Design and Construction of the Rich Street Bridge over the Scioto River, Columbus, Ohio

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ABSTRACT

The newly constructed Rich Street Bridge is a landmark structure spanning the Scioto River in Columbus, Ohio. The new bridge is a 5-span, 563 foot long modern rib arch structure, designed to be pedestrian-friendly and to accommodate festival events. The bridge is one of three crossing the Scioto River in the city's historic Civic Center. The configuration of the new bridge was selected in response to design criteria set by community representatives requiring that the bridge compliment the surrounding "family" of arch bridges while respecting the architectural character of the surrounding area.

The bridge is supported on four lines of concrete arches which are constructed integrally with the bridge's four girder lines so that the resulting structure behaves as a rigid frame. Both the arches and girders consist of precast concrete segments constructed using high strength lightweight concrete. Standard radii and cross sectional dimensions were established for the precast segments to allow common formwork to be used for each segment type. The precast segments were erected on temporary shoring and tied together with cast-in-place closure units. The arches, girders, and the deck are longitudinally post-tensioned over the entire length of the structure.

Keywords: Arch, Community Participation, Context Sensitive Design, Post Tensioned Concrete, Precast Concrete, Rigid Frame

INTRODUCTION

For many years the three bridges crossing the Scioto River in downtown Columbus have been an important part of both the city's traffic infrastructure and its self image. The bridges are the foreground in postcard views of the city's skyline. They are the setting for summertime concerts and festivals on the riverfront. The festivals attract great crowds from all over the region. During these events the bridges are closed to vehicular traffic and become wholly pedestrian. Temporary booths and shops line them from end to end. When it became necessary to replace all three bridges over a 20 year period, the city was determined to build new bridges equal in aesthetic quality to the old.

HISTORICAL DEVELOPMENT OF THE SITE

ESTABLISHMENT OF THE CIVIC CENTER

The Scioto River flows in a north to south direction through the center of Columbus. In the early 1900's, as part of the City Beautiful movement, the city of Columbus developed a plan for the parcels bordering its Scioto River frontage. The plan converted the whole area into a Civic Center with a series of monumental public buildings. The river was to be dammed to create a constant pool elevation, the east bank was to be reinforced with a flood wall, and three arch bridges in a traditional style were to be built at Main Street, Town Street and Broad Street. The curved reach of the river between Town Street and Broad Street was seen as particularly important because it is essentially symmetrical about an east-west axis.

Over the ensuing 80 years most aspects of the plan were realized. The dam was built and a minimum pool elevation established. The floodwall and the Broad Street and Town Street arch bridges were built in a classical style. The Main Street Bridge was built later as an arch bridge in an Art Deco style. The Columbus city hall, police headquarters and the Veterans Memorial Auditorium were built adjacent to the river banks. Most important, two monumental, symmetrical buildings were built on the axis of symmetry, the Ohio Judicial Center on the east bank and Central High School on the west bank. These buildings plus the Broad and Town Street bridges created visual boundaries for a large outdoor civic space that came to be known as the "River Room".

By the late 1980's the Broad Street Bridge, a seven span earth filled concrete deck arch, had deteriorated to the point that it had to be replaced. An extensive community outreach program resulted in a design that reduced the number of spans to three full arches and two half arches in the end spans. Using half arches in the end spans allowed for river walks to be built on both banks. The memory of the City Beautiful plan was still strong and the community envisioned the new bridge to be built with similar architectural features to the previous bridge. Thus, the bridge has, among other features, pilasters and overlooks at the piers. To emulate the balustrades of the previous bridge and the floodwall the new bridge includes a monumental railing with a large bronze handrail and concrete pylons alternating with sections of ornamental steel railing. The bridge has the circular curves of traditional arches, even though structurally it is not an arch. It acts as a girder with very deep haunches.

Since the reconstruction occurred just before the five hundredth anniversary of Christopher Columbus' first voyage to America, the Broad Street Bridge was renamed the Discovery Bridge (Figure 1).

Figure 1 - The Discovery (Broad Street) Bridge

A CHANGE IN THE CONTEXT

In the late 1990's the Central High school was converted into the Center of Science and Industry (COSI). A new wing was built on the land side of the existing building. It stretches almost the whole way between Town Street and Broad Street (Figure 2). The wing was built in an ultramodern style. Its facade is curved in plan and it is covered in white precast concrete panels that are curved in two directions and separated by stainless steel strips. The construction of this building signaled that the community was no longer wedded to the historical architectural styles envisioned in the City Beautiful plan and used for all previous Civic Center buildings.

Figure 2 - The Center of Science and Industry (COSI).

The Main Street Bridge was the next of the historic bridges to reach a deteriorated state. With the example of COSI now in place, a much wider range of options were considered, moving way beyond conventional deck arches, though the arch theme remained a constant. The city decided to replace the historic bridge with an ultra-contemporary three span bridge with a through arch in the long center span. The arch is tilted in elevation. The bridge is patterned to some degree after several bridges by the Spanish designer Santiago Calatrava. This structure was opened to traffic in 2010 (Figure 3).

Figure 3 - The Main Street Bridge

That left only the Town Street Bridge to be replaced. It had also reached an advanced state of deterioration (Figure 4). Its concrete is gradually crumbling into the river. Both sidewalks and one traffic lane were closed. Preliminary design of a replacement bridge began in 2002.

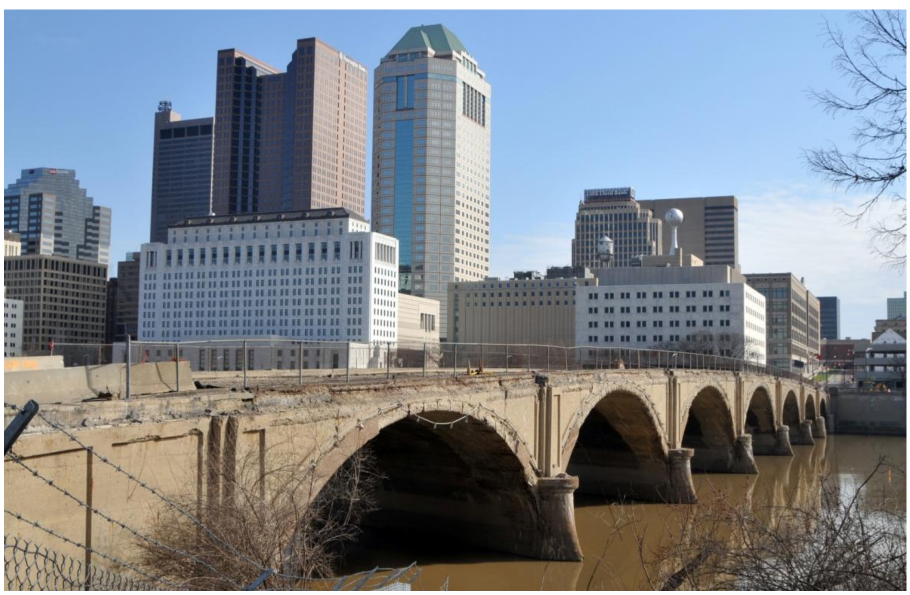

Figure 4 - The Town Street Bridge in 2009

REROUTING TOWN STREET TO RICH STREET

While the design of a replacement Town Street bridge was still in its early stages the city embarked on a new planning process to redevelop the area along the east bank of the river, a concept that came to be known as the Scioto Mile. One consequence of the plan was a decision to connect Town Street on the west bank to Rich Street on the east bank (Figure 5). The new bridge would be called the Rich Street Bridge. Because of the realignment the new bridge would cross the Scioto at a right angle, so it would be both shorter and simpler in appearance than the Town Street Bridge, which crossed the river with a skew of approximately 30 degrees.

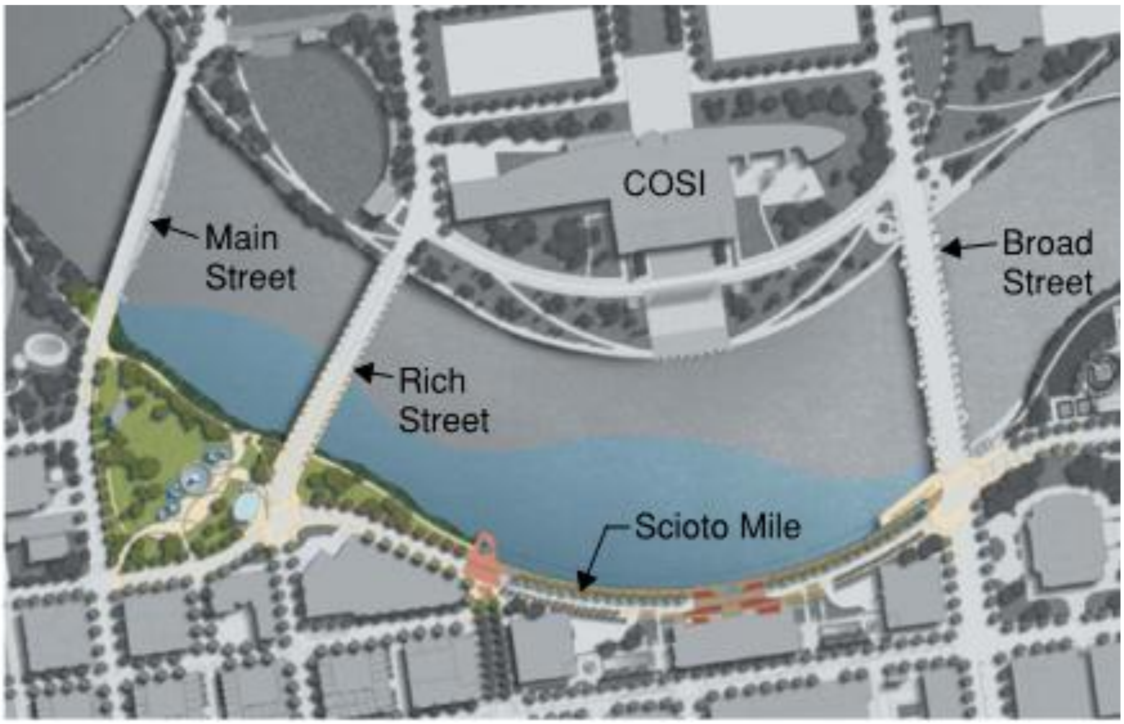

Figure 5 - The Scioto Mile plan showing the realignment of the Town Street Bridge to Rich Street. The Main Street Bridge is on the left and the Discovery Bridge on the right.

This decision alters the historic symmetry of the River Room. At the same time it unifies the Main Street-to-Town/Rich Street reach of the river with the Town/Rich-to-Broad Street reach. Under the City Beautiful plan the river reach from Main Street to Town Street was always a bit of an afterthought.

With this unification in mind a goal was established to make the three bridges a "Family of Bridges". As the middle bridge of the three, the goal for Rich Street became to establish a visual link with both the traditional Broad Street Bridge and the ultra-contemporary Main Street Bridge. Guidelines were established identifying arches as the overriding theme and suggesting certain features of the Broad Street Bridge and the floodwall that should be emulated. The design of COSI, which is at the west end of the Rich Street Bridge, also suggested a vocabulary of contemporary details.

All of these guidelines fit the community's evident desire to look toward the future, not the past, as it rebuilds and further develops its Civic Center.

CONCEPTUAL ENGINEERING

STRUCTURAL CONCEPTS

Since the Rich Street Bridge still functions as the southern boundary of the River Room, the team decided to emulate several features of the Discovery Bridge. The new bridge would have a rise of about three feet from the abutments to the center of the bridge, created by a gentle crest vertical curve. The new bridge would use the same span arrangement as the Discovery Bridge, three full arch openings and two half arched openings. This allowed for the extension through the bridge of the river walk on the west bank. (As part of the replanning of the east bank the east river walk was raised to the top of the floodwall and is now a feature of the reconstructed Civic Center Drive.) With these features the Rich Street Bridge would still function visually as the southern border of the River Room and some of the visual symmetry so important to that space would be retained.

With these considerations in mind early concepts focused on cast-in-place concrete arches with multiple reuses of a standardized set of forms. The final result of this effort was an arch concept that used doubly curved concrete thin shells as the arch compression members. This concept became known as the "ribbon arch" or "potato chip" bridge (Figure 6). The openness and flowing members of the concept gave this concept a graceful appearance. It was greeted with enthusiasm by the Mayor and other civic leaders. However, the continued deterioration of the Town Street Bridge and the impending celebration of the Columbus Bicentennial required that the schedule be accelerated. There was concern that this concept would require an extended time of construction, and it was dropped.

Figure 6 - The ribbon arch concept

The team next focused on developing a concept that would use precast concrete members while retaining the openness and grace of the ribbon arch. The precast members could be manufactured during foundation and site preparation work, thus accelerating the completion of the project. The selected concept uses four lines of precast concrete arch ribs supporting four lines of precast haunched girders (Figure 7). The space above the piers is left completely open. That combined with the thinness of the ribs makes this concept even more transparent than the ribbon arch. The ribs are tapered in accordance with structural needs to minimize their thickness. The sides of the ribs were given large chamfers. The upper one will reflect more light and the bottom one less, so that the arch shapes will be split into two facets of different brightness. This will visually minimize their thickness still more. (See Figure 11 for the rib cross section.) The radii of the ribs and all other relevant dimensions are standardized from span to span. That combined with the biaxial symmetry of the structure means that all of the precast structural members could be cast with just three sets of custom forms.

Figure 7 - The precast arch concept

This concept looks like an arch bridge consistent with the arch theme established for the Family of Bridges. However, like the Discovery Bridge, the new Rich Street Bridge uses an alternative structural system. It is basically a rigid frame rather than a true arch. Loads applied between the arch crests (over the piers) create moments and shears in the rigid frame formed by the beams and arch ribs. This system allows the “spandrel” areas over the piers to be left completely open. Observers can to see right through the bridge from most angles. Because of the transparency of the bridge the Main Street-to-Rich Street reach of the river will be visually reunited with the Rich Street-to-Broad Street reach. The bridge will have the span arrangement and general shape of the Discovery Bridge while having the open contemporary appearance of the new Main Street Bridge, thereby making the three bridges truly a Family of Bridges.

DESIGN DEVELOPMENT

STRUCTURAL COMPONENTS

The Rich Street Bridge is a 562-foot long five-span precast concrete open rib arch structure. Diagrams showing plan and profile views of the bridge and a bridge typical section are shown in Figure 8.

The superstructure consists of four individual lines of precast arch ribs and deck beams using 7,000 psi sand lightweight concrete (125 lb/ft^3). At the piers, the arch rib segments are linked by a cast-in-place arch block. The riding surface of the bridge is a 10-inch cast-in-place concrete deck with a 1 ½" micro-silica modified concrete overlay. The cast-in-place deck is composite with the precast beam segments. Strip seal expansion joints are provided at each abutment.

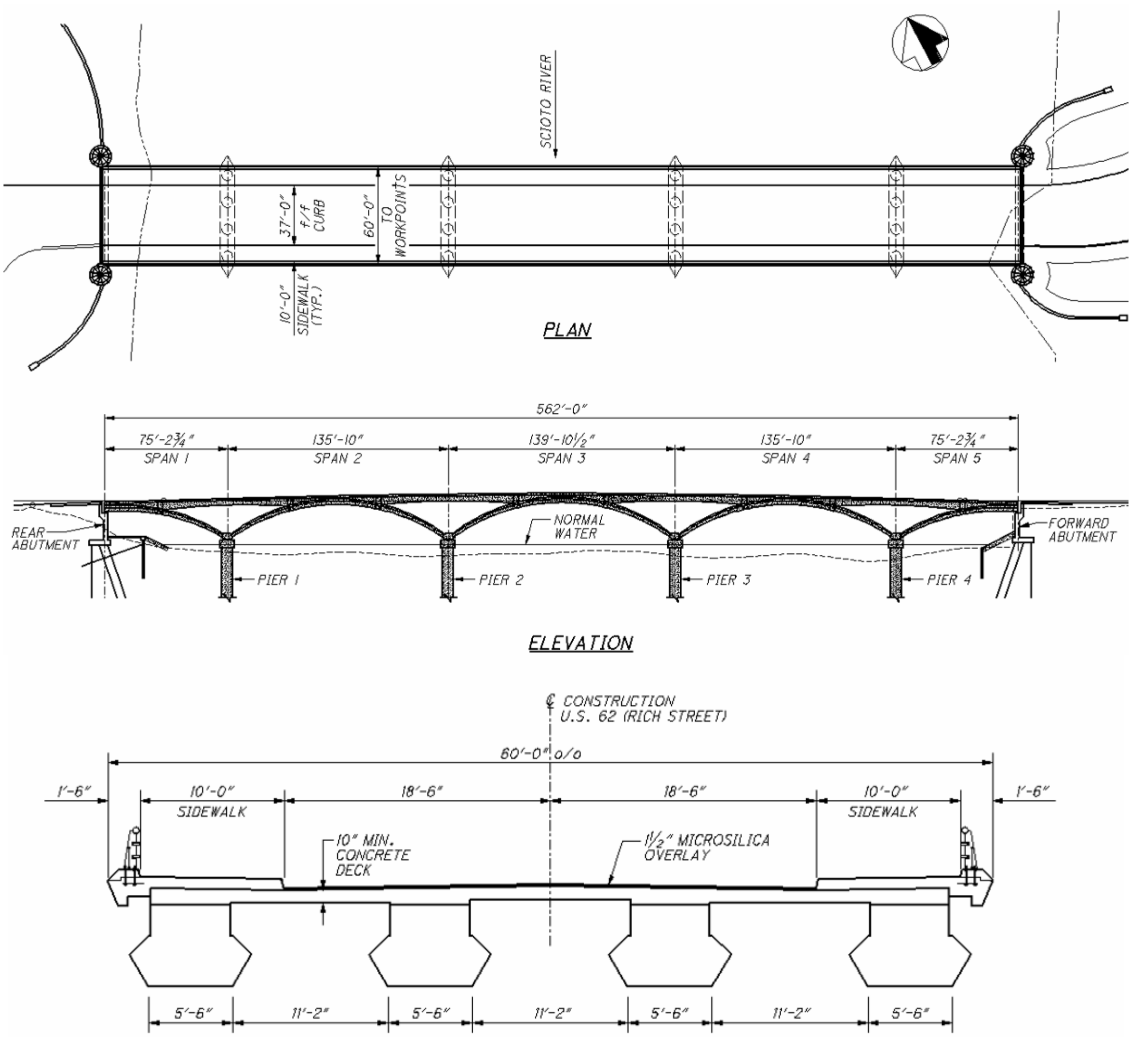

Figure 8 - Plan, Elevation, and Typical Section

The arch ribs, beams, and composite deck are longitudinally post-tensioned. Four 19-strand tendons are contained in each arch rib, passing through a tight (3.25 ft radius) bend in the arch block at each pier location. Each set of rib tendons passes through one arch block, with anchorages located at the abutments and in the cast-in-place closure beyond the arch crest in each span. Full-length longitudinal tendons are used in the beam segments and in the cast-in place deck. These tendons are tensioned from both ends of the bridge. The layout of the post-tensioning tendons is shown in Figure 9.

The bridge substructure consists of reinforced concrete wall type abutments and four reinforced concrete piers. At the abutments, the superstructure is seated on laminated elastomeric bearings with a PTFE (polytetrafluoroethylene) sliding surface to allow for free longitudinal movement. Each pier consists of a reinforced concrete cap supported on four 5.5-foot diameter drilled shafts, with one shaft directly beneath each arch rib line. The superstructure is fully integral with the pier cap at a single fixed pier (Piers 3) and seated on laminated elastomeric bearings at the expansion piers (Piers 1, 2, and 4).

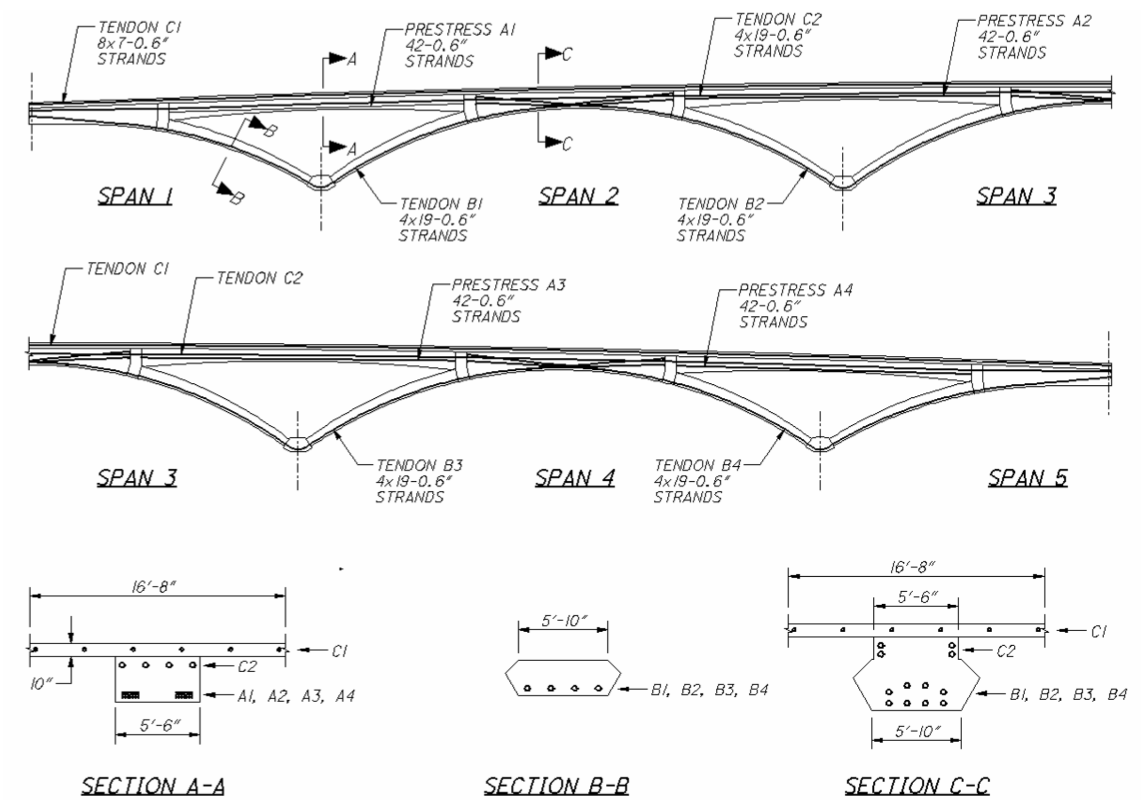

Figure 9 - Post-Tensioning Layout

FOUNDATIONS

The subsurface material in the river generally consists of three distinct strata: natural overburden soils, weathered shale bedrock and limestone bedrock. The natural overburden is comprised of discontinuous layers of sand, gravel, cobbles, boulders, silt, and clay. These overburden soils extend to approximately 25-30 ft below the flowline, where weathered shale bedrock is encountered. This layer of bedrock is very weak. Beneath the weathered shale bedrock is a more competent layer of limestone bedrock. The top of the limestone bedrock is approximately 60-65 feet below the flowline at the pier locations.

The foundations for each substructure derive their support from the limestone bedrock. The abutments are supported on HP12x74 piles driven to the underlying limestone. An oversized pile hammer was specified in order to ensure that the piles penetrated the upper layer of weathered shale. Drilled shafts supporting the piers were socketed into the underlying bedrock.

PRECAST SEGMENTS

The superstructure of the bridge consists of three segment types: the arch rib segments (B1 to B8), the arch crest segments (C1 to C5), and the drop-in beam segments (A1 to A4). A diagram showing the layout of the precast segments for the structure is shown in Figure 10.

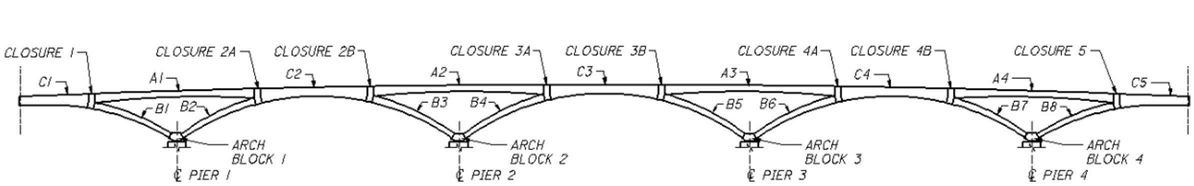

Figure 10 - Precast Segment Layout

Transportation of the precast segments to the site was a primary concern during design. Through coordination with the Ohio Prestressers Association, it was determined that the segments could be transported to the site by truck if weights were kept below 100 tons. This led to the decision to use lightweight concrete for all of the precast segments. Formed block-outs were also necessary to keep the weight of the interior arch crest segments (C2, C3, and C4) below 100 tons.

The arch rib segments (B1 to B8) make up the portion of the rib that connects the pier arch block to the arch crest. The geometry of the arch rib is defined by two circular arcs, one forming the top of the rib and one forming the bottom of the rib. The resulting shape is a rib of variable thickness, with the thickest section occurring at the crest and the thinnest section at the base. The edges of the ribs are formed by two intersecting surfaces, oriented at angles of 30 and 45 degrees from the top surface of the rib. A single set of custom forms was used for all of the B1 to B8 segments. Individual pieces were cast by shifting the bulkheads within the forms. Details for the arch rib segments are shown in Figure 11.

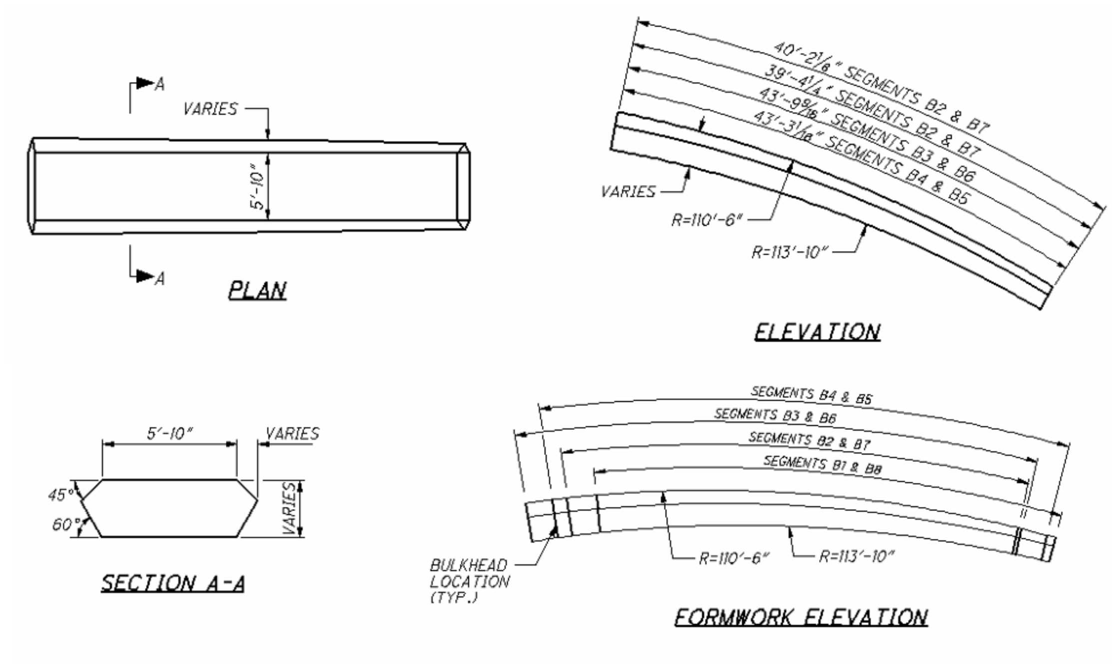

Figure 11 - Arch Rib Segments

The drop-in beam segments (A1 to A4) are rectangular in shape. The width of these segments is constant, and the depth of the segments varies over their length. The bottom of the segment is defined by a circular arc. The radius of the bottom surface of is held constant in all spans. The top surface is finished to match the profile grade of the bridge. For the exterior beam lines, the exterior (exposed) face of the beams is cast using a formliner to create vertical rustication grooves. This provides a textured appearance that visually separates the vertical beam face from the sloping face of the ribs. A single set of forms was used for segments A1 to A4 with bulkheads shifted to meet individual segment dimensions. Details for the drop-in beam segments are shown in Figure 12.

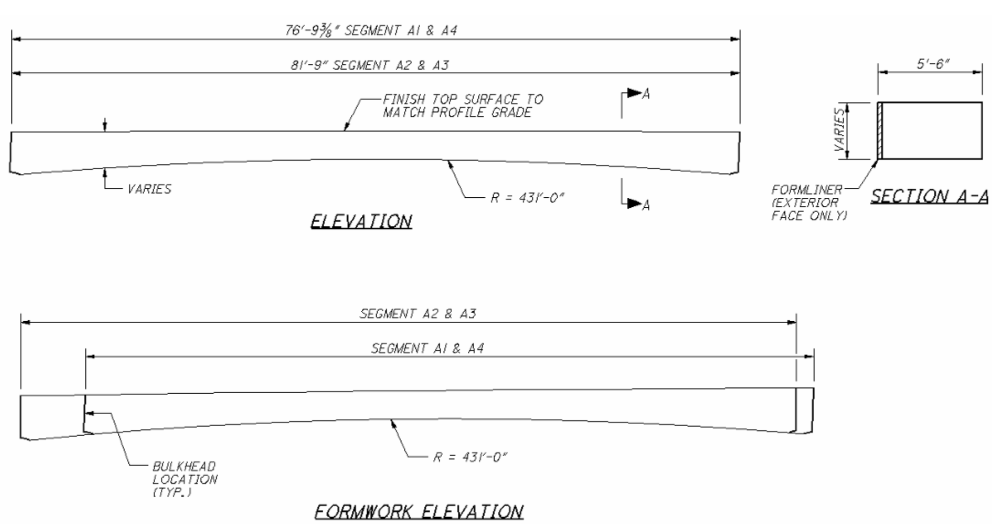

Figure 12 - Drop-in Beam Segments

The arch crest segments (C1 to C5) combine the geometry of the arch rib segments and the drop-in beam segments. The top portion is a rectangular beam section and the bottom portion is the variable depth arch rib. As with the drop-in segments, the exterior face of the beam is finished with vertical rustication grooves. The arch crest segments for the interior spans (C2, C3, and C4) are the most massive segments on the project. In order to keep the transportation weight of these segments below 100 tons, block-outs were formed in the top surface of the segment. These block-outs were filled with cast-in-place concrete on site after the segment was erected. A single set of forms was used for segments C1 to C5 with bulkheads shifted to meet individual segment dimensions. Details for the arch crest segments are shown in Figure 13.

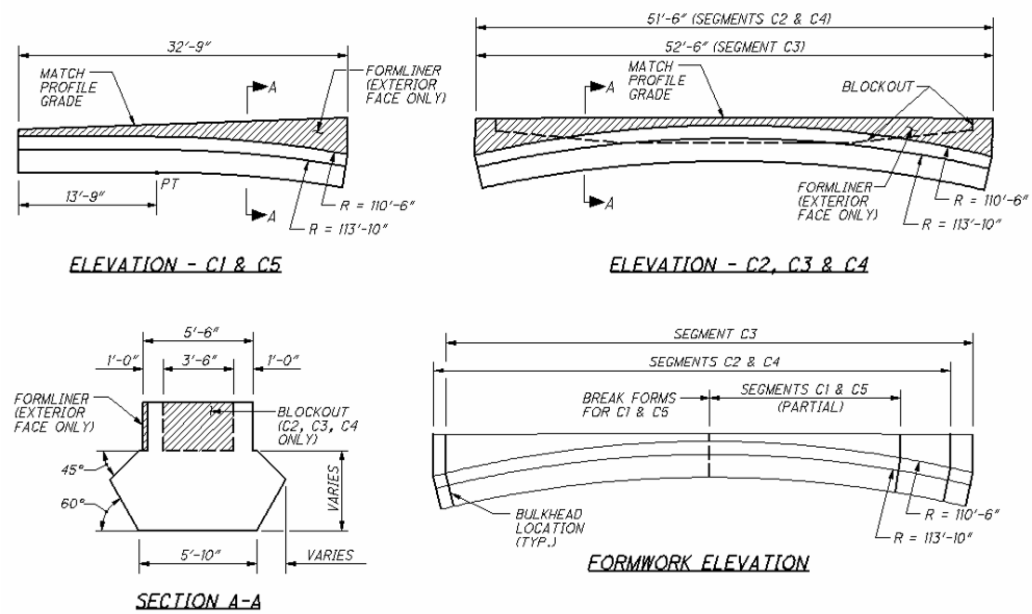

Figure 13 - Arch Crest Segments

ERECTION SEQUENCE

The precast segments were erected on falsework towers on site and tied together by cast-in-place closure pours. Girder closures were provided at the interface of the arch and girder segments (Segments A, B, and C). Sleeves were embedded in the closure in order to allow for continuous post-tensioning between the segments. At the piers, the arch rib segments are linked by a cast-in-place arch block. Prior to the construction of the deck, lateral support of the ribs and girders was provided by the falsework towers alone. The proposed erection sequence is fully detailed in Figure 14.

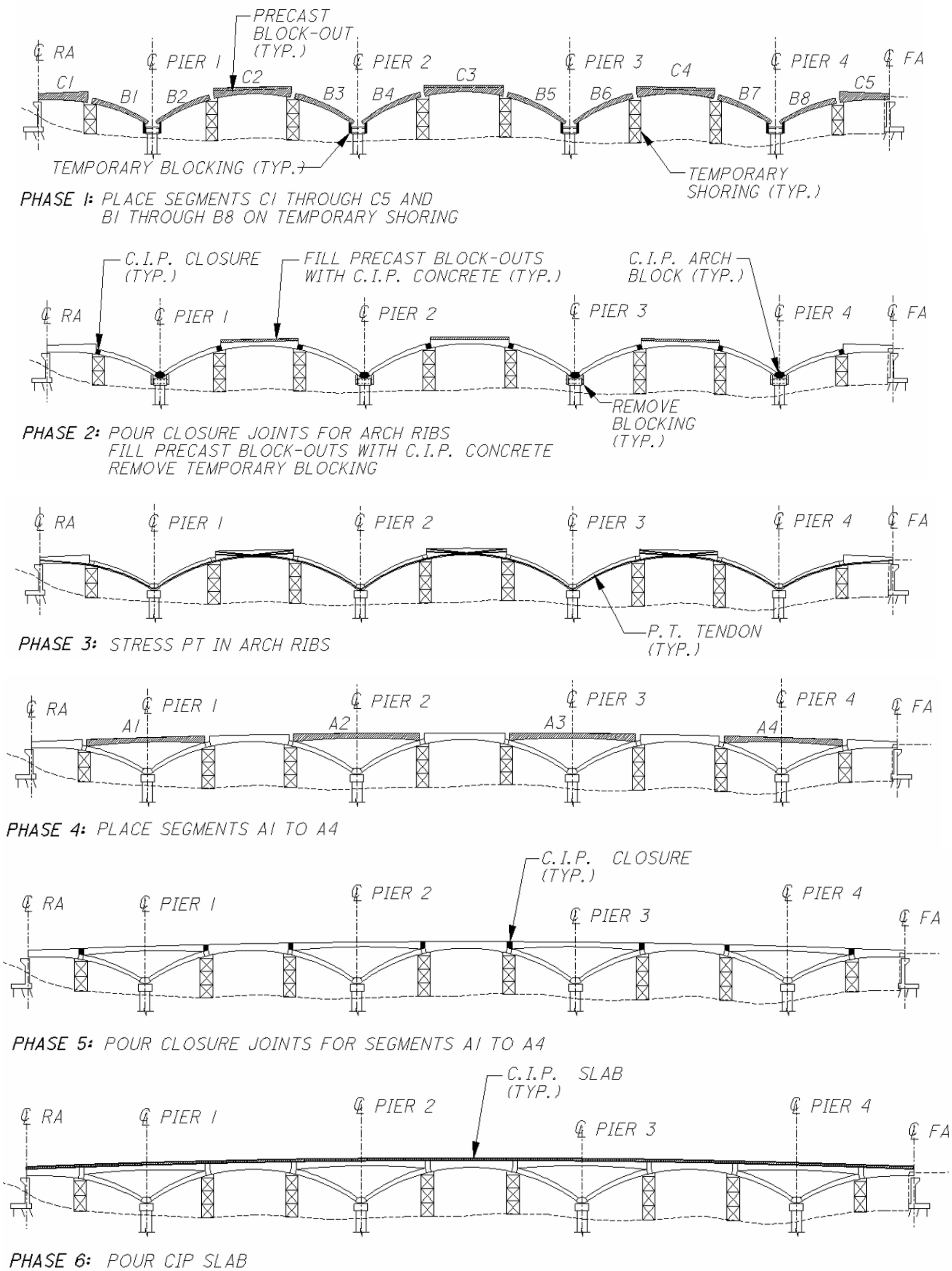

Figure 14 - Erection Sequence (Part 1 of 2)

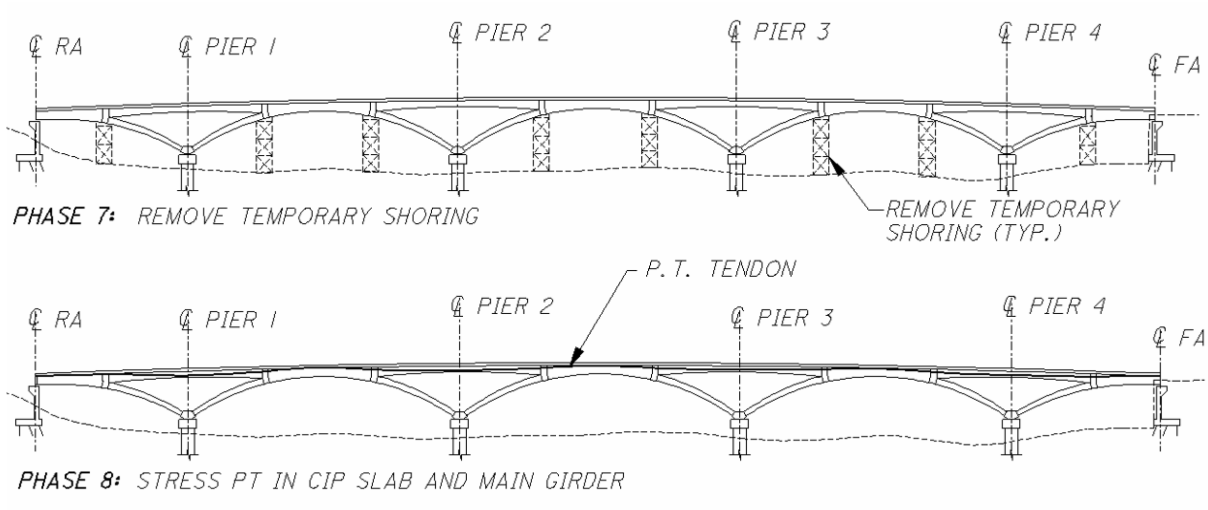

Figure 14 - Erection Sequence (Part 2 of 2)

ANALYSIS

Structural analysis of the bridge was conducted using a 3-dimensional finite element model. Both girders and ribs were modeled using beam elements. A stiffness analysis of the pier, including the properties of the drilled shafts and the surrounding soil strata, was conducted in order to establish boundary conditions for the model. The stiffness of the elastomeric bearings was also calculated and included. Interaction between adjacent girder lines was modeled by including transverse beam elements between girder lines to simulate the behavior of the concrete deck.

A multi-stage analysis was conducted to examine the behavior of the structure during the various stages of construction. Due to the nature of the erection sequence, separate analyses are required for each construction phase to reflect changing loading and boundary conditions. Because continuity conditions change during the erection process, each construction stage creates embedded forces that affect all subsequent stages. Thus a full stage construction analysis is needed in order to accurately predict the embedded forces in the finished structure. For construction stages occurring after the construction of the cast-in-place concrete deck, composite action between the deck and the precast concrete segments was included in the model.

Time dependent material behavior was incorporated into the stage construction analysis. Creep, Shrinkage and Relaxation effects were calculated in accordance with the CEB-FIB Model Code. Shear lag effects were included in accordance with the Guide Specification for the Design and construction of Segmental Concrete Bridges. Post-tensioning tendons and anchorages were included in the model using equivalent prestressing loads. The geometry for each tendon was defined in the model, and prestress loss calculations were conducted for each construction stage.

Due to the unusual nature of the structure, two independent models were created using two different software packages. Burgess and Niple used Midas Civil software to conduct one analysis and Leonhardt, Andrä, und Partner used TDV software to conduct a second analysis. Generally good agreement was achieved between the two models with some variations noted in the prediction of time dependent behavior.

An isotropic view of the analysis model is shown in Figure 15.

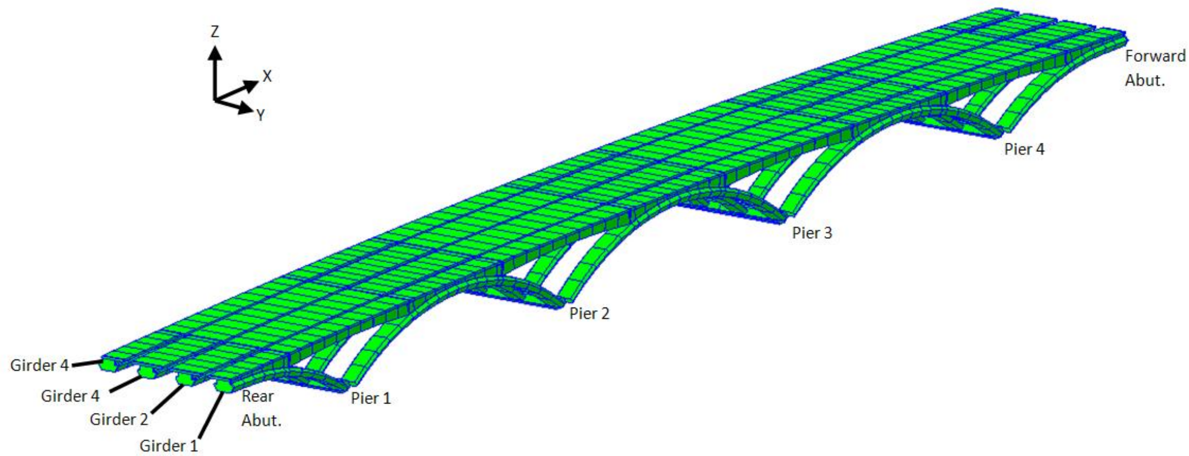

Figure 15 - Analysis Model

DETAILS AND LIGHTING

PYLONS, RAILINGS AND FINISHES

In response to the Family of Bridges guidelines the team decided to emulate certain key features of the Discovery Bridge and the new Main Street Bridge when developing the details of the new Rich Street Bridge. The architectural features of COSI also inspired some of the details.

Four pylons are placed at the four corners of the bridge. These emulate large circular pylons that are a prominent feature of the Discovery Bridge. However, their shape emulates the curved panels of COSI, projecting its contemporary aesthetic to the east bank. The pylons also house electrical equipment that serves not only the bridge lighting and the adjoining park but also the temporary power for the periodic festivals hosted on the bridge. The pylons are visible in the elevation view of the bridge shown in Figure 16.

The abutment walls between the pylons are formed with a jagged "fractured fin" form liner and coated with a reflective sealant. The faceted and reflective surfaces will pick up reflections from the water and make the underside of the bridge and the riverwalk brighter and more appealing. They will also discourage graffiti.

The Scioto River carries a fair amount of debris during high water periods. The pier nosings are shaped to shed this debris, while at the same time emphasizing their function as the connection point for the ribs.

Figure 16 – Elevation view of the Rich Street Bridge

The railings emulate the Pylon-Railing-Pylon pattern of the Discovery Bridge by spacing the railing posts in a short-long-short pattern. However, in order to match the open, contemporary design of the bridge, the railing design itself is more contemporary with a wide horizontal band that emphasizes the flow of the deck from abutment to abutment, similar in some ways to the railing of the new Main Street Bridge. The horizontal band is made from aluminum industrial grating, an unusual use of a durable and sturdy material. The railing is topped by a visually dominant handrail, as on the Discovery Bridge at Broad, but it is aluminum, not bronze.

To add interest to the pedestrian’s trip across the bridge the sidewalks are subdivided with panels of buff-washed concrete. The panel spacing is coordinated with the railing post spacing (Figure 17).

Figure 17 - Details of the railing

LIGHTING

The features of the Broad Street and Main Street bridges are lighted at night, as are many of the buildings adjoining the river. The lighting for many of the buildings includes lighted corporate titles or logos. Taken together, all of these lighted elements make the nighttime environment of the Civic Center a rich and interesting visual experience. The Rich Street Bridge has a varied and prominent aesthetic lighting program so it can hold its place in the center of this environment and enhance it (Figure 18).

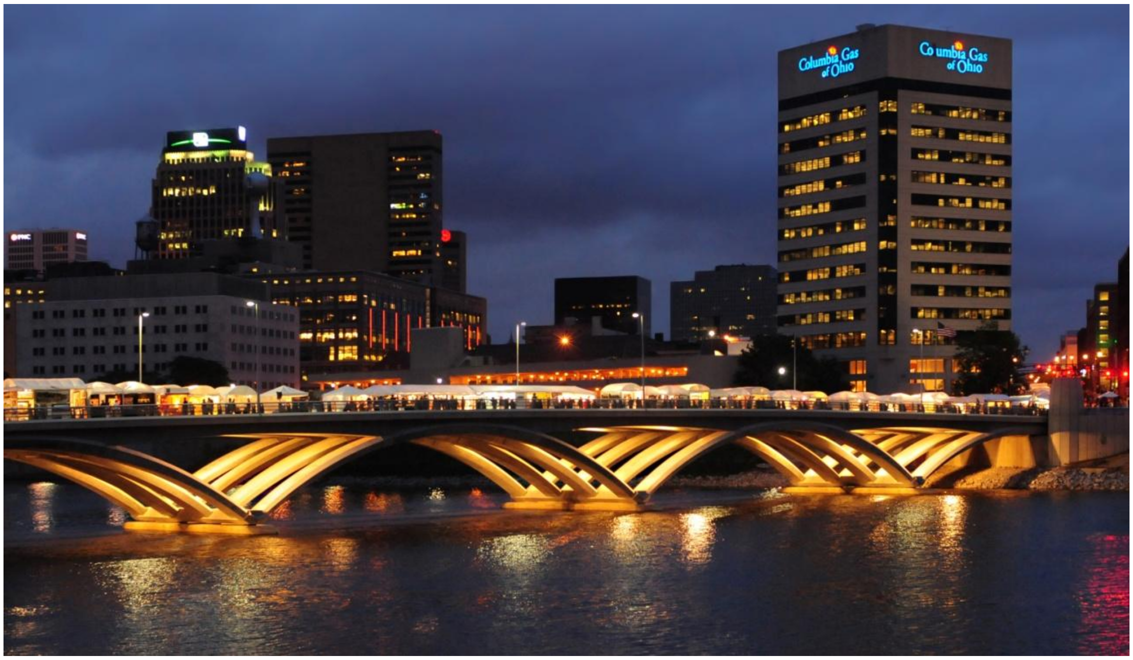

Figure 18 – Rich Street Bridge Lighting

The lighting of the Broad Street Bridge uses both blue and white light. The Main Street Bridge uses entirely white light. Blue is also the dominant color used in the night lighting of COSI. The Rich Street Bridge also uses both blue and white lighting.

The ribs are floodlit from fixtures mounted just under the deck, between the inner ribs, and near the arch apexes. The inner surfaces of the ribs are bright while the fascia surfaces of the bridge are dark and silhouetted against them. This brings out the structural system and transparency of the bridge while making the river and riverwalk seem a more inviting place.

Each railing post has a pair of small blue fixtures at the same height as the aluminum grating band, a fluorescent fixture facing outward toward the river and a Light Emitting Diode (LED) fixture facing inward toward the sidewalk. These bring out the short-long-short spacing rhythm of the railing posts. Taken together they form a line of bright spots that emphasize at night the sweep of the bridge from abutment to abutment, highlighting the profile line of the deck and giving the bridge another layer of interest. Finally, short LED strips in blue are placed in the vertical rustications of the pylons near their tops. These draw attention to the pylons and signify the beginning and end of the bridge at night

This lighting program ensures that the Family of Bridges is as evident in the nighttime as it is during the day (Figure 19)..

Figure 19 - The Rich Street Bridge within the nighttime Civic Center