DEVELOPMENT AND CONSTRUCTION OF A PRECAST INVERTED T SYSTEM FOR EXPEDITING MINNESOTA SLAB SPAN BRIDGE PROJECTS

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ABSTRACT

The subject of this paper is a precast slab span utilized by the Minnesota DOT (Mn/DOT) to expedite construction of short span bridges. The precast concept was a technology identified during the FHWA/AASHTO 2004 International Scan on Prefabricated Bridge Systems. Prestressed inverted T's are used as the precast section. The system employs a robust looped reinforcing bar connection between the precast sections coupled with a cast-in-place pour to assure monolithic performance of the superstructure. This joint was designed to minimize the potential for reflective cracking at the joints between the side by side precast inverted T's. The system is an alternate to conventional slab span bridges using temporary false work for construction. The authors will describe development of the system with input from local fabricators, construction of two bridges in 2005 utilizing the system, and the ongoing monitoring being conducted with the University of Minnesota.

Keywords: Precast, Inverted T, Slab Span

INTRODUCTION

Minnesota, like most states, is searching for new ways to rehabilitate and replace substandard bridges with minimal impact to the traveling public. This is especially true in northern-tier states, where a cold climate means that a large number of projects must be concentrated in the few available months of each construction season. New techniques for rapid construction are of particular interest, to minimize the time that a road must be detoured, or to perhaps compress major project construction time from two seasons to one.

As part of the desire for new rapid construction technology, one of the authors (Dorgan) participated in the FHWA/AASHTO 2004 International Scan Tour.

The purpose of this tour was to investigate new rapid construction techniques being used for prefabricated bridges in Europe and Japan. One technique in particular, the Poutre Dalle system in France, showed promise for rapid construction of small bridges. The decision was made to try something similar in Minnesota.

Two Minnesota bridge projects were selected for this new system:

(1) TH 72 over the Tamarac River, near Waskish in northern Minnesota. This is a superstructure replacement project for an in-place bridge with a badly-deteriorated voided-slab concrete deck. This bridge has 3 equal spans of 45 feet.

(2) TH 8 over a boat channel near Center City, about 35 miles northeast of St. Paul. This is a new bridge over a channel to be cut between two lakes on either side of the highway. It will have 3 spans of 22, 27 and 22 feet.

Prior to the rapid construction study, both of these bridges were planned with cast-in-place (CIP) slab construction. Since such a design takes a long time to construct, due to large amounts of formwork as well as the need for temporary supporting falsework, they were seen as ideal “proof-of-concept” projects for the rapid construction techniques. For the Center City Bridge, additional measures were taken to speed up construction by designing precast substructures.

Because of the need for traffic staging with both projects, as well as major grading work being done in conjunction with the Center City Bridge, actual construction time for both bridges will not be appreciably less than a conventional CIP slab. However, by trying the new system on these projects, the groundwork will be laid for future projects that will take advantage of the significantly shorter construction time.

PRELIMINARY SECTION DESIGN

Two preliminary inverted T sections were initially proposed for use in the Mn/DOT Precast Slab System. Trial Section 1, shown in Figure 1, was 6 feet wide while trial Section 2, shown in Figure 2, was 4 feet wide. The section width, prestressing pattern and transverse bar location were varied between the two sections. Both of the sections incorporated the same flange shape.

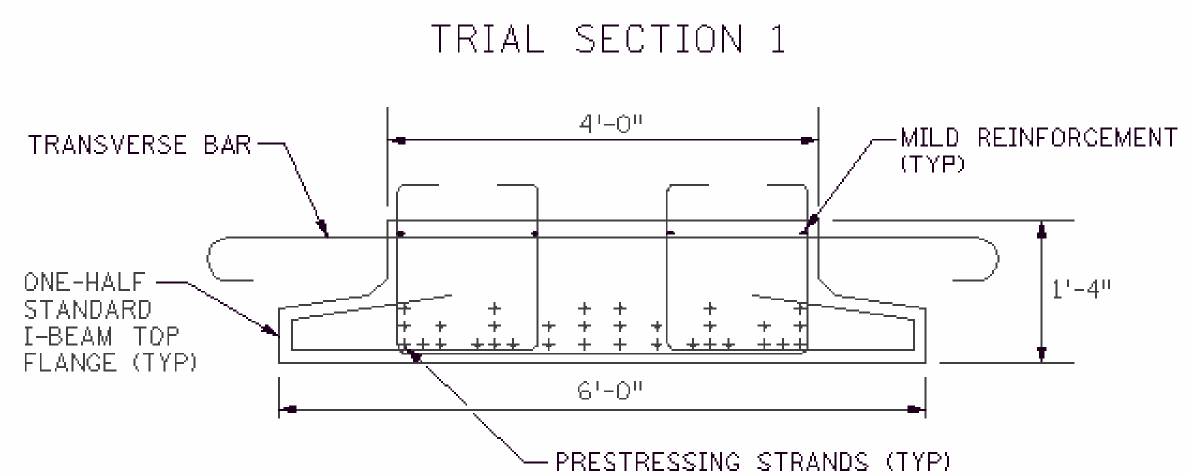

Figure 1. Trial Section 1. This section is 6-ft wide and incorporates the top flanges from Mn/DOT's standard precast I-beam. Although the transverse bar is shown in the top of the section, later in the design process it was decided that the transverse bars would be placed just above the flanges.

The 6-foot wide section was preferred by Mn/DOT because being wider, it would reduce the number of longitudinal joints between sections on the bridge. The 4-foot wide section was developed as a possible alternate if fabricators did not have a bed capable of producing the 6-foot wide section. The 4-foot wide section was designed using a prestressing pattern identical to that of Mn/DOT's standard precast I-shapes. This detail was intended to allow fabricators that currently produce the standard I-shapes to produce the 4-foot wide section with few modifications to their prestressing beds. Ultimately, since the 6' wide section could be produced by at least 3 local prestress fabricators, only the 6' wide section was detailed in the plans.

The location of the transverse bar extending through the web was varied to determine whether fabricators had a preference toward one location over the other. The transverse bar in Trial Section 1 was initially detailed near the top of the section to make fabrication easier. The transverse bar extending through the section in Figure 2, however, was placed just above the top of the flanges. Subsequent discussion and analysis led to positioning the transverse bar as low as possible in the section to have it closer to the tension face and closer to the joints in the bottom of the slab to more effectively intercept transverse joint cracking and improve durability.

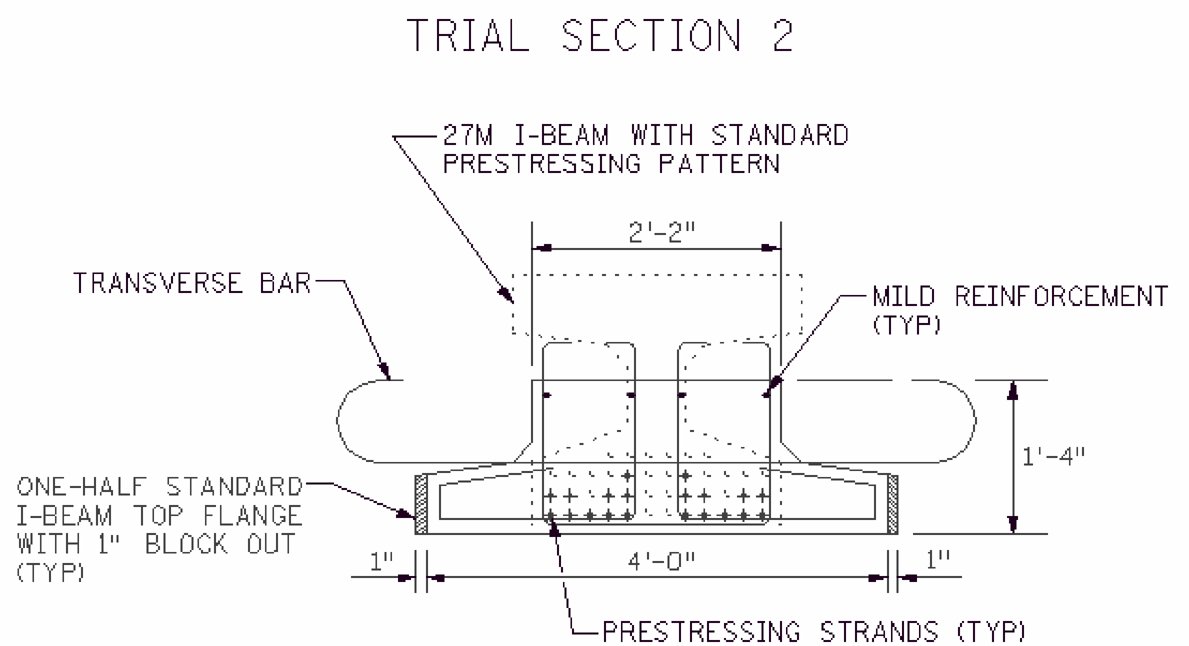

Figure 2. Trial Section 2. This section is 4-ft wide and incorporates the top flanges from Mn/DOT's standard precast I-beam. The Mn/DOT standard 27M I-beam is superimposed onto the inverted T cross section to show that the prestressing patterns are identical.

Both trial sections were designed with a flange shape that was identical to the shape of the top flange on Mn/DOT's standard I-beams. This shape was selected in an attempt to make the section more economical, thinking that fabricators may possibly be able to use the forms that they already had. The top flange shape was chosen over the bottom flange shape because the standard top flange is thinner than the standard bottom flange. The reduced joint depth between abutting sections would lessen the likelihood of cracks developing at the longitudinal joint, and therefore increase the durability of the section.

From the preliminary design, it was determined that for 45-foot spans, the 6-foot wide section would require 32 - ½" strands. This equates to an initial prestress force of about 1 million pounds. For the same span length, the 4-foot wide section would require 20 – 0.6" strands, which equates to about 875,000 pounds of initial prestress. During preliminary design, it was also decided that all of the precast surfaces which would be in contact with cast-in-place concrete should be intentionally roughened to promote composite action when the superstructure is complete.

FABRICATOR INPUT

After the preliminary design of the trial beam sections was completed, six prestessed concrete beam fabricators in the Minneapolis/Saint Paul area participated in the development of the proposed inverted T section. Mn/DOT scheduled meetings with each of the fabricators to discuss the feasibility of building the proposed trial sections and to gather any additional comments or suggestions that the fabricators had regarding the development of the inverted T section.

Prior to the fabricator meetings, Mn/DOT developed an input form to standardize feedback from the fabricators. The input form served as a checklist of the issues that would possibly be problematic to the fabrication of the inverted T section. The major fabrication issues that were addressed on the input form were:

- obtaining a roughened surface on the faces of the precast elements that would be in contact with cast-in-place concrete,
- using forms that would allow the transverse reinforcing bar to protrude through the section,
- adapting prestressing beds to fit the proposed section geometry,
- obtaining the required initial prestress capacity on the 6-foot wide section, and
- fabricating asymmetrical fascia sections with pre-installed railing bars.

All of the fabricators that were involved in the development process were prequalified based on prior certification by the Precast/Prestressed Concrete Institute. Because some of the fabricators involved in the input process typically do not do bridge work, the proposed concrete strengths and strand sizes for the inverted T beams were also discussed to determine which fabricators would be capable of building the section.

At the conclusion of the meetings with the fabricators, Mn/DOT had found the trial section that had been developed could be built without major revisions. We also discovered that it was not feasible for the fabricators to use forms for the standard I-shape to form the inverted T section. Since new forms would be needed, the flange shape could be modified as desired. The major fabrication issue that still had to be resolved was obtaining the desired roughness on the surfaces of the precast beams to be in contact with cast-in-place concrete. Mn/DOT decided that it would specify ¼” amplitude of roughness, leave the method for arriving at that roughness up to the fabricator, and require a roughened test section from the fabricator that would be approved by the Engineer prior to fabrication of the beams.

DESIGN CONSIDERATIONS

The design of the prestressed reinforcement for the inverted T beams was performed using the AASHTO LRFD Bridge Design Specifications, Third Edition, 2004. Design of the prestressed reinforcement was automated by using an in-house prestressed beam design spreadsheet that is typically used to design Mn/DOT's standard I shapes. The inverted T beams were designed to be simply supported under dead loads and continuous for live loads. The design of the mild reinforcement in the top of the superstructure over the piers was designed similar to the top reinforcement of a cast-in-place slab span bridge.

For the design of both prestressed reinforcement and mild reinforcement, live loads were considered to be distributed to the superstructure based on the Equivalent Strip Widths for Slab-Type Bridges (AASHTO LRFD, Sect. 4.6.2.3). Other live load distribution factors from AASHTO were evaluated for comparison; however, Mn/DOT concluded that a slab-type live load distribution factor would be the most appropriate.

Shear design of the inverted T beams was performed using the Modified Compression Field Theory (AASHTO LRFD, Section 5.8.3.4.2). Normally, Mn/DOT does not make precast/prestressed concrete beams continuous, so the shear design of the inverted T beams at interior supports was more complicated than usual. Because the inverted T beam's prestressing reinforcement is not on the tension side of the beam over the pier, longitudinal strain was calculated using the procedure outlined in AASHTO LRFD section C5.8.3.4.2. Also, because the inverted T beams are continuous over interior supports and the top of the slab is therefore in tension, longitudinal reinforcement checks (AASHTO LRFD, Section 5.8.3.5) at the piers were performed considering mild reinforcement in the top of the slab.

Because the inverted T beams were made continuous over interior supports, secondary effects needed to be considered, as well. Secondary effects develop because simply supported precast beams have a tendency to camber either up or down after they are made continuous. If the beams are made continuous at an early age (i.e. 28 days), they will have a tendency to camber up, causing a positive restraint moment to develop at the bottom of the superstructure over the pier. If the beams are made continuous at an older age (i.e. 90 days), the majority of camber growth will have already occurred allowing dead load creep to cause the beam to have a tendency to sag. This effect causes a negative restraint moment to develop at the top of the superstructure over the pier. The magnitude of the restraint moments were determined using a method outlined in a Portland Cement Association (PCA) article on the "Design of Continuous Highway Bridges with Precast, Prestressed Concrete Girders," (August, 1969). Full restraint moments were considered in the design of the pilot projects.

Final design data for the two Mn/DOT Precast Slab System pilot projects are shown in Table 1.

Table 1. Final Design Data. Final Design Data for the inverted T beams on Mn/DOT's two Precast Slab System pilot projects.

Final Design Data

	Waskish Bridge	Center City Bridge
Span Lengths (ft)	45 - 45 - 45	22 - 27 - 22
Max Beam Length	44'-9"	26'-8"
f'_c (psi)	6500	6500
f'_{ci} (psi)	4500	4500
Strand Diameter (in)	0.5	0.5
Number of Strands	32	16
Initial Prestress (lb)	991,440	495,720
Interior Beam Wt (T)	21.7	10.6
Exterior Beam Wt (T)	24.7	9.9

DETAILING CONSIDERATIONS

The main concern when detailing the inverted T section and reinforcement for the precast slab system was durability. Since this system does not incorporate transverse post-tensioning to protect against the development of longitudinal cracking between sections, placement of the mild reinforcement across longitudinal joints and the detail of the concrete at that joint needed to be considered carefully. Two considerations were made for the longitudinal joint between the precast sections in an effort to arrest possible crack propagation.

First, a ¾” chamfer was specified at all of the corners of the inverted T beams, including at the top of the flanges that abut next to each other when the beams are placed in their final position. This chamfer provides more length at the interface between sections, and should therefore reduce stress concentrations at the longitudinal joint. Reduced stress concentrations will hopefully result in reduced cracking.

Second, the flanges of the inverted T sections were detailed to be as thin as possible to reduce the height of the joint between the precast sections, so that the transverse reinforcement extending through the precast sections and overlapping at the longitudinal joint could be placed as close as practicable to the bottom of the superstructure. In order to make the flange as thin as possible while reinforcing it with #4 bars bent at 180°, the cover for reinforcement at the top of the flange was reduced to 0”. Using 0” of cover at the top of the flange was determined to be acceptable because the flanges would be covered by a substantial depth of cast-in-place concrete. Putting the reinforcement lower in the superstructure allows it to be more effective in resisting tension forces that will develop due to transverse bending. By reducing the flange depth and placing reinforcement directly above the joint between sections, the potential for longitudinal cracks to form should be lessened greatly.

Also, regarding durability, all surfaces of the precast sections that will be in contact with cast-in-place concrete were detailed to have surfaces roughened to ¼” amplitude. This detail is meant to assure that the superstructure will remain composite when in service. Figure 3, below, shows the final precast cross section used on the Waskish Bridge including chamfered corners, thin flanges to allow transverse reinforcement to be as low as practicable and roughened surfaces that will be in contact with cast-in-place concrete.

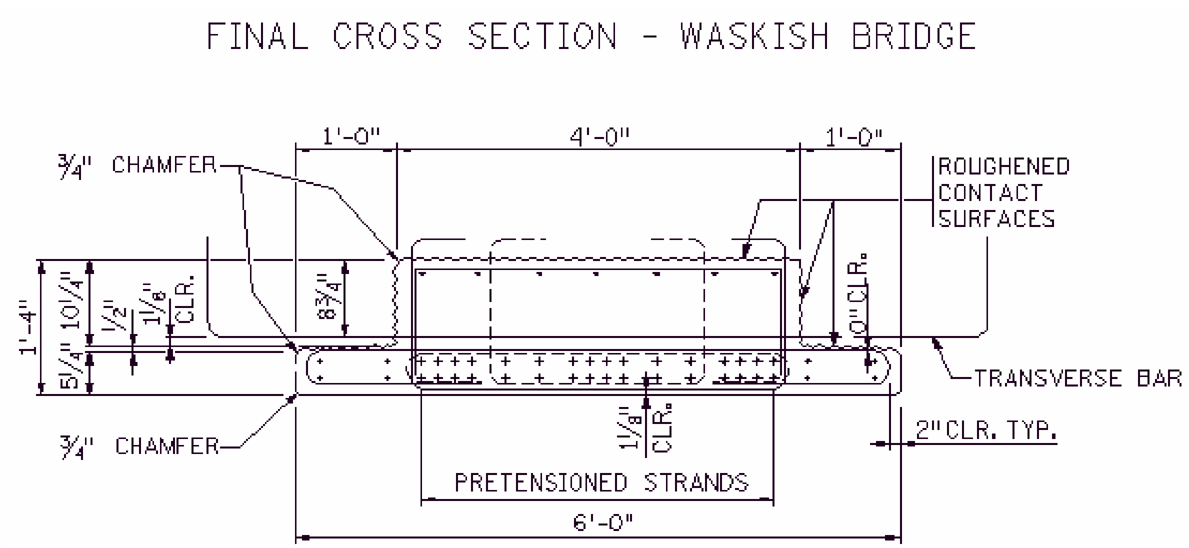

Figure 3. Final Cross Section – Waskish Bridge. This is the final cross section that was used on the Waskish Bridge (similar cross section for the Center City Bridge). The flanges were made as thin as possible by specifying 0” clear from the top of the flange to the top of the U-shaped flange reinforcement. The transverse bar was placed as close as practicable to the top of the flange. All corners were specified to have ¾” chamfers. All contact surfaces were specified to be roughened to ¼” amplitude.

Lastly, to increase the durability of the sections during transport, Mn/DOT reinforced the Inverted T beam flanges with U-shaped #4 bars. Using this reinforcement forced the flanges to be slightly thicker than those used the French system, and put reinforcement close to all surfaces of the flange. In addition, Mn/DOT specified that the inverted T beams could be lifted or supported only within 1'-6" from their ends during transport to prevent excessive tension at the top of the beam due to prestressing forces.

Speed of construction was also considered when detailing the precast section. A 90° hook was used at the end of the transverse reinforcement extending through the inverted T sections instead of the 180° hook that is shown in the French system. A cage of reinforcement is to be placed above the flanges of the inverted T section to reinforce the cast-in-place concrete that will be poured over the precast beams. Using a 90° hook allows this reinforcement cage to be pre-tied and then dropped into place instead of placing each bar individually as would have to be done if 180° hooks were used. Figures 4 and 5, below, show this detail.

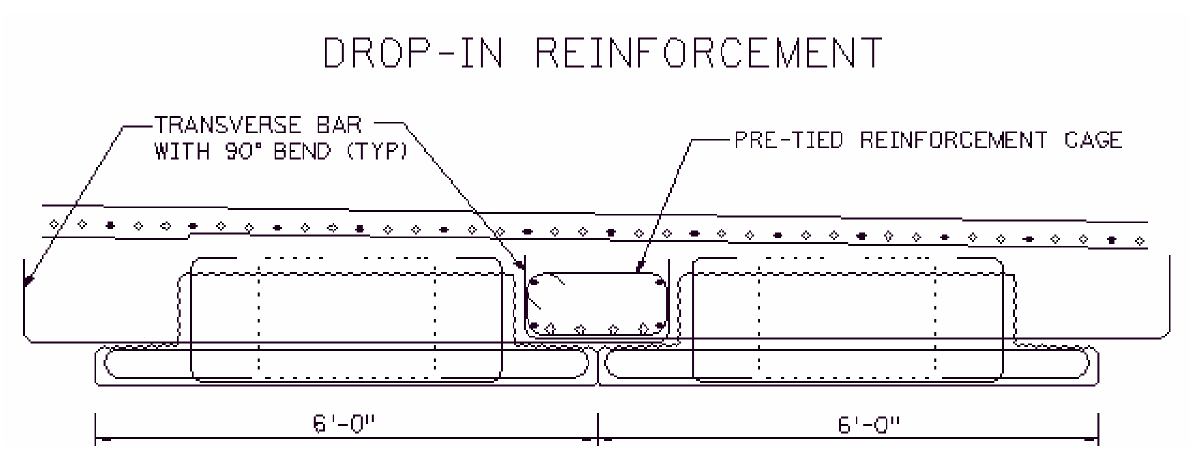

Figure 4. Drop-In Reinforcement. Transverse bars extending through the precast sections were fabricated with 90° bends to accommodate a pre-tied reinforcement cage. This detail was chosen to promote rapid construction.

Figure 5. Drop-In Reinforcement at Construction – Center City Bridge.

Finally, at the ends of the precast beam sections, the flanges were blocked out to allow for an integral connection to the substructures. A 9" length of each flange at each end of the beam is blocked out to allow for anchor rods to protrude into the superstructure from the substructure. Cast-in-place concrete is then poured in the pockets at abutting beams to interlock the reinforcement that projects from the beams and substructure. This detail, shown in Figures 6 and 7 below, provides the beam with a ready-made attachment system to the substructures, allowing construction to move along at a rapid pace.

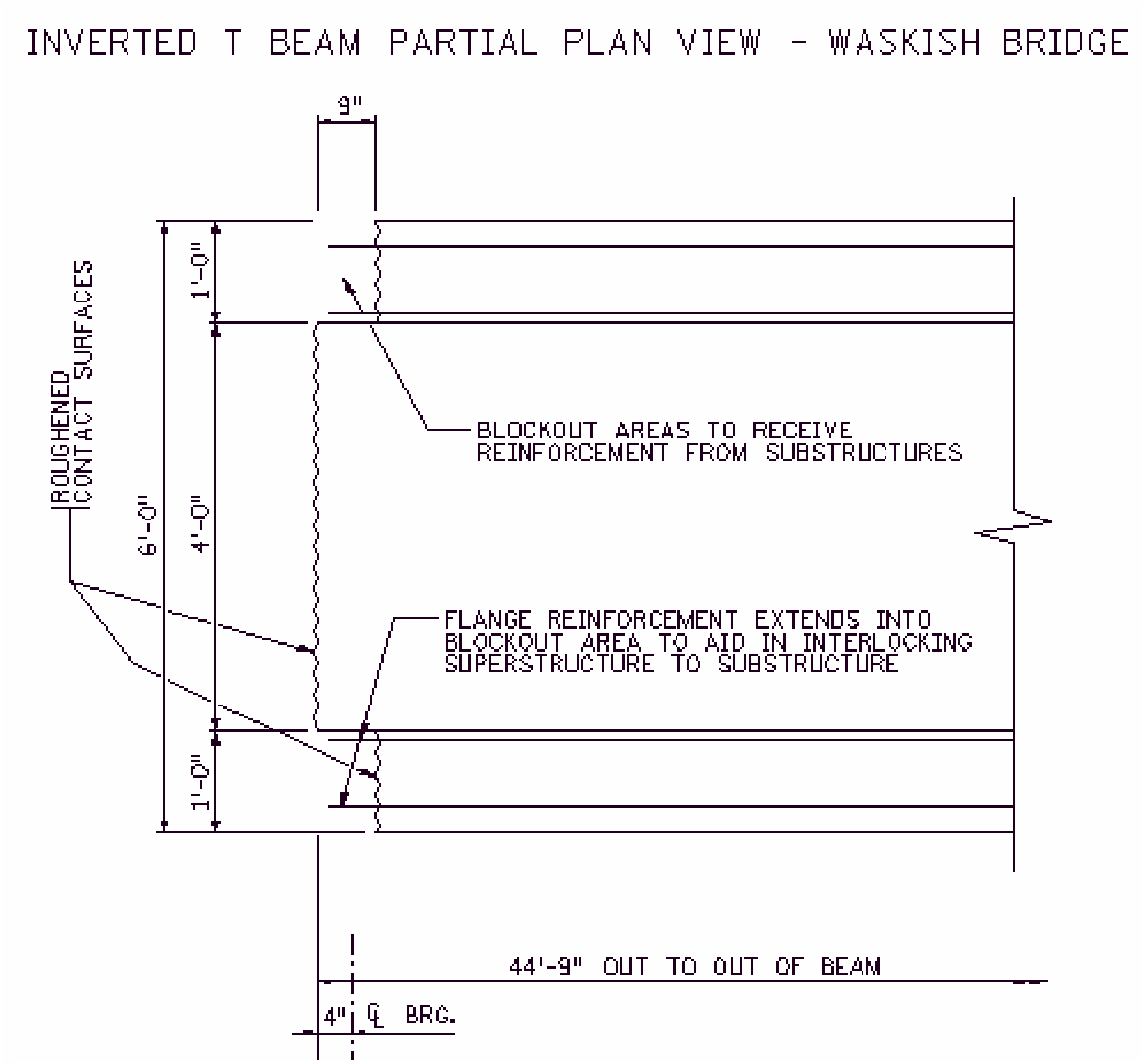

Figure 6. Inverted T Beam Partial Plan View – Waskish Bridge. This detail shows the blocked out portions of the flanges to receive reinforcement from the substructure. Reinforcement protruded from the flanges to aid in interlocking the superstructure to the substructure. As shown, the ends of the beam are roughened to aid in interlock, as well.

Figure 7. Pier Blockout Detail at Construction – Center City Bridge. In this photo the pier is running vertically and the beams are running horizontally. Anchor rods still need to be drilled into the pier cap.

Complete plan sets for both of Mn/DOT's pilot projects showing all details can be found at:

http://www.dot.state.mn.us/bridge/PrecastSlabSystem/PrecastSlabSystem.html

BEAM FABRICATION

During the fabrication of the inverted T beams, the prestressed beam fabricator proposed two changes to make fabrication easier. First within 3' from the ends of the prestressed beams, double stirrups were detailed to meeting bursting requirements and to resist peak horizontal shears at the interface of the prestressed beams and cast-in-place concrete. The stirrups detailed in the plans were of the same height and were tied next to each other beneath the bottom row of prestressing. The fabricator proposed shortening one of the stirrups and tying it to the top row of prestressing directly above the other stirrup. This change would provide more space between the reinforcement at the ends of the beam, and would allow the concrete to flow between the reinforcement more easily.

The other change proposed by the fabricator was to replace the mild, longitudinal reinforcement in the flanges with prestressing strands. These strands would then be tensioned to a nominal 5000 psi to hold them up, with minimal sag, prior to and during the concrete pour. The fabricator proposed this change to avoid using chairs to hold the longitudinal flange reinforcement during pouring.

The fabricator proposed a variety of different roughed surface samples that had been obtained using form liners. Roughened surfaces were obtained using forming techniques that are shown in Figure 8. These techniques included ball peen dents hammered into a flat steel form, angle blockouts attached to the inside of the form, raised pattern plate metal forms, and a metal lath form liner.

Figure 8. Roughened Surface Samples. Forming descriptions starting at the top, left going clockwise are: ball peen dented form, angle blockouts attached to form - variation 1, raised pattern plate metal form, angle blockouts attached to form - variation 2, metal lath form liner - variation 1, and metal lath form liner - variation 2.

After reviewing the roughened surface samples, Mn/DOT decided to use variation 1 of the metal lath form liner (shown bottom, middle in Figure 8). This surface was selected because it provided the desired roughness amplitude of ¼” and it also provided the largest roughened surface area. This type of surface is to be present on the entire face of the surfaces to be roughened. Figure 9, below, shows the roughed surface on one of the finished beams.

Figure 9. Final Roughened Surface. The surface shown on the side of the beam is typical for all formed contact surfaces except for the top of the beam. The top of the beam is broomed transversely.

INSTRUMENTATION

In order to test some of the assumptions used for the design of the inverted T sections, and to monitor performance of the completed structure under traffic, Mn/DOT contracted with the University of Minnesota's Civil Engineering department to install instrumentation in one of the bridges. The Center City Bridge was selected for instrumentation due to its proximity to the Twin Cities, where the U of MN campus is located.

The intent of the monitoring is twofold: (1) To check for reflective cracking between parallel inverted T sections, and (2) verify the assumption of continuous behavior for live loads over the piers. A total of 96 VW (vibrating-wire) spot-weldable and embedment strain gages will be installed in the deck prior to pouring the CIP deck section.

The strain gages are installed as shown in Figure 10. Wiring from the gages is routed through steel conduits to multiplexers located in junction boxes mounted to the east face of pier 2. From there, conduits carry the wiring through the east abutment to data loggers mounted in an electrical cabinet east of the bridge. U of MN personnel will periodically travel to the bridge site and download strain gage data from this cabinet.

In addition to the field instrumentation, four additional inverted T sections are being equipped with strain gages prior to fabrication. These four sections will be shipped to the U of MN civil engineering lab for further research, and will not be used in the bridge.

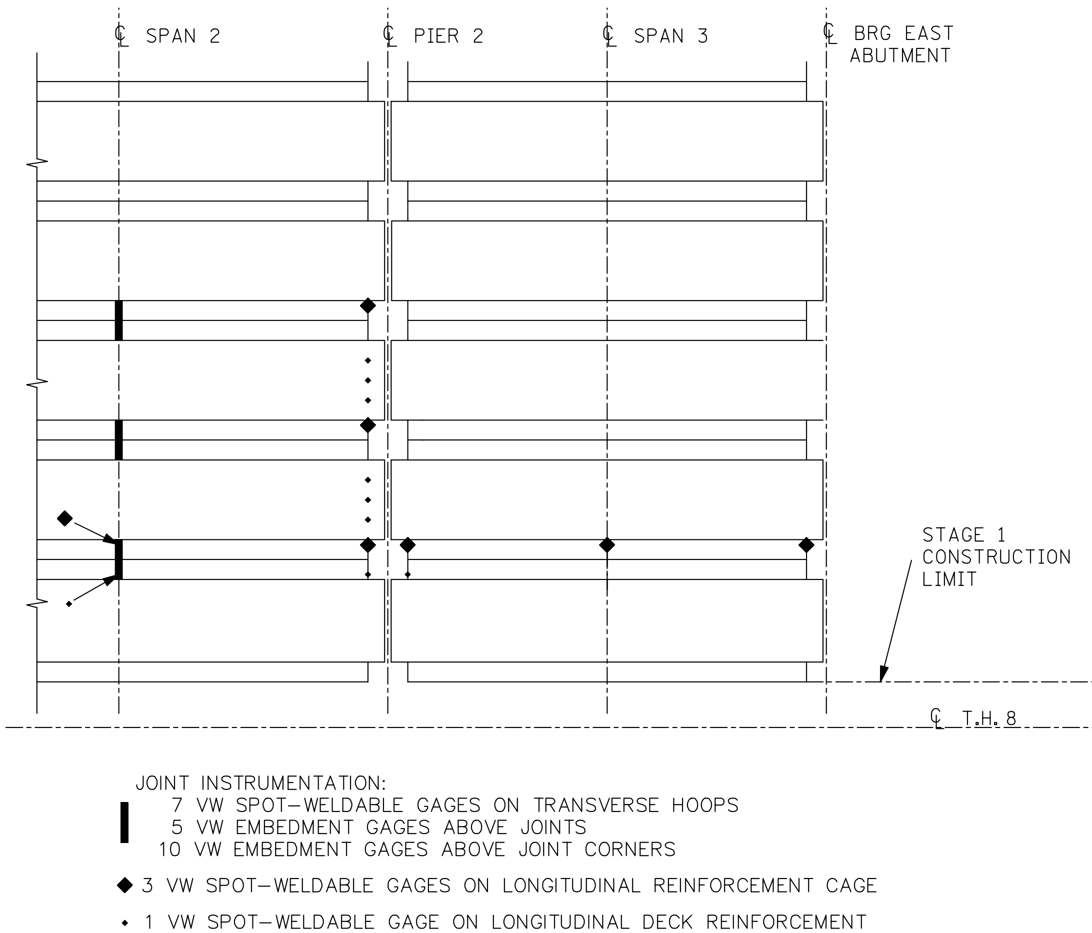

Figure 10. Strain gage layout for Center City Bridge

NEXT STEPS

At the writing of this paper, Mn/DOT's two Precast Slab Span pilot projects were in the construction process. Figure 11, below, shows the first stage of construction for the Center City Bridge. Construction will be completed for the pilot projects in the fall of 2005.

Figure 11. Stage 1 Construction – Center City Bridge.

Once the construction phase of this project is complete, data will be gathered from different sources for consideration of possible refinements to the design and detailing of this system. Results from the U of MN instrumentation along with observations regarding the general performance of the system will be major factors in determining design related modifications to the system. Feedback from the fabricator and construction crews will be considered when revising the details of the system to make construction less difficult and more rapid.

Because of the growing demand for reduced construction related traffic delays, it is Mn/DOT's intent to continue to refine the system as a rapid construction alternative to conventional slab span bridges.