DESIGN, FABRICATION, AND CONSTRUCTION OF A SINGLE POINT URBAN INTERCHANGE

By
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PROJECT BACKGROUND

Pennsylvania State Route 15 (Market Street) crosses the West Branch of the Susquehanna River in Williamsport, Pennsylvania. Immediately north of the river crossing, S.R. 15 also spans a railroad line, four lanes of Interstate 180, and a local roadway prior to touching down in downtown Williamsport. One ramp also exits the mainline above the interstate and connects to Via Bella and Mulberry Street, below the bridge. Currently, no direct connection exists between S.R. 15 and I-180.

Michael Baker Jr., Inc. (Baker) was initially hired to perform an in-depth structural inspection of the 50 year-old structures and develop rehabilitation options. The extensive deterioration of the open grid steel deck required continual maintenance and since the open grid offered no protection to the superstructure, it too was extensively corroded and in dire need of replacement. As a minimum, the client, PENNDOT District 3-0, wanted to replace the existing open grid steel deck and as a maximum, replace the superstructure. Both options were investigated in depth, however, neither was found to be economically feasible.

The need to replace the existing structures presented an opportunity for the Department to investigate options for directly connecting S.R. 15 and I-180 via an elevated interchange that would be structurally independent of the main river crossing. As a result, Baker was tasked with performing an alternatives analysis to compare various interchange types.

Alternatives Analysis of New Interchange

The main stipulations in selecting an interchange configuration was that it provide for all traffic movements, that the structural plan area be minimized, and that the design and construction costs be kept to acceptable limits. Several interchange types were considered, but only a diamond, a single point, and a left-hand exit interchange met these requirements and were studied in depth.

While each of the three interchange types would provide all traffic movements between the two roadways, the single point urban interchange (SPUI) would do so with the highest levels of service. In addition, the

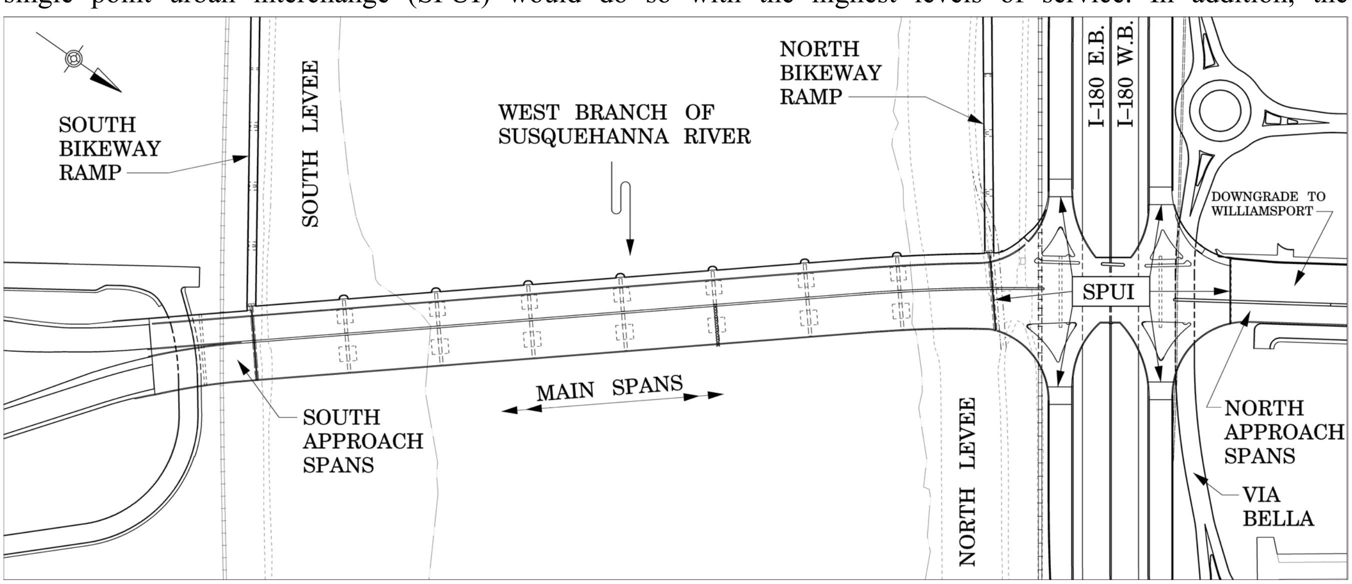

Figure 1. Plan of Project Area. Limits of the elevated Single Point Urban Interchange shown at right.

configuration of a SPUI would place the on/off ramps so that they would straddle the interstate (see Figure 1) and provide a more functional configuration than the configuration that utilized left hand exits. Another benefit that was realized with the configuration was allowance for future widening of the interstate.

In recent years there have been several Single Point Urban Interchanges constructed in the United States. The original intent for these structures was to provide for an interchange in rural area. The structure is typically a single span with a configuration that allows the ramps to be supported by fill and the connection between the ramps and the structure is not necessary. A few of the SPUI bridges that have been constructed are elevated SPUI's (similar to the topic structure). The connections utilized on these structures are traditionally full moment connections between the structure members.

Structure Type Study

Once the interchange configuration was selected, a structure type study was performed to determine the most cost effective solution that would meet the horizontal and vertical geometric constraints as well the aesthetic requirements set forth by the client and community partners. The structural depth had to be established so the rail line and roadways would be cleared and the at-grade touch-down point on the Williamsport approach could be maintained close to the existing location (see Figure 2). Additionally, since the SPUI would be designed to carry pedestrian traffic as well, the grade could not exceed 5% at any location. These requirements yielded an allowable superstructure depth of less than 7.5 feet.

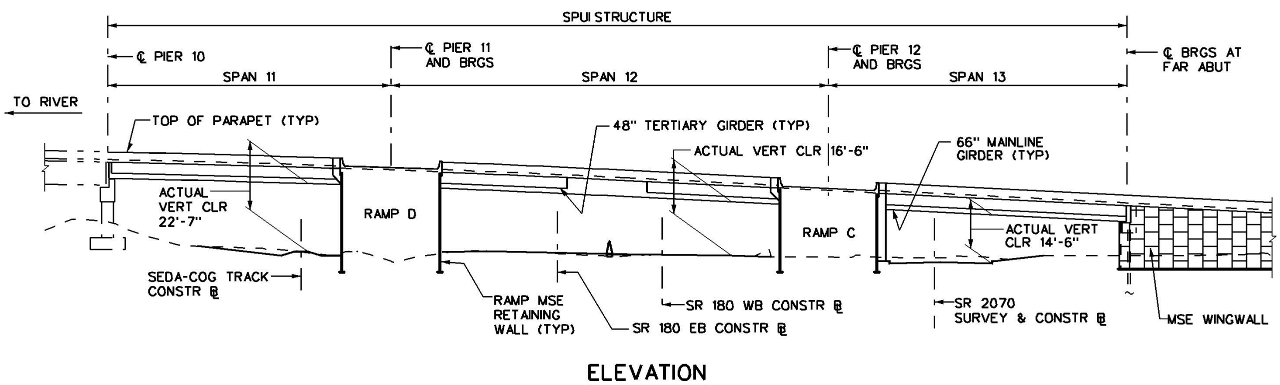

Figure 2. SPUI Structure Elevation View.

Several different concrete superstructures were investigated (prestressed concrete "I" girders, prestressed concrete box beams, and post tensioned boxes). The use of a concrete superstructure would require the railroad to be lowered significantly or another pier to be added. In addition, all the concrete superstructure options resulted in an excess amount of deck area. Because of these issues, concrete superstructure options were not considered further.

SUPERSTRUCTURE DESIGN

Framing Plan

Several framing plans were investigated. One extreme was represented by systems that focused on simplistic framing. These included only straight members without framed-in sub members. As would be expected, this resulted in the largest plan areas and the most unused deck space. The other extreme was represented by systems that focused on minimizing structural plan area. These options included irregular and complex framing that included many curved girders as well as framed-in sub and tertiary members. These systems provided virtually no superfluous superstructure and closely paralleled the idealized edges of travel way.

The ideal solution was one that could minimize superfluous structure area and do so with the most efficient framing. The design team soon realized that eliminating all framed-in connections could only be accomplished by systems that provided large extraneous deck areas. Rather than trying to eliminate all framed-in connections, the design focused on a system that would allow one or two relatively complex details that could be standardized for use throughout the structure. This allowed economies of scale, which in turn, allowed a compromise that reasonably satisfied both goals, minimizing the superfluous area and efficiency of the framing. Standardizing these details resulted in an expected lower cost for both fabrication and erection.

A system was developed that incorporated main, secondary, and tertiary members in which all framed-in connections would follow the same erection procedure and be either 90° or 45°. The eight main girders are three-span continuous, 66" deep, parallel, steel plate girders. Each of the four ramps consists of 54" deep secondary members and 48" deep tertiary members. The secondary members are parallel, steel plate girders, supported on an abutment at one end and frame into the fascia girders of the main spans at 90 ° at the other end. The tertiary girders frame into the mainline and secondary girders at 45°. Painted steel conforming to ASTM A709, Grade 50 was specified throughout.

Ultimately, the decision was made to deviate slightly from the above concept of employing only straight, parallel girders, by adding curved fascia girders to each ramp. However, all curved girder connections were designed to accommodate the established erection procedure. The benefit of using curved fasciae was to decrease the superfluous deck area even further and enhance the overall aesthetics.

The framing plan resembles a double spider web and initially appears very complicated. However, when the above nuances are considered, the overall concept is significantly simplified. Additionally, all diaphragms are normal to the adjacent girders, with the exception of the curved fascia girders (see Figure 3).

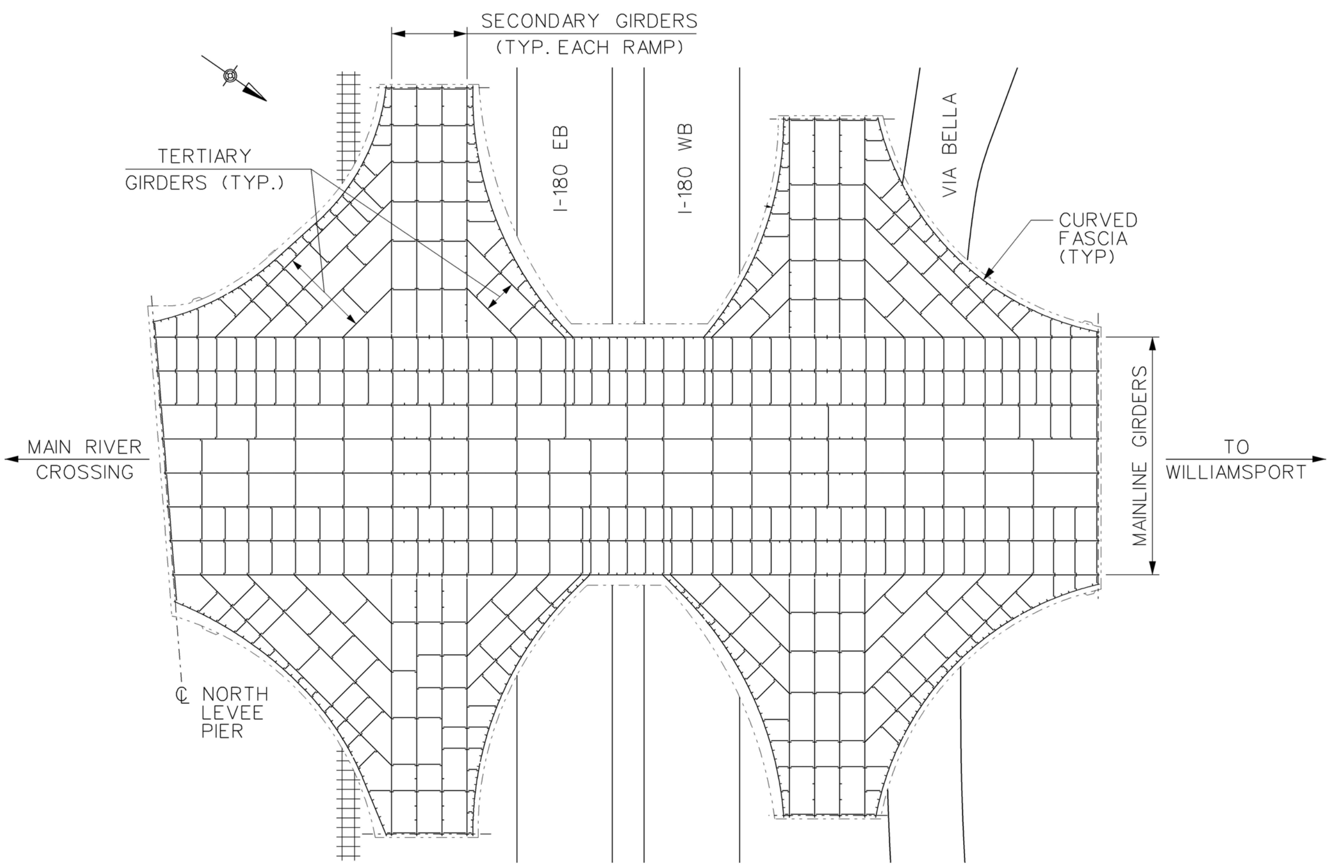

Figure 3. SPUI Framing Plan

Connections

Arranging the framing to accommodate either 90° or 45° skewed connections throughout was the first challenge and could be solved by considering the framing in only two dimensions. However, establishing efficient connection details and a practical erection procedure required consideration in three-dimension, and were much more challenging tasks.

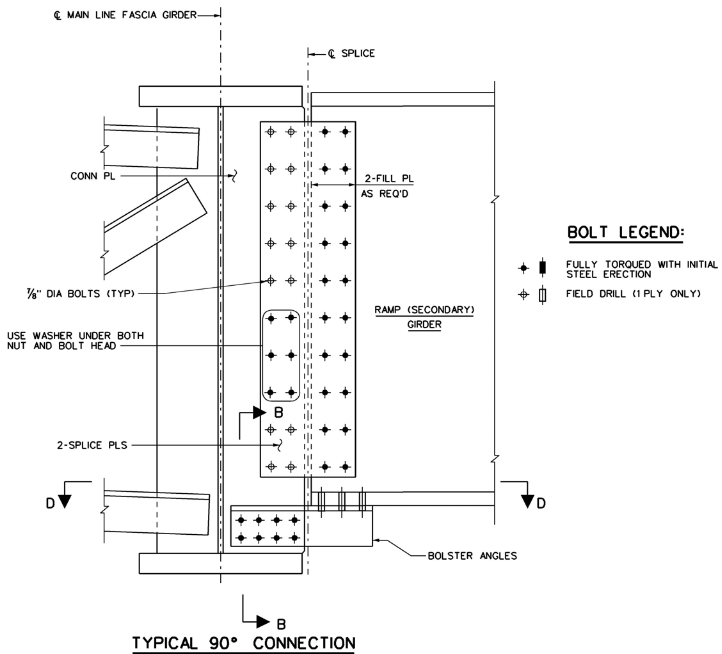

Figure 4. Typical 90° Framed-in Connection Detail

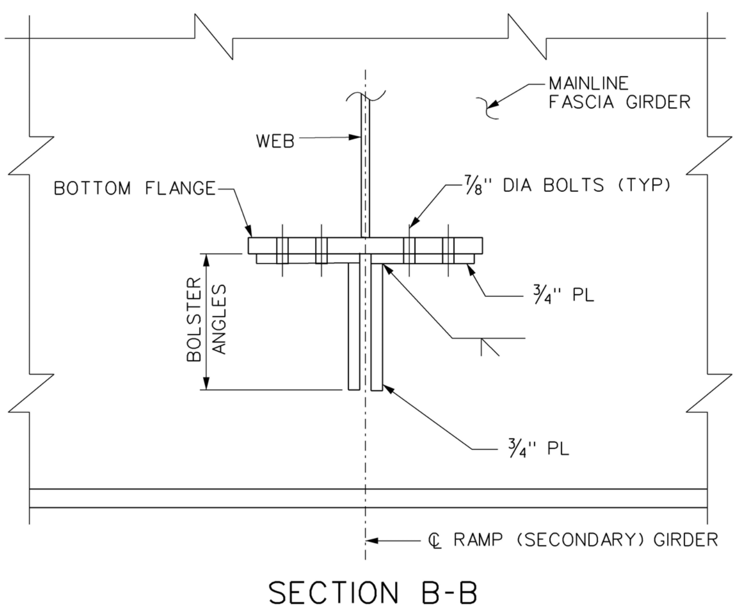

Figure 5. Section View B-B (see Figures 4 & 6 for location)

Due to superelevations and vertical geometry, none of the girder sets is entirely horizontal: the main girders have higher bearing elevations at their south end, the secondary girders rise toward the main girders, and the tertiary girders split the difference. Flange-to-flange connections would be feasible but cost prohibitive due to each individual connection being unique.

Instead, the deck slab reinforcement was utilized to provide the top connection. In addition to alleviating the geometric challenge of vertically unaligned adjacent flanges, significant economy was realized by eliminating fabricated steel connections. Obviously, the bottom flanges presented the same alignment problem. This problem was solved by making the main girders deeper than the secondary, and the secondary deeper than the tertiary. Where a shallower girder frames into a deeper one, the bottom flange of the shallower girder is attached through a bolster connection, which in turn, transfers load directly into the bottom chord of a diaphragm (see Figures 4 & 5).

By providing a top connection via the deck reinforcement, the top connection would not become effective until the deck was cured. Therefore, the web and bottom connections had to be designed to accommodate the steel self weight, the wet concrete (including the weight of barriers and islands), as well as construction loads. Additionally, dead-load-induced, in-plane rotations had to be accommodated and out-of-plane rotations had to be minimized. This was accomplished through a detailed erection sequence.

The connections were designed to resist different loadings during different stages of the erection process. During Stage 1, rotations would be allowed, but shear would be resisted. This involved setting the framed-in girder on a bolster and connecting only a center group of

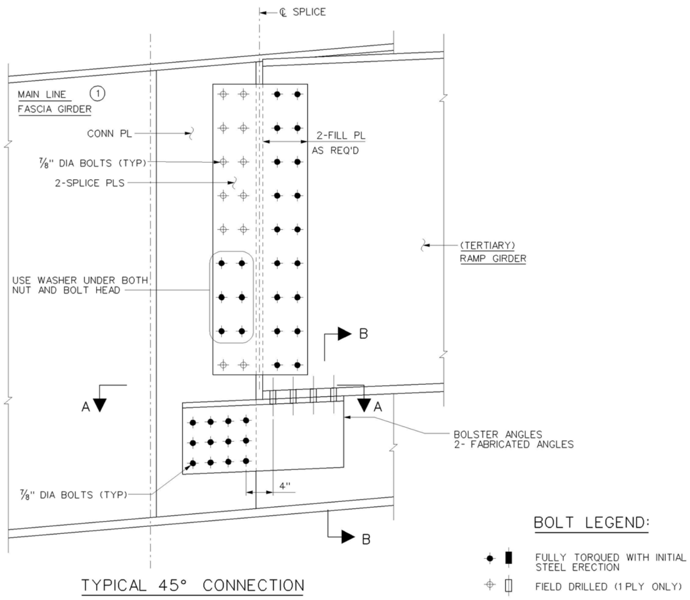

Figure 6. Typical 45º Framed-in Connection Detail

bolts. With the application of the wet concrete and construction equipment, end rotations could not be avoided. The center group of bolts would allow rotation while still resisting shear (in combination with the bolster). Stage 2 requires field drilling for the remaining connectors and tightening them to specification. For initial dead loads, the web connection and bolster were conservatively designed as hinged connections. Under full live load, the top deck reinforcement connection (in combination with the web connection and bolster) was designed to provide a moment connection (see Figures 4 to 6).

Deck Pouring Sequence

A deck pouring sequence was developed in conjunction with the overall erection procedure. The first pour involved placing concrete on the main girders only and allowing sufficient curing time. This was to ensure the main girders work as a unit and distribute the incoming ramp load beyond the main fascia girders and partially into the interior girders.

Next, the ramp decks, barriers, and islands were poured. Finally, the closure pours, which incorporated the top connections, were placed. The actual deck placement involved many sub stages; however, the three described above convey the concept (see Figures 7 & 8).

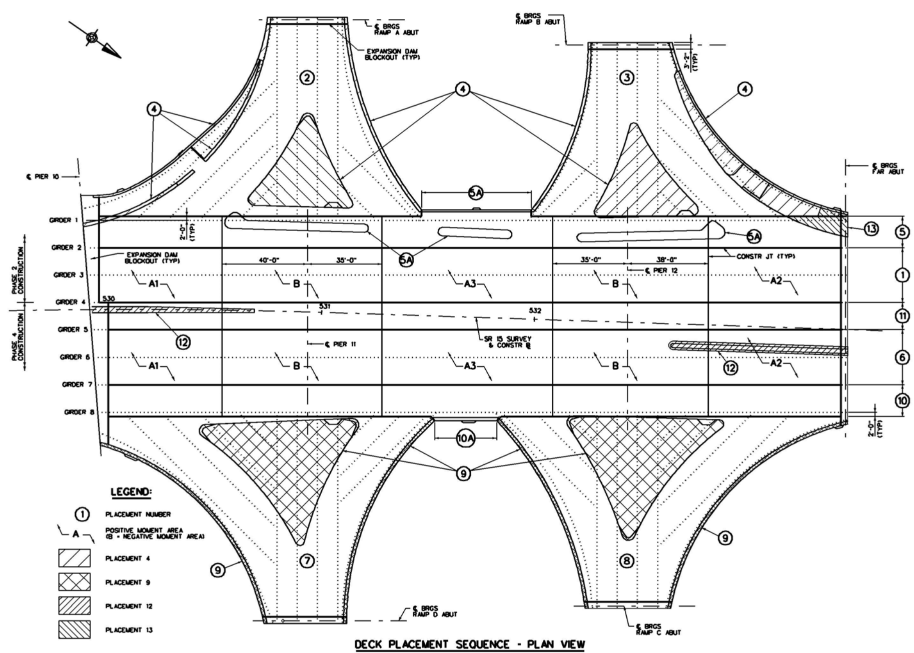

Figure 7. Deck Pouring Sequence

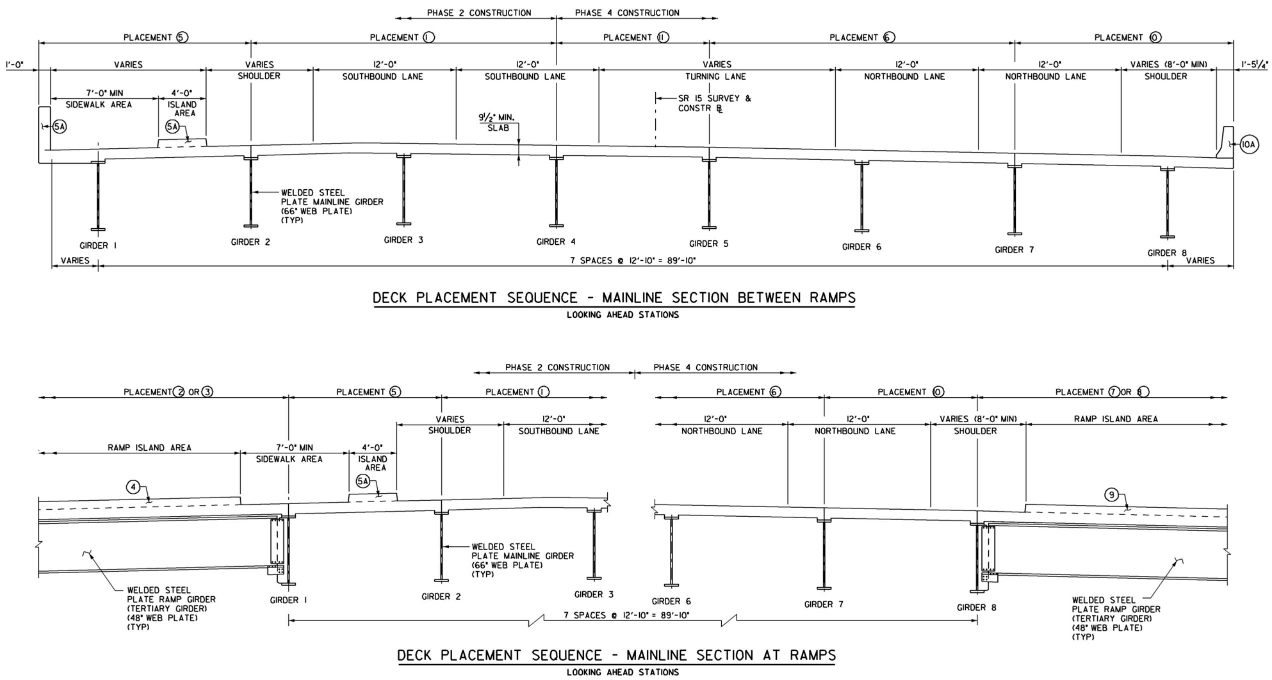

Figure 8. Typical Sections showing Deck Pouring Sequence

Structural Analysis

The 3-D finite element program developed by Bridge Software Development International, Ltd. (BSDI) was used to perform the structural analysis. Due to the vast number of members, non-standard configuration, staged erection sequence, and the limitations of the existing software, the ramps and main girders were modeled as five separate units and analyzed individually for all loadings. Next, a step-by-step, iterative process was utilized that involved connecting one ramp model at a time to the mainline model. This procedure involved several iterations for each ramp and was performed for all four ramp models separately. These models provided approximate plate and cross frame member sizes for the ramp and tertiary girders.

Once the girders, both ramp and mainline, were appropriately sized, three additional models were developed to finalize the structure. These models consisted of a southbound structure, a northbound structure, and a mainline structure. The sequence of construction requires that the southbound half of the structure be erected and open to traffic while the northbound is under construction. Therefore, the southbound model consisted of the west ramps connected to the western four mainline girders. The northbound model consisted of the east ramps connected to the eastern four mainline girders. After plate sizes and cross frame members were finalized for these two models, a third model was developed that consisted of the mainline girders alone. The data gathered from the first two "half" models were then applied to the final, mainline girder model to provide a final verification of member sizes.

Each deck pouring sequence was also analyzed in each model described above. In addition, member and diaphragm sizes were adjusted until rotations remained within acceptable limits during all stages of construction. The BSDI software was used to analyze the girders for lateral flange bending as well as primary bending. In an effort to reduce the effects of torsion, the framing configuration provided "back-up" diaphragms at all locations where the ramp girders connected to the mainline fascia girders.

FABRICATION

The general contractor, Trumbull Corporation (Pittsburgh, PA), selected High Steel Structures, Inc. (Lancaster, PA) to fabricate and erect the steel superstructure for the SPUI. Knowing that the steel delivery schedule was in the critical path, all parties worked closely to exchange information in a timely manner. While shop drawing reviews began in early April 2005, intense coordination began in September of the previous year.

Camber

Because the SPUI consists of several ramps converging with the mainline, the longitudinal grades and cross slopes of the deck are quite complex. In areas of convergence where the traditional perpendicular offset method could not be used to calculate elevations, computer software was utilized to mesh the deck slab elevations through "warping". Thus, a three-dimensional deck slab surface was created which provided a tool to cross check elevations against manual and spreadsheet calculations.

Geometric camber had to be calculated for each individual girder. While a great deal of camber information was provided on the contract drawings, High Steel's detailer, Upstate Detailing, Inc. (UDI – Burnt Hills, NY), requested elevations for supplemental points of interest to ensure fabrication tolerances were met. Prior to the shop drawing submission, Baker and UDI worked closely to cross check all geometry on the project and to verify the "fit-up" in three dimensions.

CONSTRUCTION

Erection of the first phase of the SPUI structure began on August 4, 2005. Girders 1 through 4 of the mainline are currently in place at the time of this writing. The first deck pour (between girders 2 and 4) is scheduled to be completed by October 2005. Erection of the structural steel for Ramps A and B will begin in early November 2005. The reinforced concrete decks for these ramps will be constructed in the spring of 2006.

During the construction of the main span deck the contractor requested a few revisions for the lap locations of the deck reinforcement. These requested were made for the convenience of the construction. The reinforcement was moved in critical areas so as not to be damaged during erection of the remaining steel.

CONCLUSIONS

While both concrete and steel options were initially studied for the SPUI superstructure, the versatility of steel made it the obvious material of choice. The adaptability of steel to conform to the complex geometry of the superstructure enabled the framing to closely parallel the roadway edges and eliminate excess deck area. This advantage led to both cost savings and an aesthetically pleasing structure. In addition, the use of steel allowed the development of a detailed erection procedure which involves multiple stages of connectivity of the framed-in members. No other material type could have met all of the project criteria for this structure.

ACKNOWLEDGEMENTS

The authors would like to thank PennDOT District 3-0 and the Federal Highway Administration for having the innovative spirit to build this unique structure.