CROSSTOWN SEGMENTAL DESIGN STANDARDS

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ABSTRACT

The Crosstown Project near Minneapolis, Minnesota is employing precast, segmental concrete construction for the first time in the state. There are six curved ramps in the project, each with varying geometry. PB was tasked to serve as program manager and develop principal details (Standards) that would work for all six structures.

Standards development focused on modifying the AASHTO/PCI/ASBI standard segments to envelope the demands of the six unique ramps. Bulkhead details were developed to identify the number of shear keys, P.T. bars, and tendon ducts that would be utilized in any scenario. Tendon arrangement, blister details, deviator details and segment dimensions were standardized as well. Project specific design and loading requirements were included in the development process. Standardization provided a basis for the three consultants' bridge design efforts while enabling the use of a common casting machine set.

This paper highlights the results of a consensus building design effort amongst the three design consultants and the owner, MnDOT. It presents the more significant aspects of the development and utilization of the design standards.

Keywords: Precast, Segmental, Post-tensioning, Balanced, Cantilever, ASBI, Standards

INTRODUCTION

Just south of Minneapolis, Minnesota on Interstate 35W is the junction with T.H. 62, an east-west corridor that is currently one of the most congested stretches of interstate in the region. These two thoroughfares meet in a reverse curve junction where traffic is combined for a mile until the routes diverge again. The area is known as the Crosstown Commons and it has become notorious for its consistently high congestion levels. The Minneapolis/St. Paul metro region has seen substantial growth in the suburbs while retaining many of the employment opportunities and major attractions. The unbalanced growth has increased traffic volumes significantly, especially in the Crosstown Commons area. T.H. 62 serves commuters from the rapidly growing southwest suburbs while also providing a direct route to Minneapolis-St. Paul International Airport. I-35W traffic, while serving a vital role to North-South interstate transportation, has primarily seen its volume increased due to commuters from the southern suburbs and business areas, including the Mall of America. The combined effects of suburban sprawl, increased southern business attractions, and airport access have created congestion levels which generate economic losses, decreased safety and commuter frustration.

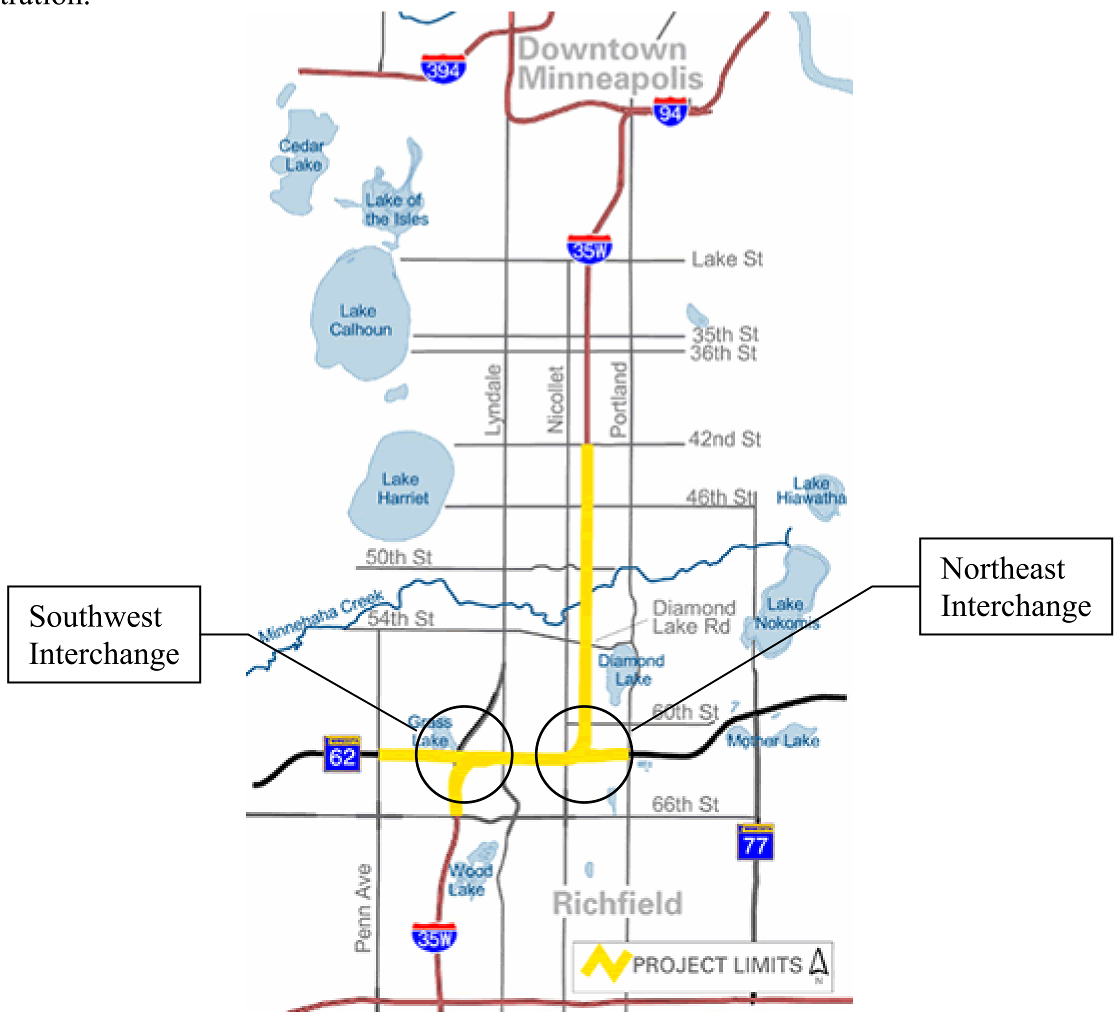

Figure 1: Project Location [1]

The Commons, originally designed in the 1960's, do not meet current traffic requirements. Increasing traffic capacity in the area today is complicated by the fact that the resultant footprint area was minimized in the original design to decrease land acquisition costs. Today's land acquisition costs play an equally important role. In addition, maintenance of traffic during construction has become an increasingly vital consideration. In fact, an early reconstruction plan that would have caused long-term construction closures was rejected because it was deemed unacceptable to a large portion of users and area residents. A new configuration was developed by PB as part of a study to identify options for reducing impacts to the traveling public which proved to be a winning compromise of increased capacity, safety, and traffic maintenance. This concept was then advanced into a type, size & location study by a local transportation consultant. The design called for six flyover ramps, three in each of the interchanges. Preliminary bridge design narrowed the flyover ramp bridge type to that of precast segmental concrete. Two cross-sections were indicated for the ramp superstructure, one for the narrow ramps and another for the wider ramps. The segmental option was chosen for its increased durability, low maintenance, and construction flexibility.

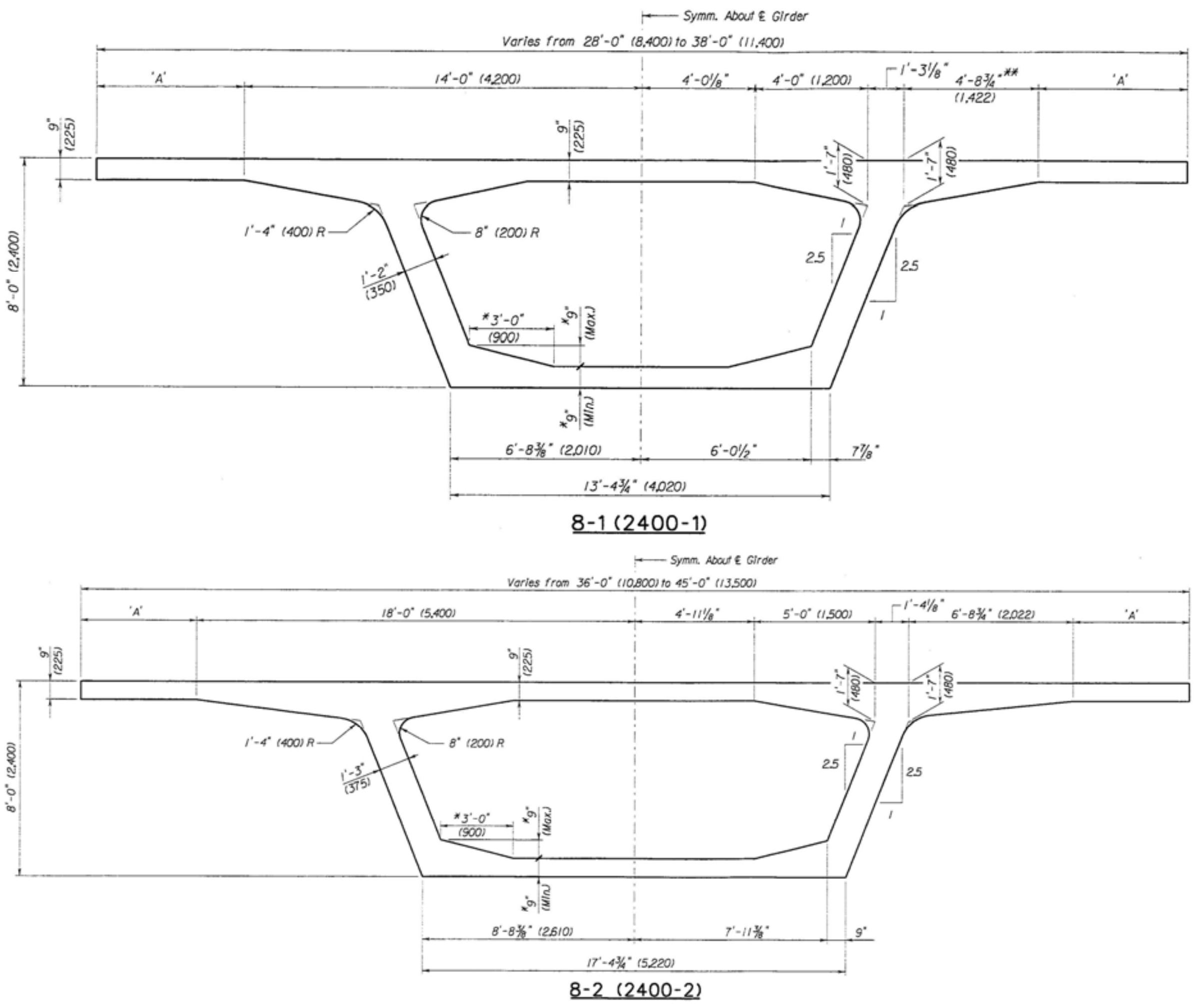

Figure 2: AASHTO Standard 8'-0" deep (2400mm) Segments

Minnesota has used segmental construction on three prior occasions (Plymouth St. Bridge - Minneapolis, Wabasha St. Bridge - St. Paul and Wakota Bridge - Newport), all of which employed cast-in-place segmental construction. However, the six Crosstown Commons bridges will use precast segmental construction for the first time in the state.

PB was one of three consultants[1] awarded bridge design contracts, each being responsible for two bridge designs. MnDOT chose to break the design package out for two reasons – to support multiple local consultants and to increase the comfort level of adopting the new structure type. PB also served as program manager tasked with developing segmental design standards for the six bridges. These standards would serve to fix principal features of the superstructure elements in order to realize savings by maximizing repeatability in the segmental precast construction. As part of the management contract PB also provided training on precast segmental design and construction to MnDOT staff and facilitated design meetings amongst the bridge consultants. PB was also charged with developing design criteria.

The six ramps varied in curvature, width, span range and overall length. Three bridge widths: 45’-4”, 43’-4” and 33’-4”, were shared by two bridges each. The main span lengths varied from 170 feet to 200 feet with a degree of curvature up to 8.5°+/-. Figures 3 and 4 show the various bridge geometrics. The assumed construction technique for the bridges is balanced cantilever construction. Design was performed using the 2004 AASHTO LRFD Specifications.

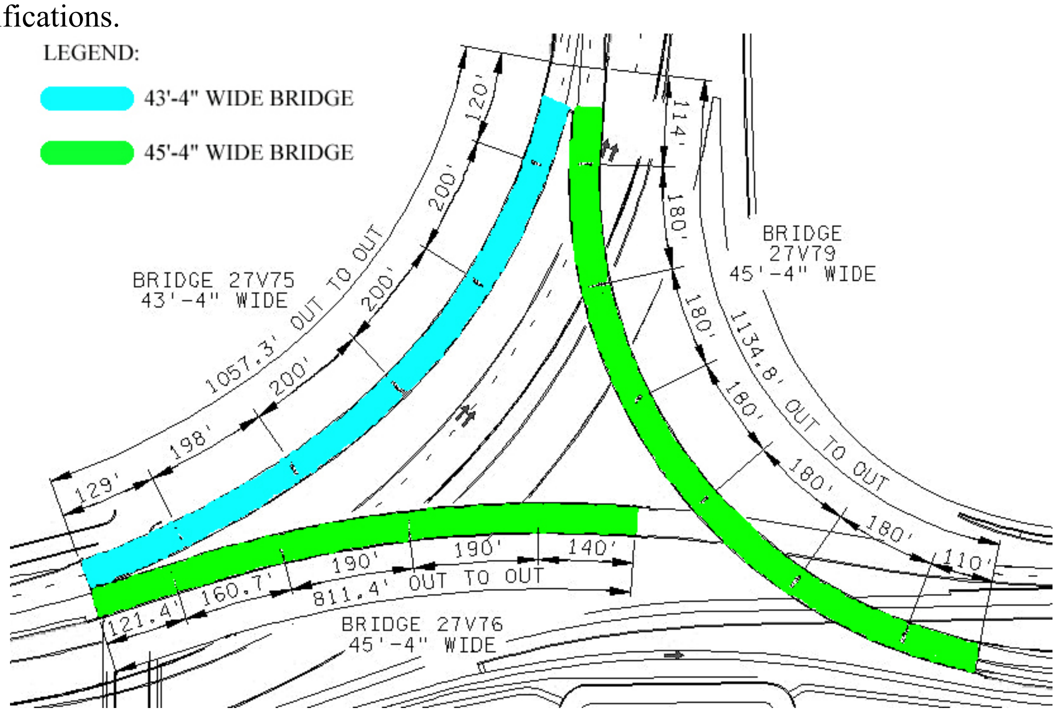

Figure 3: Northeast Interchange of Crosstown Commons

[1] Other bridge design consultants were PTG and URS. SRF served as roadway consultant and reviewed construction staging area requirements.

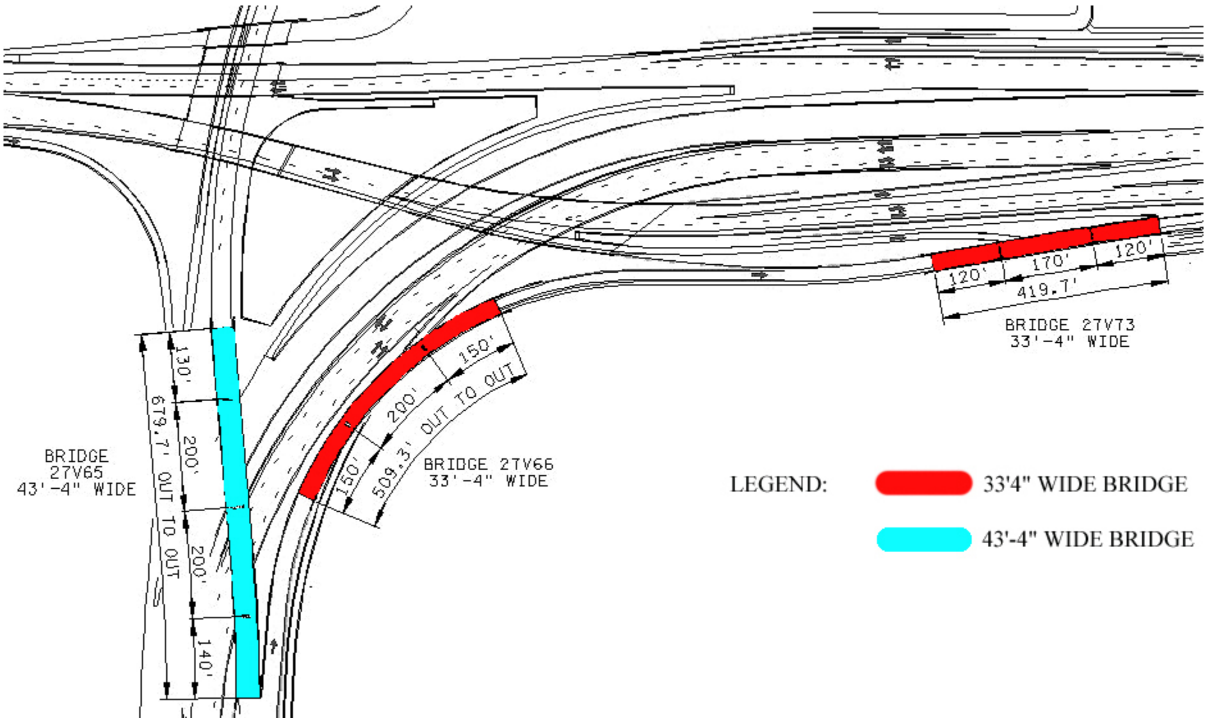

Figure 4: Southwest Interchange of Crosstown Commons

PRECAST SEGMENTAL STANDARDS

The standards developed on the Crosstown project may be grouped into several areas: Segment Shape, Standard Components, Tendon Layout standards, Standard Segment Types, and Transverse P.T. standards. These areas are often inter-related but will be examined separately for clarity.

SEGMENT SHAPE

The segment depth and shape were the first parameters addressed in the design. AASHTO has adopted box girder standards for various construction methods and span ranges. The tight geometric constraints at the site require the choice of the 8'-0" (2400mm) deep AASHTO Standard box girder in lieu of a deeper section. A review of the bridge lengths shows that there are less than 100 of the narrower deck segments, Type 8-1. This relatively low number of segments would make the investment in an additional set of casting forms dedicated to the narrower sections questionable. Studies completed prior to this time were based on the understanding that the project schedule would require 2 sets of forms to produce the segments on the demanding time line. However, for the bridges requiring the smaller cross-section (Type 8-1), such a low number of segments would underutilize the smaller forms. PB considered a special hybrid version of forms that were an intermediate size. In the end, further study showed that the AASHTO Type 8-2 could be modified to work for all

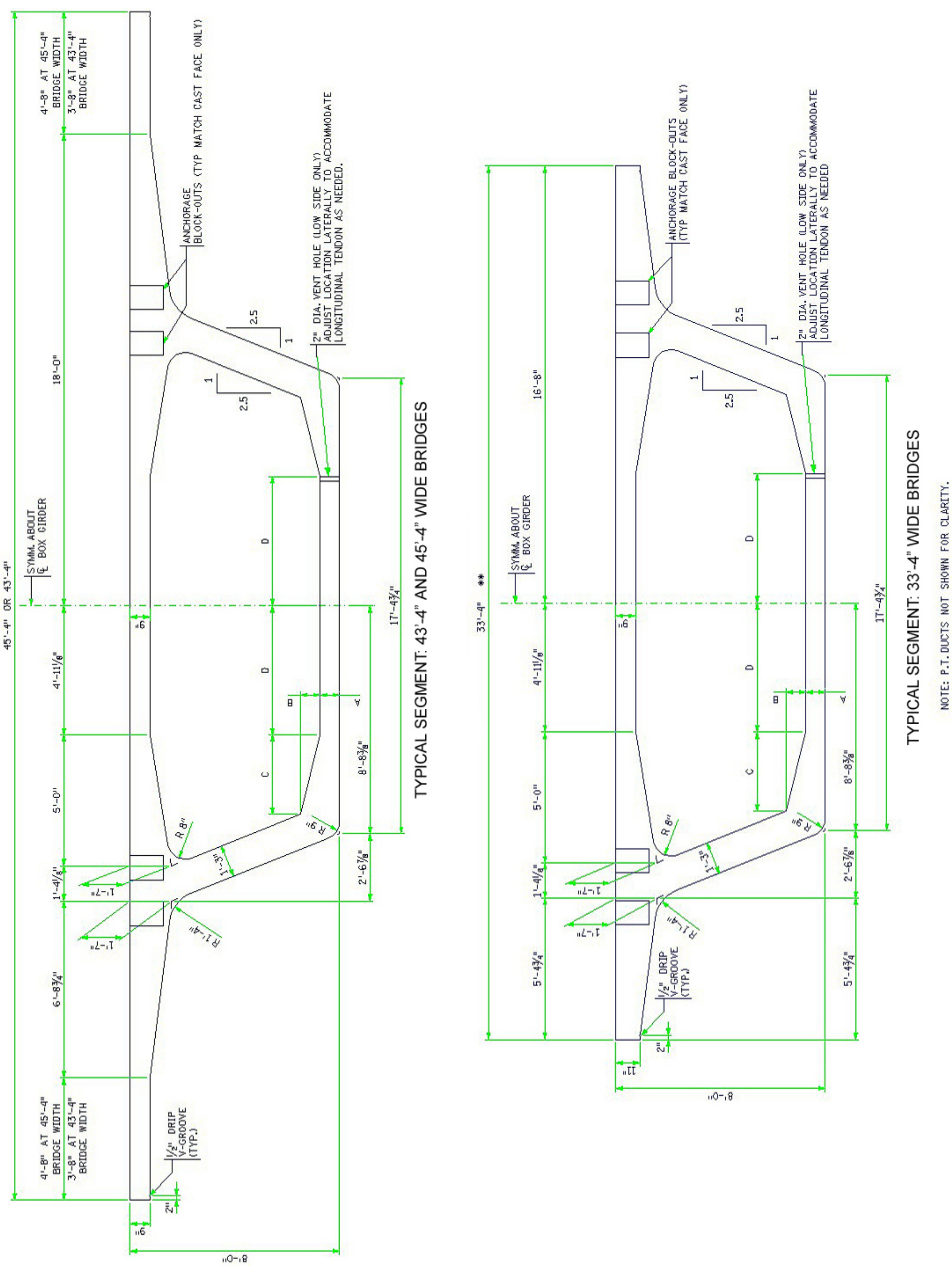

Figure 5: Typical Segment used on Crosstown Bridges.

bridges. Furthermore, use of standard AASHTO forms was desired by MnDOT partially due to potential use of the same forms for other future projects. Use of the wider Type 8-2 would require that the overhanging flanges be adjusted to achieve the varying roadway widths. The wider bottom of the Type 8-2 was a concern because the wider bottom flange combined with superelevation further reduced what was already a tight vertical clearance. In the end, it was decided that the use of just one type, i.e. the Type 8-2, met both economical and geometric considerations. The final typical sections were 10’-0” long and are shown in Figure 5.

The standard box girder shape limits the number of variables by locking in the segment depth, web angle, web thickness and deck thickness. This is important because it increases the economy of segment production by limiting the number of form changes / adjustments that must be utilized. The bottom slab is one location where variances could not be avoided. The bottom slab thickens as it nears the pier supports to accommodate the increased moment demands. The thickness variation is described in Table 1 with accompanying
Figure 6. Note that variables “B” through “D” are defined in Figure 5.

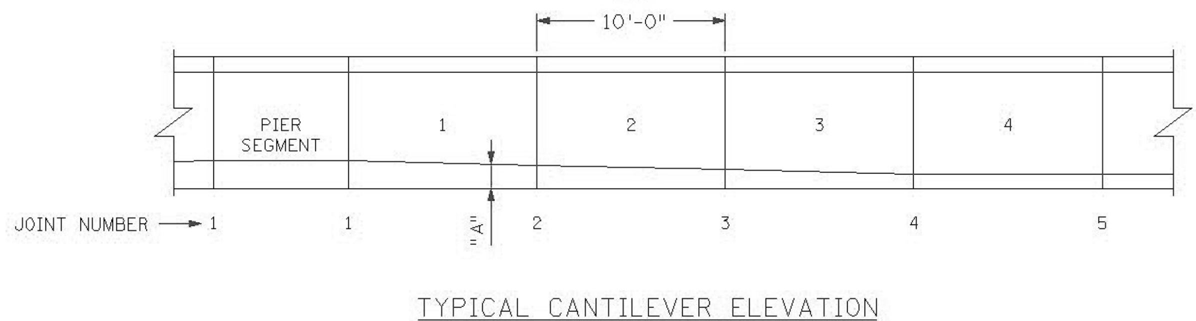

Figure 6: Typical Segment Bottom Slab Variation

TABLE OF VARIABLE DIMENSIONS					
JOINT NO.	1	2	3	4	5
DIMENSION "A"	2'-0"	1'-7"	1'-2"	9"	9"
DIMENSIONS "B"	0	0	4"	9"	9"
DIMENSIONS "C"	0	0	1'-4 1/8"	3'-0 3/8"	3'-0 3/8"
DIMENSIONS "D"	8'-2"	8'-0"	6'-7 3/8"	4'-11 1/8"	4'-11 1/8"

Table 1

BULKHEAD DETAILS

Selection of the standard shape is tied to the bulkhead details. The bulkhead is the form used to cast the newest segment face in the construction sequence. It is a form that must accommodate all the necessary variations that may exist at the interface between segments. Considering this, the definition of the bulkhead details is perhaps one of the most crucial aspects of setting a precast segmental standard. Refer to Figure 7 for the various bulkhead components. The bulkhead for the Crosstown bridges identifies 36 cantilever ducts in the top slab, and 16 bottom or span tendon ducts in the bottom slab. In addition, there are 3 pairs of bar tendon ducts and 5 pairs of continuity tendon ducts. Cantilever and span ducts were sized to accommodate up to 12-0.6" strand and continuity ducts up to 7-0.6" strand.

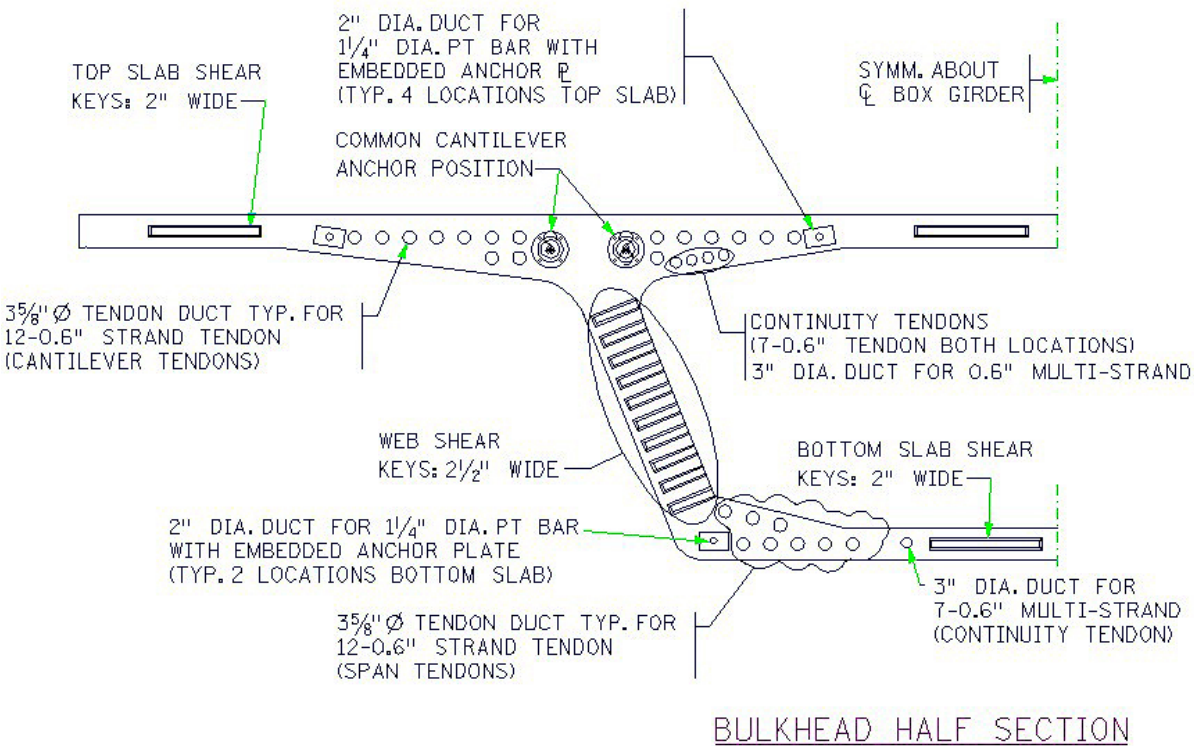

Figure 7: Bulkhead Components

In order to arrive at a common bulkhead design that would work for all six segmental bridges, a preliminary analysis must be conducted for governing aspects of all the bridges in the project. Post-tensioning requirements for segmental bridges constructed by balanced cantilever may be governed by construction requirements or final, in-service requirements. Cantilever tendon post-tensioning is often either governed by construction requirements or the state of stress when the structure is just opened to traffic. Span tendon post-tensioning is usually governed for conditions at time=infinity, when concrete creep has occurred and increased the positive moments between the supports.

Balanced cantilever construction may progress either by lifting the new segment from the ground (by crane) or by hoist and lift, in which case the hoisting equipment creates an additional load at the cantilever. Ground cranes were assumed for the erection of the

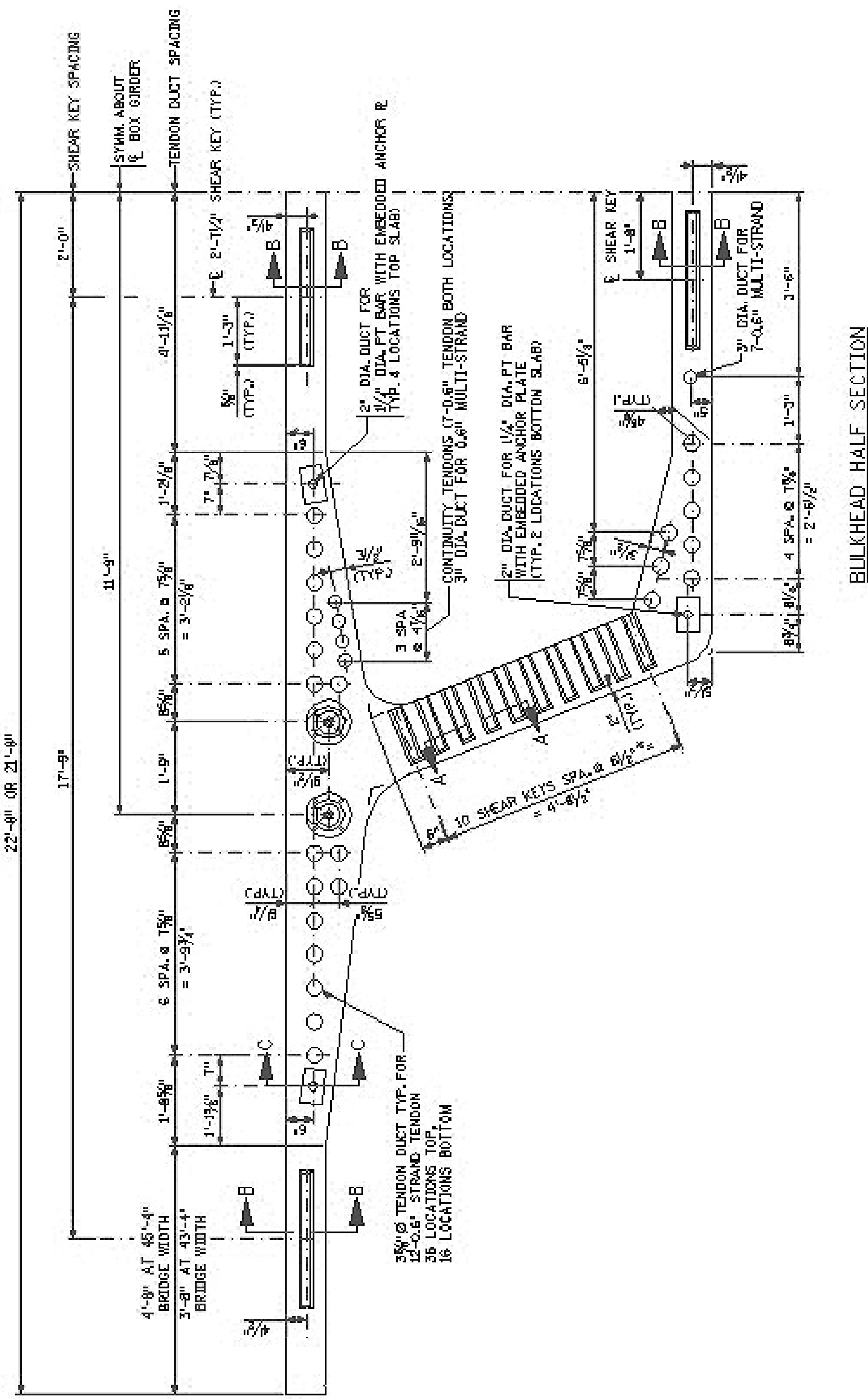

Figure 8: Bulkhead Configuration

segments in the Crosstown project. To satisfy the requirement that there be 5% reserve post-tensioning capacity, it was decided to simply provide 5% more post-tensioning material than the minimum required by design. This was, in general, accomplished by specifying an initial jacking force of $0.86f_{py}$ rather than $0.90f_{py}$. This decision gave the contractor 5% reserve at any segment rather than the provision of a spare duct as enumerated in the AASHTO Specifications.

Six post-tensioning bars are used to compress and expel excess epoxy out of the match-cast joints during erection and to temporarily hold the new segment until the cantilever tendons are installed. Considering the limited space available in the bulkhead, it was decided that these bars should be made permanent and factored into the resistance capacity of the section. This decision also fulfills the desire to minimize the number and size of openings in the deck given the deicing chemicals used in Minnesota.

Span tendons constitute the positive moment resistance once a closure pour is made. For the six segmental bridges, a maximum of 16 span tendon ducts were required. Bridge 27V75 utilized all 16 span tendon ducts, whereas, Bridge 27V66 utilized 10 span tendons, Bridge 27V73 utilized 12 span tendons, and the remaining bridges used a maximum of 14 span tendons.

Continuity tendons cross the closure pour and anchor on the opposing face of the pier or abutment diaphragm. These tendons provide top slab continuity across the closure pour. The bottom slab span tendons serve a similar function as the continuity tendons across the closure pour, and with the exception of a few cases, the bottom continuity tendons were not utilized. The continuity tendons are in place primarily to address thermal stresses and other global forces. A sample tendon layout for one span is shown in Figure 9. The top view shows the girder elevation and the bottom two views show a half-plan of the top and bottom slabs. One can see the top slab tendons drop off as they tend toward mid-span, and the bottom slab or span tendons drop off as one moves away from mid-span. The tendon termination is directly related to the moment and location of tensile demand in the section.

Shear keys are the most basic component of the bulkhead. They serve as a shear transfer mechanism and an aid to the fit-up of segments. In conjunction with the compressive post-tensioning forces across the joints, well distributed shear keys would ensure full transfer of shear forces as if the joint is not there.

Web thickness was governed by either shear strength or principle stress limitations, depending on the structure. Vertical post-tensioned bars have been added in a number of segments near the pier supports to meet the principle tensile stress requirement. The post-tensioned bars are not considered for computing the shear strength of the structure, but rather are considered only for the serviceability requirements of reducing the principal tension in the webs. The alternative of increasing the thickness of the webs was considered but not pursued, because, given the restriction in girder depth, an increase in structural weight would send the design in a spiral of increasing number of tendons, corresponding haunch sizes in the top slab, and eventually web thickness again. The decision of using post-tensioned bars in the web was agreed upon after confirming that a number of significant bridges, in service for more than 15 years, have shown no sign of problems using the proposed Crosstown details; many of these bridges are in northern states with similar climate-related concerns.

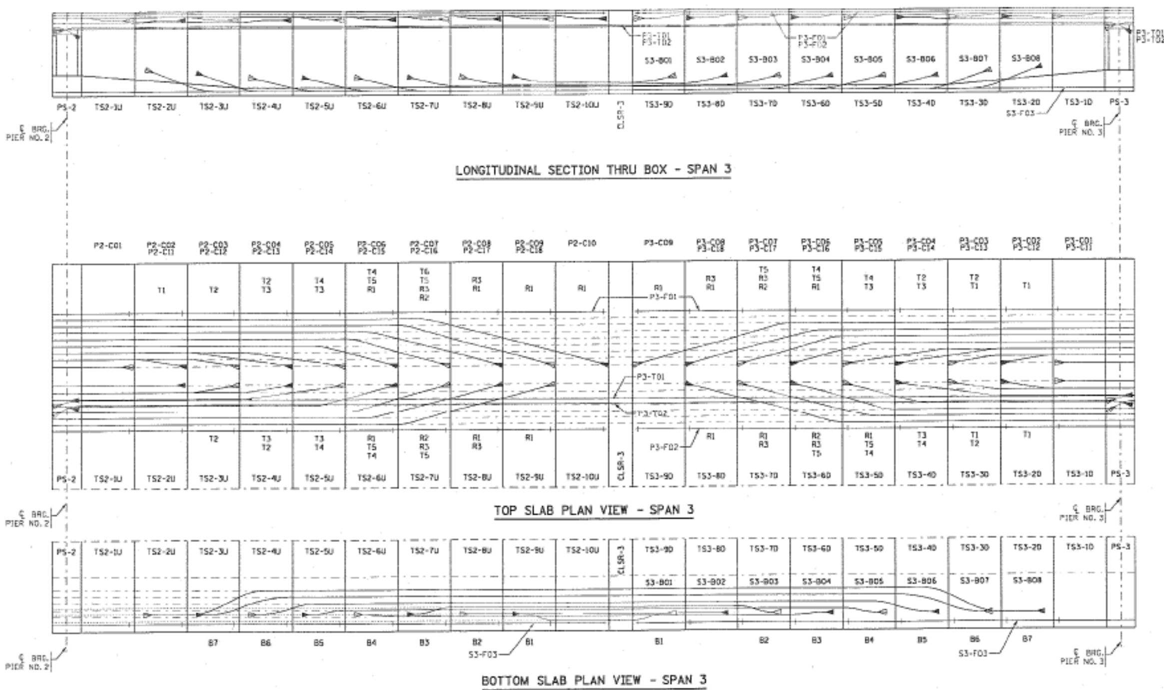

Figure 9: Typical Longitudinal Tendon Layout

ANCHORAGE LOCATIONS

The anchorage location is defined for both cantilever and span tendons. Span tendon anchors in bottom slab blisters are located away from the segment face. Bottom slab blisters must be configured to accommodate any tendon angle that may be required within the span. The blister location must consider jacking clearance, which is a potential issue at terminations near the pier segment, and anchorage congestion. Two scenarios form the bounds for a blister that will be substantial enough to contain the various anchorage conditions. Span tendons terminating near the closure pour require a minimal blister size since the bottom flange is relatively thin. Near the pier segment, however, the bottom slab becomes thicker and a span tendon terminating in this region will have a larger angle change. Congestion is a potential issue not only within the blister but in the bottom slab where continuing span tendons are located. Full detailing plays an important role in the feasibility of blister reinforcement and the mitigation of bar congestion.

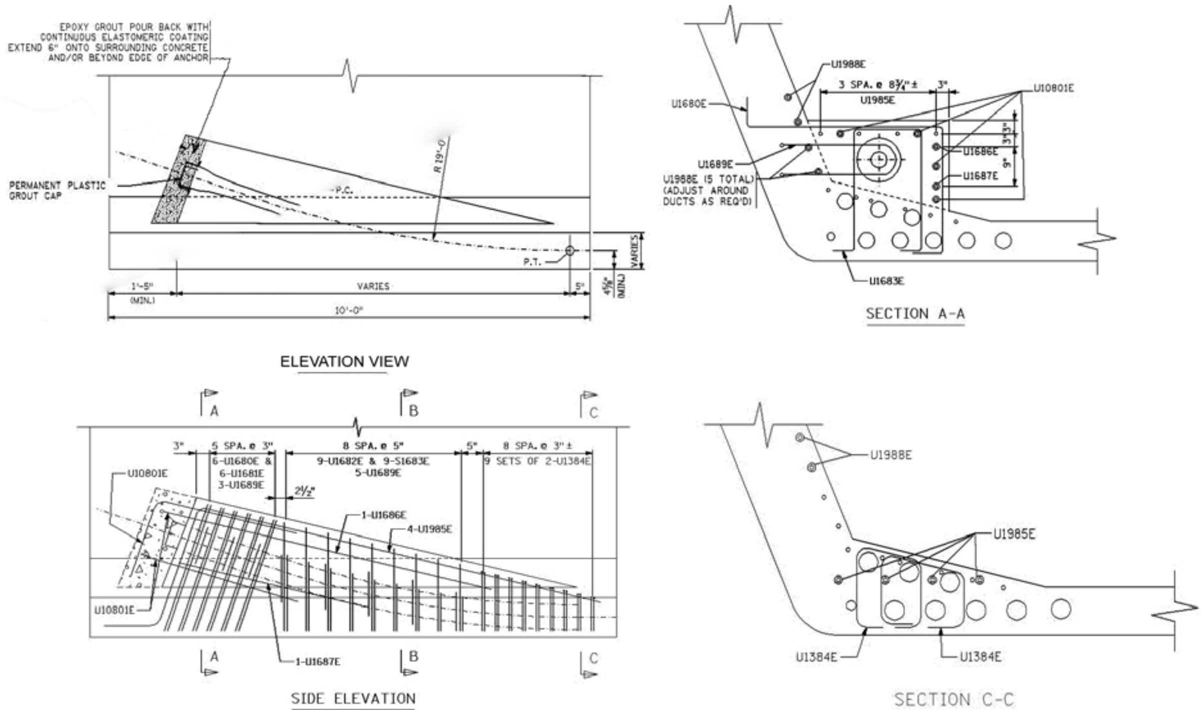

Figure 10: Bottom slab blister details.

Cantilever tendons anchorages are located directly above either side of the web. Designers sometimes have the cantilever tendons anchor in a top slab blister that hangs below the top slab (See Figure 11). However, this arrangement would have required blister formers that fall inside the core form assembly which is expected to be complex given the shallow depth of the cross-section.

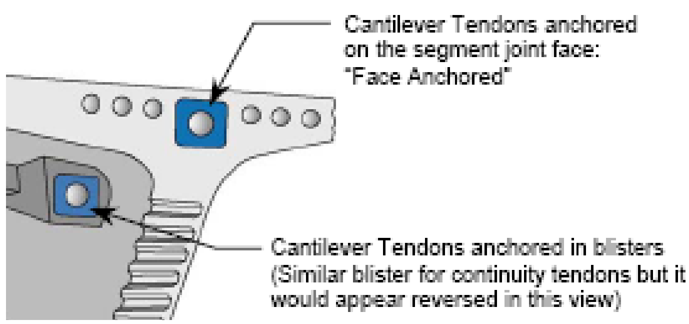

Figure 11: Potential cantilever tendon anchor positions[2].

Another advantage of anchoring the cantilever tendons at the segment face is that the anchor pocket is more easily grouted since grouting is done from the top. Placing anchors at the segment face does have a drawback in that the anchors heads are nearer to the roadway surface. There are various recommendations on the grout pocket details, but the principle is the same: To ensure proper integrity to the anchor protection system. Figure 12 illustrates the standard treatment of the anchorage pocket. The grouted pocket will be supplemented by the aforementioned two inch overlay and a coating of elastomer in addition to the permanent plastic grout caps.

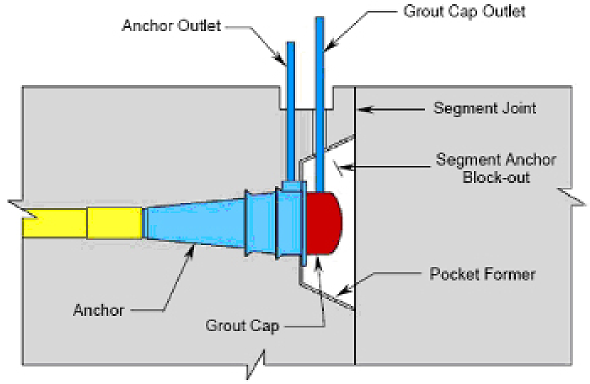

Figure 12: Cantilever Anchorage with Permanent Grout Cap[3].

SEGMENT TYPES

The typical segments shown in Figure 5 are one of three precast segment types on the bridge. The other two segment types are the abutment segment and pier segment. These segments are shown in Figures 13 and 14. They incorporate many of the same features such as web slope and soffit radius, but that's where the similarities to the typical segment end. The abutment segment accommodates a modular joint blockout 24 inches deep by 13 inches wide. Joints were sized to include a 150 degree thermal range and 120% of the movements due to creep and shrinkage. The largest joint required a 9 inch movement rating.

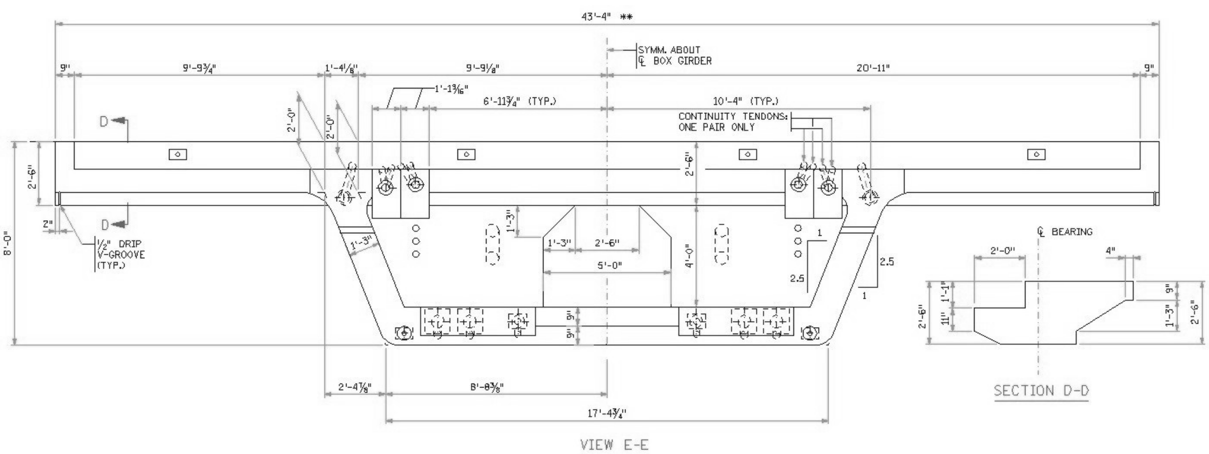

Figure 13: Abutment Segment Looking at Expansion Joint Face.

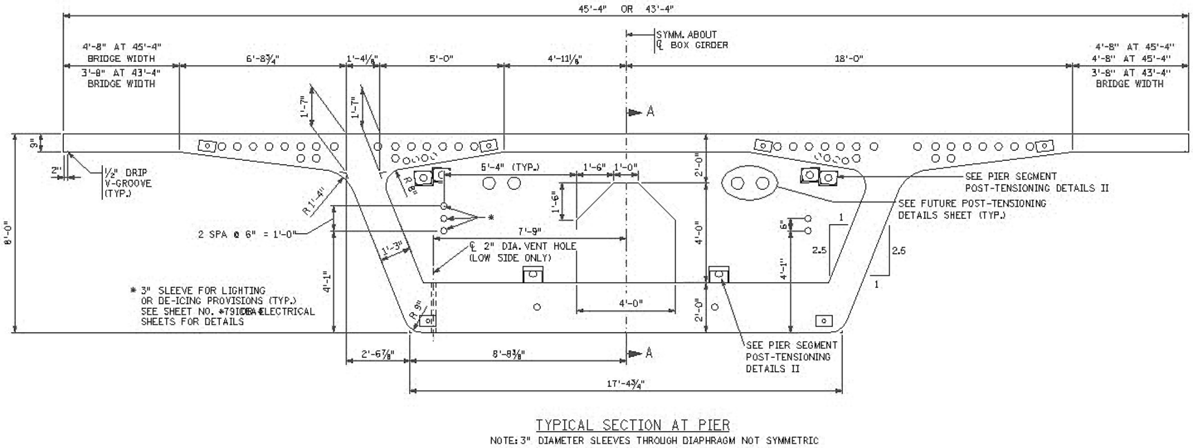

Figure 14: Pier Segment.

Both support segment types include a diaphragm sized to transfer the reactions to two bearings. A two-bearing configuration was selected to control the size of the diaphragm and diaphragm post-tensioning. Diaphragm thicknesses of 3’-0” and 4’-0” were used at the abutment segment and pier segment, respectively, as shown in Figure 15. The pier diaphragm naturally takes more load and required 4 draped tendons each carrying 12-0.6” strand in addition to the aforementioned headed reinforcement. These strands ensure a load path from the webs to the center of the bearing. The abutment segment diaphragm required no diaphragm post-tensioning. The pier segment and pier diaphragm reinforcement are shown in Figure 16.

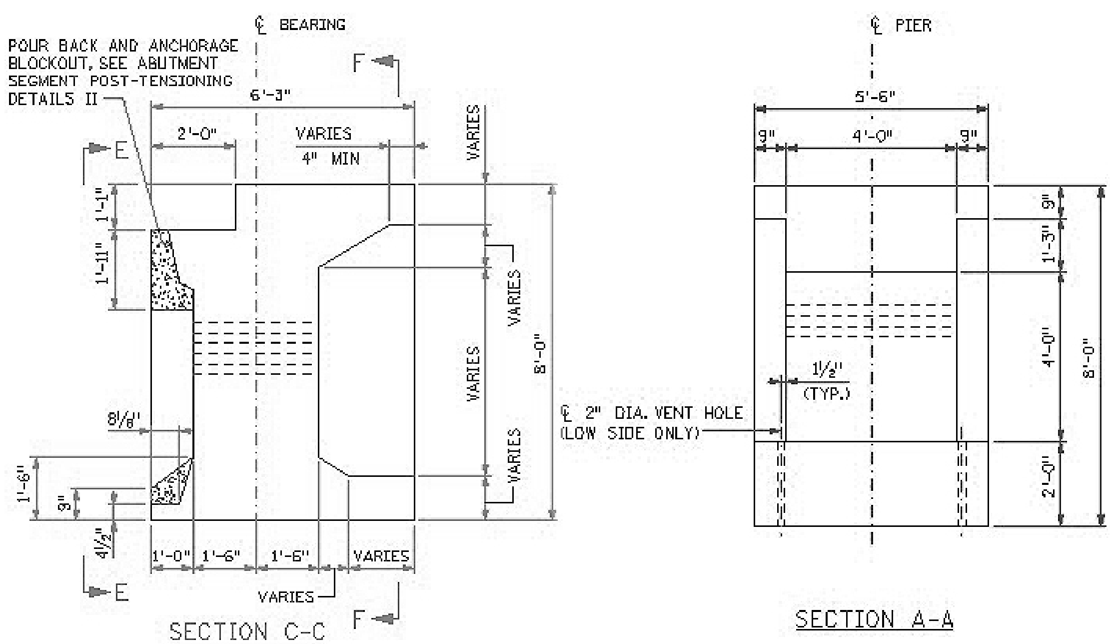

Figure 15: Abutment Diaphragm and Pier Diaphragm

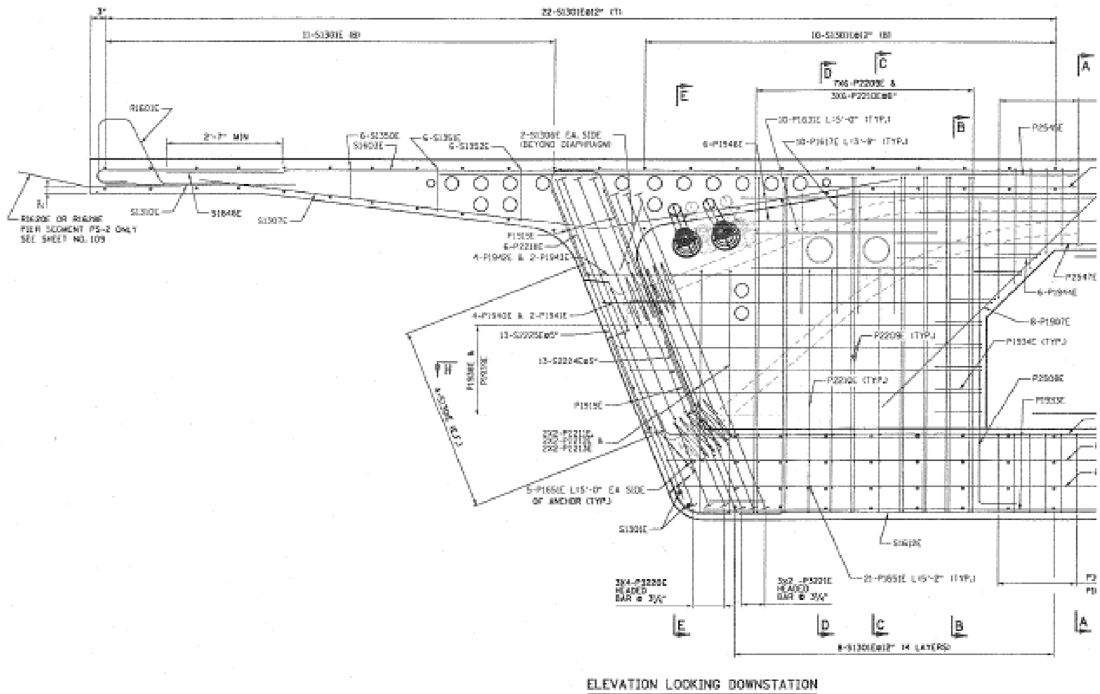

Figure 16: Pier segment reinforcement.

The pier segment required substantial shear reinforcement in addition to draped diaphragm post-tensioning. Headed mild reinforcement was specified to alleviate the rebar congestion problem typical of diaphragm designs. Vertical post-tensioning in the pier segment diaphragm was considered but excluded, even though web post-tensioning is used in the webs of the typical segments. The rationale is that any loss of the vertical post-tensioning in the diaphragm due to roadway contaminants and corresponding corrosion would compromise the strength of the spans, whereas any loss in the webs would at most cause a serviceability concern.

FUTURE POST-TENSIONING

Future post-tensioning provisions provides a means for strengthening the structure in the future should unforeseen serviceability or strength concerns arise. The basic provisions for future post-tensioning include a clear path for tendons capable of imparting no less than 10% of the positive and negative moment post-tensioning forces, and tendon anchorage areas at segment diaphragms. The path provided in the Crosstown Project involves overlapping of tendons at the pier segment diaphragms, which would allow provision of future post-tensioning only in spans needing additional prestressing. The details of this path may be seen in the sections of Figures 17 and 18. At the future drape point, a standard deviator block was developed for use in each span. The tendon location within the deviator block considered the range of bridge curvature and potential conflicts with future post-tensioning, which will be chorded between deviator blocks and support segments. Diablo trumpets were shown at the pier and deviator to accommodate angular variations amongst the six structures. At the abutment and pier segments it is expected a heavy steel plate will serve as the tendon anchor in the event the future post-tensioning is installed.

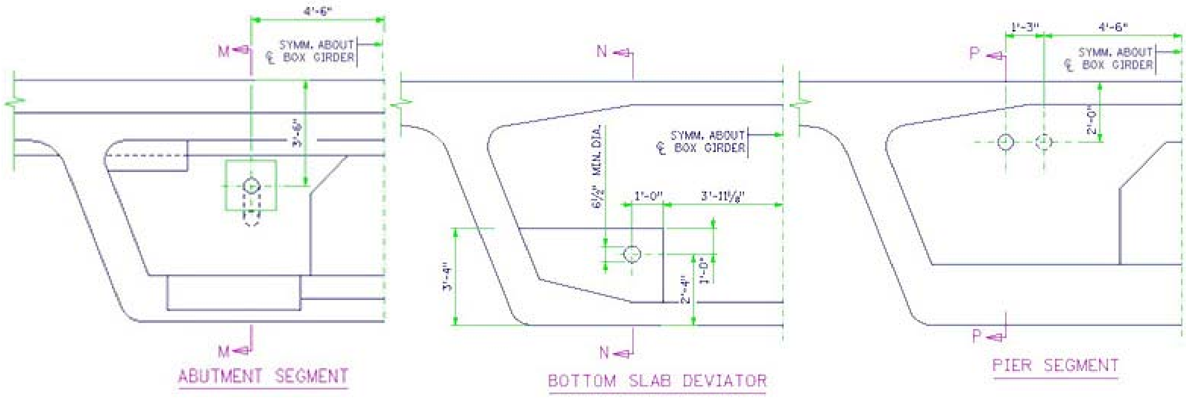

Figure 17: Future tendon path through abutment segment, deviator and pier segment.

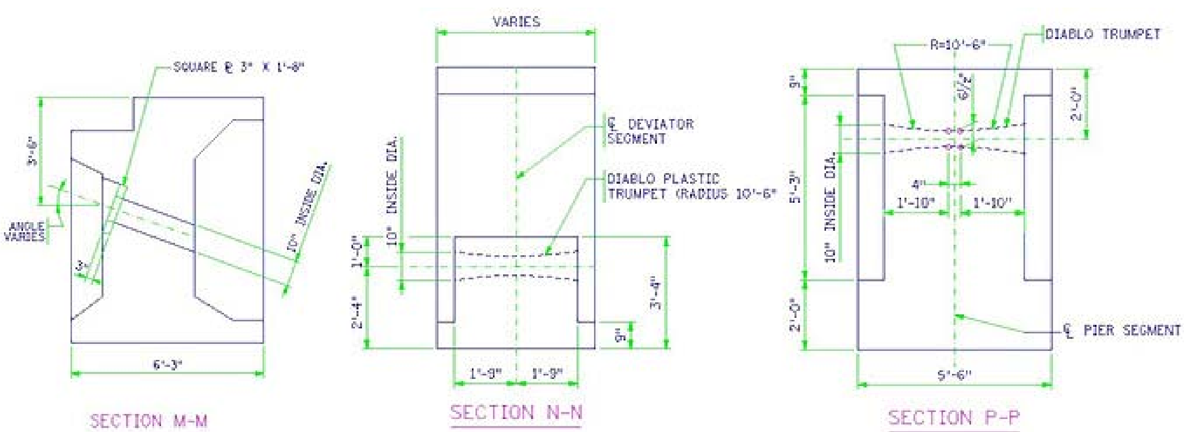

Figure 18: Sectional view of future tendon path.

TRANSVERSE DESIGN

Transverse tendons were designed as the primary reinforcement of the top slab. A transverse profile was generated for each deck width. The tendons are comprised of 4-0.6" dia., 270 ksi, strands in 4" x 1" corrugated plastic flat ducts. Negative moment at the root of the long overhangs for the widest roadway section governed the transverse design in tension at the top of the top slab. For the narrow roadway section, positive moment at mid span between the webs governs the design in tension at the bottom fiber of the top slab. For simplicity in forming and segment fabrication, the tendon size and spacing were held constant for all deck widths.

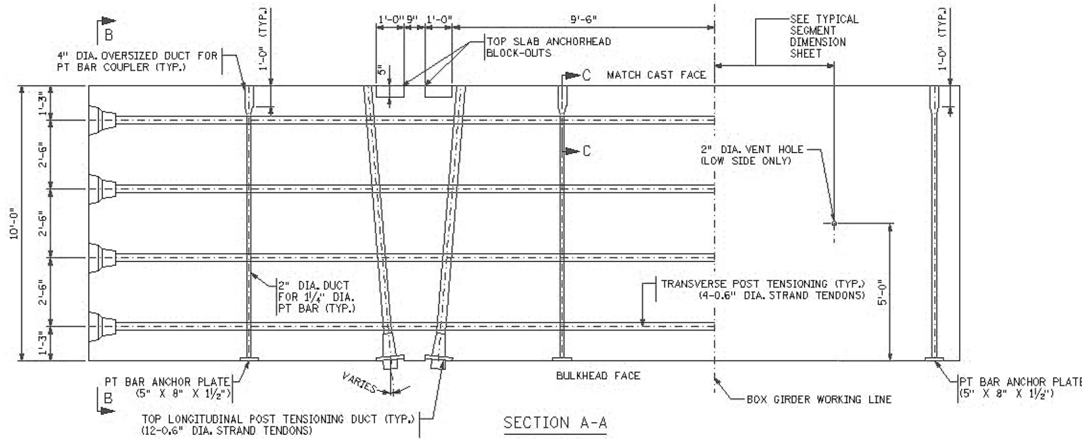

Figure 19: Typical transverse tendon plan.

OWNER'S PERSPECTIVE

Bridge Type Selection

The decision to utilize precast, segmental, post-tension concrete box girder construction was based on a combination of factors.

- The box girder geometry and balanced cantilever construction method offered a construction approach that better fit the confined work area.
- The segments could be erected during brief night-time or weekend traffic closures.
- Steel girder bridges were considered but deemed less desirable because clearance issues necessitated integral pier caps. Integral steel pier caps introduced fracture critical concerns Mn/DOT wished to avoid. Integral post tensioned concrete pier caps introduced vertical clearance problems with their falsework and the staged traffic lanes. Additionally there were long-term maintenance concerns.
- With six bridges and over 450 segments required, MnDOT believed the volume was sufficient to offset the casting yard investment and provide an alternative that was more economical than other bridge types

Considering long term maintenance, costs of future deck replacements, and future painting costs associated with steel girder type bridges, the precast segmental construction offered the most advantages and was the most attractive option.

Consultant Selection

The design of precast segmental bridges is highly specialized and requires expertise and prior experience. Since the MnDOT Bridge Office had not completed prior designs with precast segmental box girders, consultant services were required. Consultant selection was made from a list of pre-qualified firms with previous precast segmental design experience. Three firms were selected, each being awarded two bridge designs. Project magnitude, the time frame available to complete designs, and the desire to distribute consultant work when possible were the primary reasons for three selections.

MnDOT staff understood the importance of an initial standardization effort for precast segmental sections and details to minimize the variability and construction costs. The approach of utilizing a lead consultant to develop segmental bridge standards was employed to provide a template for each designer to utilize. As final design progressed, a "Consensus Building Approach" evolved. Each firm offered their expertise and recent project experiences. The end result was the development of final standards that were utilized for all bridges.

Other Issues

Embarking on precast segmental construction for the first time did present several unique challenges to MnDOT. The design phase of the project was initiated at a time when the LRFD Specification was undergoing a major transformation to include the provisions of segmental construction. This departure from the past use of the "Guide Specifications" for segmental bridges added some difficulty due to the need to work through several AASHTO LRFD agenda items that were approved but not yet incorporated into the current printing of the Specifications. Copies of several AASHTO LRFD Agenda Items were submitted to the designers early on, and were incorporated into project design requirements.

MnDOT made use of experiences from other states, in particular from the evolving technical information on segmental bridges that has been documented by the Florida DOT. Generally, the design directives and special requirements that were being proposed by the State of Florida were regarded as the most current requirements for segmental bridge designs that Minnesota used as a starting point.

One of MnDOT's goals was to provide details that would result in maximum durability. As an example segment joint duct couplers were specified to provide an additional layer of corrosion protection at the precast joints. However, the post-tensioning suppliers had not completely verified that the stringent pressure testing requirements for the post-tensioning systems was achievable with inclusion of the duct couplers. After designs were complete, a contractor questioned how he could provide a bid on a post-tensioning system that included both the duct couplers and the air-tight pressure testing requirements, since the post-tensioning suppliers did not yet have an approved airtight system available for the particular angled tendon geometry layout. In response, MnDOT issued a project addendum late in the bidding process that would still require the use of duct couplers, but changed the air-tight testing requirements. Rather than making the air-tight testing an absolute requirement, a cash incentive payment for passing the pressure testing requirements was written into the Contract. As of the writing of this paper, it appears that the stringent pressure testing requirements will be satisfied based on pressure tests recently completed.

For Bridge Ratings, each consultant was assigned the task of providing a bridge ratings manual for each bridge they designed. Florida publications utilizing the LRFR Bridge Rating Method were useful as a template. It was important to establish the bridge ratings process using the same design behavior assumptions that were made in the original designs which utilized the LRFD method. Using traditional LFD Bridge Ratings procedures would have required extensive re-analysis due to the different behavior models and live load vehicles in the LFD and "Guide Specifications". Since the LRFR design behavior assumptions are consistent with the LRFD Specifications, the Bridge ratings process was consistent with the design approach.

Because of the complexities of segmental bridge construction verses standard bridge construction, MnDOT has retained a specialty segmental bridge construction engineering firm to augment MnDOT field personnel in administering the construction contract. They will provide rapid review of the Contractor's shop drawings and provide expert advice during construction. The exchange of information and approval process requires quick turn around to Contractor questions and quick resolution to issues as they arise. The three original design firms were each issued a construction contract to address bridge design specific questions that may arise during construction.

As of the writing of this paper, the Contractor has begun to quickly make use of the standardization process that was employed during the design. Some minor adjustments to the bulkhead layout have been proposed, but all designers have indicated that the proposed modifications will have a very small effect on the resulting stresses indicating that the consensus building approach during the design process was a successful endeavor.

CONCLUSIONS

Standards development is a crucial aspect for organizing a multi-consultant design effort. It is rare that bridges having the same construction type be developed under parallel designs by three consultants. However, MnDOT chose to break the design package out for two reasons – to support multiple local consultants and to increase the comfort level of adopting the new construction technique. In this regard the design approach and the development of the design standards served MnDOT well. In particular, MnDOT became part of an ongoing healthy professional exchange on design issues characterized by a mix of professional preference that reflect the equally varied views of the construction industry. The team effort that created six complex bridge designs was a success because it met MnDOT's vision for the future of Crosstown Commons while simultaneously generating confidence in the designs.

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