

# Minnesota Crosstown Project Features Precast Concrete Segmental Bridges

by Keith Molnau, Minnesota Department of Transportation and Franklin Hines, FIGG

**Precast segmental construction offered the most advantages and was the most attractive option**



With the casting of this pier segment on October 18, 2007, Minnesota's first precast concrete segmental bridge gets underway. Photo: Mn/DOT.

The Minnesota I-35W/Hwy 62 Crosstown Project features precast concrete segmental bridges utilizing balanced cantilever construction within one of the most highly congested sections of interstate highway system in the region. Approximately 200,000 vehicles per day travel through the project, which is situated in the southern portion of Minneapolis and into Richfield, with the Mall of America and the Minneapolis-St. Paul International Airport nearby.

The old configuration was essentially an at-grade interchange. The traffic from Hwy 62 merged into the left-most (fast) lane of I-35W and caused traffic delays as the traffic wove together. This 1960s design had exceeded its design capacity, had a high accident rate, and was outdated with an aging infrastructure. Additionally, the area has long since undergone densely populated urban sprawl, with homes and businesses built to the edge of the right-of-way along the corridor.

The new layout includes elevated structures that separate the traffic and eliminate the merging and weaving requirements. The use of precast balanced cantilever techniques permits construction in these highly confined areas.

The \$288 million contract, the largest in Minnesota's history, includes \$99 million for bridges, of which \$42 million is the total for the six precast segmental bridges. Construction began in 2007 and is on schedule for the planned 2010 completion date. This project was the first use of precast segmental construction in the state of Minnesota.

## Bridge Type Selection

The bridge type selection process for these flyover ramps was based on a combination of several factors.

- The box girder geometry and balanced cantilever construction method offered an approach that better fits the confined work area.

## profile

### MINNESOTA I-35W/HWY 62 CROSSTOWN PROJECT / CROSSTOWN COMMONS, MINNESOTA

**ENGINEERS:** *(Each firm designed two segmental bridges)* PB Americas, Minneapolis, Minn. (Lead Designer), URS, Minneapolis, Minn., Parsons Transportation, Minneapolis, Minn.

**ENGINEER:** *(Project Layout, Staging Plans, and Roadway Plans)* SRF Consulting Group Inc., Plymouth, Minn.

**CONSTRUCTION ENGINEERS:** McNary Bergeron and Associates, Broomfield, Colo.

**OWNER'S REPRESENTATIVE:** FIGG Construction Engineering Inspection, Eagan, Minn.

**PRIME CONTRACTOR:** ALS—A Joint Venture of Ames, Lunda, and Shafer construction companies, Minneapolis, Minn.

**SUBCONTRACTOR:** High Five Erectors Inc., Shakopee, Minn.

**CONCRETE SUPPLIER:** Aggregate Industries, Eagan, Minn.

- The segments could be erected during brief night-time or weekend traffic closures.
- With six bridges comprising 461 precast segments, Minnesota Department of Transportation (Mn/DOT) believed the volume was sufficient to overcome the investment for a casting yard and provide an alternative that was more economical than other bridge types.
- Steel girder bridges were considered but deemed less desirable because piers necessitated integral caps that resulted in vertical clearance issues. Integral steel pier caps introduced fracture critical concerns Mn/DOT wanted to avoid. Integral post-tensioned concrete pier caps needed with steel bridges introduced vertical clearance problems due to falsework and the staged traffic

lanes. Additionally there were long-term maintenance concerns.

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

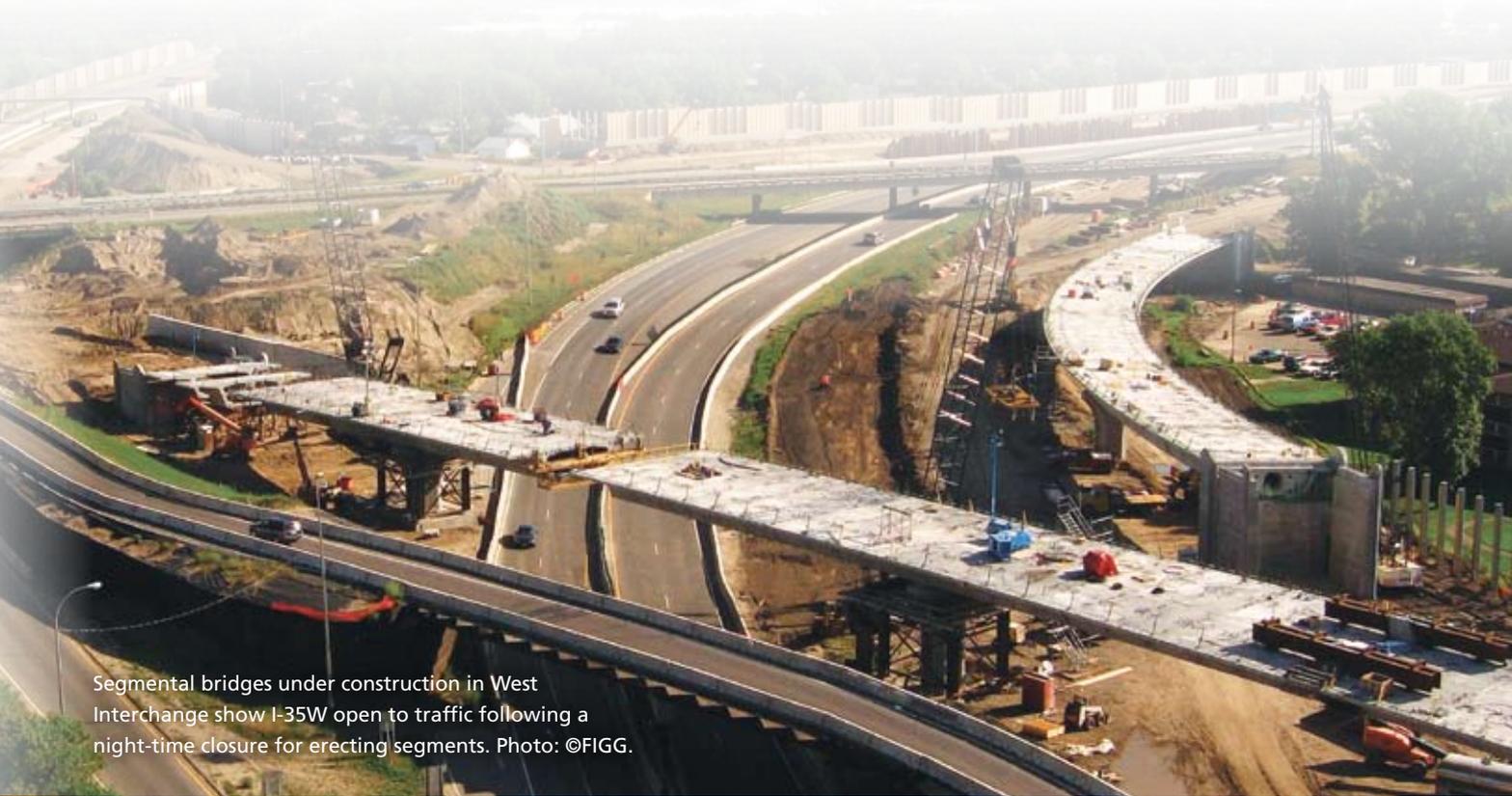
### Bridge Design Standards and Other Design Considerations

During design, a special effort was made by the lead segmental designers to standardize the precast segmental superstructure components.<sup>1</sup> Initial analysis included verification that one basic precast concrete section would be adequate for the project. In addition to the LRFD design loads, the section

would suffice for the special permit truck loading cases required by Mn/DOT.

Therefore, a modified AASHTO/PCI/ASBI Section 8-2 (2400-2) was selected for all six segmental bridges, even though there were three unique roadway widths varying from 33 ft 4 in. to a maximum of 45 ft 4 in. The deck flanges would simply be narrowed or extended as needed to accomplish the bridge width variations. Also, the bottom slab thickness was increased to 24 in. at the pier then tapered to 9 in. thick for the typical precast segments.

More standardization was accomplished following the project letting. The contractor and his segmental specialty engineer wanted to adjust the tendon layouts to eliminate some double layer stacking in both the upper and



Segmental bridges under construction in West Interchange show I-35W open to traffic following a night-time closure for erecting segments. Photo: ©FIGG.

## PRECAST, POST-TENSIONED BOX GIRDERS / MINNESOTA DEPARTMENT OF TRANSPORTATION, OWNER

**FORMWORK FOR PRECAST SEGMENTS:** Southern Forms Inc., Guild, Tenn.

**POST-TENSIONING SUPPLIER:** VSL, Grand Prairie, Tex. **BRIDGE DESCRIPTION:**

**BRIDGE DESCRIPTION:** Six precast concrete segmental bridges with 200-ft-long maximum spans

**STRUCTURAL COMPONENTS:** 461 precast AASHTO/PCI/ASBI Modified Section 8-2 segments

**PRECAST SEGMENTAL BRIDGES COST:** \$42 Million (six bridges)



The East Interchange near Nicolet Avenue begins to take shape. The two bridges shown come together near a gore area, located off the bridges to allow for clearance of the full-width segments.  
Photo: © FIGG.

## The use of precast balanced cantilever techniques permits construction in these highly confined areas.

lower corners of the box section where the slab thickens near the webs. The proposed changes were acceptable because the stresses in the structures were not significantly affected.

Such changes were reviewed in a streamlined shop drawing review process. In this process, the initial concept approval for a given change was made in advance by the respective designer. Then, final approval was made following a detailed review by the owner's construction engineer, requiring final concurrence from each designer. This streamlined shop drawing review process minimized review cycles and helped avoid delays.

### Indoor Casting Facilities

The contractor established a casting yard on property they owned by converting a building into a short-line casting facility. Two sets of forms were used to construct all segments. One set of forms used adjustable form inserts so that it could fabricate pier segments, abutments segments, and typical segments. The second set of forms was non-adjustable and used for production of only typical segments.

Segments are cast, cured, transversely post-tensioned, and stored at the casting yard; approximately 25 miles hauling distance to the project site. Some 6 months after the notice to proceed, the contractor had cast the first segment on October 18, 2007. Casting was completed on January 22, 2009, for all of the project's 461 segments.

During the 2008 construction season, the contractor erected 248 segments, completing three of the smaller bridges in the project's West Interchange and portions of the three larger bridges in the project's East Interchange. The remaining 213 segments will be erected in spring 2009 when weather is favorable. Erection of segments throughout the winter is not practical due to restrictions on the required temperature for grouting operations and minimum temperature requirements for the epoxy in the match-cast joints.

### Lessons Learned

**Duct Couplers.** Recently, post-tensioning suppliers have been urged to develop duct couplers that can be used at the joints of precast segmental bridges. The intent is to provide an additional layer of corrosion protection for the post-tensioning tendons at the match-cast joints. The Crosstown project initially had specified that duct couplers

were required based on the Florida DOT's initiative with duct couplers. (See *ASPIRE™* Winter 2008.)

After the Crosstown project letting, a prototype duct coupler was tested for acceptance. Couplers were cast into mock-up concrete test blocks. The duct with couplers was pressurized with compressed air to test for leakage and maximum sustainable pressure. The assemblage of the duct with the duct couplers was then grouted to also test the installation and grouting procedures and establish a safe upper bound grouting pressure.

When the specimen was cut apart at the joint and examined, the duct coupler was rejected by Mn/DOT based on an excessive void area within the coupler. The concern was that this void would trap water and chlorides that could lead to accelerated deterioration of the tendons and top slab. To resolve the situation, the couplers were eliminated from the contract. It was reasoned that the high-strength epoxy joint at the match-cast face offered adequate long-term durability and corrosion protection. Ultimately, proper attention was focused on match-casting operations so no grouting cross-over (grout leaking at the joints from one duct into another) was experienced during the entire 2008 season.

Segmental bridges under construction in the East Interchange showing traffic on temporary alignments.  
Photo: Mn/DOT.



Mn/DOT will not likely specify duct couplers on future segmental projects until the couplers from each supplier are fully developed, tested, and preapproved for use. Mn/DOT certainly wants to maximize corrosion protection of the tendons, but not at the expense of potentially reducing the service life of the bridge deck. The decks for these segmental bridges are critical to the longevity of the structures.

**Falsework.** Precast balanced cantilever segmental bridges are constructed with minimal use of falsework. However, four-legged falsework towers used adjacent to the piers are critical for structural stability during construction. The AASHTO *Guide Design Specifications for Bridge Temporary Works* includes a diagram showing a 1-ft-minimum setback clear distance behind a barrier for falsework leg placement. This is shown for a tangent section of highway with full shoulder widths. The Crosstown project has curving, nonstandard temporary alignments weaving through the construction area with minimum shoulder widths.

Recent crash studies show that when a truck impacts a barrier, the upper portion of the vehicle extends beyond the barrier into what is termed as the "zone of intrusion." To maintain a safe work-zone, the falsework support legs cannot be allowed to be placed within this zone of intrusion.

The contractor understood the risk and responded to this issue by casting a temporary concrete wall, taller than the "zone of intrusion." Two legs of the tower were then fixed to the top of the wall.

**Cold Weather Issues.** The segment casting cycle allows a 3-day curing period after which the segment is moved into an outdoor storage area. Concrete test cylinders are kept with the segment during the initial curing period. When the segments are moved outdoors, the cylinders are put on an outdoor curing rack, which happened to be on the north side of the building. These control cylinders then become the basis for determining when the concrete reaches its required strength to erect the segment.

During cold weather, the required 28-day compressive strengths were not



## AESTHETICS COMMENTARY

by Frederick Gottemoeller

Economy and elegance have a fruitful convergence in Minnesota's Crosstown Reconstruction. The Minnesota DOT has learned, as New Mexico, Florida, and other states did before them, that concrete segmental construction provides both an economical and attractive solution for flyover ramps in complex interchanges.

Let's start with the economics. In these interchanges the ramp widths can usually be sufficiently standardized to produce long lengths of bridges with similar widths. This means that there will be a large number of similar segments that in turn justifies the establishment of a casting yard. It also allows the standardization of the substructure, resulting in additional economy through the repeated use of a few standard pier forms. Once those economic basics have been met, the inherent advantages of the box girder come into play. The small footprint of the piers compared to a typical multi-column pier bent means there are more places to put the piers, a great advantage in a complex interchange. That, plus the fact that the critical vertical clearance point is often not on the bottom of the girder but on the bottom of the thin overhanging wing, usually eliminates the need for costly and unsightly straddle bents. Finally, balanced cantilever construction minimizes falsework and allows traffic to be maintained with minimal disruption, another savings.

All of these points of economy have their aesthetic payoff as well. First, the box girder, with its wide overhang and deep shadow line, looks thinner than a typical girder bridge of the same depth. The piers occupy a much smaller part of the visual field than typical multi-column pier bents. All piers are essentially the same, varying only in height. They don't have to be modified or rotated from place to place, as multi-column pier bents often do, in order to fit into tight locations. The result is an interchange that is easy to see through and to understand, a great advantage to drivers trying to navigate it. Finally, the girders themselves smoothly and continuously parallel the curves of the ramps. They fit right into the interchange. After all, an interchange is basically an assembly of curves.

achieved on several segments. Prior to erecting these segments in the early spring, the contractor moved them and their corresponding cylinders to a heated enclosure to help increase strength gain. When the initial 28-day strengths were not met, additional cylinders were tested or, as a final step, the segments were cored and the cores tested. All segments eventually attained their required strength. The curing process must be carefully monitored and coordinated with the erection schedule to ensure the proper concrete strength is attained prior to erecting the segments.

### Conclusion

Precast segmental bridges are proving to be economical and a good choice for the Minnesota Crosstown project flyover ramps. Being highly elevated structures,

they are especially aesthetically pleasing and are expected to provide the added lasting value of low, long-term maintenance costs.

### Reference

1. Tse, Joseph K., Paul J. Pilarski, Laura M. Amundson, and Keith Molnau, 2007, "Crosstown Segmental Design Standards," Proceedings of the PCI-FHWA National Bridge Conference, October 22-24, Phoenix, Ariz., 19 pp.

---

*Keith Molnau is bridge design unit leader with the Bridge Office of the Minnesota Department of Transportation, Oakdale, Minn., and Franklin Hines is resident engineer with FIGG, Tallahassee, Fla.*

**For more information on this or other projects, visit [www.aspirebridge.org](http://www.aspirebridge.org).**



Concrete blocks were cut apart for examination of the duct coupler where installation procedures were tested in this mock-up of a precast segmental joint. Photo: Mn/DOT.



The void area around the duct coupler raised concerns where chlorides could potentially collect in the top slab. The duct couplers were tested, but not used within any of the Crosstown segmental bridges. Photo: Mn/DOT.

# MINNESOTA I-35W/HWY 62 CROSSTOWN PROJECT / CROSSTOWN COMMONS, MINNESOTA



Photo: Mn/DOT.

**Precast segmental construction offered the most advantages and was the most attractive option.**



Short-term closures occurred at night to allow for safe erection over traveled ways. Photos: © FIGG.



Photo: Mn/DOT.

**A modified AASHTO/PCI/ASBI Section 8-2 was selected for all six segmental bridges**

Photo: Mn/DOT.



## Aesthetic Design Considerations

A total of 27 bridges were required for the project. These include a mix of bridge types, each serving a unique purpose. Of the total, 12 were precast, prestressed concrete girder bridges and six were precast concrete segmental bridges, five were steel beam bridges, one was a pedestrian steel truss bridge and three were temporary bridges. Compared with conventional construction, segmental structures have a relatively small footprint that allows for a radial placement of the substructures while allowing room to fit traffic lanes between the radial supports. The final plans were developed using an overall aesthetic design guide that reflects the desired architectural theme of the community and provides a uniform visual experience throughout the reconstructed corridor.

Pier shapes and other substructure components such as pilasters were also standardized. Split forms allowed the use of identical curved formwork on the tops of the fluted pier columns. To address variable slopes, the tops of pier caps were set to the nearest slope of 0%, 2%, 4%, or 6% with any additional variation taken up in the bridge seats. This allowed for repeatable use of side forms even with the variation in the superelevation transitions within the bridges.

The project also includes extensive use of precast wall components including precast mechanically-stabilized earth (MSE) wall panels and precast posts for noise walls. Details were also developed to standardize the connections between precast wall panels and the cast-in-place walls at the ends of the bridge abutments.

Simple pier shapes, repetitive in nature, minimize the footprint of the bridge and reduce congestion in a complex construction zone.

Photo: Mn/DOT.



Aesthetics were considered in all aspects of the project through the use of a design guide that incorporated architectural themes. Photos: Mn/DOT.



## CROSSTOWN SEGMENTAL DESIGN STANDARDS

**Joseph K. Tse**, PE, PB, New York City, NY  
**Paul J. Pilarski**, PE, SE, PB, Minneapolis, MN  
**Laura M. Amundson**, PE, PB, Minneapolis, MN  
**Keith Molnau** PE, MnDOT, Oakdale, MN

### 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.

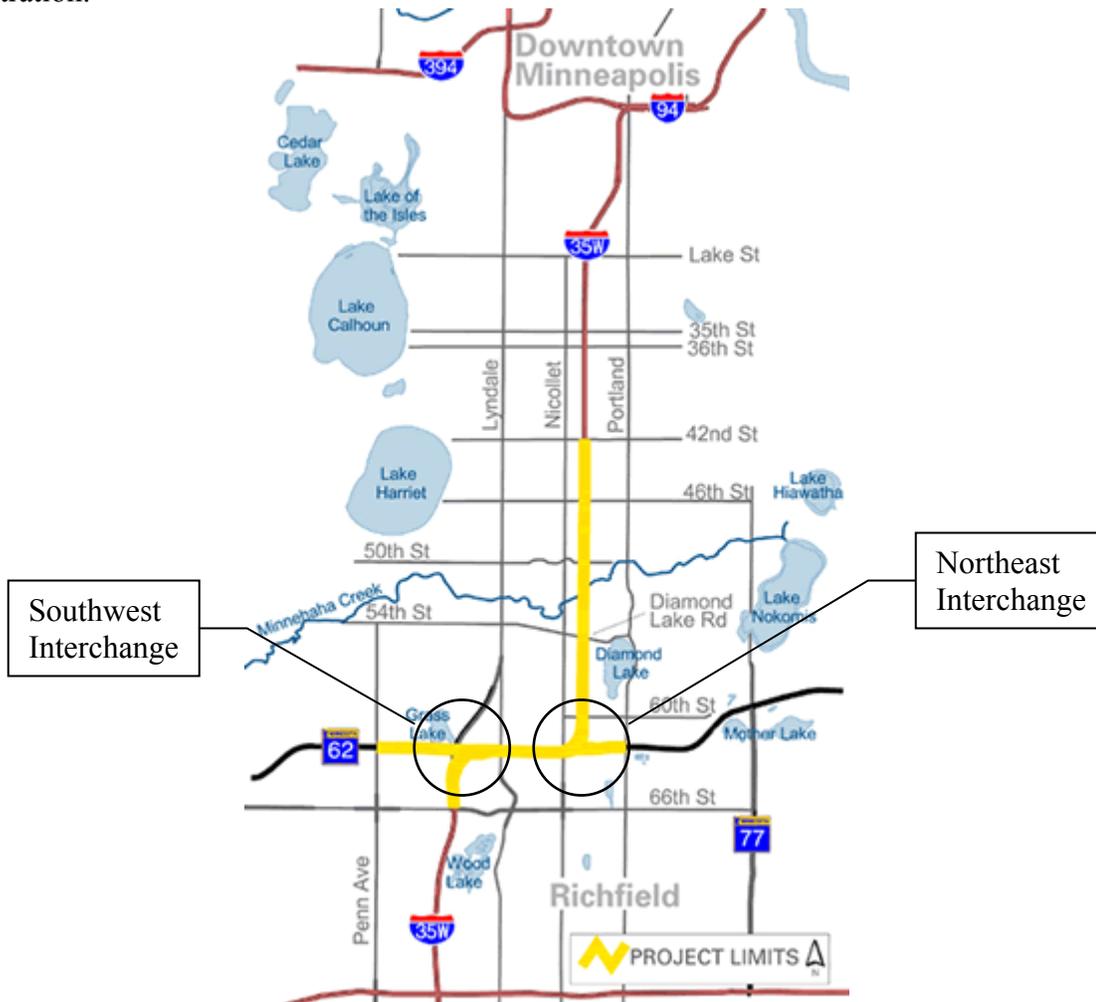


Figure 1: Project Location <sup>1</sup>

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.

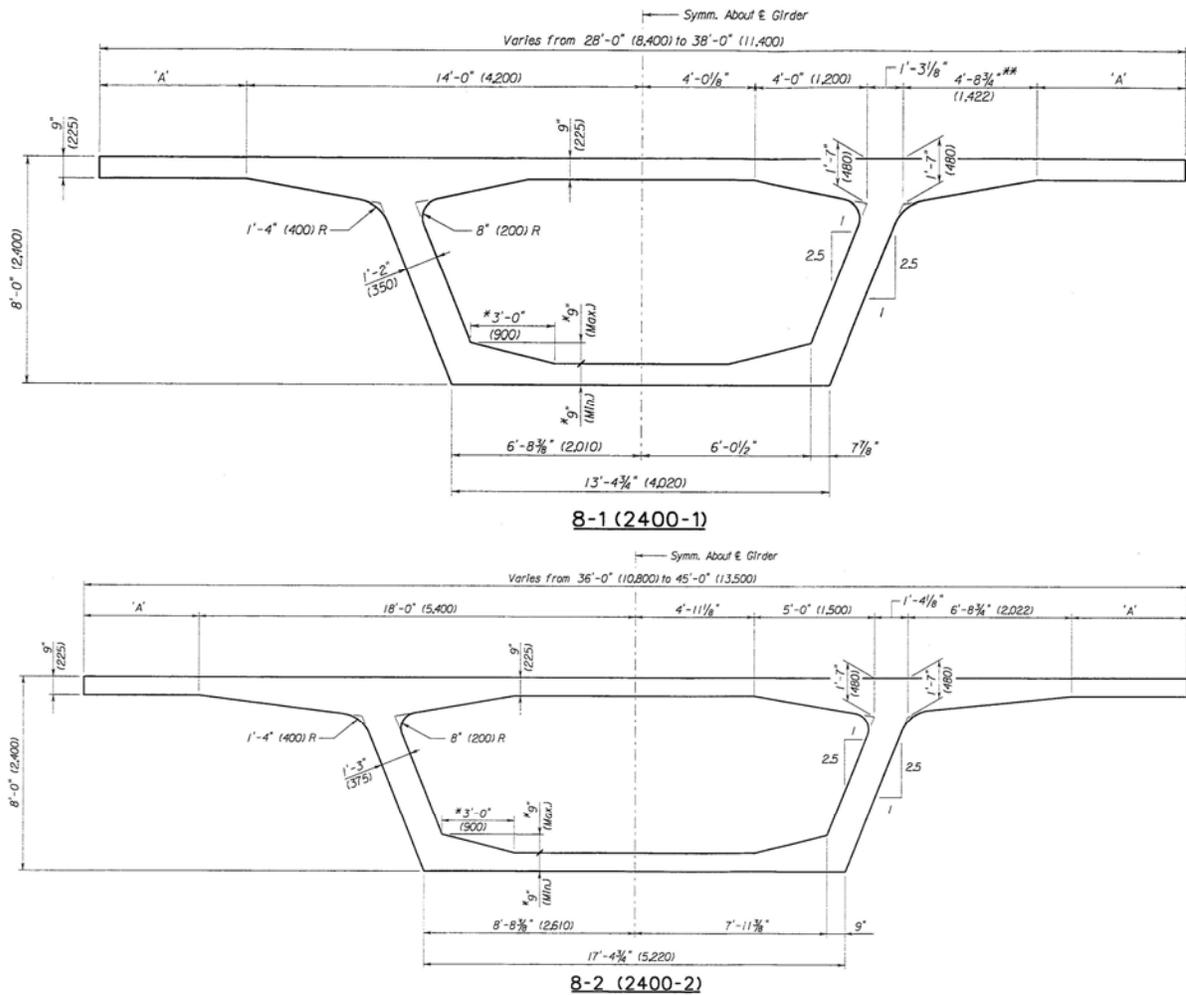


Figure 2: AASHTO Standard 8'-0" deep (2400mm) Segments

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<sup>1</sup> 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.

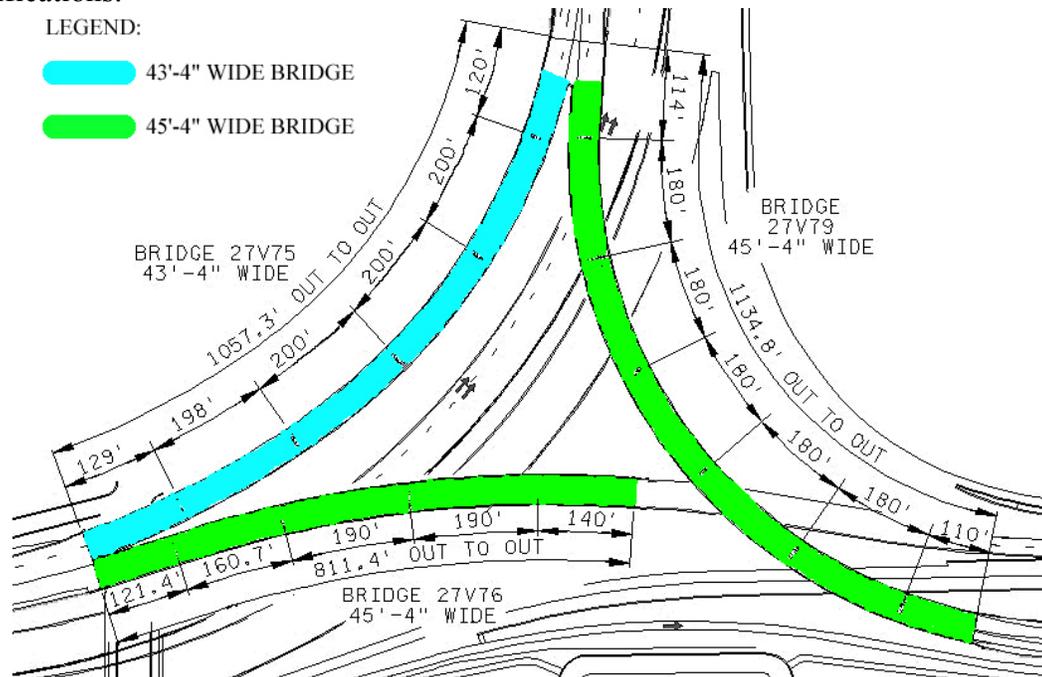


Figure 3: Northeast Interchange of Crosstown Commons

<sup>1</sup> Other bridge design consultants were PTG and URS. SRF served as roadway consultant and reviewed construction staging area requirements.

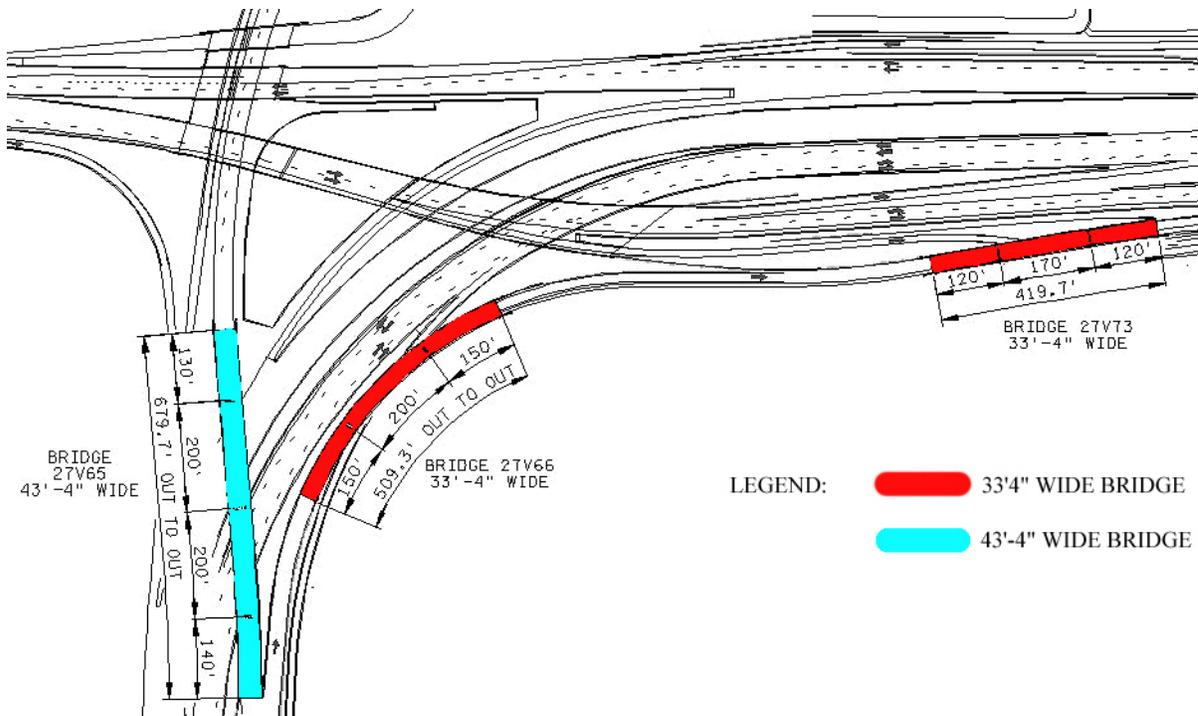


Figure 4: Southwest Interchange of Crosstown Commons

## 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



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.

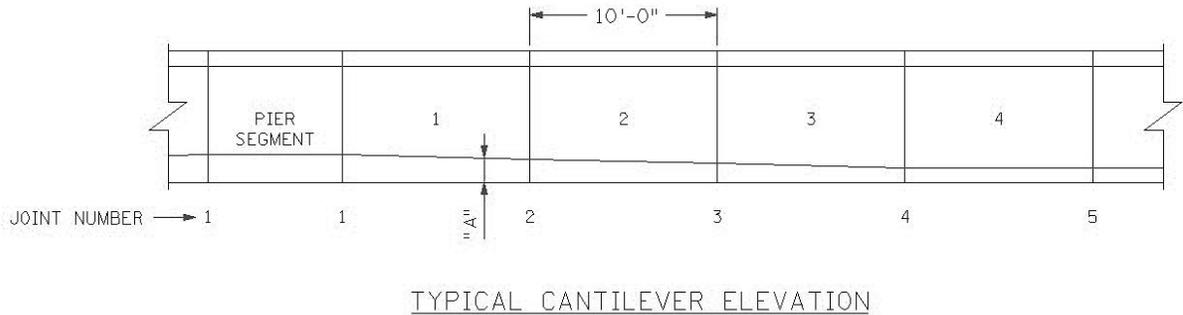


Figure 6: Typical Segment Bottom Slab Variation

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 <sup>1</sup> / <sub>8</sub> "	3'-0 <sup>3</sup> / <sub>8</sub> "	3'-0 <sup>3</sup> / <sub>8</sub> "
DIMENSIONS "D"	8'-2"	8'-0"	6'-7 <sup>3</sup> / <sub>8</sub> "	4'-11 <sup>1</sup> / <sub>8</sub> "	4'-11 <sup>1</sup> / <sub>8</sub> "

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.

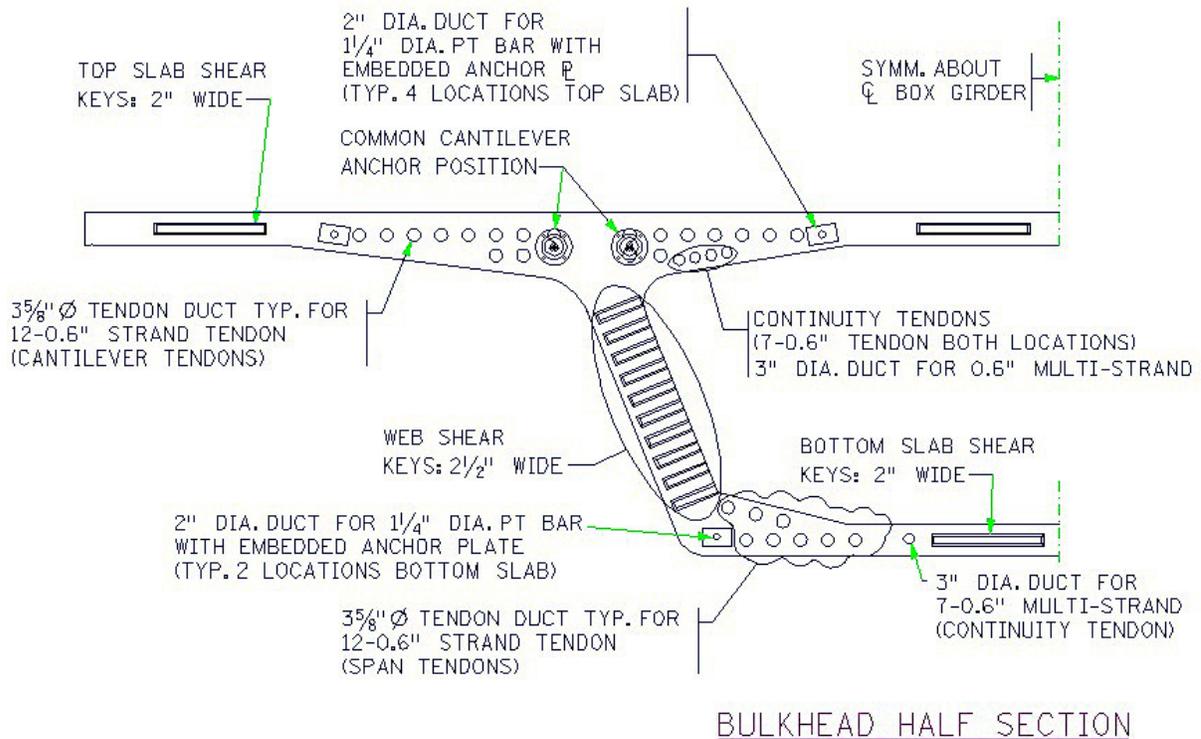


Figure 7: Bulkhead Components

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



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.

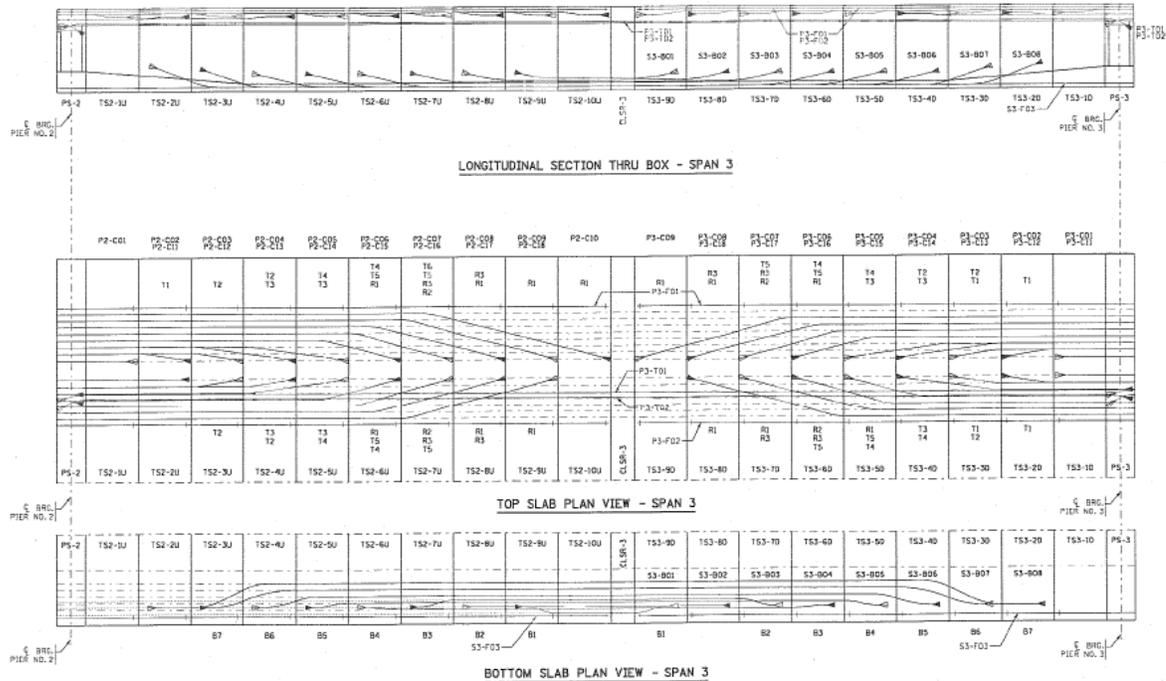


Figure 9: Typical Longitudinal Tendon Layout

### 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.

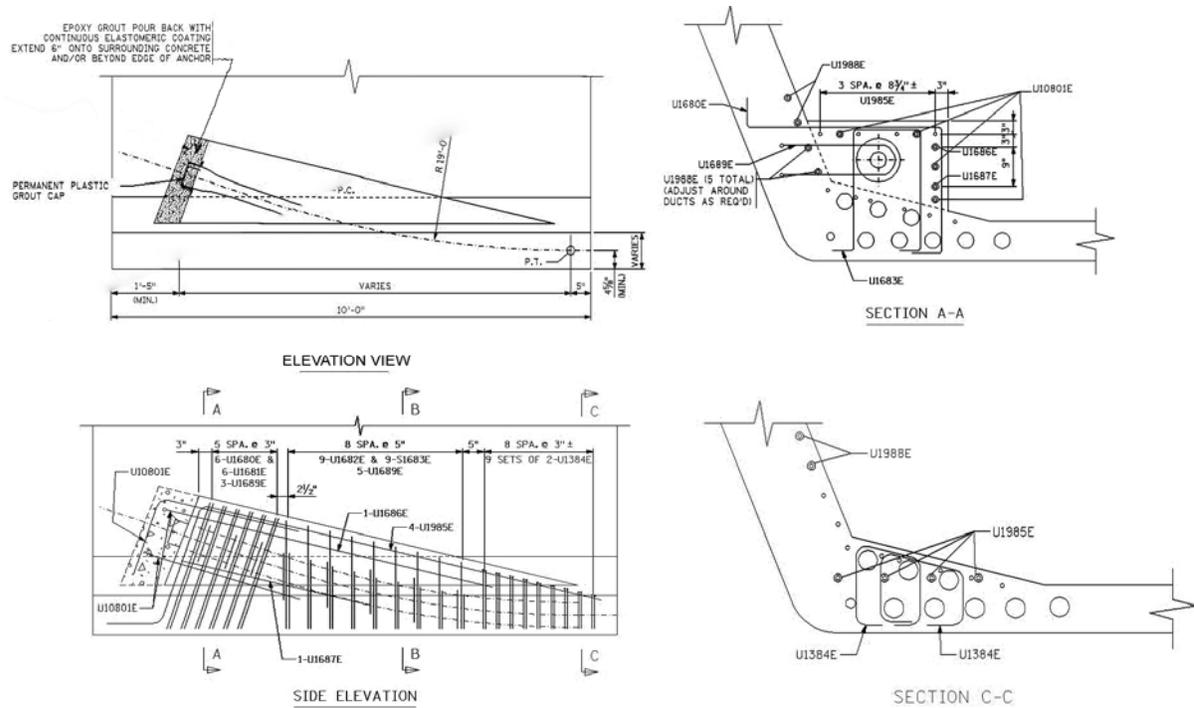


Figure 10: Bottom slab blister details.

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.

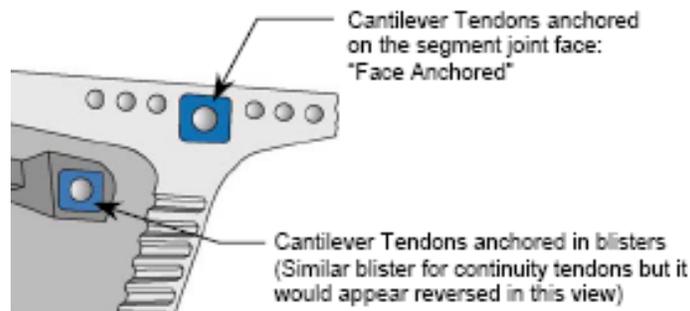


Figure 11: Potential cantilever tendon anchor positions<sup>2</sup>.

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.

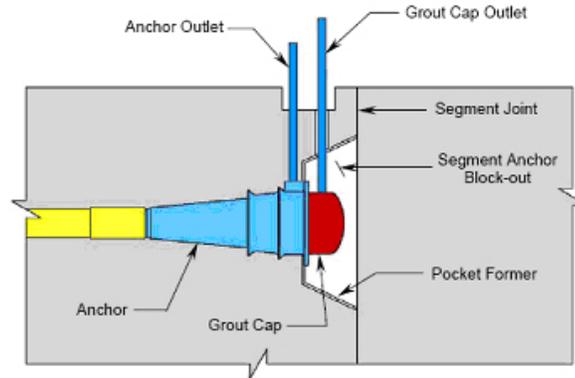


Figure 12: Cantilever Anchorage with Permanent Grout Cap<sup>3</sup>.

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.

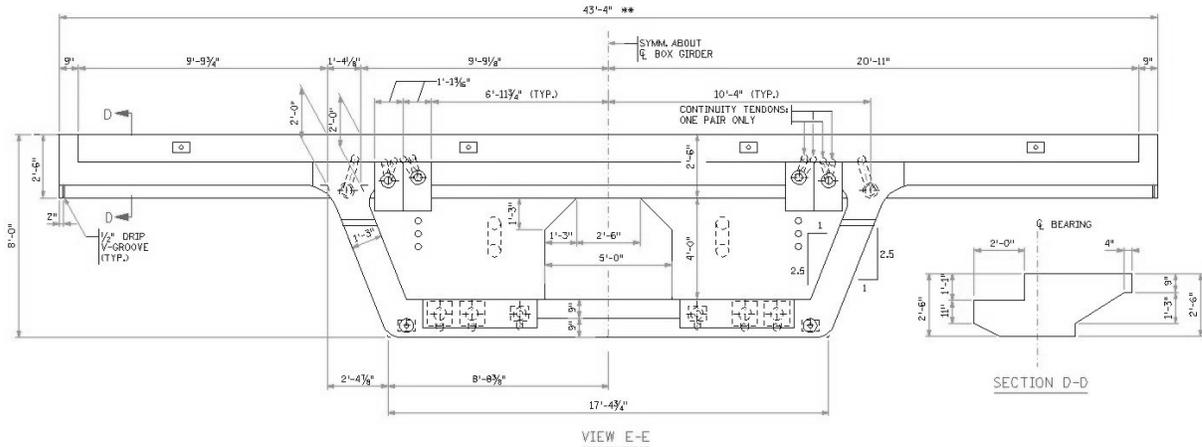


Figure 13: Abutment Segment Looking at Expansion Joint Face.

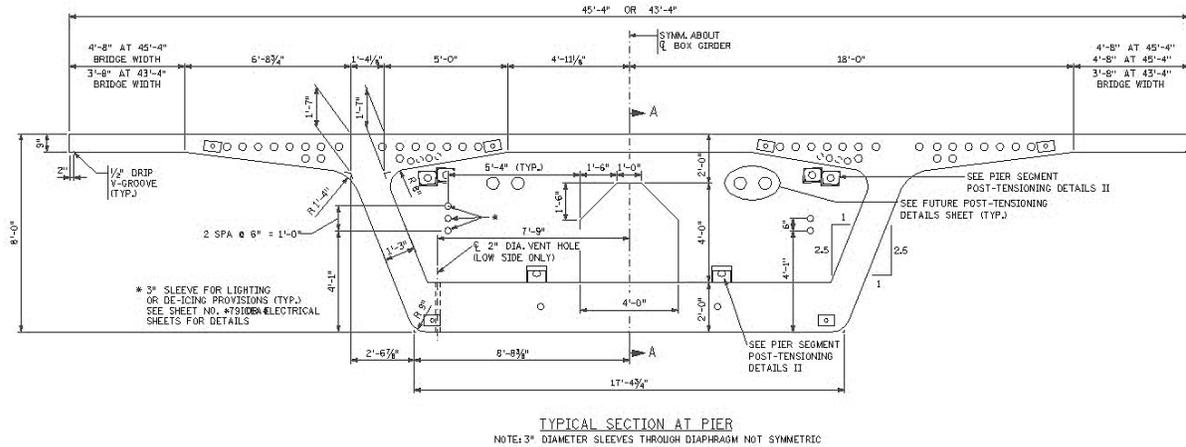


Figure 14: Pier Segment.

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.

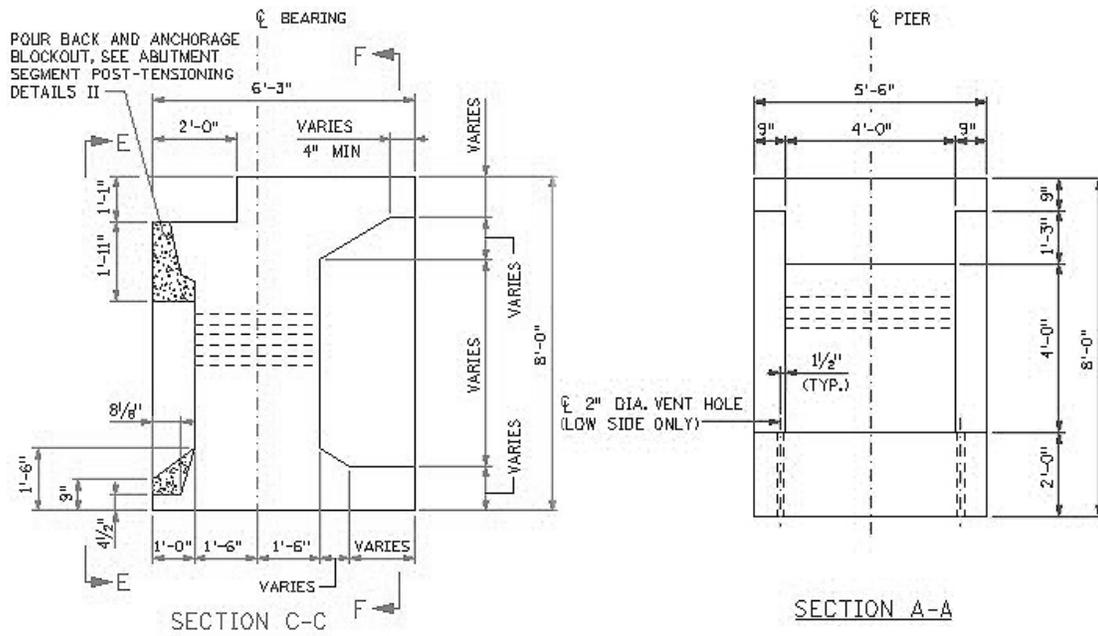


Figure 15: Abutment Diaphragm and Pier Diaphragm



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.

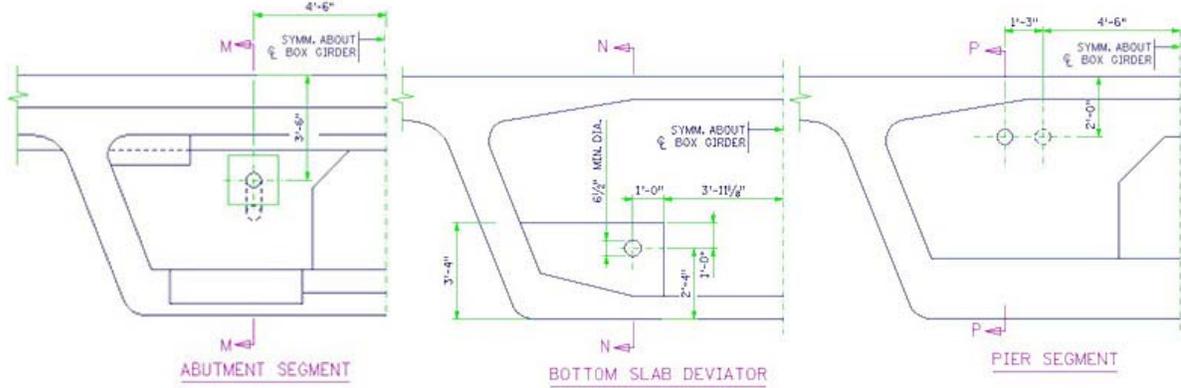


Figure 17: Future tendon path through abutment segment, deviator and pier segment.

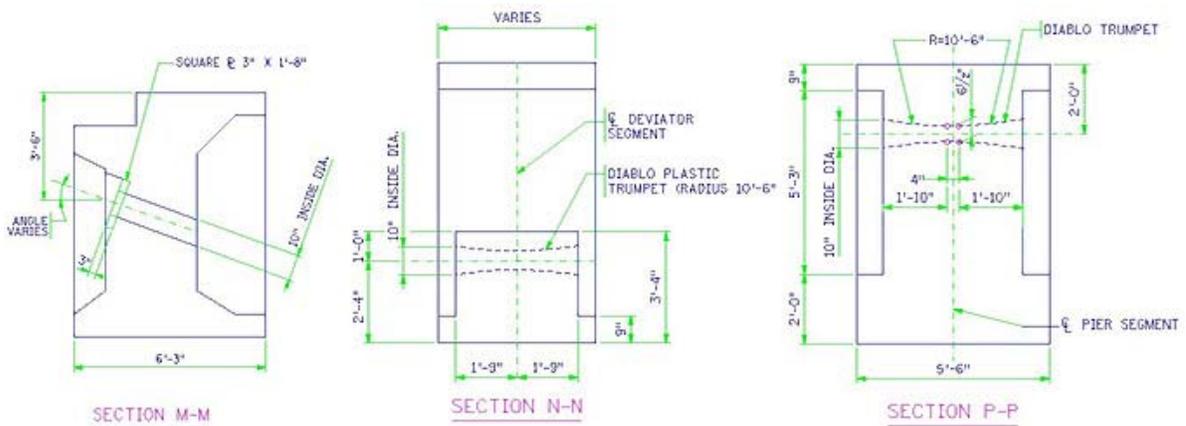


Figure 18: Sectional view of future tendon path.

### 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.

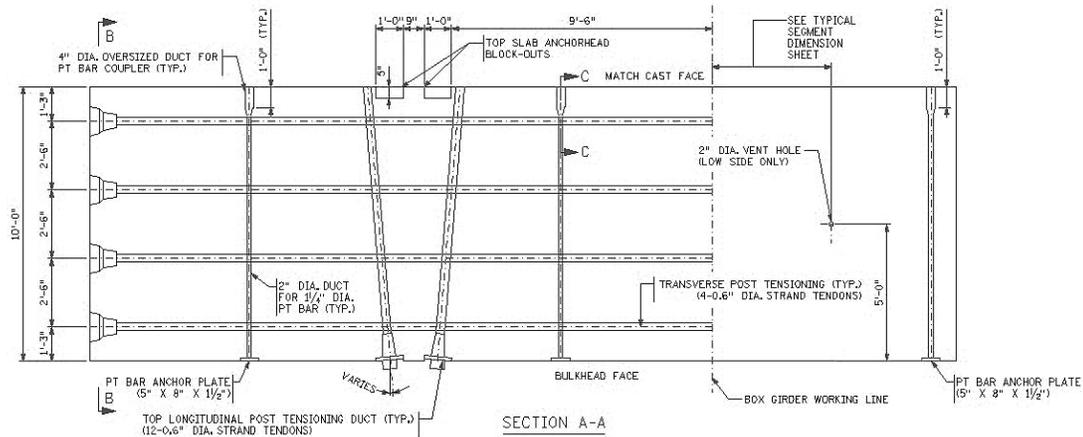


Figure 19: Typical transverse tendon plan.

## 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.

## **REFERENCES**

1. Map graphic from MnDOT with permission:  
<http://www.dot.state.mn.us/projects/crosstown/maps-projectarea.html>
2. FHWA Post-Tensioning and Grouting Manual, May 2004, Chapter 2, p.22
3. FHWA Post-Tensioning and Grouting Manual, May 2004, App. D, p.15