4.17. Interaction Diagram of the Columns

The interaction diagram of the columns was drawn to determine if the maximum axial load and moment exceeded the capacity of the column. The complete calculation to determine the important points of the interaction diagram is provided in Appendix XX. For all the columns of these two bridges, the maximum axial load and moment were far below the capacity of the column, as shown in Figures 4.16 and 4.17. The maximum shear forces in the columns were also far below the shear strength of the columns, as shown in Appendix XXII.

4.18. Moment Strength of the Pier Cap Beam

The moment strength of the pier cap beam was calculated for each bridge to see if or not it was exceeded by the maximum moment in the pier cap beam. In order to simplify the calculation of the moment strength, the side reinforcing bars of the pier cap beam were ignored. The actual cross section of the pier cap beams, which are shown in Figure 4.18 and 4.19, became those shown in Figure 4.20 and 4.21. The complete calculation of the moment strength of the pier cap beam is presented in Appendix XXI.

West Bound:	East Bound:
$\phi M_n = 2674$ k-ft	$\phi M_n = 2174$ k-ft
$M_u = 552$ k-ft	$M_u = 516$ k-ft
$\phi M_n > M_u$	$\phi M_n > M_u$

Thus the moment capacity of the pier cap beam was not exceeded for either bridge.

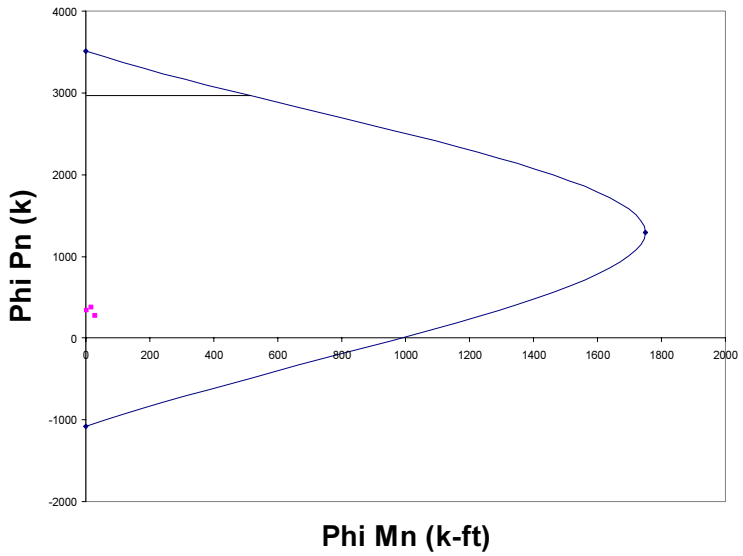

Figure 4.16. The interaction diagram of the West Bound bridge columns. The grey points are the factored axial loads and moments in the columns.

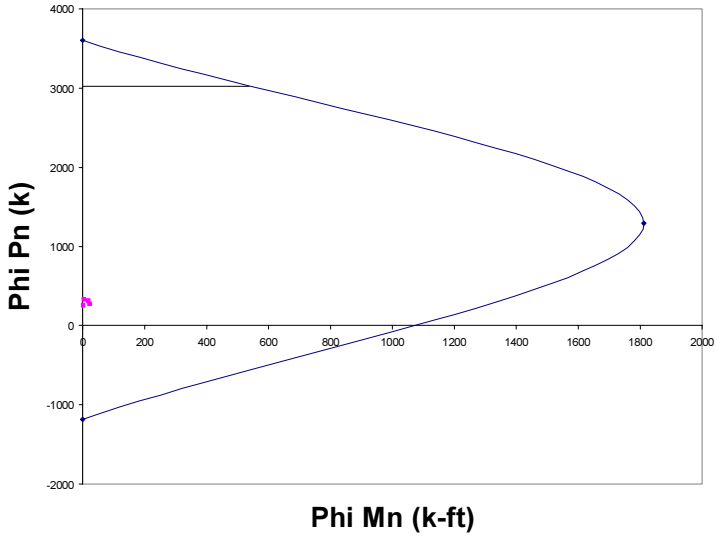

Figure 4.17. The interaction diagram for the East Bound bridge columns. The grey points are the factored axial loads and moments in the columns.

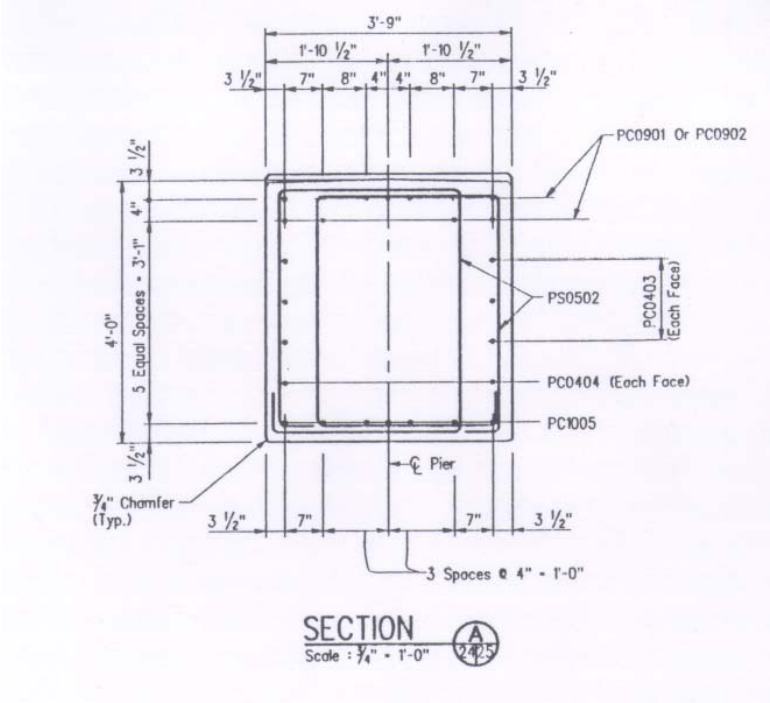

Figure 4.18. The actual cross section of the West Bound bridge pier cap beam [Brown, 1993].

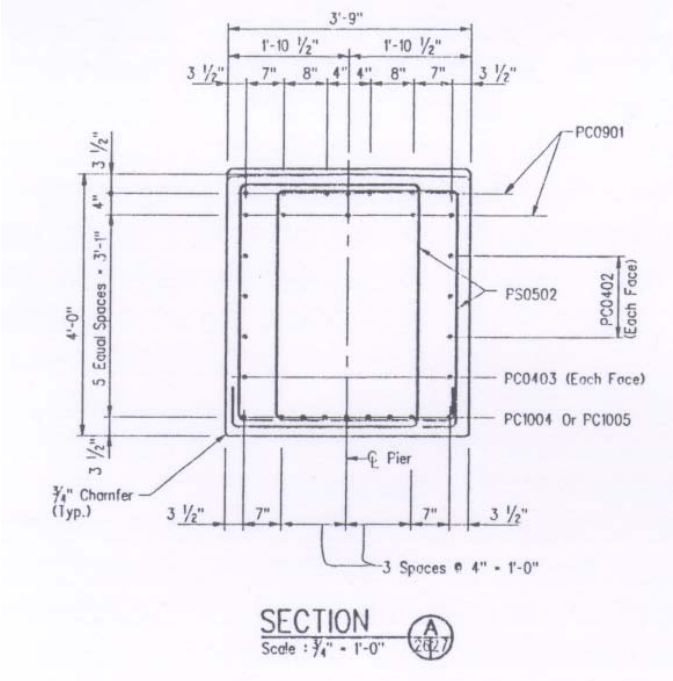

Figure 4.19. The actual cross section of the East Bound bridge pier cap beam [Brown, 1993].

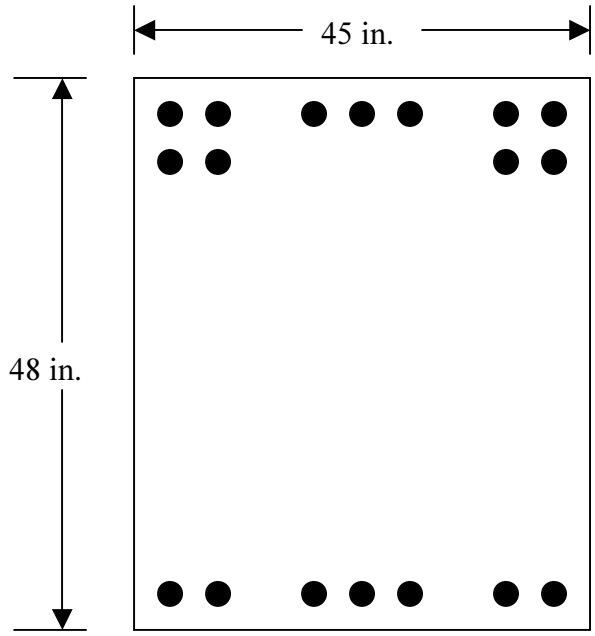

Figure 4.20. The simplified cross section of the West Bound bridge pier cap beam.

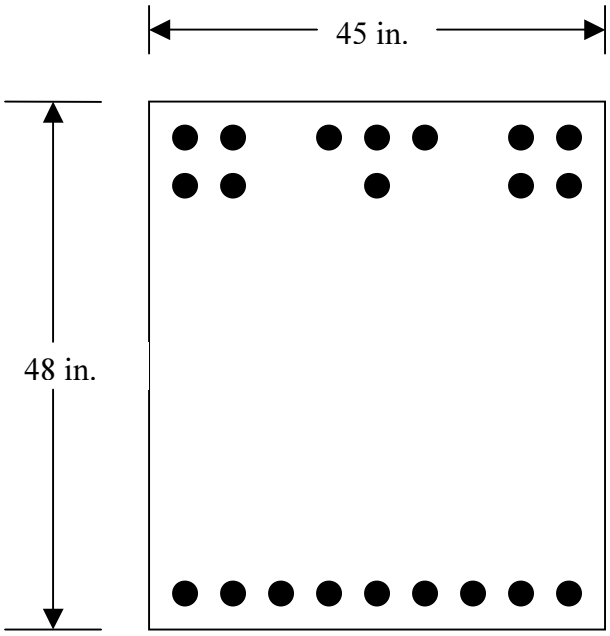

Figure 4.21. The simplified cross section of the East Bound bridge pier cap beam.

4.19. Explanation of the Results

Similar to the prestressed concrete girder bridge in Chapter 3, the fact that the capacity of the columns was far higher than the maximum axial load and moment in the columns and the moment strength of the pier cap beam was far above the maximum moment it was subjected to, showed that these two bridges were modeled with the substructure much stiffer than the superstructure.

4.20. Detailing Changes due to the New LRFD Guidelines

The details of the two bridges were checked according to the required Seismic Design Requirement, which was SDR 5 for these two bridges. The summary of the checks for the West Bound and East Bound bridges are given in Tables 4.1 and 4.2, respectively.

Table 4.1. The results of the detailing requirement checks for the West Bound bridge using Seismic Design Requirement 5.

Number	Requirement	Required	Provided
1a	Transverse Reinforcement in Potential Plastic Hinge Zones using the Implicit Shear Detailing Approach	0.00135	0.000572
1b	Transverse Reinforcement outside the Plastic Hinge Zones using the Implicit Shear Detailing Approach	-0.00223	0.000572
2a	Transverse Reinforcement in Potential Plastic Hinge Zones using the Explicit Shear Detailing Approach	$V_u - \phi(V_p + V_c) = -78.9k$	$\phi V_s = 43.9k$

Number	Requirement	Required	Provided
2b	Transverse Reinforcement outside the Potential Plastic Hinge Zones using the Explicit Shear Detailing Approach	$V_u - \phi(V_p + V_c) = -153.5k$	$\phi V_s = 43.9k$
3	Transverse Reinforcement for Confinement at Plastic Hinges	0.00297	0.00114
4	Spiral Spacing for Longitudinal Bar Restraint at Plastic Hinges	6.77 in.	10.5 in.
5	Transverse Spiral Reinforcement at the Moment Resisting Connection Between Members (Column/Beam and Column/Footing Joints)	0.01944	0.00114
6	Minimum Required Horizontal Reinforcement	0.00478	0.00114
7	Stirrups in the Pier Cap Beam	3.2 $in.^2$	7.44 $in.^2$ for the left and right columns, and 4.96 $in.^2$ for the center column
8	Lap Splices at the top and bottom one-quarter of the column	Not Allowed	Used
9	Column Joint Spiral Reinforcement to be Carried into the Pier Cap Beam	0.00584	0

Table 4.2. The results of the detailing requirement checks for the East Bound bridge using Seismic Design Requirement 5.

Number	Requirement	Required	Provided
1a	Transverse Reinforcement in Potential Plastic Hinge Zones using the Implicit Shear Detailing Approach	0.00155	0.000572
1b	Transverse Reinforcement outside the Plastic Hinge Zones using the Implicit Shear Detailing Approach	-0.00223	0.000572
2a	Transverse Reinforcement in Potential Plastic Hinge Zones using the Explicit Shear Detailing Approach	$V_u - \phi(V_p + V_c) = -78.9k$	$\phi V_s = 43.9k$
2b	Transverse Reinforcement outside the Potential Plastic Hinge Zones using the Explicit Shear Detailing Approach	$V_u - \phi(V_p + V_c) = -153.5k$	$\phi V_s = 43.9k$
3	Transverse Reinforcement for Confinement at Plastic Hinges	0.00339	0.00114
4	Spiral Spacing for Longitudinal Bar Restraint at Plastic Hinges	6.77 in.	10.5 in.

Number	Requirement	Required	Provided
5	Transverse Spiral Reinforcement at the Moment Resisting Connection Between Members (Column/Beam and Column/Footing Joints)	0.0215	0.00114
6	Minimum Required Horizontal Reinforcement	0.00478	0.00114
7	Stirrups in the Pier Cap Beam	3.52 $in.^2$	7.44 $in.^2$ for all the columns
8	Lap Splices at the top and bottom one-quarter of the column	Not Allowed	Used
9	Column Joint Spiral Reinforcement to be Carried into the Pier Cap Beam	0.00584	0

To bring these two bridges up to the new standards, the spiral spacing must be changed from 10.5 in. to 6.5 in., and the spiral size has to be changed from #3 to #10 for the West Bound bridge and from #3 to #11 for the East Bound bridge. These changes approximately will result in an additional 1.0% of the total construction cost, which is insignificant. The complete detailing requirements and cost increase calculations are presented in Appendix XXII.