{20.685}}{275.8} = 0.00478$$

ρ_s provided = 0.00114 < ρ_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 (42 in.) = 21 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 = 0.16A_{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]

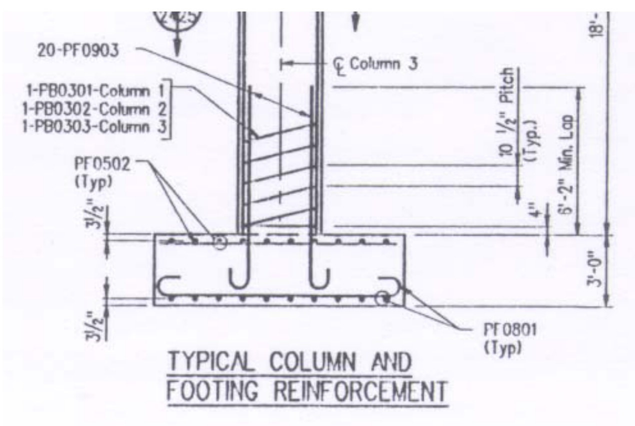

Figure XXII-2. Lap splices that are used at the bottom of the columns of the East Bound Bridge [Brown, 1993].

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

ρ_s = the volumetric ratio of column joint hoop or spiral reinforcement to be carried into the cap or footing

$$\rho_s required = \frac{0.4A_{st}}{l_{ac}^{\ 2}} = \frac{0.4\left(22in.^2\right)}{\left(37in.\right)^2} = 0.00643$$

ρ_s provided = 0, because the column spiral reinforcement is not continued into the pier cap beam.

ρ_s provided = 0 < ρ_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 (ρ_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 ρ_s:

$$\rho_s\, provided = \frac{4A_{bh}}{D''s}$$

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

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

$$A_{bh} = 1.16in.^2$$

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.

Item	Quantity	Units	Material Unit Price	Labor Unit Price	Equipment Unit Price	Total Unit Price	Subtotal Cost
Concrete, Class A3 (3000 psi)	512.4	CY	70			73.15	37,482
Concrete, Class A4 (4000 psi)	676.4	CY	76			79.42	53,720
Slab Formwork	20,098	SF	6.1	3.07		9.44	189,816
Pier Cap Beam Formwork	1512	SF	1.86	4.61		6.55	9,909
Column Formwork	126	LF	35	9.55		46.13	5,812
Footing Formwork	882	SF	1.6	3.13		4.80	4,235
Placing Concrete	1188.8	CY		15.92	8.5	24.42	29,030
Concrete Finishing	19,380	SF		0.27		0.27	5,233
Concrete Curing Blankets	19,380	SF	0.415			0.43	8,405
Bridge Deck Grooving	2002	SY		0.18	0.56	0.74	1,481
Reinforcing Steel in Place	25.445	Ton	602	460	7.1	1096.19	27,893
Reinforcing Steel in Place							
Epoxy Coated	79.450	Ton	812	460	7.1	1315.64	104,528
Structural Steel Plate Girders	218.95	Ton	1,525	430	134	2157.63	472,412
Structure Excavation	910	CY		2.48	4.76	7.24	6,588
Steel Piles, HP 10x42	420	LF	9.8	3.31	2.77	16.32	6,855
Pile Point for 10" Steel Pile	21	Ea.	66.5	70.5		139.99	2,940
Steel Piles, HP 12x53	849	LF	12.55	3.42	2.87	19.40	16,475
Pile Point for 12" Steel Pile	32	Ea.	66.5	70.5		139.99	4,480
Concrete Parapet	87.6	CY	123	223	23.5	375.04	32,853
Porous Backfill	193	CY		0.65	0.8	1.45	280
6" Diameter Pipe Underdrain	392	LF	1.59	1.67		3.33	1,306
Concrete Slab Slope Protection, 4"	1142	SY	8.5	5	2.18	16.06	18,343
Total Cost							**1,040,075**

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

$$= \sqrt{(36.625\pi)^2 + 10.5^2}$$
$$= 115.5 in.$$

The number of turns

$$= \frac{221.5}{10.5}$$
$$= 21.1$$

Total length of the spiral reinforcing bar for one column

$$= 115.5 in. \times 21.1$$
$$= 2437 in.$$

Total volume of the spiral reinforcing bar for one column

$$= \frac{1}{4}\pi(0.375 in.)^2(2437 in.)$$
$$= 269.2 in^3$$

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

$$= 3 \times 269.2 in.^3$$
$$= 807.6 in.^3$$
$$\approx 0.467 ft.^3$$

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

$$= 807.6 in.^3 \times 0.284 \frac{lb}{in.^3}$$

$$= 229 lb.$$

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

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

= 281.5 in.

The length of one full turn

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

$$= 115.2 in.$$

The number of turns

$$= \frac{281.5 in.}{6.5 in.}$$

$$= 43.3$$

Total length of the spiral reinforcing bar for one column

$$= 115.2 in. \times 43.3$$

$$= 4988 in.$$

Total volume of the spiral reinforcing bar for one column

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

$$= 6318 in.^3$$

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

$$= 3 \times 6318 in.^3$$

$$= 18954 in.^3$$

$$\approx 10.97 ft.^3$$

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

$$= 18954 in.^3 \times 0.284 \frac{lb}{in.^3}$$
$$= 5383 lb.$$

Additional rebar that has to be put in the West Bound pier

$$= 5383 lb. - 229 lb$$
$$= 5154 lb$$

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 (ρ_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 ρ_s:

$$\rho_s \, provided = \frac{4A_{bh}}{D"s}$$
$$0.0215 = \frac{4A_{bh}}{(36.625 in.)(6.5 in.)}$$
$$A_{bh} = \frac{(0.0215)(36.625 in.)(6.5 in.)}{4}$$
$$A_{bh} = 1.28 in.^2$$

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 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

$= \sqrt{(36.625\pi)^2 + 10.5^2}$

$= 115.5 in.$

The number of turns

$= \frac{208.625}{10.5}$

$= 19.9$

Total length of the spiral reinforcing bar for one column

$= 115.5 in. \times 19.9$

$= 2298 in.$

Total volume of the spiral reinforcing bar for one column

$= \frac{1}{4}\pi(0.375 in.)^2(2298 in.)$

$= 253.8 in^3$

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

$= 4 \times 253.8 in.^3$

$= 1015.2 in.^3$

$\approx 0.5875 ft.^3$

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

$= 1015.2 in.^3 \times 0.284 \frac{lb}{in.^3}$

$= 288 lb.$

#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

$$= \frac{268.625 in.}{6.5 in.}$$
$$= 41.3$$

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

$$= \frac{1}{4}\pi(1.56 in.)^2(4758 in.)$$
$$= 9094 in.^3$$

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

$$= 4 \times 9094 in.^3$$
$$= 36{,}376 in.^3$$
$$\approx 21.05 ft.^3$$

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

$$= 36{,}376 in.^3 \times 0.284 \frac{lb}{in.^3}$$
$$= 10{,}331 lb.$$

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

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

$$= 9{,}997 dollars$$

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

$$= \frac{9{,}997 dollars}{1{,}040{,}075 dollars} \times 100\%$$

$$\approx 1.0\%$$