CASE STUDY: REPLACEMENT OF THE BAYONNE BRIDGE PRECAST SEGMENTAL APPROACH STRUCTURES

Chester Werts, PE, SE, P.Eng, HDR, Olympia, WA

ABSTRACT

As part of the Port Authority of New York & New Jersey's Bayonne Bridge Navigational Clearance Program to increase the navigational clearance over the Kill Van Kull to 215 ft. and provide access for the next generation of post-Panamax container ships, more than two miles of precast concrete segmental bridge are being used to replace the aging steel approach bridges and connect to the new elevated roadway on the main span arch 65 ft. above the existing roadway. Both superstructure and substructure include precast concrete segments erected in place and post-tensioned to provide accelerated bridge construction. High strength concrete with 10,000 psi compressive strength is used to minimize weight for the superstructure, and segment weights are limited to 112 tons. The new precast Bayonne approach structures consist of twin, single-cell, segmental bridges, constructed in balanced cantilever in stages, starting with the northbound structures while maintaining traffic in both directions on the existing structure. Precast superstructure segments vary in both width and depth, and precast substructure segments vary as well to form tapered piers with classic aesthetics that match the architecture of the existing structure. In addition, future light rail has been designed to be included on the southbound bridges. There are approximately 1,100 precast superstructure segments and 500 precast substructure segments to construct a total of 52 spans. In order to improve performance for the 100-year service life of the bridge, precast concrete was designed for zero tension stress under service loads.

Keywords: Accelerated Bridge Construction, Concrete, Construction, Innovative Solutions, Post-Tensioning, Precast Substructure, Segmental Bridge

INTRODUCTION

With more than two miles of bridge structure to be constructed as part of the approach bridge replacement for the Bayonne Bridge Navigational Clearance Program, precast concrete proved to be an excellent choice on this multi-faceted project. Precast concrete segmental construction is effectively being used on both the balanced cantilever superstructure and the piers and pier caps. Hollow precast segments are utilized at all 24 of the 2-column pier locations (see Fig. 1 & 2), as well as the post-tensioned precast pier cap segments, for a total of 512 precast substructure segments. Precast segmental construction is utilized for all 52 spans of the NY & NJ approach superstructures (see Fig. 1 & 2), for a total of 1079 precast superstructure segments. All design was performed in accordance with AASHTO LRFD Bridge Design Specifications, 6th Edition, 2012[1].

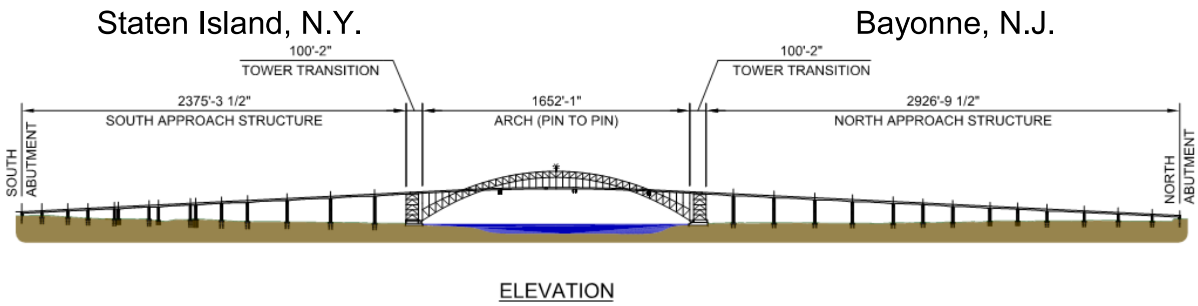


Fig. 1 – Complete Bridge Elevation

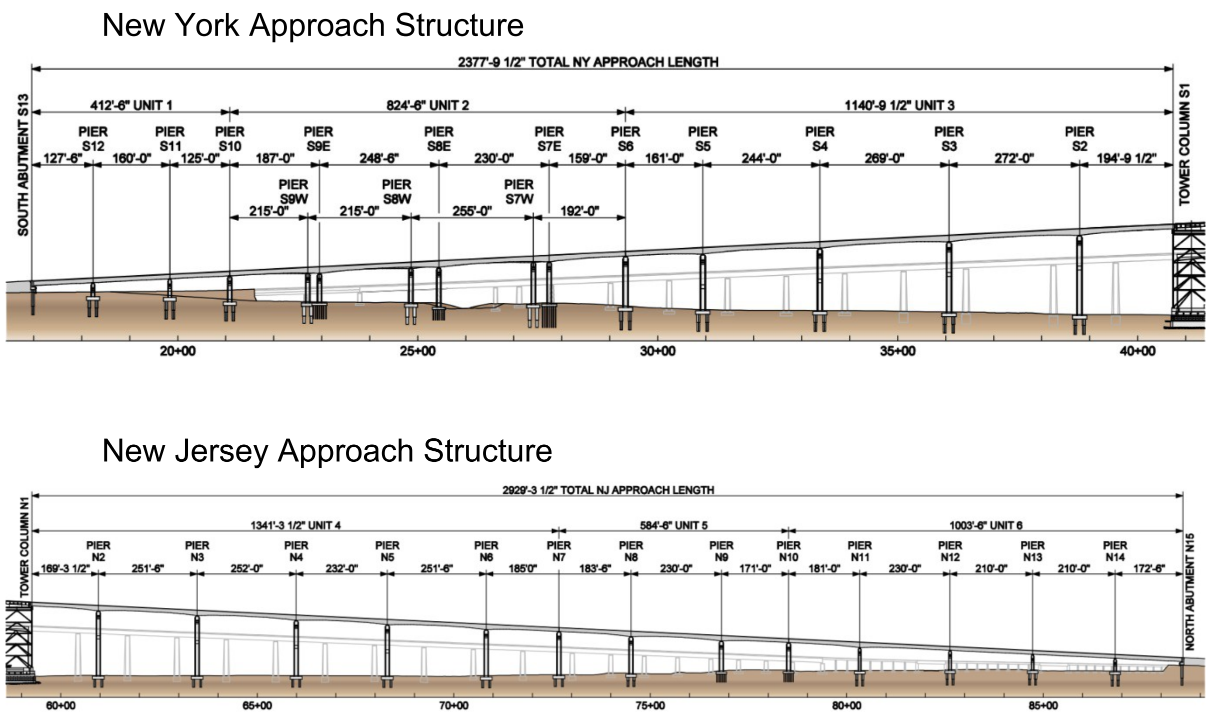
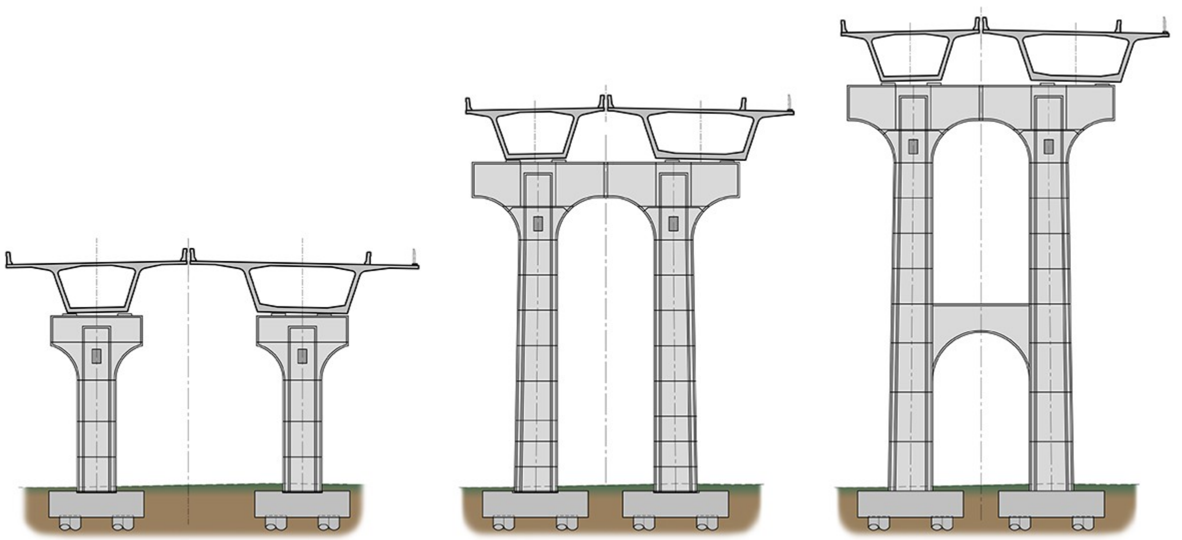


Fig. 2 – Approach Structures Pier Layouts

HOLLOW PRECAST COLUMNS

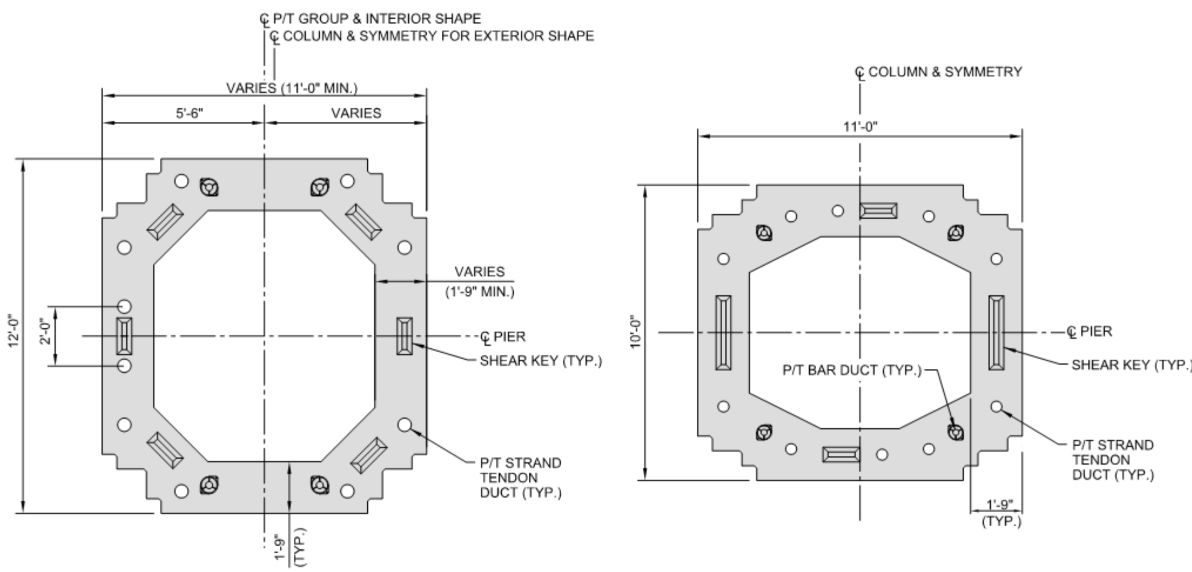
Hollow precast columns and arched precast pier caps were designed with aesthetics and architectural edge treatments included to complement the existing architecture of the original 1931 Bayonne Bridge. All precast column segments are erected in place with the use of mobile cranes. Precast columns are divided into two groups. Where the structures include a typical 36-ft. wide roadway template, a combined Type 1 - 2-column pier is used (see Fig. 3) and Type 1 column sections (see Fig. 4) are included. In the areas adjacent to the abutments on either end of the bridge, where the acceleration and deceleration lanes add up to an additional 12 ft. to the roadway template, two Type 2 single column piers are used (Fig. 3) and Type 2 column sections (Fig. 4) are included.



Single Pier (Type 2) Combined Pier (Type 1) Combined Tall Pier (Type 1)

Fig. 3 – Precast Column Pier Types

It should be noted that for the Type 2 single piers (Fig. 3) the centerline of box is concentric to the centerline of column on both the Northbound (NB) structure on the right and the Southbound (SB) structure on the left. The post-tensioning (PT) for these columns is then doubly symmetric for the Type 2 column section (Fig. 4). On the other hand, the Type 1 combined piers (Fig. 3) are laid out such that the SB centerline of box is concentric with the associated left Type 1 column section, but the NB centerline of box is eccentric to the associated right Type 1 column section. This occurs due to the wider NB structure, which accommodates an additional 12-ft. wide shared use path and a pedestrian barrier. It was not possible to locate the NB superstructure centered over the NB columns because of the location of the existing superstructure edge girder that remained in place during the first stage of construction, which restricted the location of the NB columns. The edge girders, floor beams and a majority of the deck slab were required to remain in order to maintain two lanes of traffic during the entire construction duration, per the project design criteria. During staged construction, the NB Type 1 piers were constructed first without being connected to the SB pier caps and the loading of the superstructure was eccentric to the centerline of column by approximately 7.7 ft. This eccentricity is significant because the NB structures are supported on eccentric, cantilever piers. Eccentric PT must then be used (Fig. 4) both to resist overturning moments and to mitigate lateral displacement during construction. This intermediate stage is shown in the As-Bid Northbound Column in Figure 8 below.



Type 1 Column Section Type 2 Column Section

Fig. 4 – Precast Column Sections

Geometry of the column sections were designed to match the original architecture of the 1931 Bayonne Bridge piers, while providing an efficient structural section that could be cast, transported and erected as expeditiously as possible. Both precast column type sections included hollow walls with minimum 1 ft., 9 in. wall thickness. Type 2 columns are prismatic while the Type 1 columns include an outside wall taper of 1:60 along the length of the column. All reinforcement is epoxy coated ASTM A615 Grade 60 and an 8,500 psi concrete mix was chosen to provide the required compressive capacity for the tall piers. Column PT is comprised of two different types for erection and for final service condition loads. High strength 150 ksi PT bars are used during segmental erection of the column segments to provide the required minimum average compression of 40 psi for epoxy squeeze and to provide resistance to lateral loads, such as construction wind, while the column is being erected. These PT bars are generally located in the four corners in a doubly symmetric pattern (Fig. 4). The bars are stressed after each successive segment is erected, including the pier cap segments at the top of the pier (Fig. 5). Once the column and pier cap have been erected to the top of cap elevation, 270 ksi PT strands are placed into the longitudinal vertical tendon ducts which are looped and anchored into the concrete foundations at the base. These loop tendons are then double-end stressed from the top of the pier (Fig. 5). As noted previously, the Type 1 columns for the NB structures include additional eccentric PT tendons to resist loads due to the eccentric dead and live loads from the superstructure. Since these additional tendons are spaced only 2 ft. apart (Fig. 4) it is not possible to form a 180-degree loop at the bottom. Instead, these eccentric tendons include an approximate 90-degree bend anchored in the footing and the lower anchorage for these tendons is located in the side face of the footing (Fig. 5).

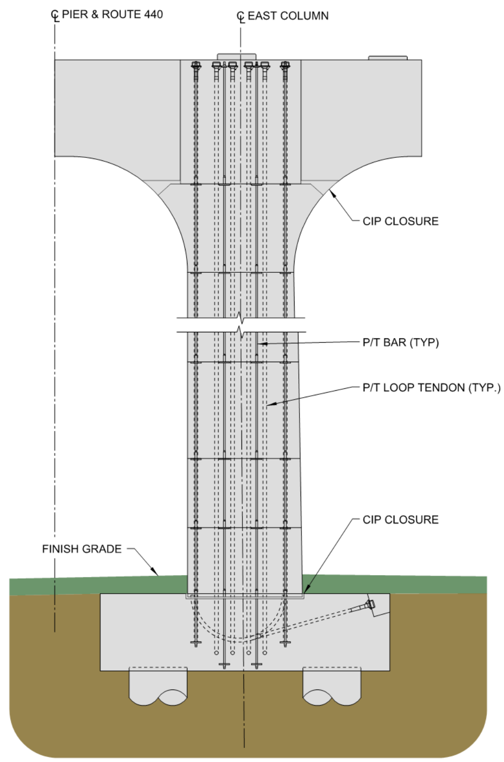


Fig. 5 – Precast Column Longitudinal Post-Tensioning

This eccentricity on the NB structure proved to be challenging both during design and during construction of the superstructure. The total amount of eccentric PT included was limited by the temporary condition following pier PT and erection of the superstructure pier table segments. During this stage, the gantry is launched forward onto the pier and in position ready for balanced cantilever construction. If the pier PT is designed to balance the final dead load effect of the eccentric superstructure, then at this early stage there is a surplus of eccentric PT. If this overturning of the pier due to PT is then combined with a construction wind load, using the sail area of the gantry and a relatively small axial load, then a critical design condition for the substructure may occur during the construction of the superstructure. In addition to the design implications of the eccentric PT, the construction implications also had to be considered. Following the stressing of pier PT, the piers generally are not loaded with superstructure loads for two to six months if the piers are not on the critical path.

During this time, the pier concrete will creep and additional lateral transverse movement due to the PT will occur. Both the elastic and creep deflection of the pier to the west, together with the superstructure dead load deflection of the pier to the east, must be considered when accounting for the transverse pier camber and initial setting of the superstructure pier table segments. Per the project design criteria included in the Contract Drawings, creep and shrinkage strains are computed using the CEB-FIP Model Code for Concrete Structures, 1978 Version[2]. Although service level stresses were checked using the 1978 version of the CEB-FIP Model Code, it is permitted during construction for the contractor's construction engineer to utilize the CEB-FIP Model Code for Concrete Structures, 1990 Version[3], for geometry control.

PRECAST PIER CAPS

Accelerated bridge construction of the substructure extended through to the top of the piers with precast pier cap segments. These pier caps are erected following the top flared "pier capital" segment of the column. All precast pier cap segments are erected in place with the use of mobile cranes. As mentioned previously, the piers are divided into two types; Type 1 pier caps with combined 2-column piers are larger and consist of three separate segments (Fig. 6) in order to satisfy weight limitations. The center C1 segment includes all vertical longitudinal PT, while the other two segments, C2 & C3, include and are erected using transverse PT. In addition, there is also a relatively small pour back in each top corner of the pier capital segment for this type. These small triangular pourbacks were reinforced with embedded #6 u-bars in each of the adjacent segments to mitigate potential spalling and improve the integrity of the pour. The transverse PT was designed to accommodate the vertical reactions from the bearings, as well as the self-weight of the pier caps. Following the construction of the SB structures, the two Type 1 pier caps are joined by casting the concrete closure pour between the two pier caps, then stressing a pair of PT tendons transversely along the length of the combined cap (Fig. 6).

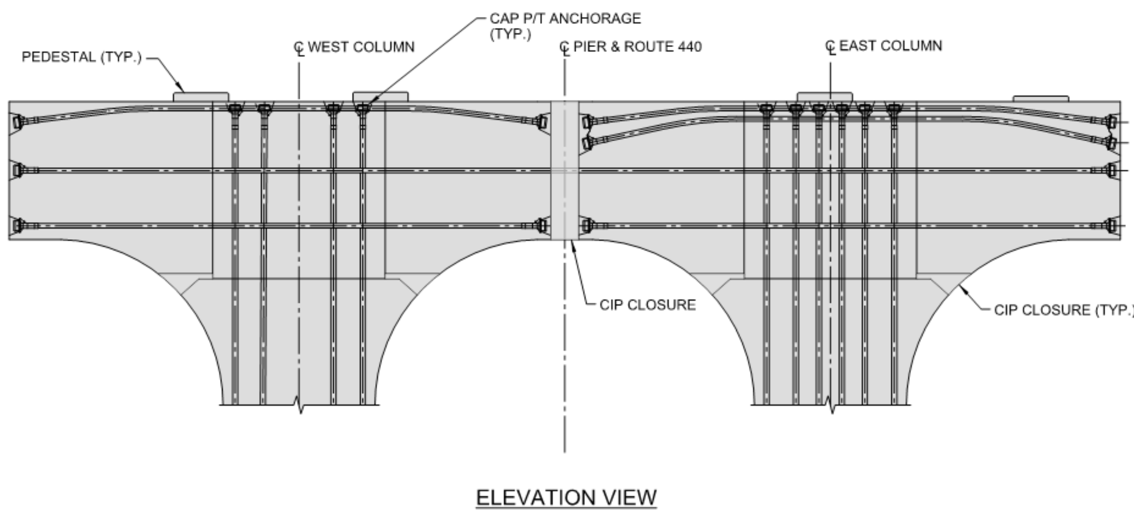


Fig. 6 – Precast Pier Cap Type 1

Type 2 pier caps (Fig. 7) are generally smaller that the Type 1 pier caps and therefore can be accommodated as a single precast segment that includes all vertical longitudinal pier PT without the need for any transverse PT. Pier cap segments are similar to column and superstructure segments in that they are temporarily stressed using four PT bars and the segments have shear keys located around the perimeter of the segment for alignment and for shear during construction.

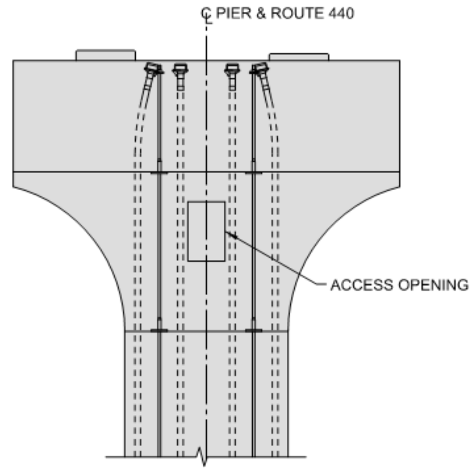


Fig. 7 – Precast Pier Cap Type 2

NORTHBOUND TYPE 1 PIER CONSTRUCTION

Final design, as-bid Contract Drawings for the Bayonne Bridge approaches included a sequence for construction of the tall Type 1 piers that utilized cast-in-place (CIP) construction for both the bottom portion of the SB and NB columns up to the top elevation of the cast-in-place intermediate concrete cross beam (Fig. 8). The top of the intermediate cross beam was located under the existing structure that remained in place during NB structure construction. This intermediate cross beam was included in the tall Type 1 piers for providing stability during construction of the NB piers and reducing the overall lateral moments in the columns during construction and through the service of the bridge. It should be noted that since the bridge project is being constructed in stages to maintain two lanes of traffic during the duration of the project, traffic will be moved onto the NB structure and it will be more than a year before the SB structures are constructed and the closures are made for the 2-column Type 1 piers.

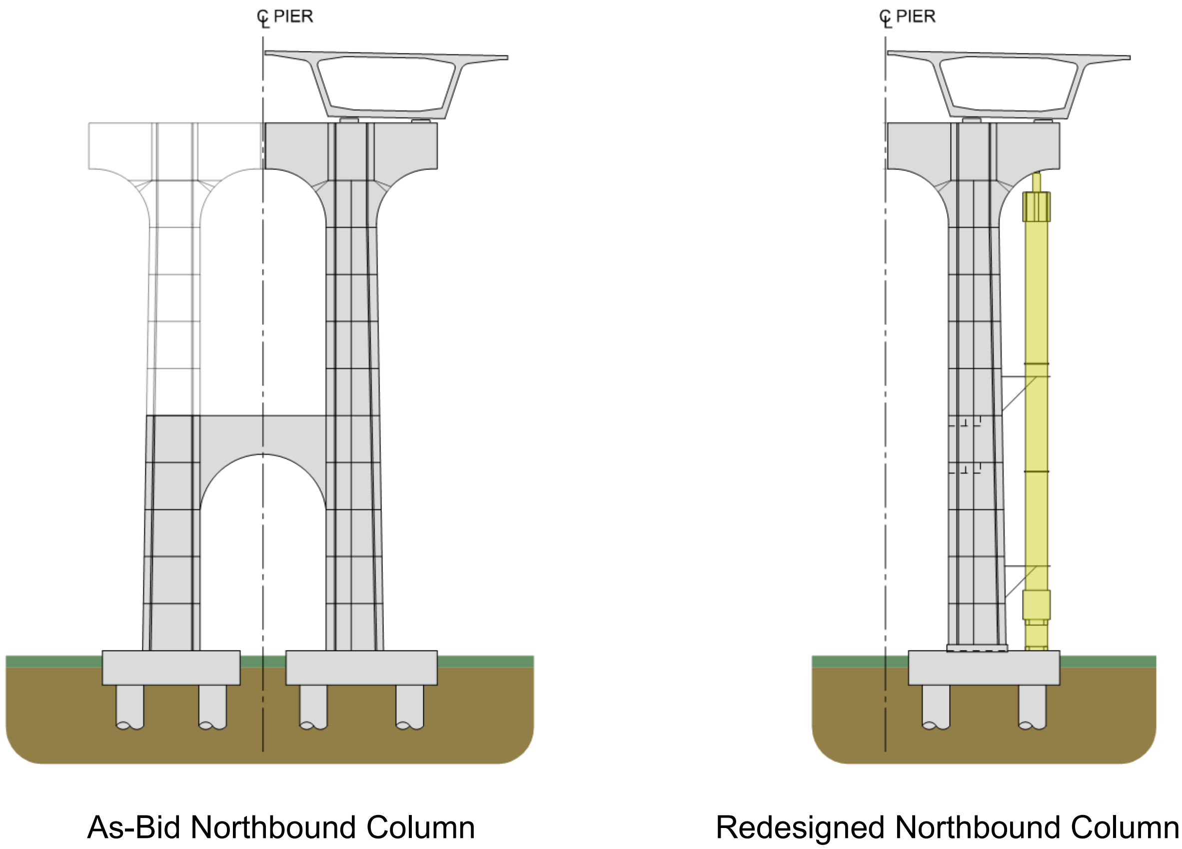


Fig. 8 – Redesigned Tall Type 1 Pier to Fully Precast Column

After the construction contract was awarded and construction was underway, a joint effort was made between the contractor, the engineer of record and the owner to develop a modified construction sequence that would expedite the construction schedule for the substructure and therefore the entire approach structures. Through this team collaboration, an innovative construction procedure was adopted that would allow the entire NB Type 1 pier to be constructed independently without the need for the intermediate cross beam until construction of the SB column. The concept included changing the construction of both the NB and SB piers to be fully precast construction, and to use a temporary steel pipe compression strut under the east hammerhead cantilever of the NB pier cap to mitigate transverse overturning moments and transverse lateral deflections during construction (Fig. 8). The steel pipe struts are included at four piers on the NB New York approach structure and at six piers on the NB New Jersey approach structure. Pier N7E was determined not to require a steel pipe strut because the lower bearing reactions at this expansion joint pier did not have the same overturning demands due to the superstructure eccentricity, and because there was not an appreciable increase in lateral transverse movements of the same magnitude as the adjacent piers.

This change to fully precast pier segment construction allowed for a savings in construction time following the completion of the foundations. Fully precast substructure allowed for decoupling the construction of the SB roadway foundations from the Milestone 1 opening of the NB roadway and saved the contractor considerable time in schedule. It should be noted that the design change associated with this modification had to be carried fully down into the foundations, since the PT at these piers would now be anchored into the foundations similar to the shorter Type 1 piers and the Type 2 piers. Additionally, in order to better accommodate the axial forces from the steel pipe strut, the east drilled shafts at these locations were shifted outboard of the NB piers to match up closer with the pipe strut location (Fig. 8). These changes were made early in the project before the drilled shaft construction had begun at the Type 1 pier locations.

A reinforced CIP “starter pour” 16 in. high was added to the base of the precast columns for better construction tolerance. This starter pour was used to provide small geometric adjustments to achieve the required camber at the top of the pier. Three jacks were installed underneath the first two pier segments and the direction of the pier column was then adjusted to account for the required camber effects. Three permanent steel bolsters were inserted with shims and the temporary jacks were then removed. The concrete for the CIP starter pour was then placed, permanently setting the proper course for the subsequent pier construction. Further adjustments were achieved using thin extruded steel shims between segments as required.

Lastly, the design of the intermediate cast-in-place concrete cross beam was changed to steel frames with precast concrete panel cladding to further accelerate the construction schedule during SB structure construction. This last change essentially eliminated all cast-in-place construction above the footings for the approach structures.

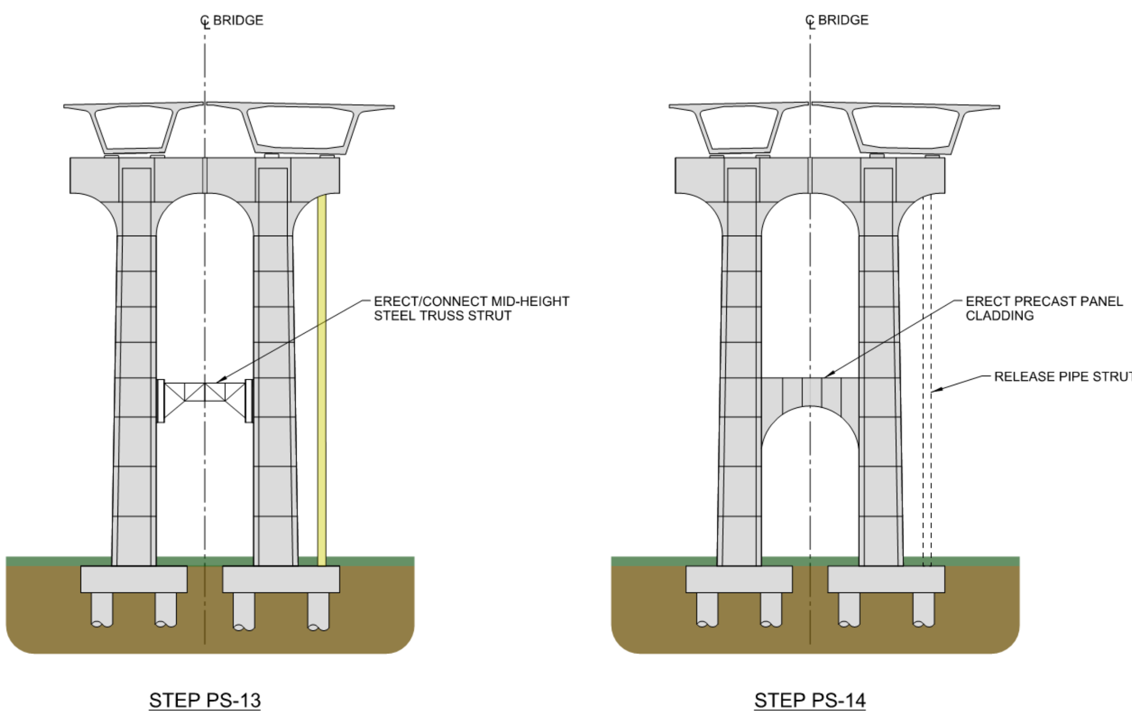


Fig. 9 – Intermediate Cross Beam Construction

PRECAST BOX GIRDER SUPERSTRUCTURE

Nearly 1,100 precast concrete segments are being used to construct more than two miles of segmental concrete approach roadway. The lengths of the precast segments vary from the minimum precast segment length of 7 ft. to the maximum typical segment length of 10 ft., 9 in., and are limited in weight to approximately 112 tons. The precast superstructure consists of twin, side-by-side, single-cell, box girder bridges as rendered in section below (Figure 10).

Fig. 10 – Twin Side-by-Side Precast Box Girders

There are a total of 52 spans, both haunched and constant depth, that are erected using balanced cantilever construction. Span lengths vary from as little as 125 ft. to as great as 272 ft. (Fig. 2). For aesthetics, longer haunched girder spans are located closer to the main span arch and shorter spans with constant depth are located closer to the abutments. In general, all spans that are 210 ft. or less in length have a constant depth box of 10 ft. and all spans that are greater than 210 ft. in length include a haunched box with a depth of 14 ft. at the pier and 10 ft. at the mid span. These box girder sections vary in both depth and width in various locations. Both structures include a typical roadway width of 36 ft. that increases up to 48 ft. near the abutments to accommodate the acceleration and deceleration lanes. In addition to the roadway, the NB structure also includes a 12-ft. wide Shared Use Path (SUP). To accommodate this additional deck width, the NB structure box is 8 ft., 6 in. wider than the SB structure box and each of the NB cantilevers is 2 ft., 7in. longer for the typical section width. A split view of each of the structure sections is shown in Figure 11 with the maximum pier depth of 14 ft. shown on the left of centerline of box, and the mid span or constant depth of 10 ft. shown on the right. Bottom slab fillets were included for the wider NB box, but were not required for the SB box girder. Both box girders included webs with a 3:1 slope to mitigate the weight of the section at mid span and add to the visual aesthetic of the profile of the structure. The deck fillets on either side of the webs were held constant to simplify formwork and widening of the deck slab was accommodated solely through the lengthening of the constant depth portion of the cantilevers on either end. In addition to the utilities racks, which are contained inside of each of the box girders, there is also a fire standpipe supply line inside the NB box girder and drainage pipes supported by the cantilevers of each of the structures, as well as a suspended maintenance catwalk that spans the entire length of the NB structures.

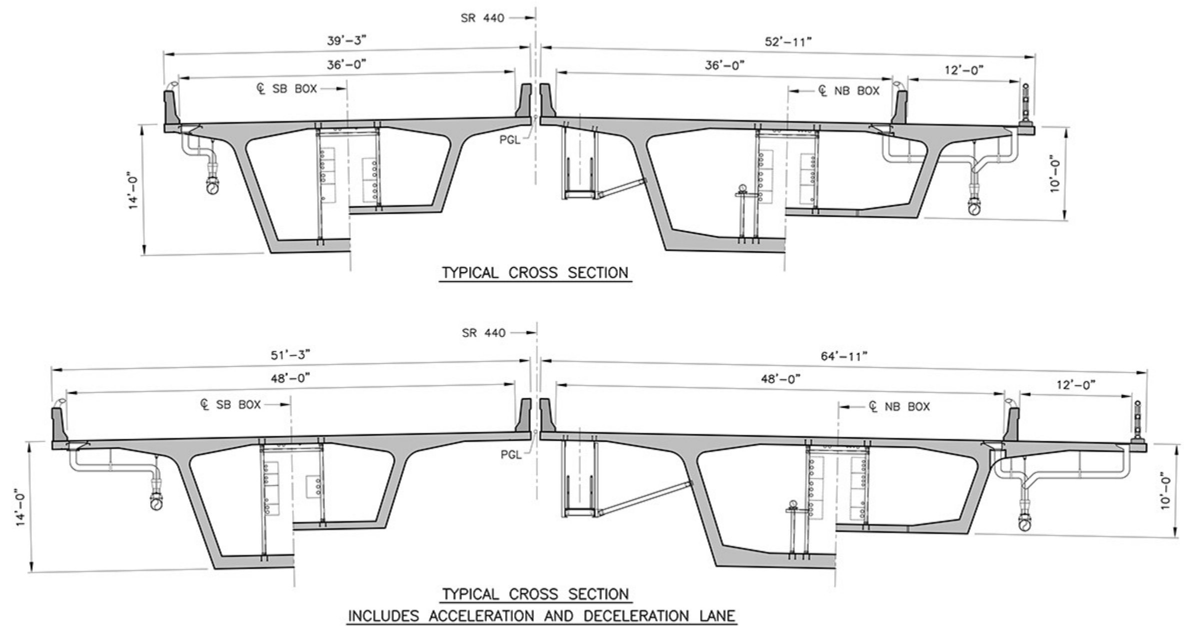


Fig. 11 – Typical Cross Sections for Typical and Varying Width

The typical single-cell box girder is one of the most common sections used in segmental concrete construction due to its construction simplicity and structural efficiency. The thickened deck fillets on either side of the web provide ample room for the longitudinal cantilever tendons and structural capacity for negative transverse deck moments (Fig. 12). As stated previously, the additional deck width is provided by simply extending out the 10.5 in. thick constant depth cantilever slab. Transverse PT is provided in the deck slab at approximately 27 in. spacing using 4-0.6 in. strand tendons. The maximum number of strands is required for the longer cantilevers, while only 3-0.6 in. strands are required for the shorter cantilevers where positive moment between the webs governed the design stress check. Tension stresses were limited to zero tension for longitudinal stresses and 0.095*sqrt(f'c) for transverse stresses per AASHTO LRFD Table 5.9.4.2.2-1[1]. As with all balanced-cantilever, segmental concrete construction, the time-dependent effects of concrete play a significant role in the redistribution of forces and the final dead load stresses that exist in the structure. Per the project design criteria included in the contract drawings, creep and shrinkage strains and the resulting stresses are computed using the CEB-FIP Model Code for Concrete Structures, 1978 Version[2]. The reduced effects of creep and shrinkage and high quality of precast construction are two of the reasons that precast concrete was chosen to be used to support a structure with a 100-year design life. Future loading on the structure included Light Rail Transit (LRT) located on the west side of the SB box. For the widened deck slab, LRT loading on the SB box governed both the transverse deck design and the shear and torsion design of the webs.

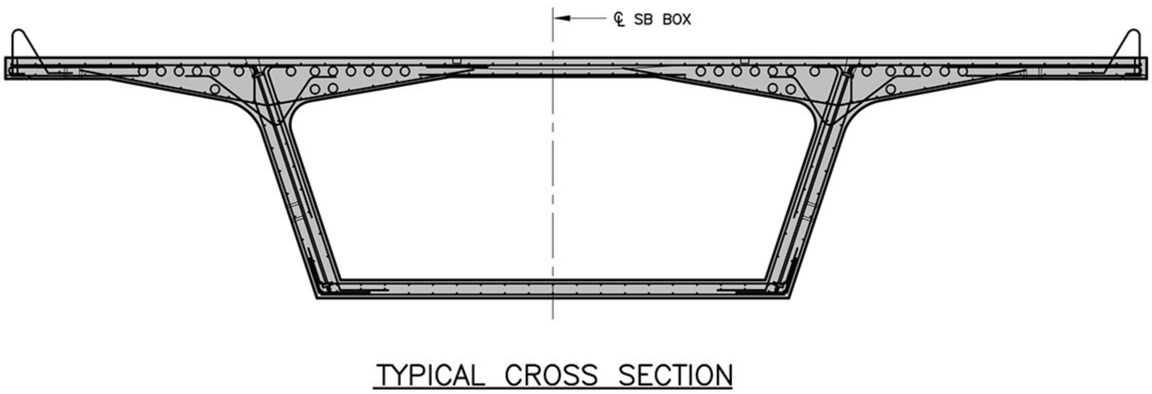
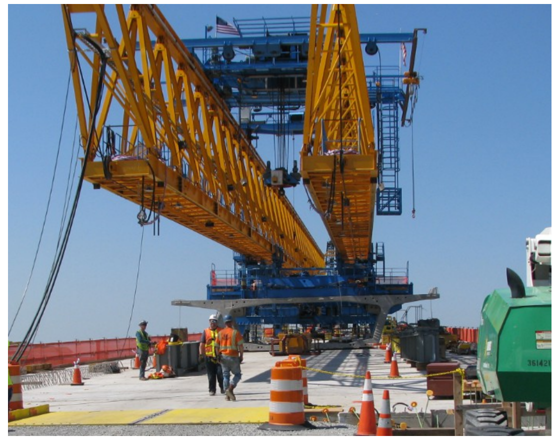


Fig. 12 – Typical Southbound Cross Section Detail

In order to mitigate the dead load effects on the structure by minimizing the dimensions of the webs and soffits, 10,000 psi concrete was used on all precast superstructure segments. This also allowed slightly higher limits for transverse tension stresses and principal stresses in the webs. In some locations where the principal tension stresses in the webs were high, vertical PT bars were required to meet the stress limits. ASTM A955 Grade 75 stainless steel reinforcement was required per the project design criteria for all reinforcement that was included in the top slab and haunches, and all reinforcement that was anchored into the top slab as well. Therefore, all web reinforcement was 75 ksi stainless steel and this additional strength was utilized as allowed per AASHTO.

PRECAST SPLIT PIER SEGMENTS

Precast concrete is used for the superstructure pier segments as well. All precast pier table segments are erected in place using mobile cranes, with the pier table consisting of the pier segment, or segments, and the first up-station and down-station typical segments on either side. All other typical segment erection is performed using an overhead gantry crane.



Mobile Crane Overhead Gantry

Fig. 13 – Crane Types for Segment Erection

The advantage in using precast concrete for the pier segments is the speed of construction that is allowed without waiting on concrete curing time to proceed with PT stressing. The challenge in using precast concrete is that the pier segments are the deepest segments on the bridge and they include pier diaphragms that add substantial additional weight to the segments such that it is difficult to meet the precast weight limitations. There are two common precast alternatives that may be used in this situation where weight limitations are exceeded:

1. Precast Pier Segment with Cast-in-Place Diaphragm – This alternative is a compromise between fully precast segment and a fully cast-in-place pier table. It allows the erection to proceed at a reasonably fast pace; however, time must still be taken to tie the diaphragm reinforcement, build the forms, pour the diaphragms and allow the concrete to cure before any substantial loads can be applied to the diaphragms.
2. Precast Split Pier Segments – This alternative essentially divides the pier segment into two and splits the diaphragm into two as well, allowing a smaller diaphragm to be included in each half segment and therefore reducing the overall weight by nearly 50%. This alternative allows the fastest speed of construction, albeit with a small overall gain in concrete weight for the two segments and the addition of horizontal PT bars required for clamping the two precast split pier segments together during construction.

Two precast split pier segments 5 ft. in length were used for the 14-ft. deep piers as shown in Figure 14. Weight limitations were not an issue on the 10-ft. constant depth piers, and single pier segments 6 ft. in length were used at these locations.

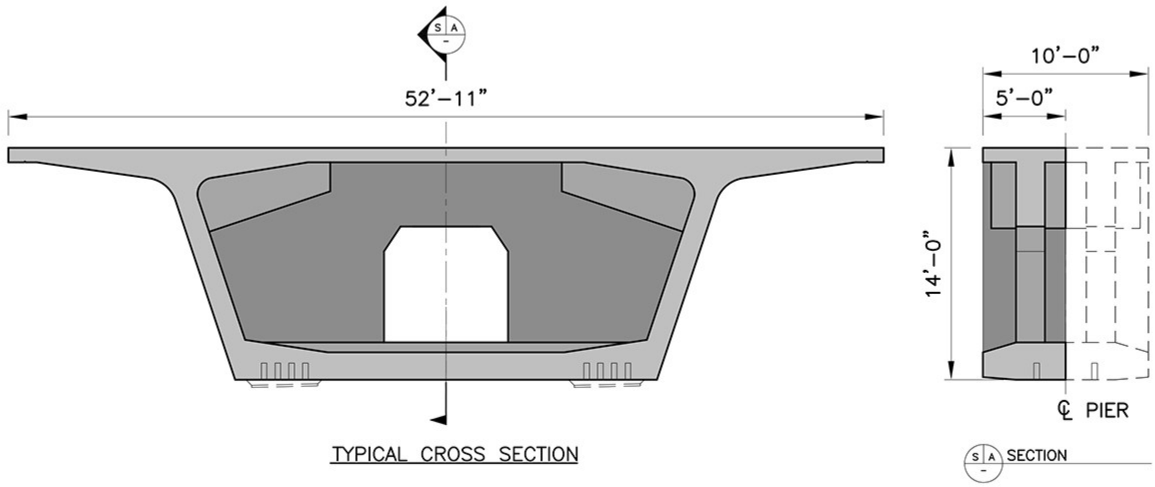


Fig. 14 – Precast Split Pier Segments

PRECAST EXPANSION JOINT PIER SEGMENTS

Another application where precast pier segments allowed for the fastest possible construction speed were at the expansion joint piers. Since the overall length of structure varied up to approximately 2,929 ft., two intermediate expansion joints were required on each of the four approach structures. Expansion joints are typically located in one of three locations on continuous concrete box girder structures: at the quarter point, at the mid span point or at the centerline of pier. The design team chose to locate the expansion joints at the centerline of pier for the Bayonne Bridge and used precast expansion pier segments to provide a construction procedure that would allow faster construction. The procedure included temporarily clamping the two expansion joint segments together and then building the short cantilever using the same general balance cantilever procedure as all of the other piers. The construction steps are as follows:

1. Erect the first expansion joint segment on temporary jacks using temporary tie-down bars for stability (similar to split piers).
2. Erect the second expansion joint segment on temporary jacks using temporary tie-down bars with a 3-in. gap in between the adjacent segment faces.
3. Form and pour the temporary 3-in. thick concrete blocks in between the two segments located as shown in Figure 15.
4. Install spacers between the down-station and up-station expansion joint segments to maintain the gap and stress four horizontal PT bars (two top & two bottom) to 30 kips each.
5. Apply bond-breaking agent and form and pour temporary CIP blocks.
6. After concrete has reached 2,500 psi strength, add two additional PT bars and stress all horizontal PT bars to 200 kips each.
7. Proceed with pier table construction similar to other locations.
8. Proceed with balanced cantilever construction similar to other locations.

9. Cast closure pour, launch gantry to next pier, build next cantilever, cast next closure pour and launch gantry forward again.
10. De-stress temporary cantilever tendons at the expansion joint location, de-stress and remove temporary horizontal PT bars, and remove all temporary CIP concrete blocks.
11. Release bearing temporary restraints.

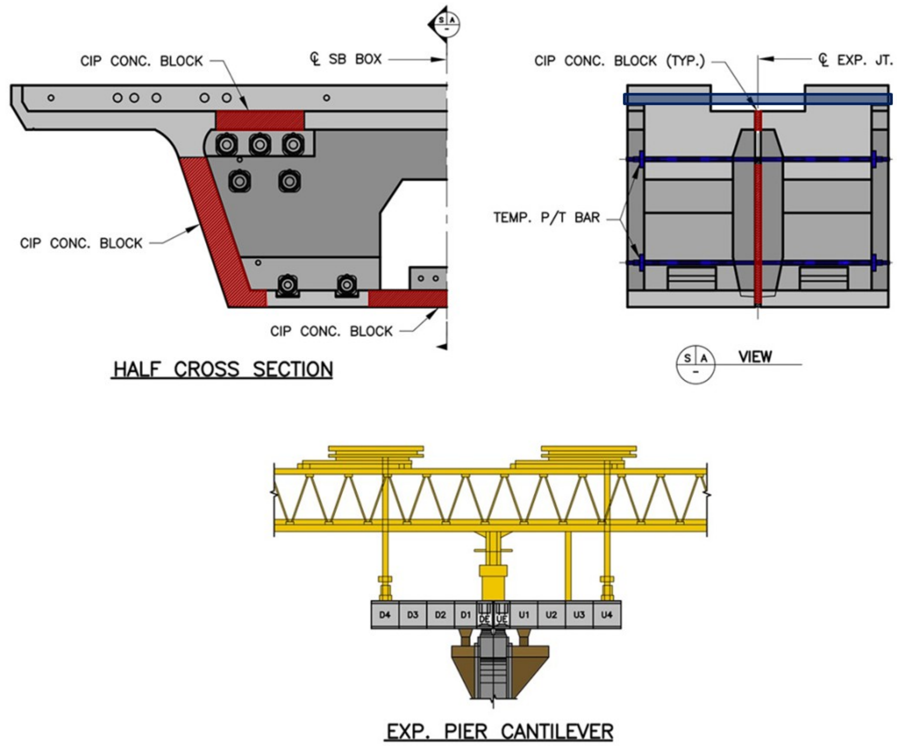


Fig. 15 – Precast End Diaphragm Segments

CONCLUSION

Precast concrete segments are effectively being used on the Bayonne Bridge approach bridge replacements to speed construction, improve quality, improve safety and reduce the overall critical path construction schedule. The use of precast pier, pier cap and superstructure segments allow for construction in a residential area to be performed much quicker and safer on-site, and reduce the overall time of construction while working in and above a residential area. Off-site fabrication is provided by a PCI certified fabricator and segments are transported to the construction site, avoiding the cost of on-site fabrication and storage. The precast fabrication is performed in Cape Charles, VA and then segments are barged to Bayonne, NJ where they are trucked to the construction site. Precasting allows for limited use of false work and reduction in construction schedule, which also limits the impact on the surrounding neighborhoods, businesses and roads in this densely populated urban setting. Design of both the substructure and the superstructure required consideration of intermediate construction stages and locked-in construction forces and displacements, using staged construction analyses. The 100-year service life requirements of the project are achieved through the use of stainless steel and epoxy coated reinforcement, high quality concrete mixes, post-tensioned concrete design with zero tension stress limits and the quality of precast concrete construction. The greater than two miles of approach structure construction and more than 1,600 substructure and superstructure segments allow for the repetitive efficiency and superior quality of precast concrete construction to be used on this epic project. As of the writing of this paper, the two NB structures have now been completed for all precast construction and traffic should be moved over onto the new elevated NB roadway in the first quarter of 2017.

ACKNOWLEDGMENTS

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Roger Haight, PE – Parsons Brinckerhoff

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