DEEPLY HAUNCHED SPLICED PRECAST GIRDERS MEET ARCHITECTURAL DEMANDS OF CITY HISTORIC DISTRICT

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ABSTRACT

Spliced precast girder construction techniques were developed to extend the range of application for concrete girders to longer span bridges. This type of construction is now finding application on shorter span bridges that have architecturally demanding sites. Spliced girder construction provides the designer with greater flexibility to customize the shape of the girders to meet the requirements of the project. The High-Main Street Bridge over the Great Miami River in Hamilton, Ohio is set in the heart of the city historic district and carries the City's main thoroughfare across the river. A partnering and workshop process involving state, county, municipal, business and civic representatives resulted in the selection of a structure type that would mimic the appearance of the existing closed spandrel filled concrete arch structure. The proposed five-span replacement structure uses deeply haunched girder segments and spliced-girder construction methods to achieve the desired appearance.

Keywords: Aesthetics, Precast Prestressed Concrete, Post-Tensioning, Spliced Girder

INTRODUCTION

The High-Main Street Bridge is set in the heart of the City of Hamilton, Ohio and its Historic Civic Center. It is a vital transportation link that unifies the High Street and Main Street downtown districts, and carries nearly 40,000 vehicles per day on the City's main thoroughfare, State Route 129, over the Great Miami River (see Fig. 1).

Despite the high traffic volume on the bridge, the crossing provides a notably personal experience. This is due to a combination of factors, among which include a casual 25 mph speed limit, wide pedestrian walks on both sides of the bridge, sweeping views of the river, and a bikeway which routes across the bridge. A strong sense of community and history is expressed through a blend of historic, civic and business landscape. The bridge is located at the former site of Historic Fort Hamilton (active from 1791 through 1796), and a concrete replica of the old log fort wall flanks the east bank bridge abutment. The four-story tall Sailors and Soldiers War Monument and Hamilton Municipal Building dominate the landscape at the eastern end of the bridge. American flags fly on each riverbank and small plazas at the eastern end of the bridge hold different plaques and monuments.

The existing structure is a five-span spandrel filled concrete arch bridge (shown in Fig. 2) constructed in 1914/1915 to replace the previous single span steel truss bridge that washed away in the Great Flood of 1913. All spans measure 95 feet clear between supports. The bridge is eligible for the National Register of Historic Places and is a contributing structure in the Hamilton Civic Center Historic District. Earlier predecessors at this site include a suspension bridge (built in 1867) similar in style to the Roebling Bridge in Cincinnati, Ohio, a wooden covered bridge (built in 1819), and initially a ferry. Images of these noteworthy bridges are memorialized on a plaque at the eastern end of the existing bridge[3].

The existing bridge is heavily deteriorated and is determined to be structurally and functionally obsolete.

Fig. 1. Looking South at Existing Bridge

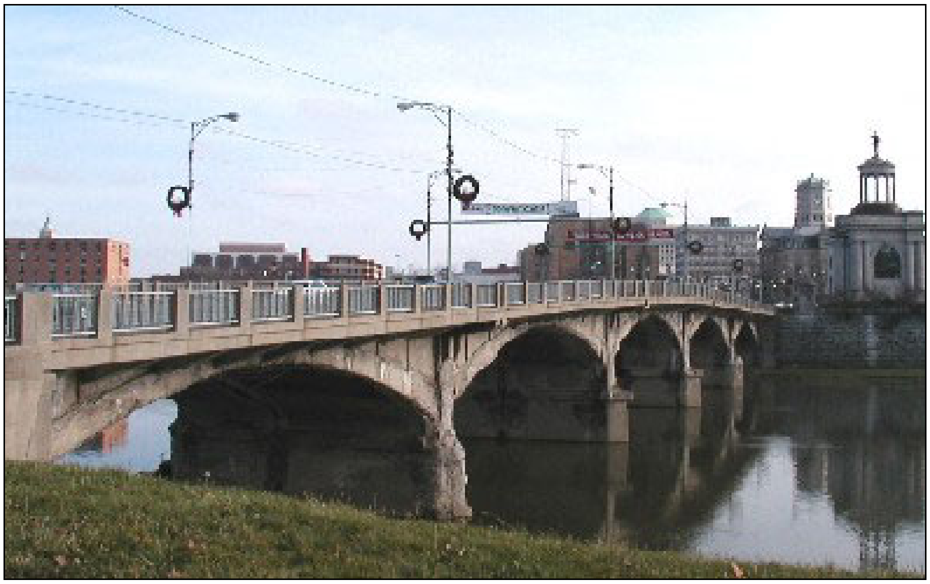

Fig. 2. South Face of Existing Bridge

DESIGN DEVELOPMENT PROCESS

The Ohio Department of Transportation (ODOT) and the City of Hamilton are replacing the High-Main Street Bridge pursuant to a Memorandum of Agreement (MOA) between the Federal Highway Administration (FHWA) and the Ohio State Historic Preservation Office. The MOA was established for this project as a result of the consultation process required by the National Historic Preservation Act. The MOA establishes fundamental aesthetic guidelines and mandates “consultation with local historic groups and/or interested parties” in the development of the final design. To meet this requirement, a Design Review Group (DRG) made up of individuals from the state, county, city, and local business and civic groups was established to provide guidance, review and comment to the design team regarding the aesthetic guidelines adopted in the MOA. To create a close working relationship between the design team and the DRG, a collaborative process was used consisting of a series of workshops and public information meetings.

PROJECT REQUIREMENTS

The basic scope of this project was to replace the existing deficient four-lane bridge with a new six-lane bridge meeting the aesthetic requirements of the MOA and other functional requirements related to hydraulics, maintenance of traffic and utilities, alignment and profile. As with most any project, the structure type selected must meet the fundamental project requirements while keeping time of construction and costs in reasonable balance.

AESTHETICS

The MOA stipulated that the proposed bridge be "a four-span concrete arch that shall recall the aesthetic appearance of the existing structure and be similar in design to the Broad Street Bridge in Columbus, Ohio." The Broad Street Bridge (shown in Fig. 3) consists of a 5-span (three full-arch spans and ½-arch end spans) arrangement with a cast-in-place post-tensioned deep arch plate girder superstructure. The DRG concluded that they desired a bridge equal in quality to the Broad Street Bridge, but not necessarily one that imitated it exactly.

Fig. 3. Broad Street Bridge, Columbus, Ohio

DRG workshops and public information meetings garnered a clear consensus for a 5-span (three full-arch spans and ½-arch end spans) arrangement with elliptically shaped arch superstructure with a depth at the piers similar to that of the existing spandrel filled concrete arch bridge. Balcony overlooks at the piers also received favorable interest. A small-scale model, built by the design team, was presented to the DRG and the public to convey the final basic arrangement and aesthetic proportions of the proposed bridge as reached by overall consensus of the group (see Fig. 4).

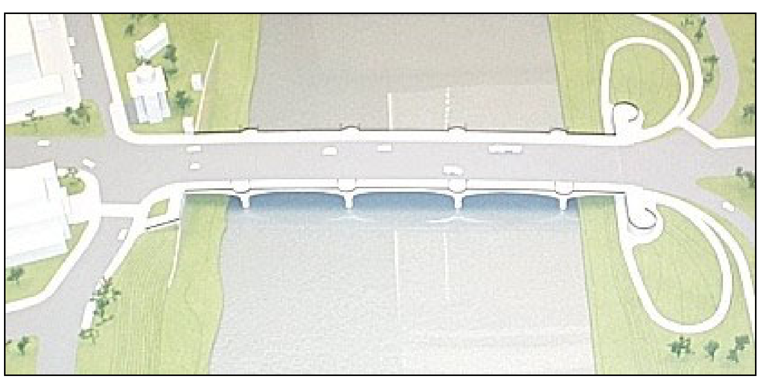

Fig. 4. Model of Proposed High-Main Street Bridge

HYDRAULICS

The ODOT Bridge Design Manual stipulates that bridge replacement projects located within designated floodways shall cause no increase in the calculated backwater for the design year and 100-year frequency storm events[2]. This project is also under the jurisdiction of the Miami Conservancy District (MCD), whom requires that the bridge replacement cause no increase in backwater for their plan flood, which is greater than a 500-year frequency storm event.

In the aftermath of the Great Flood of 1913, levees were constructed along the banks of the river to help limit flooding during future events. The Miami Conservancy District stipulated for this project that the anticipated construction conditions also be checked for hydraulic adequacy considering the MCD plan flood (> 500-year frequency event) and that a minimum of 1-foot of freeboard be maintained from the top of levee. This requirement turned out to be one of the most critical factors in conjunction with aesthetics for determining the proposed structure type.

ROADWAY ALIGNMENT AND GRADE

Due to the nature of historic, civic and business real estate surrounding High Street and Main Street and the immediate proximity of intersecting streets on each approach, the proposed bridge needed to remain essentially on the same alignment and grade as the existing bridge. The alignment of the south curb line was to be held and widening for the two additional lanes on the proposed bridge was to occur to the north, thus producing a slight shift in the centerline of roadway across the bridge.

MAINTENANCE OF TRAFFIC AND UTILITIES ACROSS BRIDGE

The scope required that all four lanes of traffic on the existing bridge be maintained throughout construction if possible. It also required that pedestrian traffic across the bridge be maintained.

A host of active utilities are carried across the river on the existing bridge, including 12-inch and 16-inch water lines, an 8-inch gas line, fourteen telephone ducts, lighting conduit and traffic signal conduit. It was necessary for all of these utilities to be maintained in service during construction and, along with some added telephone and electric ducts, to be carried on the new bridge.

The need to maintain traffic and utilities during construction and the need to hold to essentially the existing alignment dictated that the proposed structure type be well suited for part-width construction in phases.

CONSTRUCTION SCHEDULE

ODOT and the City of Hamilton committed to a 2-year construction schedule for completion of the new bridge while maintaining traffic to lessen the impact on local businesses.

DESIGN SOLUTION

The material type (concrete), profile shape of the superstructure (elliptical arch), and basic span arrangement (three full-arch spans and ½-arch end spans) having been determined by the MOA and reinforced by the DRG, meant all that remained was to settle on a suitable structural member and method of construction that would satisfy all of the design constraints.

The basic span arrangement resulted in spans of 77.5'-128'-134'-128'-75.5' for a total bridge length of nearly 550 feet (see Fig. 14). The proposed roadway and sidewalk widths demanded an overall bridge width of 103 feet. The MOA aesthetic criteria and DRG preferences generated a preliminary superstructure arch profile that ranged from about 3.5 feet deep at the apex of each span to about 15 feet deep at the piers.

SUPERSTRUCTURE TYPES CONSIDERED

The design team investigated the merits of the following superstructure types:

- Cast-in-place concrete open or closed spandrel arch similar to the existing bridge
- Cast-in-place post-tensioned concrete plate arch girders similar to the Broad Street Bridge
- Prestressed haunched concrete girders
- Segmental precast haunched concrete box girders
- Spliced precast haunched concrete girders

The first two structure types were dismissed due to the determination that the necessary falsework to build the bridge would significantly obstruct the hydraulic opening during construction causing backwater from the MCD plan flood to overtop the levees. The design team also acknowledged that cast-in-place concrete construction was likely to be more costly than precast concrete alternatives.

Prestressed concrete girders were considered assuming a variety of segment configurations and associated erection and temporary support conditions. Segments spanning completely between substructures were determined to be too deep and heavy for truck transport (railroad and navigable waterway transport are not available for this site). Shorter segments were considered that would be erected to span from substructure to temporary shoring supports at mid-spans, with continuity post-tensioning then installed. Hydraulic analysis revealed that the combined blockage of the existing bridge (in place to maintain traffic during the first phase of construction) and the new bridge segments with temporary shoring supports resulted in too much obstruction of waterway area during construction to satisfy MCD criteria. Splicing of these segments on the ground at the site was considered but the size, length and weight of the full-span assembly would require two large cranes or a single very high capacity crane to erect plus multi-stage post-tensioning to obtain full continuity end-to-end of bridge.

Segmental concrete box construction was determined to be uneconomical for this short of a bridge and additionally due to the lack of repetitive section geometry. It also is not well suited for carrying the various utilities required on this project.

SPLICED GIRDER DESIGN

Spliced precast concrete girders were determined to best fit the demands of this project. This type of construction offered the following benefits over the other alternatives considered:

- Girder segment sizes could be tailored to accommodate transportation, handling and erection limitations
- Girder erection could be accomplished with conventional size crane(s) and without the need for falsework or temporary shoring supports
- Continuity post-tensioning could be accomplished in a single operation after complete erection of all girder lines
- Comparatively rapid erection of girders helps meet project schedule constraints and limits risk associated with encountering potentially high water and inundation of the construction causeway during the erection process
- Flexibility to craft special aesthetic features using special made forms and the economy of repetition in fabricating multiple similar segments (see Fig. 5 and 6)
- Shop fabrication of members ensures better quality and uniformity of appearance

Fig. 5. Perspective of Proposed Spliced Girders

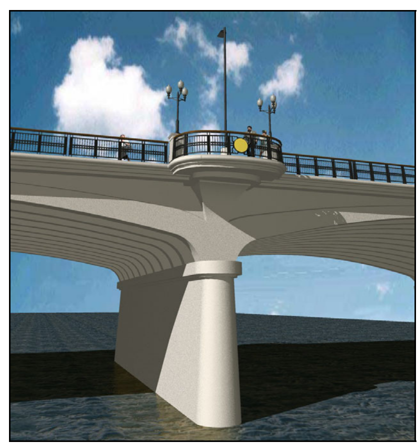

Fig. 6. Pier Balcony Overlook

Eleven girder lines were chosen spaced at 9.25 feet on center. This spacing was optimum for accommodating phase construction of the bridge (see Fig. 15). It also served to control the applied loads versus capacity given the shallow depth of the girders at mid-span, a result of needing to hold the roadway profile grade, provide the desired aesthetics for the girder shape, and obtain the necessary hydraulic opening.

The girder segments basically consisted of pier, end span and drop-in (interior span) segments. The pier segments typically varied up to 15 feet deep at the pier to 8.5 feet deep at the splice (see Fig. 7). The end span and drop-in segments typically ranged in length up to 96 feet and in depth from 3.5 feet at apex to 8.3 feet at the splice (see Fig. 8). The splice locations were chosen to limit the height and length of the drop-in segments to allow normal truck transport methods using a special bracing frame. The pier segments may also be transported by truck if laid horizontal and permitted as an extra wide load. The project plans allowed the contractor the option of casting the pier segments on site, recognizing that some transport routes could potentially be problematic depending on the point of origination.

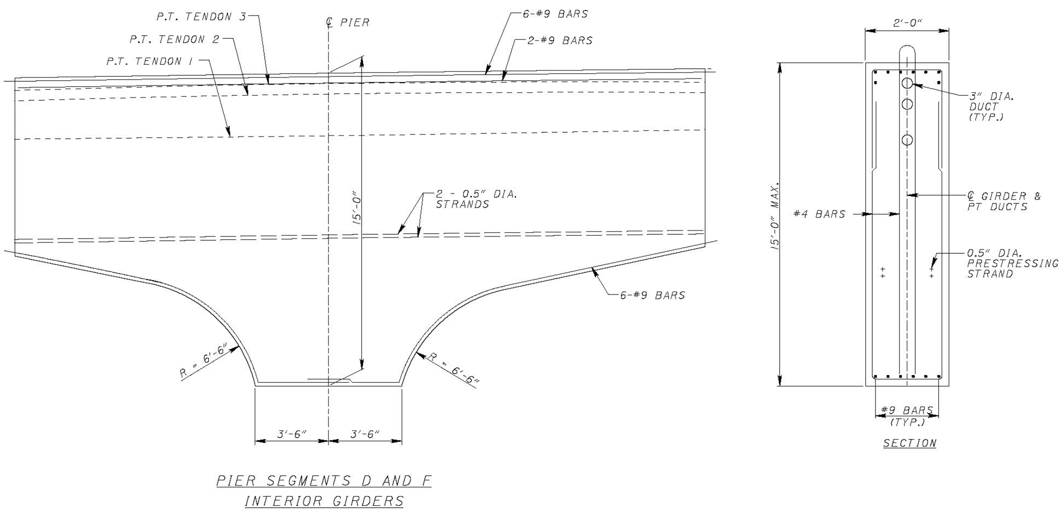

Fig. 7. Interior Girder Details – Pier Segment

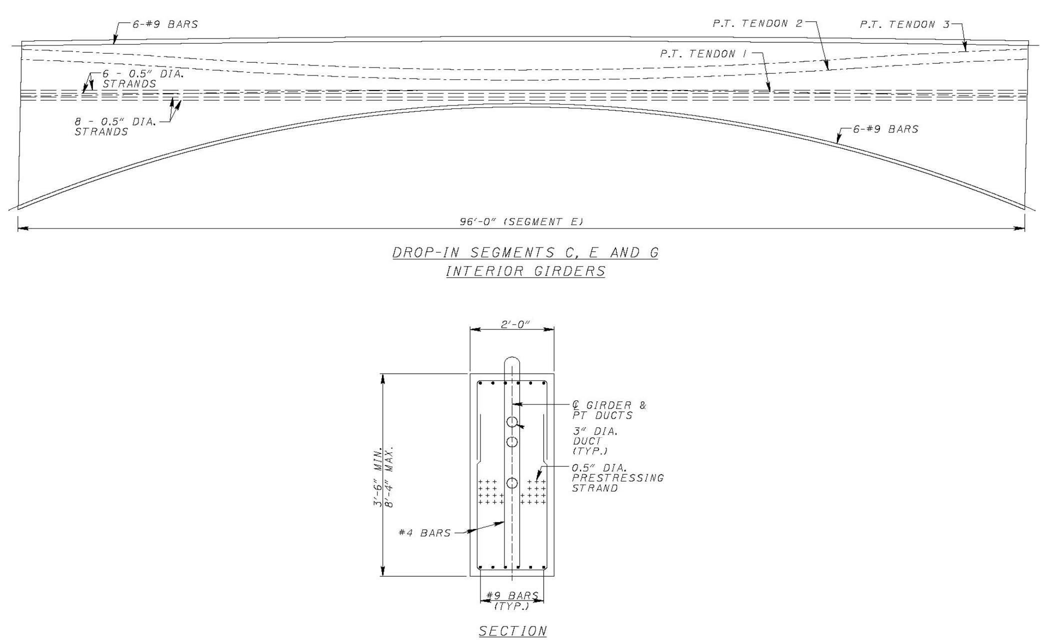

Fig. 8. Interior Girder Details – Drop-In Segment

A rectangular girder section was chosen for the design to simplify as much as possible the fabrication of the special elliptical arch girder forms. The rectangular shape also serves to provide sufficient section to accommodate all prestressing strands, post-tensioning ducts, end anchorages and splice hanger assemblies without the need to transition the web thickness at points of congestion, which would be aesthetically undesirable. The exterior girder section includes some concrete relief to give the distinct appearance of an integral bottom flange, adding to the aesthetic interest of the bridge (see Fig. 9 and 10). The effects of this asymmetry were checked in the analysis of the girders.

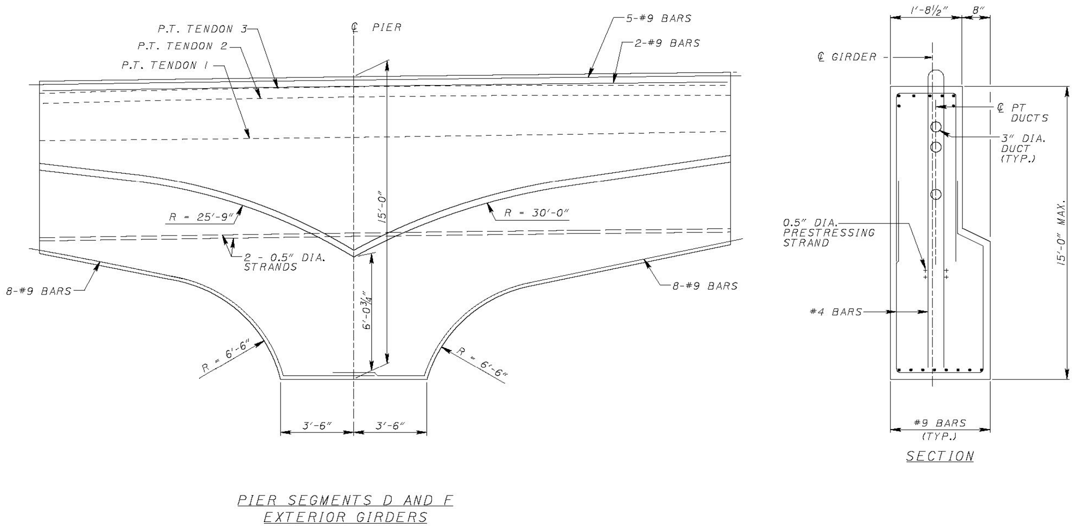

Fig. 9. Exterior Girder Details – Pier Segment

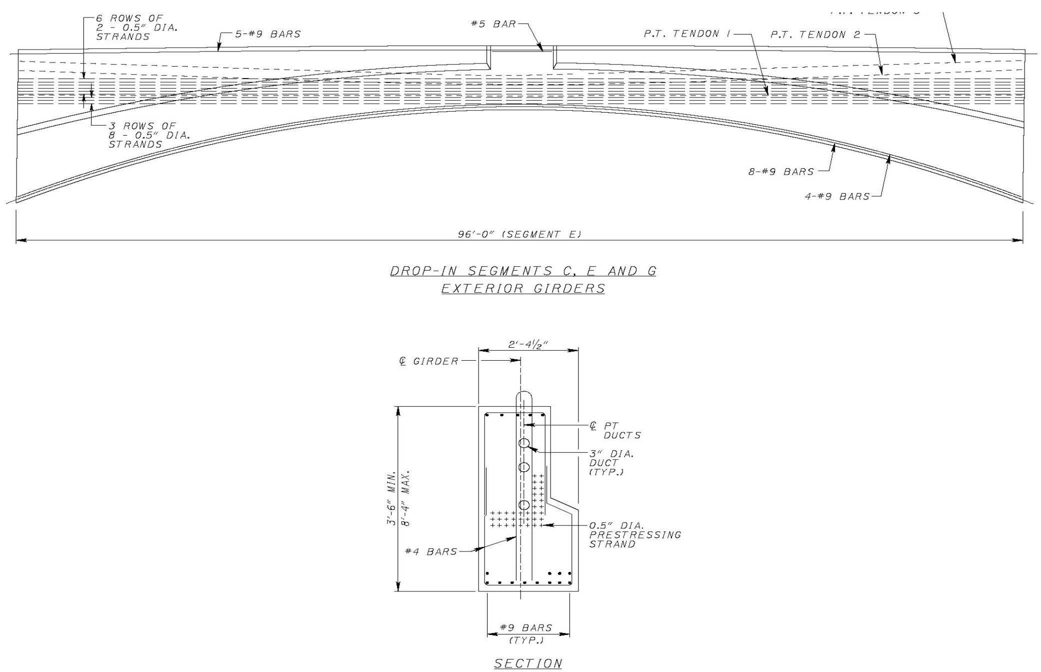

Fig. 10. Exterior Girder Details – Drop-In Segment

Concrete compressive strength specified for the precast girders is 7000 psi, with an allowable compressive strength at release equal to 5500 psi. Prestressing strands are 0.5" diameter, 270 ksi, low relaxation strands. Post-tensioning tendons are 9 – 0.6" diameter, 270 ksi, seven-wire, low-relaxation strands.

Two independent software programs were used to design and check the girders. The design was accomplished using a specialized two-dimensional finite element analysis program, LEAP Consplice PT, which accounts for time dependent behavior and construction staging. An independent check was done using the most commonly used software by designers of spliced girders, IDS BD2, supplemented with spreadsheet computations[1]. These analysis tools gave reasonably close agreement of results.

The massive wall-type piers and counterfort abutments, which have significant pile foundations, were considered as rigid supports in the modeling of the superstructure. The elastomeric bearings were modeled using appropriate spring constants.

In accordance with the stated preference of the owner, the spliced girders were designed as applying all post-tensioning force in the girders prior to casting the deck slab. The deck slab contains no longitudinal or transverse post-tensioning. The owner's preference for this detailing is predicated on the desire to simplify the process of future deck replacements. Accordingly, the design analysis construction staging includes an extrapolated case of a future deck replacement.

SPLICED GIRDER ERECTION

The erection of the spliced girder segments will proceed in the following anticipated sequence for both phases of construction using ground based crawler cranes positioned on a construction causeway in the river (see Fig. 16):

- Erect all girder pier segments on permanent bearings and temporary shim blocks to limit girder rotation
- Secure girder pier segments to the piers using contractor designed tensioned threadbars embedded with anchors in the pier and connected to a saddle beam over the top of the girder (see Fig. 11)
- Erect girder end span segments, secure temporary hanger assemblies (see Fig. 12), cast 1-foot splice closures, and install intermediate cross frames and any contractor designed temporary bracing in end spans
- Erect girder drop-in segments within next interior span and complete same work as described above. Proceed one span at a time with drop-in segments
- After all segments, splice closures, cross frames and contractor temporary bracing are installed, remove temporary tie-downs and shim blocks at piers and stress continuity post-tensioning tendons from both ends of bridge
- Cast concrete diaphragms and concrete deck

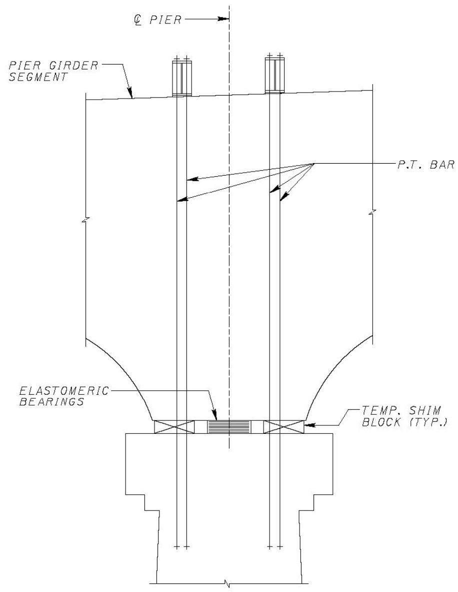

Fig. 11. Temporary Tie-Down Connection of Girder Pier Segment

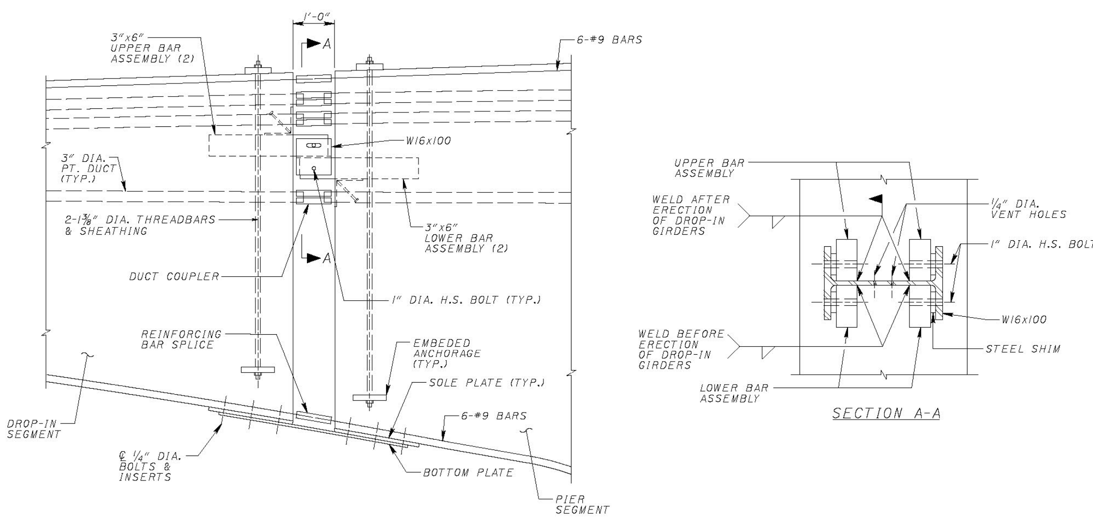

Fig. 12. Temporary Hanger Connection at Girder Splice

The piers were analyzed accounting for the above noted construction sequence. The magnitude of pier rotation associated with the eccentric reactions from the girder segment erection sequence were checked and found to be within acceptable limits of movement given the very stiff makeup of the piers.

PROJECT CONSTRUCTION COST

Construction began for the project in early spring of 2004 and is scheduled for completion in the summer of 2006. The total construction cost awarded for the project is \$16.4M, including demolition of the existing bridge and construction of approach roadway, lighting and landscaping. The award amount attributed to construction of the new bridge is $12.6M, or $222 per square foot of bridge deck. The award amount attributed to the primary components of the superstructure alone (excluding ornate bridge railing, decorative sidewalks, and balcony overlooks) is $6.0M, or $106 per square foot of bridge deck.

CONCLUSION

Spliced precast girder construction was developed primarily with the intent of extending the range of application for concrete girders to longer span bridges. With the use of higher strength and lighter-weight concretes for precast, prestressed girders, spliced girders typically are found to be appropriate in bridges with spans in excess of 160 feet up to nearly 300 feet.

But NCHRP Report 517 "Extending Span Ranges of Precast Prestressed Concrete Girders" calls attention to other valid applications for spliced girder construction[1]. The High-Main Street Bridge is an example where such application was used to improve aesthetics at a very demanding site, extend the range of application for precast concrete girders where height and weight limitations for truck transport would otherwise apply, eliminate falsework and shoring supports that would have restricted hydraulic opening at the bridge, and increase speed of construction to help meet the aggressive construction schedule set for this project.

Fig. 13. Rendering of Proposed High-Main Street Bridge

ACKNOWLEDGEMENTS

The author acknowledges the many agencies that participated in the development of the proposed bridge, including the Ohio Department of Transportation, City of Hamilton, Federal Highway Administration, Ohio State Historic Preservation Office, Butler County Engineers Office, The Miami Conservancy District, ReDiscover Hamilton, Main Street Area Association, the contractor (Kokosing Company), the precast girder fabricator and detailer (Prestress Services and Janssen & Spaans), the designers (a joint venture of prime consultant Burgess & Niple and subconsultants Rosales Gottemoeller & Associates, Parsons Transportation, and Resource International) and the citizens of Hamilton who provided valuable input throughout the public involvement phase.

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2. ODOT Bridge Design Manual, Ohio Department of Transportation, OH (2003)
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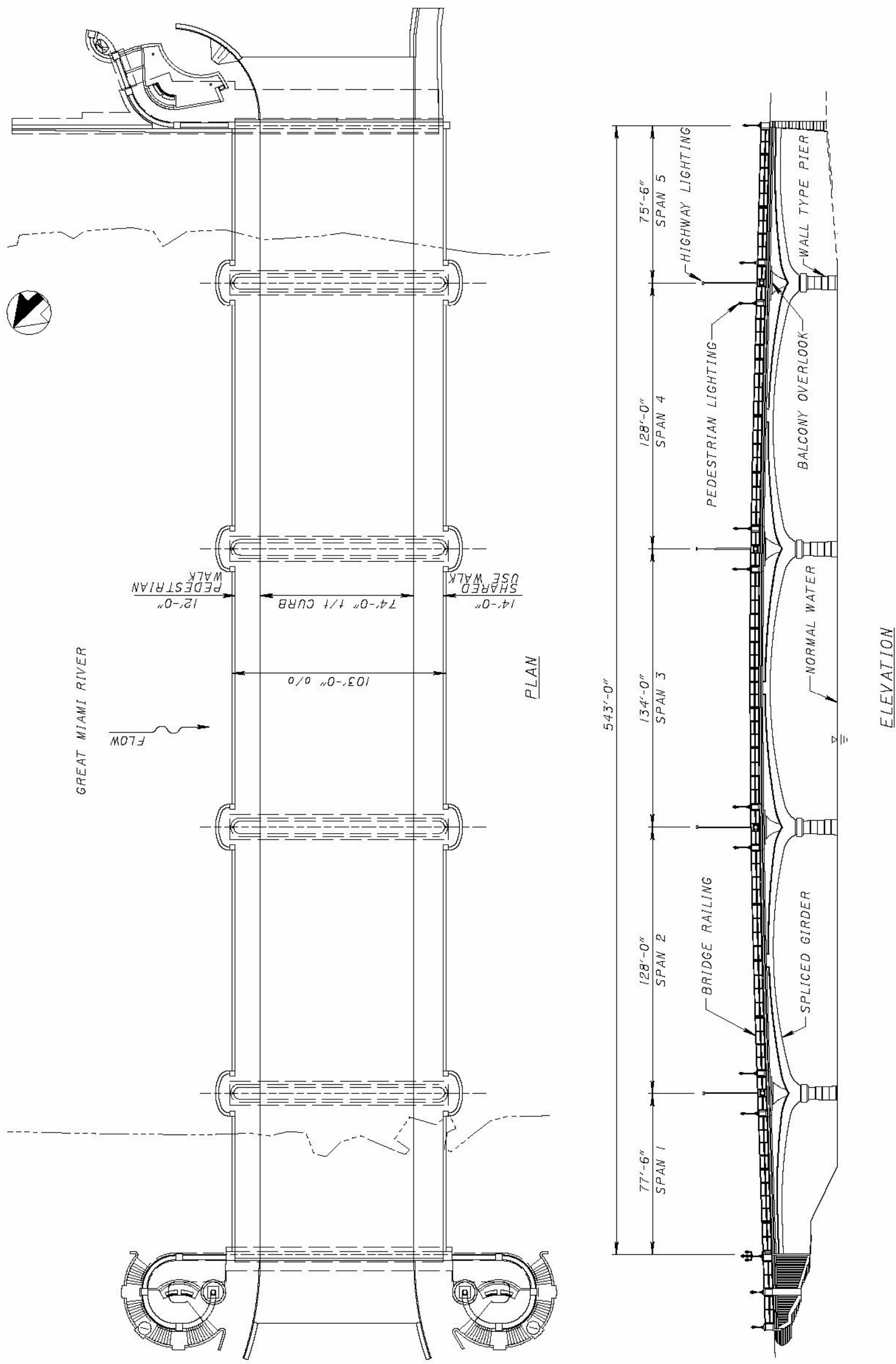

Fig. 14. General Plan and Elevation of Proposed Bridge

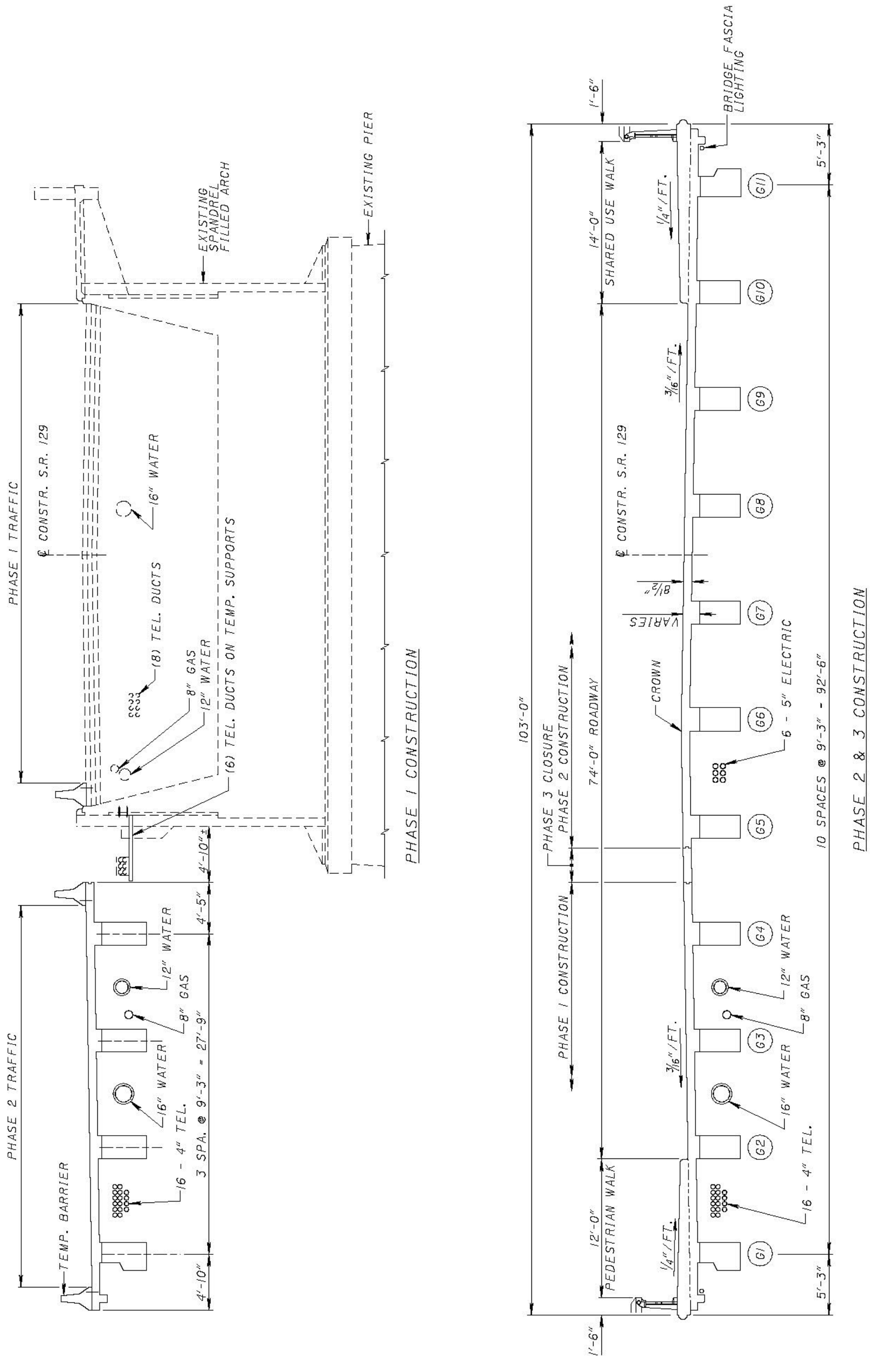

Fig. 15. Proposed Bridge Deck Phase Construction

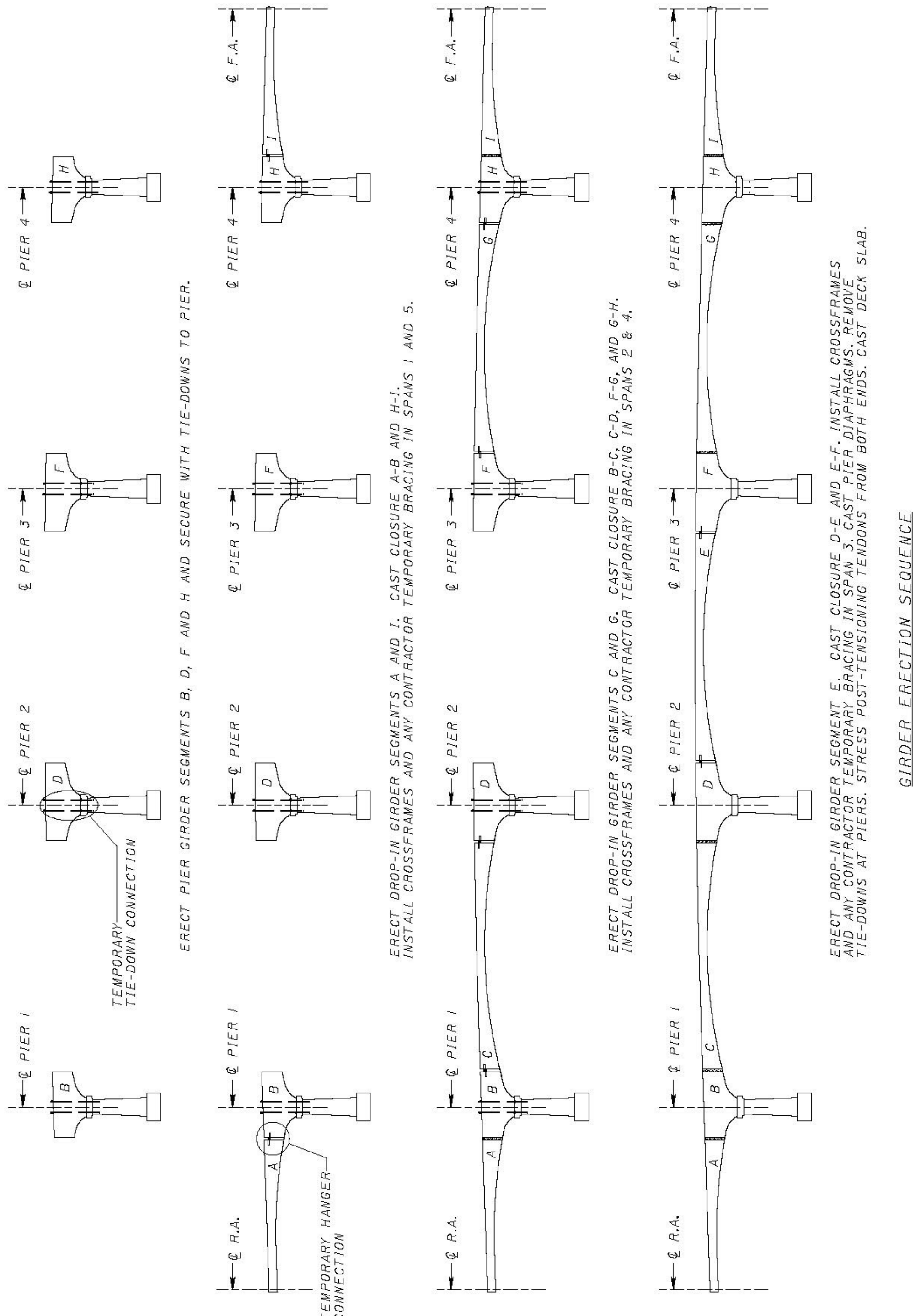

Fig. 16. Spliced Girder Erection Sequence