The Design of Precast Concrete Segmental Bridge Piers in New Jersey, USA

Abstract

The $ 900 million Rt. 295 Direct Connect Project in New Jersey, USA is a major highway and bridge construction project currently under design. This project is to be built in several stages and in four separate contracts in one of the busiest corridors in the country where three major highways meet. It has numerous long span bridges that weave through the interchange at four separate levels.

For the I-295 Direct Connect Project, the New Jersey Department of Transportation (NJDOT) required the use of precast post tensioned segmental piers where appropriate to expedite construction and to relieve motorists from construction related delays.

In precast concrete construction, much of the pier fabrication can be done in an off-site pre-casting plant. This shortens the on-site labor and construction time, thereby reducing traffic delays and detours during construction. A pre-casting plant allows for both the efficiency of mass production and a high level of quality control. Consequently, the cost of the precast substructure will be reduced. With the high level of quality control attainable in a precast plant, high performance concrete can be used. This results in more durable substructure units with higher quality and better finish. The higher strength of high performance concrete allows the use of hollow sections. Hollow sections result in material savings, lower hauling and erection weights, and decreased foundation costs.

In this paper, the design of post tensioned segmental straddle bent type piers is presented. An Excel Spreadsheet was developed for the design. The features of the spreadsheet discussed also describe the design procedure adopted. The efficient use of the spreadsheet shows that these piers can be routinely designed without complicated and expensive computer programs. The sequence of pier construction is also provided.

Key Words: Precast Concrete, Segmental Piers, Straddle Bents, Post-Tensioned Columns, Pre-Stressing

1. Introduction

The $ 900 million Rt. 295 Direct Connect Project in New Jersey, USA is a major highway and bridge construction project currently under design. This project is to be built in several stages and in four separate contracts in one of the busiest corridors in the country where three major highways meet. It has numerous long span bridges that weave through the interchange at four levels.

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In precast concrete construction, much of the substructure fabrication can be done in an off-site precast concrete plant. This shortens the on-site labor and construction time, thereby reducing traffic delays and detours during construction. A precast concrete plant allows for both the efficiency of mass production and a high level of quality control. Consequently, the cost of the precast substructure will be reduced. With the high level of quality control attainable in a precast plant, high performance concrete can be used. This results in more durable substructure units with higher quality and better finish. The higher strength of high performance concrete allows the use of hollow sections. Hollow sections result in material savings, lower hauling and erection weights, and decreased foundation costs. The use of post-tensioning with precast substructures will further improve durability by eliminating cracking under service loads and providing stiffer vertical elements that minimize deflections.

In this paper, the design of post tensioned segmental straddle bent type piers is presented. Straddle bent piers consist of two concrete columns supporting a long steel box type cap beam. They are suitable when there is no space available for the construction of bridge pier columns directly under the superstructure. This lack of space could be due to vehicular lanes, rail tracks, culverts or other objects. Figure 1 shows a typical pier that was used in this project. The pier columns consist of rectangular precast concrete hollow segments. The topmost segment is solid. The segments are stacked and post-tensioned together.

2. Design Criteria and Parameters

The design of the piers was done as per the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Manual (2010). The detailing of the piers was carried out according to the New Jersey Department of Transportation Design Manual (2009). Seismic design was performed as per AASHTO Guide Specifications for LRFD Seismic Bridge Design (2005).

The bridges in the project are designed for AASHTO LRFD HL-93 Vehicular Live Load or NJDOT Permit Vehicle whichever governs.

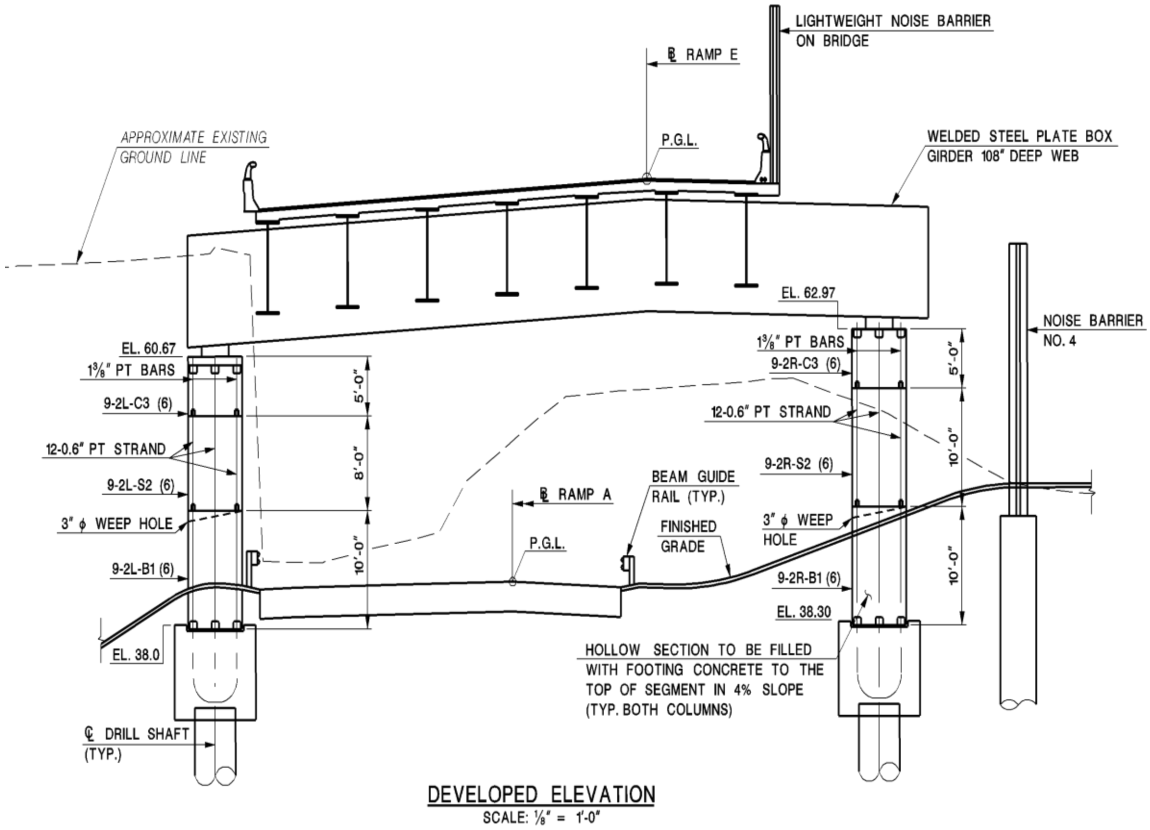

Figure 1: General View of a Typical Pier

The column heights vary from 25 feet to 60 feet. The segment size is 8’x6’ with the thickness being 12”. The width to thickness ratio was kept less than 15 as recommended by AASHTO LRFD Specifications. The heights of the segments used are 10’, 7’, and 5’. The bottom segments of the piers were always 10’ and the topmost segments were always 5’.

The compressive strength of concrete in the segments and footings are 6,000 psi and 4,000 psi respectively. The yield strength of normal reinforcing steel is 60 ksi. The ultimate tensile strength of pre-stressing steel rods and pre-stressing steel strands are 150 ksi and 270 ksi respectively.

3. Design Methodology

The live load and the dead load acting on the piers were calculated by utilizing the computer code “WIN-DESCUS I” (2005). The other loads acting on the piers such as wind, wind on live load, braking force, centrifugal force, and collision force were manually calculated. Seismic isolation bearings were used in order to reduce the seismic loads and to distribute the horizontal loads to all the piers and the abutments. Figure 2 depicts the seismic design spectrum used for the seismic analysis. Seismic and temperature loads were obtained for two different types of seismic isolation bearings. It should be noted that the above loads are required for any type of pier design and not only for post tensioned piers. Once the above design forces are obtained, the next step is to design the pier column and the pier footing.

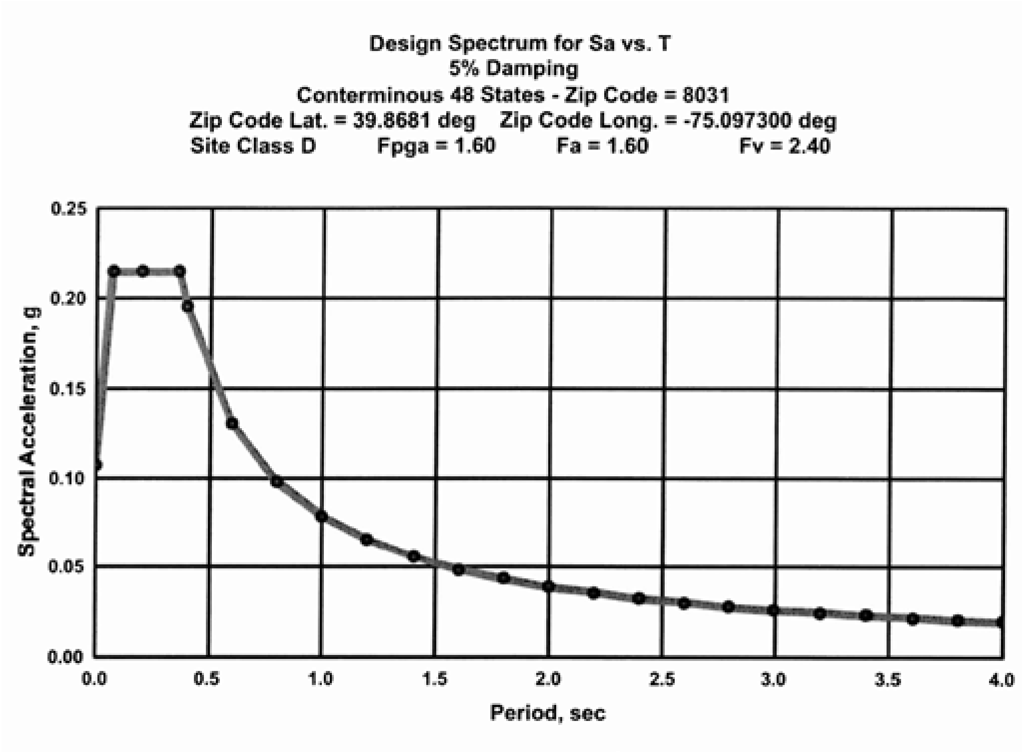

Figure 2: Seismic Design Spectrum

3.1 Design of Pier Columns

All segments in the column except the topmost segment are hollow. The segments are match cast and there are shear keys between the segments. The 10' high bottom segment is filled with footing concrete as a security measure against bomb threats. Top of this concrete pour is sloped at 3% and a weep hole is provided to expel any moisture collected in the hollow column. In order to design the pier column, an Excel Spreadsheet was developed. This spreadsheet has the following features that also describe the design procedure adopted:

- It allows the designer to place any number of pre-stressing rods and pre-stressing strands on the pier section as shown by Figure 3. The segment cross section is hollow and can be of any size.
- It checks for the minimum and maximum steel reinforcement in the column section as per AASHTO LRFD requirements.
- It calculates the pre-stress losses in the pre-stressing rods and pre-stressing strands. Pre-stressing losses due to anchor set, friction, elastic shortening, creep and shrinkage of concrete is calculated. Post-tensioning is carried out from both ends of the pre-stressing strands.
- It performs column slenderness checks using moment magnification method. According to AASHTO LRFD, slenderness effects should be considered if the slenderness ratio is greater than 22.
- It checks the serviceability limit state stresses of the column. No tension is allowed between the segments.

- It checks the axial load and moment capacity for various strength limit states and extreme event limit states such as seismic and vehicle collision. The spreadsheet generates the interaction diagrams in the two principal directions of the column. Figure 4 shows a typical interaction diagram generated in the X-X direction. The stress, strain and load diagrams used to develop the interaction diagrams in Y-Y Direction are shown in Figure 5. Similar diagrams were used to develop the interaction diagram in X-X direction.
- It checks the shear across the segments and in the joints between the segments.
- It checks the deflection at the top of the column due to service loads.
- It checks the stability of the column during construction.

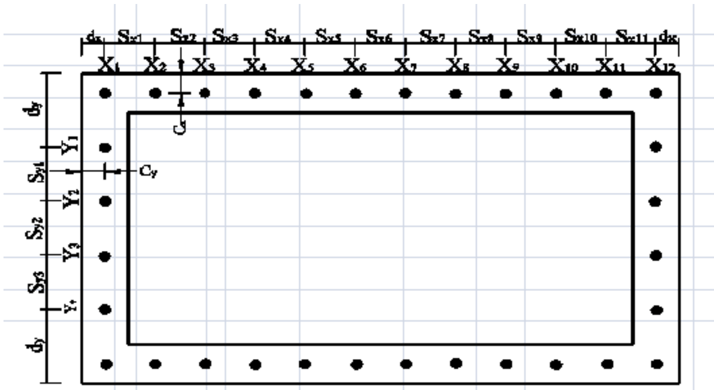

Figure 3: Pre-stressing Strands and Rods in the Hollow segment

It was found out that the use of the spreadsheet was very helpful and efficient as several limit states and many aspects of the design as given above had to be considered for several piers in the project.

The topmost segment is made solid since the bearing that support the steel cap beam sits on it. The height of the topmost segment is 5’. It has to span the hollow area of the segment below it. Due to its low span to depth ratio, it behaves like a deep beam. Therefore, a strut-and- tie model was utilized for its design.

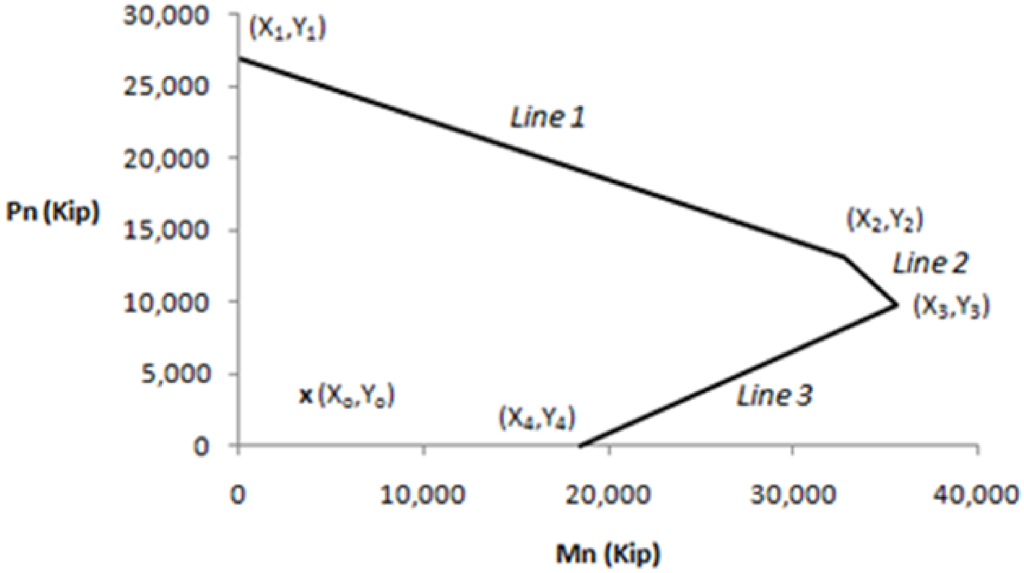

Figure 4: Interaction Diagram about X-X Axis

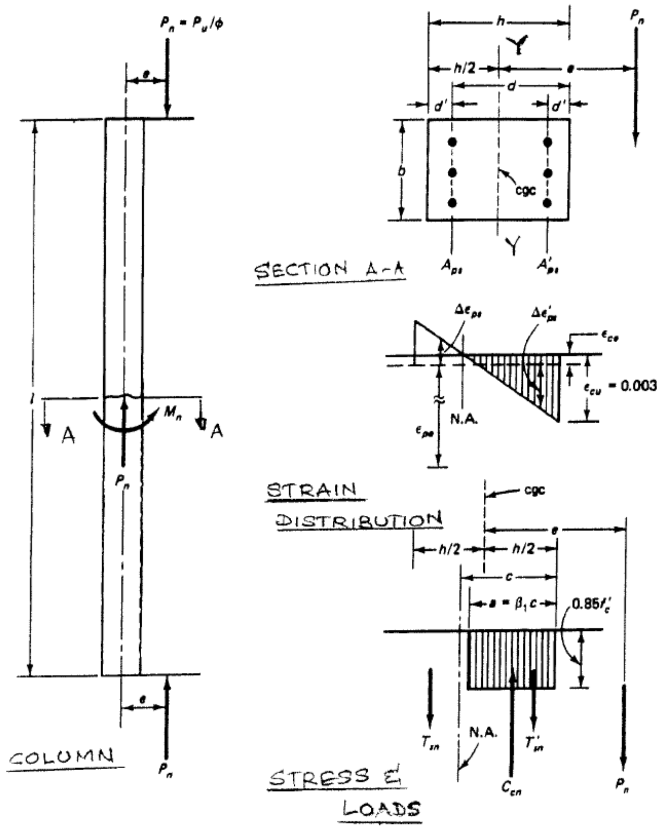

Figure 5: Cross Section, Strain Distribution, Stresses and Loads (Nawy, 2003)

Figure 6 shows a typical section of the hollow column. Detail A shows a typical shear key.

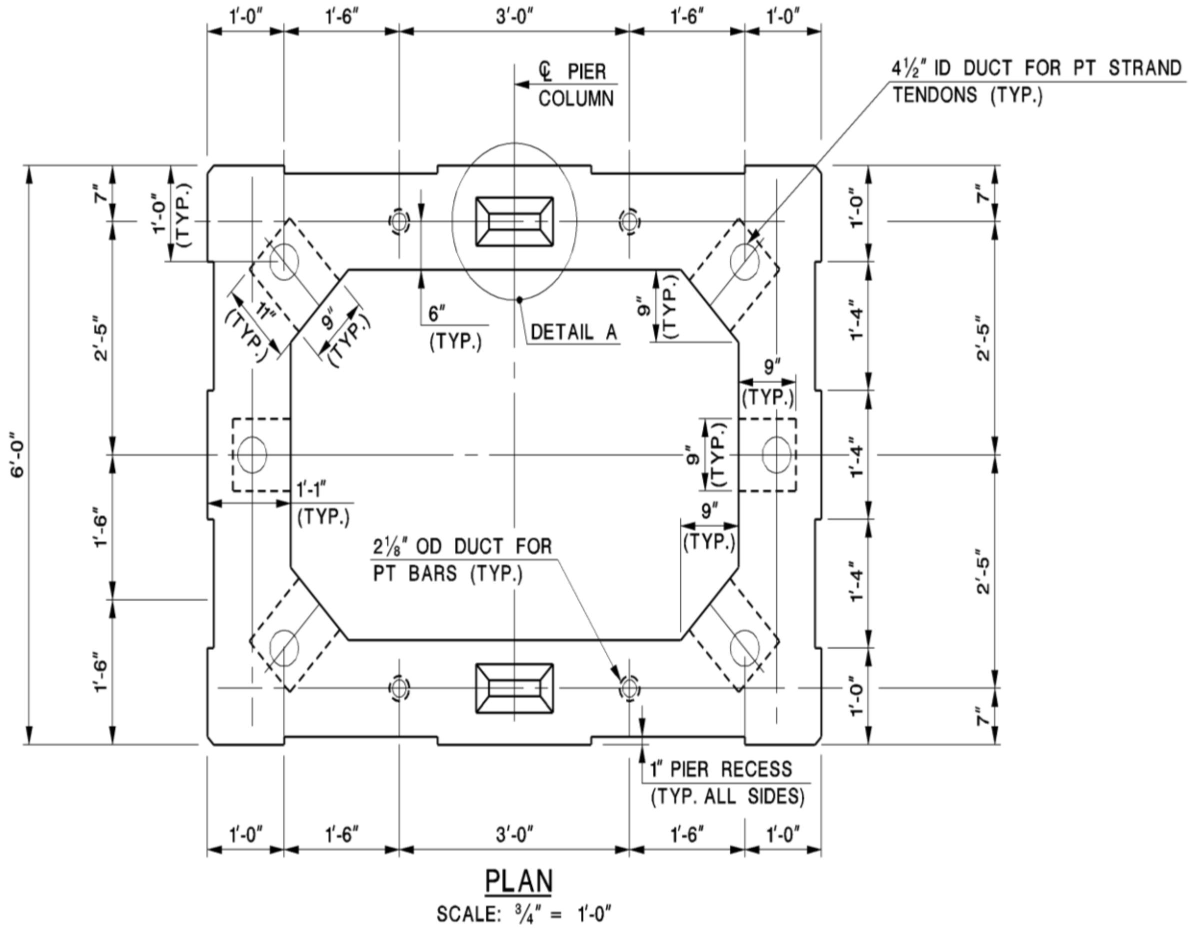

Figure 6: Typical Column Section

3.2 Design of Pier Footings

The cast-in-place concrete footings are supported on either cast-in-place concrete drilled shafts or steel H-Piles. Column segments are placed on a 6" deep recess at the top of the footing. The pre-stressing rods are anchored in the footing. The pre-stressing strands loop in and out of the footing. Rigid steel pipes are placed in the footing for this purpose. Two grout tubes are provided per pre-stressing duct. The footing is designed for bending and checked for shear. In addition to flexural reinforcement, temperature and shrinkage steel is provided. Figure 7 shows a typical footing. In Figure 7, the rigid steel pipes for the pre-stressing strands, pre-stressing rods, and the grout tubes are shown. The normal footing reinforcement is not shown for clarity.

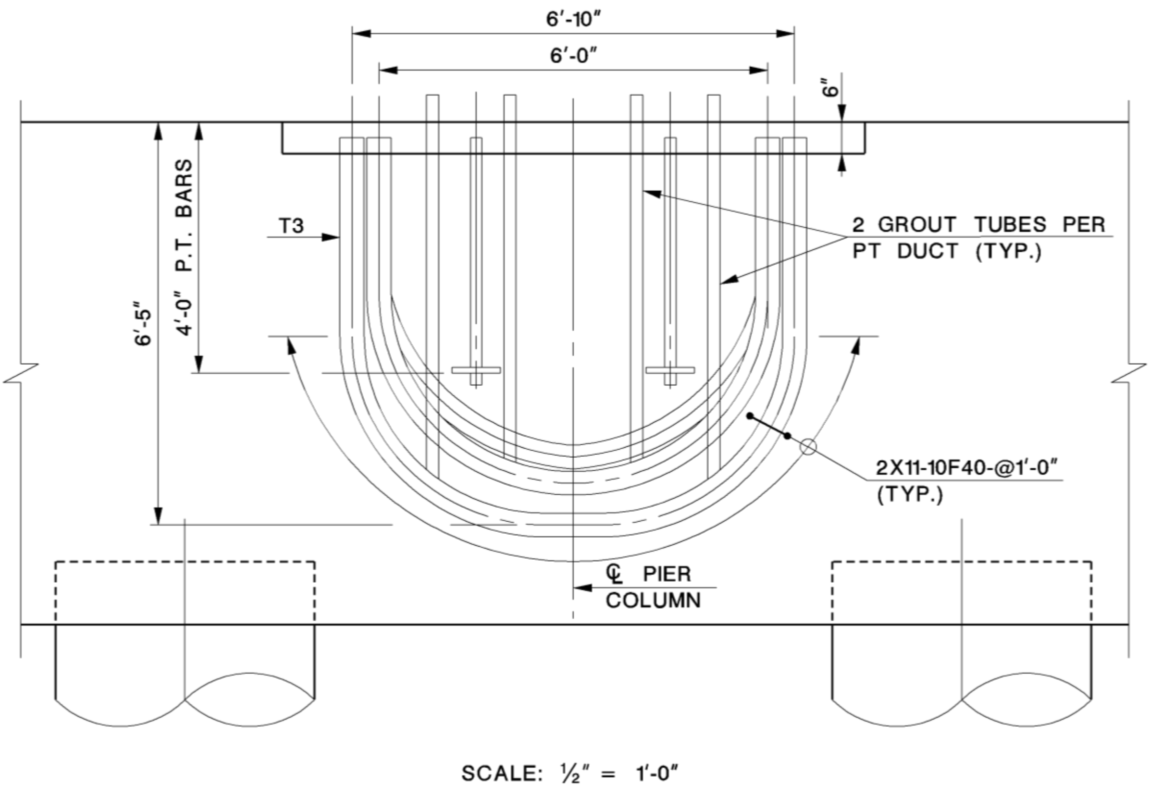

Figure 7: Typical Pier Footing

4. Pier Construction

The major steps in the pier construction sequence are as follows:

1. Place the rigid pipes, embedded pre-stressing rods, and reinforcing bars in the footing and pour the footing concrete.
2. Place the bottom segment and couple the pre-stressing rods with rods embedded in the footing.
3. Apply epoxy to top joint of the bottom segment and place the next segment coupling the pre-stressing rods.
4. Apply epoxy to top joint of the previous segment and place the next segment coupling the pre-stressing rods. Stress pre-stress rods such that each joint is provided with a minimum compression of 40 psi.
5. Repeat step 4 until entire column is assembled.
6. Install pre-stressing strand tendons. Stress vertical tendons at both ends. Fill the blockouts on bottom segment with an approved grout mix. Seal and grout the strand tendon ducts and the anchorages.
7. Seal and grout the pre-stressing rod ducts and the coupler recesses.
8. Apply permanent end anchor protection.

5. Conclusions and Recommendations

- The spreadsheet developed for the design of post tensioned segmental straddle bent type pier columns for this project was very useful given the different limit states to be considered, the different conditions to be checked, and the number of piers to be designed.
- Expensive and complicated computer programs are not required to design these piers as demonstrated by the efficient use of the Excel Spreadsheet. It is evident that post tensioned segmental straddle bent type or hammerhead type piers can be routinely designed in a mainstream design office.
- This type of piers can be built rapidly and are especially suitable for new and rehabilitation projects in areas with high traffic volumes.
- It is hoped that more post tensioned segmental straddle bent type or hammerhead type piers are used in bridge projects reducing disruption to traffic by expediting construction, lowering costs, minimizing environmental issues such as pollution, and enhancing safety and quality control.

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