DESIGN OF THE RICH STREET BRIDGE OVER THE SCIOTO RIVER, COLUMBUS, OHIO

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ABSTRACT

The Rich Street Bridge in Columbus, Ohio will replace a deteriorating 1914 earth filled concrete arch bridge with a modern open-rib arch structure. 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 Civic Center. The proposed bridge is a 5-span, 563 foot long structure supported on four lines of concrete arches. The arches 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. The precast segments are erected on temporary shoring and tied together with cast-in-place closure units, then are continuously post-tensioned with the cast-in-place concrete deck. Railings, lighting and other architectural details will be modern in style reflecting the design of the Central Ohio Science Institute and other recent buildings in the Civic Center.

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

CONTEXT OF THE SITE

HISTORICAL BACKGROUND

The Scioto River flows in a north to south direction through the center of Columbus, Ohio. 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" (Figure 1).

Figure 1. The Columbus Civic Center and "River Room" c. 1939, looking northeast. The Broad Street Bridge is in the left center; the Ohio Judiciary Building to its right and Central High School is across the river from the Judiciary Building. The Town Street Bridge is on the lower right. The Main Street Bridge is just off the bottom of the photo.

Over time a number of civic festivals developed that used the streets bordering the River Room as their venue. The festivals attract great crowds from all over the region. During these events the Town Street bridge is closed to vehicular traffic and becomes wholly pedestrian. Temporary booths and shops line it from end to end.

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 (Figure 2). 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 Chistopher Columbus' first voyage to America, the Broad Street Bridge was renamed the Discovery Bridge.

Figure 2. 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. 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 3. The new Center of Science and Industry (COSI). The Discovery (Broad Street) Bridge is on the left, the existing Town Street Bridge is on the right.

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 is now under construction.

Figure 4. The new Main Street Bridge. (Courtesy HNTB and DLZ.)

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

Figure 5. The existing Town Street Bridge.

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. The new bridge is to be called the Rich Street Bridge. Because of the realignment the new bridge will cross the Scioto at right angles, so it will be both shorter and simpler in appearance than the existing Town Street bridge, which crosses the river with a skew of approximately 30 degrees.

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.

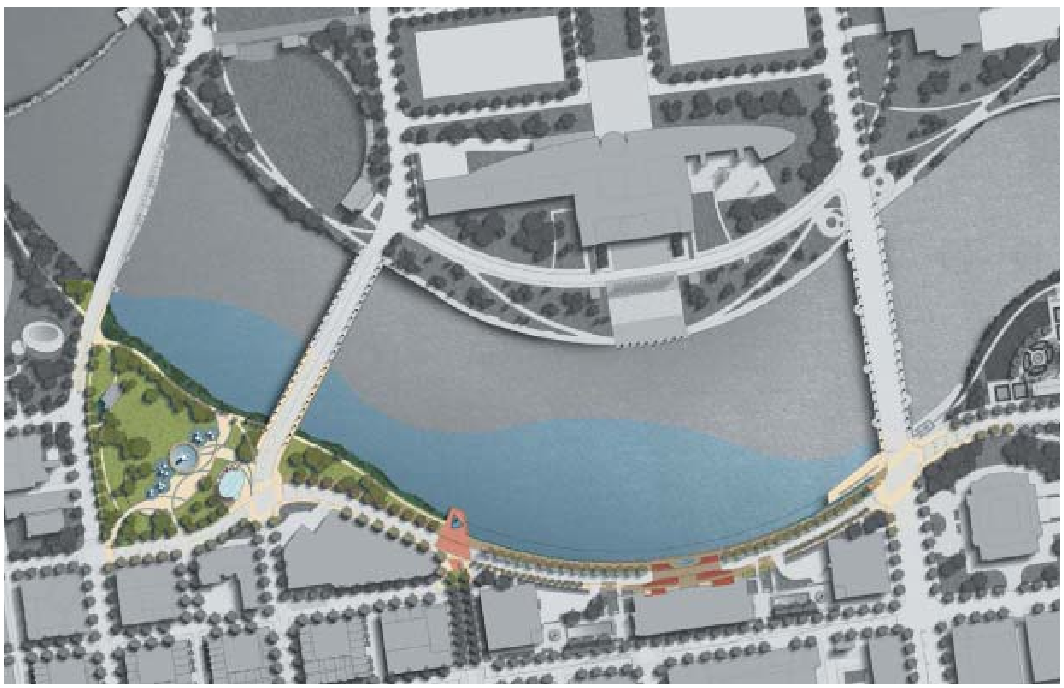

Figure 6. The Scioto Mile plan showing the realignment of the Town Street Bridge to Rich Street. The Main Street bridge is on the left and the Discovery bridge on the right.

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 Discovery Bridge and the floodwall that should be emulated. The design of COSI, which is at 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

ALIGNMENT AND SPANS

One consequence of the zero degree of skew with the river under the new alignment is that the bridge is symmetrical about its centerline. In investigating the profile of the new alignment the team realized that raising the deck at the west abutment about 1.5 feet would make the bridge symmetrical in the other direction, too. Thus, the new Rich Street bridge will have two axes of symmetry, its own centerline and the centerline of the river. This will simplify dimensioning and construction throughout the project.

Since the Rich Street Bridge will still function as the southern boundary of the River Room, the team decided to emulate several features of the Discovery bridge. The new bridge will have a rise of about three feet from the abutments to the center of the bridge, created by a gentle crest vertical curve, also symmetrical. The new bridge will use the same span arrangement as the Discovery bridge, three full arch openings and two half arched openings. This allows 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 will be a feature of a reconstructed Civic Center Drive.) With these features the Rich Street Bridge will still function visually as the southern border of the River Room and some of the visual symmetry so important to that space will be retained.

STRUCTURAL CONCEPTS

With all of 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" bridge (Figure 5). 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 7. 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 can 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. 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 Fig. 10 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 can be cast with just three sets of custom forms.

Figure 8. The new Rich Street bridge.

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 will use an alternative structural system. It will be basically a rigid frame rather than a true arch. Loads applied between the arch crests (over the piers) will 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 will be able 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 proposed Rich Street Bridge is a 562-foot long five-span (75.23’-135.83’-149.88’-135.83’-75.23’ c/c bearings) precast concrete open rib arch structure. The bridge has a 37-foot wide roadway curb to curb, 10-foot wide sidewalks and steel railing for a total width of about 60 feet. The roadway width provides two 12-foot outside lanes, an 11-foot middle lane, and 1-foot curb offsets. Diagrams showing plan and profile views of the bridge and a bridge typical section are shown in figure 9.

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 will be 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 will be provided at each end of the bridge.

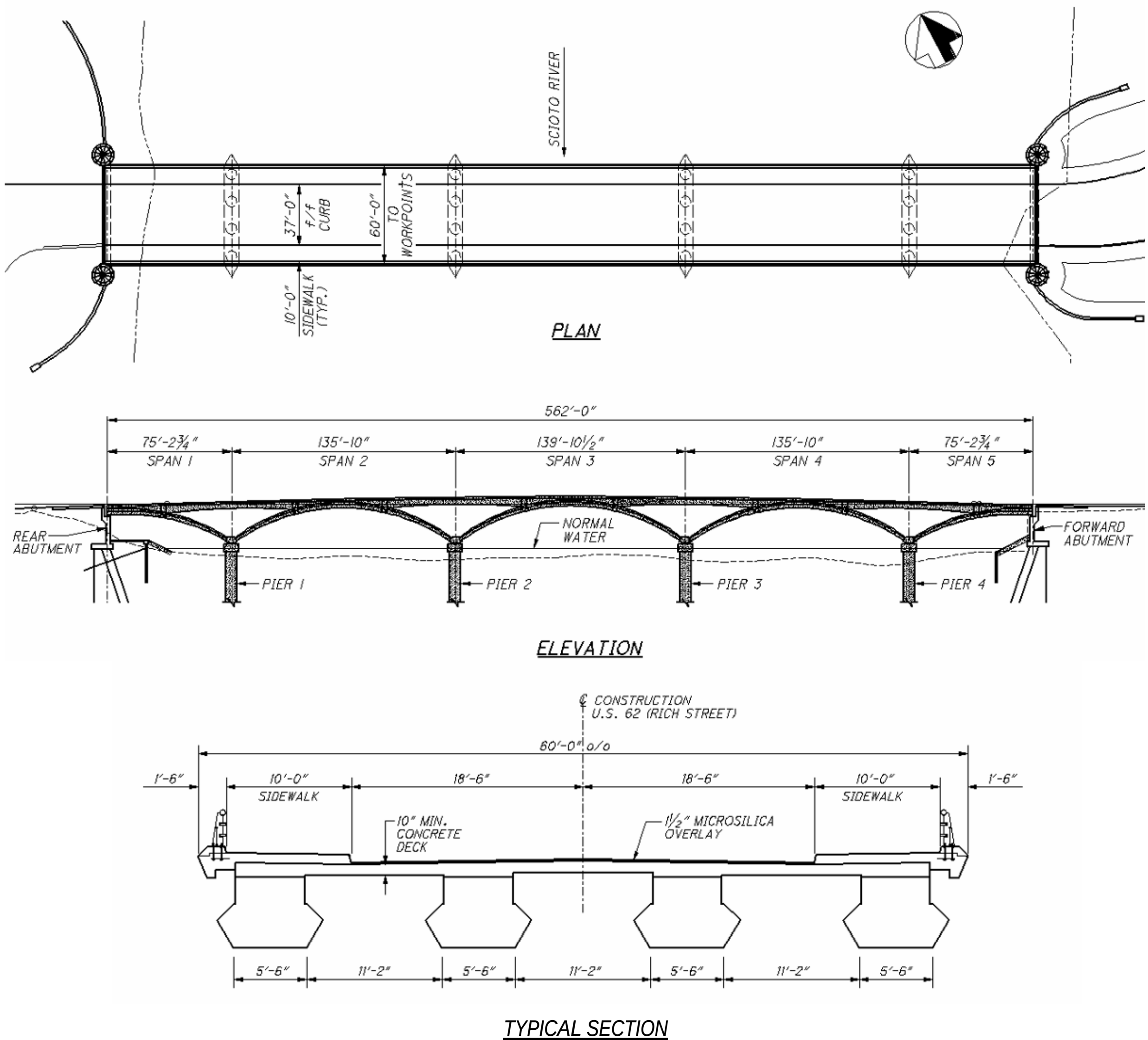

Figure 9 – Proposed Plan, Elevation, and Typical Section

The arch ribs, beams, and composite deck are longitudinally post-tensioned. Four 19-strand tendons will be placed 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 preliminary layout of the post-tensioning tendons is shown in Figure 10.

The bridge substructure consists of two 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 (one 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).

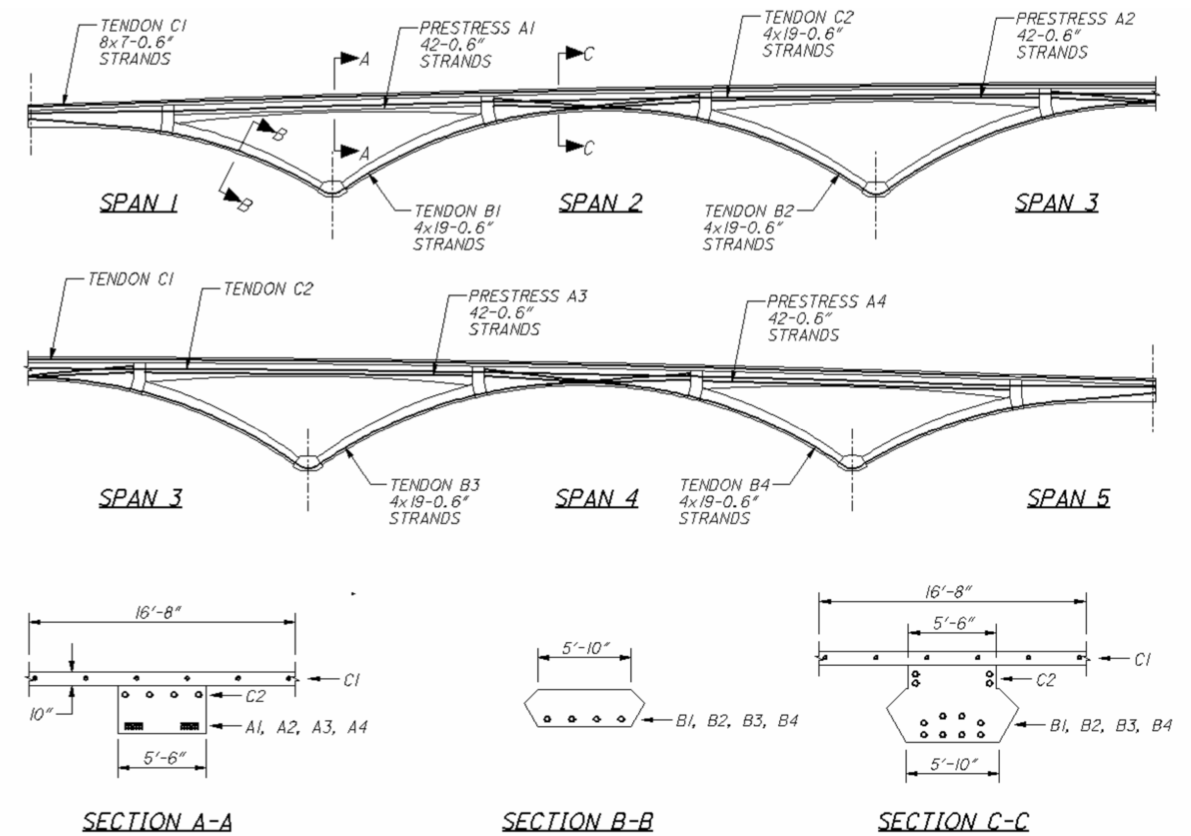

Figure 10 – Post Tensioning Layout

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 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 will derive their support from the limestone bedrock. The abutments will be supported on HP12x74 piles driven to the underlying limestone. An oversized pile hammer will be specified in order to ensure that the piles penetrate the upper layer of weathered shale. Drilled shafts supporting the piers will be 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 11.

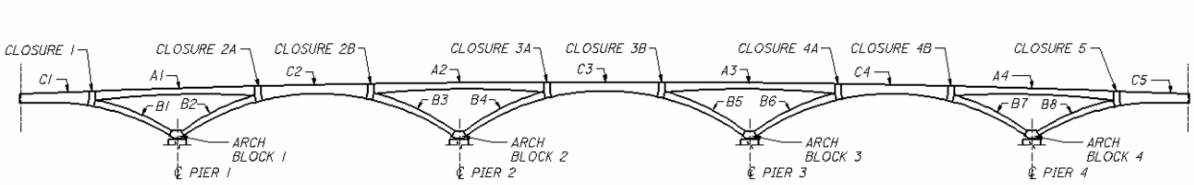

Figure 11 – Precast Segment Layout

Transportation of the precast segments to the site was a primary concern during the preliminary design process. This issue was discussed with representatives of the precast industry through the Ohio Precasters Association (OPA). Through discussions with OPA, it was determined that local suppliers were comfortable delivering the segments to the site if shipping weights were kept at 100 tons or below. This target shipping weight led to the early decision to use lightweight concrete for all precast segments. The use of lightweight concrete reduced the weight of the arch rib segments, the drop-in beam segments, and the end arch crest segments (C1 and C5) below the 100 ton limit. Formed blockouts will be necessary to achieve the desired shipping weight for the interior arch crest segments (C2 to C4).

Standard radii and cross sectional dimensions are used in all bridge spans in order to allow common formwork to be used for each segment type. A description of each segment type is given below, along with an explanation of the anticipated forming methods.

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 proposed 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 can be used for all of the B1 to B8 segments. Because the overall geometry of the segments remains constant, the individual pieces can be cast by shifting the bulkheads within the forms. Details for the arch rib segments are shown in Figure 12.

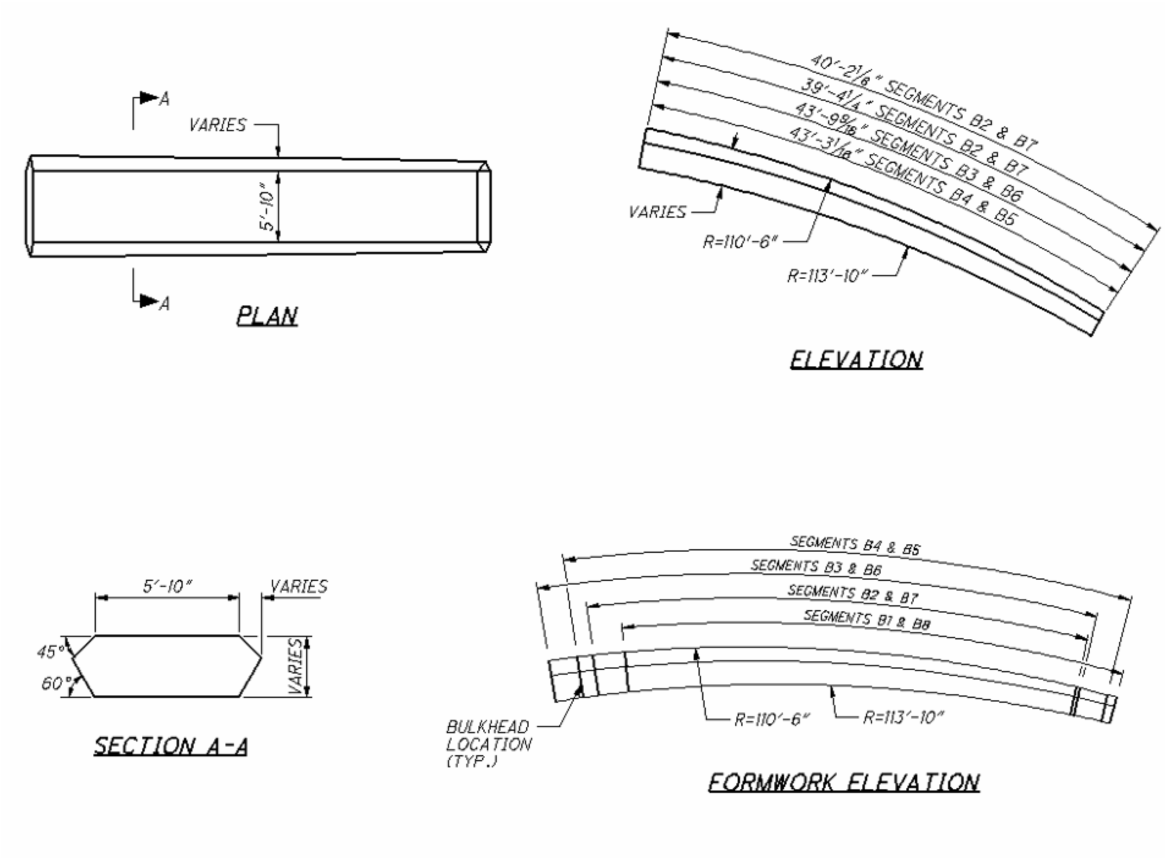

Figure 12 – Arch Rib Segment Details

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 defining the bottom surface of the beam segments is held constant in all spans. The top surface of the segment will be finished to match the profile grade of the bridge. For the exterior beam lines, the exterior (exposed) face of the beams is cast using formliner creating vertical rustication grooves. This provides a textured appearance that visually separates the vertical beam face from the sloping faces of the ribs. A single set of forms can be 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 13.

The arch crest segments (C1 to C5) combine the geometry of the arch rib segments and the drop-in beam segment. The top portion is a rectangular beam section, and the bottom portion is the variable depth arch rib. As in the drop-in beam 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 to a reasonable level, block-outs will be formed in the top surface of the segment by the fabricator. These block-outs will be filled with cast-in-place concrete on site, once the segment is in place supported on temporary falsework. A single set of forms can be used for segments C1 to C5 with bulkheads shifted to meet individual segment dimensions. Details for arch crest segment are shown in Figure 14.

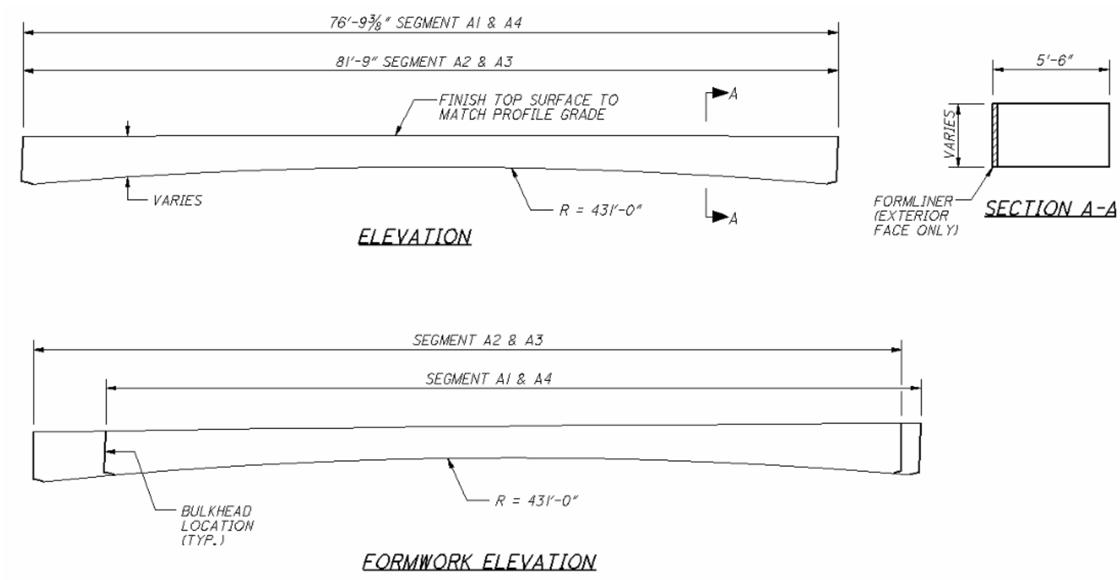

Figure 13 – Drop-in Beam Segment Details

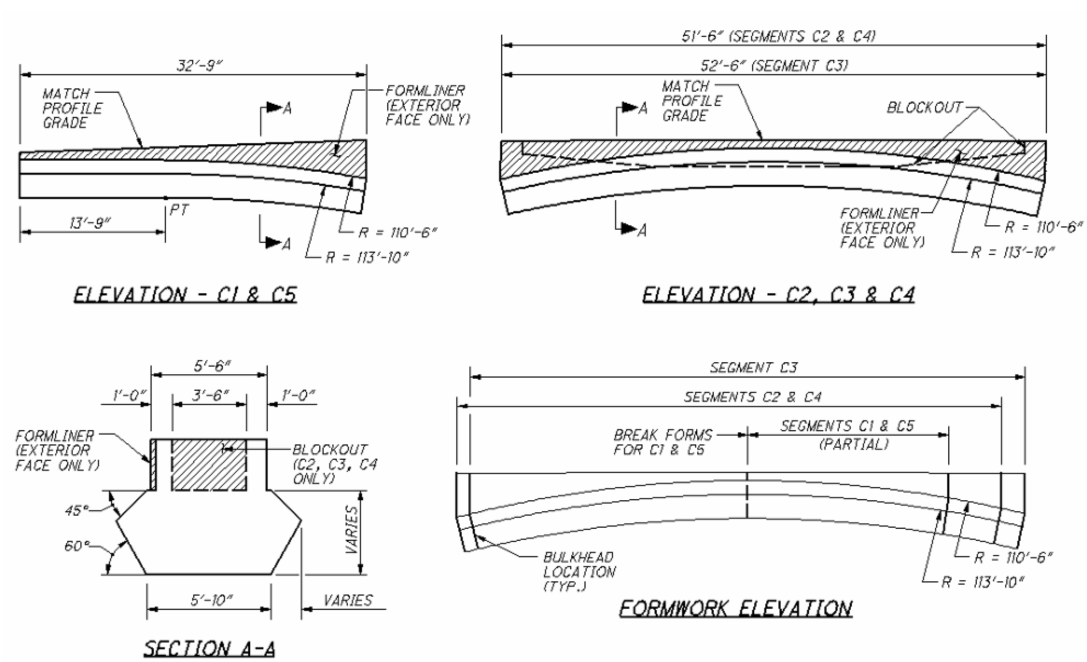

Figure 14 – Arch Crest Segment Details

UTILITIES

Due to its proximity to the City's central business district, the bridge will be required to carry numerous utilities across the river. A total of 22 fiberglass conduits, 4 inches and 5 inches in diameter, will be supported in conduit banks located under the deck between the beam lines. In addition, 18 2-inch diameter PVC conduits will be embedded in the bridge sidewalks. The utility conduits will carry telecommunication and power lines across the bridge, and will also supply power to the bridge lighting and to electrical outlets located on the bridge to be used by vendors who will occupy the bridge during festival events.

The conduits under the bridge will be supported on W6x15 steel I-beams spanning transversely between the beams at approximately 6'-0" on center. The W6x15 beams will also support FRP grating panels that will conceal the utility conduits from view from beneath the bridge. These panels will be removable from below to allow for future access to the utilities. Conduits embedded in the sidewalk will be accessible from above through pull boxes cast into the sidewalk. Details of the bridge utility conduits are shown in Figure 15.

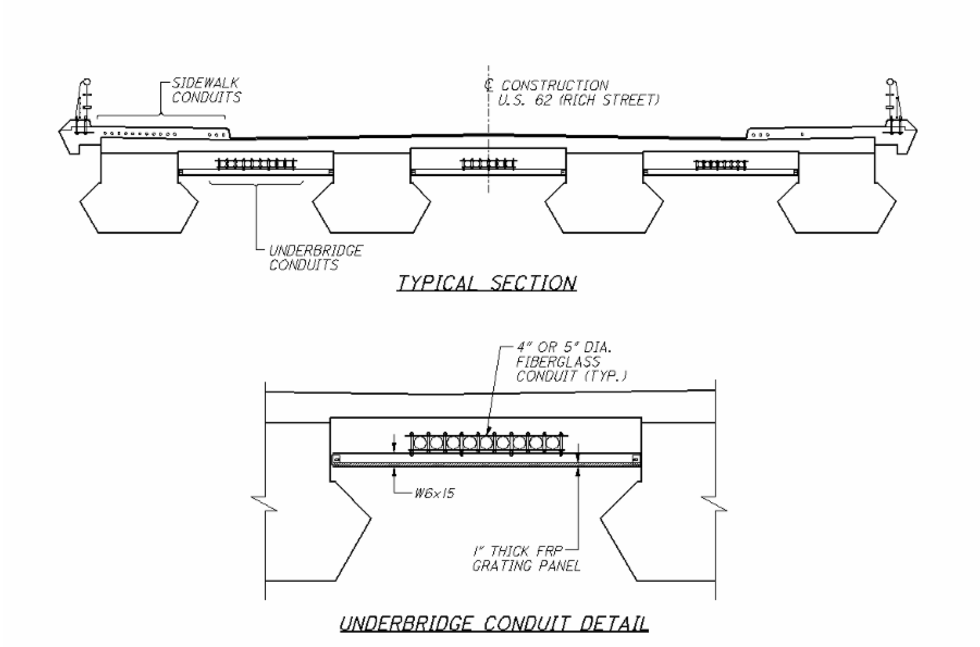

Figure 15 – Bridge Utility Conduits

ERECTION SEQUENCE

The precast segments will be erected on falsework towers on site and tied together by cast-in-place closure pours. Girder closures will be provided at the interface of the arch and girder segments (Segments A, B, and C). Sleeves will be embedded in the closure in order to allow for continuous post-tensioning between the segments. At the piers, the arch rib segments will be linked by a cast-in-place arch block. Prior to the construction of the deck, lateral support

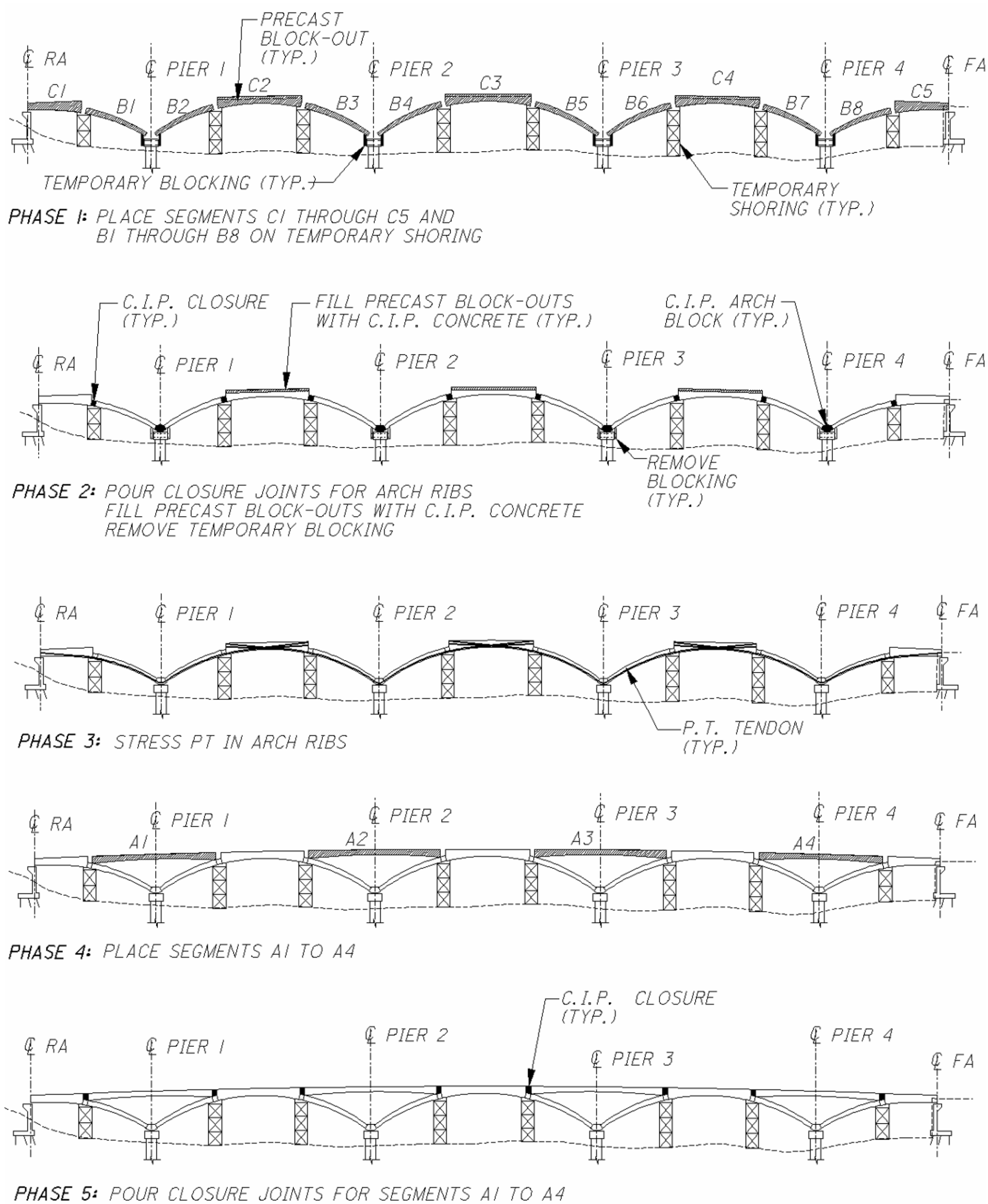

Figure 16 – Erection Sequence

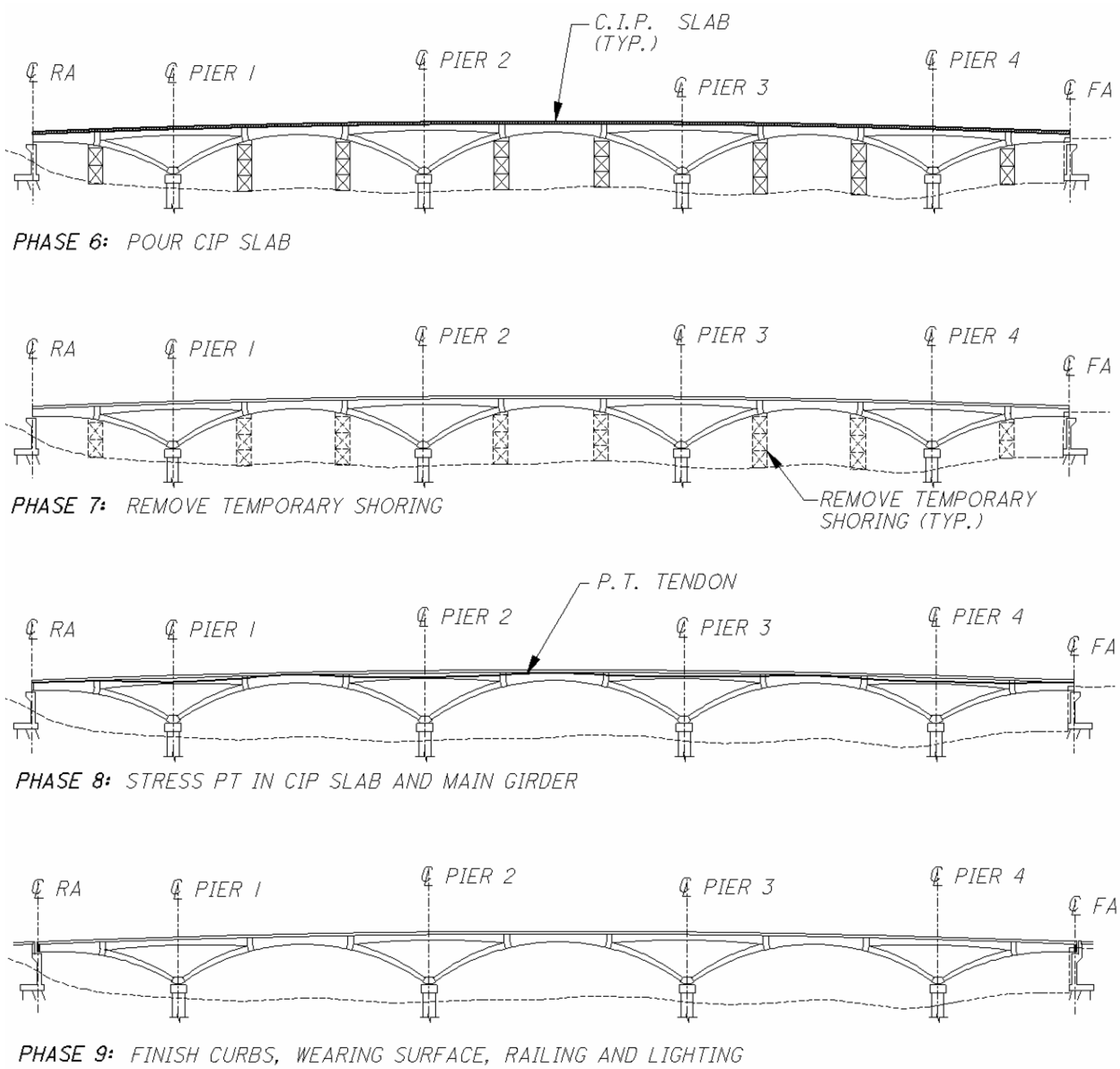

Figure 16 – Erection Sequence (Continued)

of the ribs and girders will be provided by the falsework towers. The need for additional bracing will be evaluated during final design. The proposed erection sequence is fully detailed in Figure 16.

ANALYSIS

At the time of this writing, preliminary analysis of the structure is complete and final analysis is underway. A summary of methodologies used in the preliminary analysis and some refinements to be incorporated in the final analyses are provided here.

Preliminary Design was conducted using a 3-dimensional finite element model of the structure. 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. Transverse interaction between adjacent girder lines was modeled by including transverse beam elements to model the behavior of the concrete deck.

A stage-by-stage analysis was conducted to examine the behavior of the structure during various construction phases. 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 impacts the results of each subsequent stage. An accurate model of the finished structure cannot be created without conducting a full stage construction analysis. For construction stages occurring after the construction of the cast-in-place concrete deck pour, 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[1]. Shear lag effects were included in accordance with the Guide Specification for the Design and construction of Segmental Concrete Bridges[2]. Post-tensioning tendons and anchorages were included in the model using equivalent prestressing loads. Accurate geometry for each tendon was defined, and prestress loss calculations were conducted for each construction stage.

Final Design will use a refined version of the preliminary model. Refinements to the model will include a more detailed study of temporary conditions during construction, including construction live loads and wind loads. The final design will also incorporate a more detailed study of bearing friction and longitudinal breaking force. The concrete slab will be designed separately by finite element plate design in the final stage.

An isotropic view of the preliminary analysis model is shown in Figures 17.

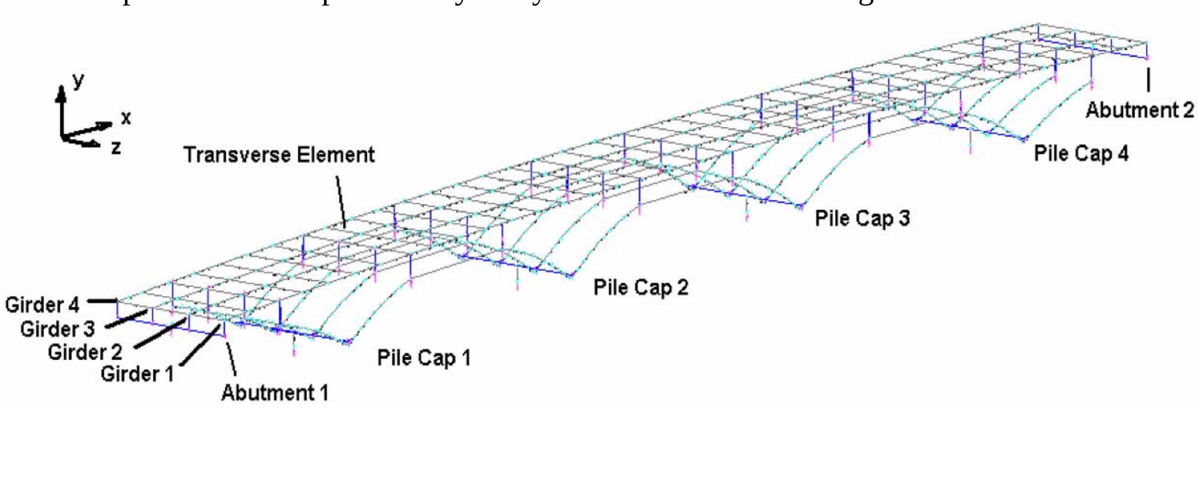

Figure 17. Preliminary Analysis Model

DETAILS AND LIGHTING

PYLONS, RAILINGS AND FINISHES

In response to the Family of Bridges guidelines the team decide 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 will be 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 will also house electrical equipment that will serve not only the bridge and the adjoining park but also the temporary power for the periodic festivals.

The abutment walls between the pylons will be 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.

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 will be made from aluminum industrial grating, an unusual use of a durable and sturdy material. The railing will be topped by a visually dominant handrail, as at the Discovery Bridge, but it will be aluminum, not bronze.

To add interest to the pedestrian’s trip across the bridge the sidewalks will be subdivided with panels of sandblasted concrete. The panel spacing will be coordinated with the post spacing.

LIGHTING

The features of the Discovery Bridge and the Main Street Bridge are lighted at night, as are many of the buildings adjoining the river. The lighting for many of the buildings include 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. So that it can hold its place in the center of this environment. the Rich Street Bridge will have a varied and prominent aesthetic lighting program

The lighting of the Discovery 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 will use both blue and white light.

The ribs will be floodlit from the center of the bridge deck. The inner surfaces of the ribs will be bright while the fascia surfaces of the bridge will be dark and silhouetted against them. This will bring out the structural system and transparency of the bridge while making the river and riverwalk seem a more inviting place. A line of blue Light Emitting Diodes (LED's) under the deck overhang will cast a thin line of blue light across the bridge emphasizing at night the sweep of the bridge from abutment to abutment.

Figure 19. The Rich Street bridge within the nighttime Civic Center

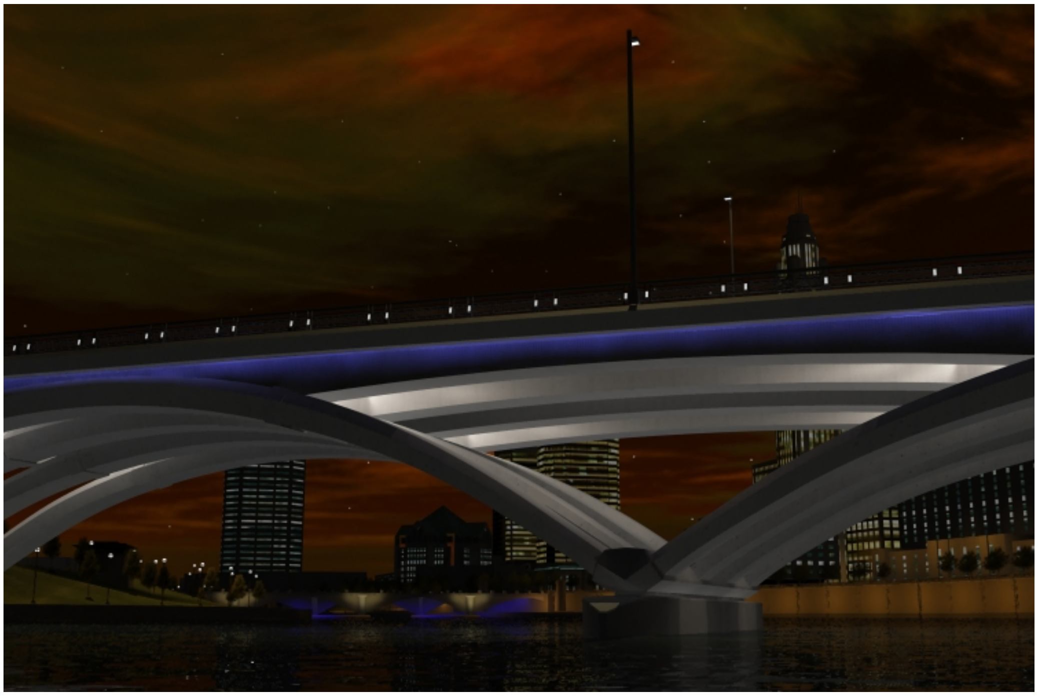

Figure 20. Details of the lighting program.

Each post will have a small white fixture at the same height as the aluminum grating band. These will bring out the A-B-A spacing rhythm of the posts. Taken together they form a line of bright spots that will also emphasize the line of the deck and give the bridge another layer of interest. Finally, short LED strips in blue will be placed in the vertical rustications of the pylons near their tops. These will draw attention to the pylons and signify the beginning and end of the bridge at night.

This lighting program will ensure that the Family of Bridges is as evident in the nighttime as it is during the day.

CONCLUSION

Many bridge engineers and bridge owners assume as standard operating procedure that "Context Sensitive Design" encourages or even requires that new bridges emulate historic bridges at or near the site, or emulate historic buildings nearby. The Rich Street Bridge shows that "Context" is in fact a fluid notion that will change as an area is rebuilt over time and as a community's image of itself also changes. Building a new bridge to emulate a historic bridge or a historic architectural style of is not always the best answer. Among other things, it identifies a community as looking backward, with its self-image placed firmly in the past. Instead, Columbus, and many other communities, prefer to see themselves as striding confidently into the future.

Such preferences do not necessarily make the designer's job any easier. Communities looking for an attractive contemporary bridge for an important civic site are unlikely to be satisfied with a standard steel or precast concrete girder bridge. Meeting these challenges often requires a high level of engineering inspiration, creativity and expertise, as exhibited in the design of the Rich Street Bridge.

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