LONG BRIDGE STUDY

DISTRICT DEPARTMENT OF TRANSPORTATION

LONG BRIDGE STUDY

Bridge and Tunnel Concept Report

January 2014

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1. Introduction

This report describes in detail each of the four bridge types that have been advanced as bridge concepts during the alternatives analysis. A variety of conceptual bridge types have been contemplated as part of the Long Bridge Study and each were evaluated against a set of criteria. This report describes the bridge types under consideration, the evaluation criteria used to differentiate between potential bridge types, and illustrates strengths and weaknesses of each type.

The Bridge and Tunnel Concept Report focused on four distinct conceptual bridge types illustrated in Figures 1 – 4 and different tunnel options discussed in section 4.5.

Figure 1 – Steel Tied Arch Bridge

Figure 2 – Steel through Arch Bridge

Figure 3 – Extradosed Bridge

Figure 4 – Concrete Deck Arch Bridge

These structure types have been evaluated against specific criteria detailed in Section 2. Consideration of height restrictions for a permanent structure as well as construction equipment due to the proximity to Ronald Reagan National Airport (DCA) are described in Section 3. Section 4 summarizes and compares the bridge types. Section 5 provides a study level, initial cost estimate for the construction of the bridge types.

2. Criteria for Consideration

This section provides a description of the criteria that needs to be considered for any future bridge or tunnel crossing the Potomac River at this location. The preparation of this report and the selection of the criteria are similar in nature to elements included in a full engineering Type, Size and Location Report (TS&L). This report is prepared in recognition that this is a pre-engineering bridge concept determination, but used the following criteria that is typical of any engineering report:

- Aesthetics
- Constructability and Construction Impact
- Initial Cost
- Long-Term Maintenance
- Adaptability

2.1 Aesthetics

Given the cultural and visual prominence of the site in connection with the nation's capital and the great number of historically and architecturally significant landmarks in close proximity, aesthetics is an important criteria by which any new structure should be judged. Among the specific aesthetic considerations that have been taken into account in the assessment of aesthetic quality are:

- To what extent does the concept fit in with other bridges near the project site? This includes the George Mason Memorial Bridge, Rochambeau Memorial Bridge, Arland D. Williams Memorial Bridge, and the Washington Metropolitan Area Transit Authority (WMATA) Metrorail Bridge.
- Does the bridge concept exhibit clean lines and graceful shapes, or present a cluttered appearance?
- To what extent does the bridge concept accommodate creative architectural enhancements and treatments?
- To what extent does the bridge concept affect view sheds from both

banks of the river, in particular from the parks and pedestrian areas?

- How does the bridge concept affect views of Washington DC for incoming commuters on the Metrorail yellow line? For many commuters and tourists, the crossing of the Potomac via the Metro represents a common first entry into the city, particularly for those arriving by way of Ronald Reagan National Airport. Does the bridge concept represent positive aesthetics for traffic on the river below the bridge such as recreational boaters or tour boats?
- Is long-term deterioration or change in the appearance of the bridge concept likely that would detract from its aesthetics?
- To what extent does the bridge concept reflect the general architecture of the other man-made physical landmarks in Washington, including historic buildings and public monuments?
- To what extent does the bridge concept permit the addition of color, lighting, or texture to enhance its visual impact?

It is important to recognize that each of these factors is subjective in nature, both in terms of how each alternative might be evaluated and in terms of how important each factor may be to a given individual. The above list is not intended to reflect any hierarchy of importance among the different factors which comprise the aesthetic evaluation.

2.2 Constructability and Construction Impact

Each alternative has been analyzed on the basis of the relative ease of construction and the extent to which complexity and the potential for delays or problems in construction are more or less likely if the concept were pursued. This criterion also looks at the extent to which erection of a bridge alternative may result in temporary or permanent impact on the surroundings. Here are questions to consider for the analysis of constructability and construction impact:

- Does the alternative require demolition and removal of the existing piers, or does it permit the exploration of potential reuse of the existing piers and foundations?
- To what extent will construction interrupt or affect traffic on neighboring structures, if at all?
- To what extent will construction interrupt or affect boating traffic on the

Potomac River beneath the bridge?

- In comparison to other bridge concepts, does this concept require more construction of piers in the river, or larger river piers?
- Does the bridge concept require any additional right-of-way for construction purposes or influence temporary or permanent right-of-way in any manner?
- Does the bridge concept require temporary falsework? If so, for how long? Will heavy equipment be required for erection and will it be feasible and practical to use such equipment in this environment?
- Are there any issues with the adjacent Metrorail Bridge in terms of construction space or safety to Metrorail riders?
- What is the impact from construction on noise, air quality, and vibration?
- Are there any issues with the approach path to Ronald Reagan National Airport that would preclude certain construction equipment or the construction height of the new bridge?
- Does the bridge concept maximize the use of local labor and materials?
- Is the construction method required for the bridge concept common to the local contracting community, or is it too complicated or unusual for local contractors to confidently bid?
- What is the schedule and time requirement for the construction method?
- Does the construction method require excessive temporary works, or non-typical construction equipment which is unfamiliar or unavailable to local contractors?
- Does the alternative require fabrication and delivery of large or unusual-sized bridge elements?
- Will the delivery of large or heavy bridge elements affect traffic in the project area?
- To what extent does the bridge concept require out-of-state fabricators and/or specialty contractors?
- Does the bridge concept, in comparison to the other concepts, present a greater or lesser probability for impacting ongoing rail operations?
- Does the bridge concept, in comparison to other concepts, represent a

larger challenge for obtaining the necessary permits for construction in the river?

- What is the depth requirements to avoid underground obstructions and provide a feasible alignment for tunnels?

Construction of a new bridge in this highly urban location presents construction challenges because it increases the possibility for impacts to commuters, tourists and a large population base.

Construction of a new bridge between the existing Long Bridge and the WMATA Yellow Line structure requires consideration of where equipment could be located and how materials would be delivered to the site and then out to the required locations within the riverbed. Construction will require large pieces of construction equipment to be delivered and maneuvered throughout the site, the ability for material delivery locations, staging and assembly areas, and the ability to access the site longitudinally along the new alignment.

Access from the shoreline on the northwest side of the Long Bridge could disturb federal park land on both sides of the Potomac River, the Virginia side being overgrown parkland (Figure 5) and the District side having a network of roadways and a park service maintenance facilities on East Potomac Park (Figures 6 and 7).

Figure 5 – Virginia Shoreline between Long Bridge and Metrorail

Figure 6 – District Shoreline between Long Bridge and Metrorail

Figure 7 – Long Bridge from Potomac Park looking towards Virginia

Construction of the 14th Street Bridges and the WMATA Yellow Line Bridge was performed at a time where ingress/egress to the site was accomplished with openings of the swing span. The swing span is no longer functional, and the operating equipment has long since been removed. An access strategy, assuming the bridge cannot open, must be pursued or the bridge must be temporarily made operational if construction access requires it.

New construction, limited to the southeast side of the bridge, would eliminate height clearance issues with movable construction equipment or bridge sections for constructing a new bridge if all construction elements can be completed on the southeast side. There are no obstructions downriver from the existing bridge so the construction equipment could float up to the bridge. Locations can be determined for temporary build sites and construction staging on the southeast side.

2.3 Initial Cost

This criterion is an analysis of the estimated initial cost of construction for each alternative. These estimates are developed keeping in mind the following:

- Initial cost estimates are approximate at this stage of the conceptual bridge type or tunnel evaluation. The costing is not based on structural quantities that have been determined from engineering analysis. Rather, the initial costs given in this report are based on historical data, preliminary assumptions on general bridge and tunnel dimensions, and preliminary evaluations of likely construction methods associated with each concept.
- A number of factors that are unknown at this time can have significant impact on initial construction cost, such as: timing of the advertisement and bidding of the construction contract; restrictions on construction schedule or access; effects of rail operations on permissible construction activities; trends in steel, concrete and precast concrete unit costing; etc.
- More detailed cost estimates will be provided during the preliminary engineering of the feasible bridge and tunnel alternatives. Those cost estimates will be based on breakdowns of structural quantities, assumed unit prices, contingencies and other estimated costs.

For these reasons, the initial construction costs are estimated on an “order of magnitude” basis in this report, and are not presented as a single value of estimated cost. This approach will still permit the evaluation of relative cost relationships between alternatives and allow for ranking of alternatives on the basis of cost. Please note that the costs presented in this report are in 2013 dollars and include a 35% contingency.

2.4 Future Maintenance and Lifecycle Costs

Future lifecycle costs refer to expenses that recur over the life of the structure, necessary to maintain the functionality, serviceability and safety of the structure. A detailed examination of anticipated ongoing costs for maintenance is typically performed by conducting a lifecycle analysis. The lifecycle analysis identifies specific anticipated capital expenditures at various future years during the life of the structure, and translates those costs to present-day expenditures, using expected inflation rates.

This type of analysis is generally carried out further into the design process, when more specific design characteristics of the bridge are known. For this report, only general differences in expected future maintenance and lifecycle costs between alternatives can be identified. Among the potential lifecycle and maintenance issues considered in this conceptual evaluation are:

- Does the bridge concept require repainting of structural elements?
- Will the bridge concept, in comparison to other concepts, present more requirements for bearing and expansion joint maintenance and replacement?
- To what extent does the concept facilitate future inspection, and accommodate reasonable access for inspection crews?
- Will the inspection be more complex in nature than what is typically addressed by the agency maintaining the bridge?
- Does the structure represent higher likelihood for long-term durability than the other concepts?
- What are the requirements for tunnel waterproofing and leak prevention?
- To what extent does the concept introduce the potential for fatigue-prone details, or introduce potential fracture-critical bridge elements?

2.5 Adaptability

This criterion refers to the ability of the different bridge or tunnel concepts to address potential changes associated with further development of the project through the upcoming environmental evaluation as well as ongoing coordination with key stakeholders. It also addresses the ability of each concept to keep existing rail operations functional during the construction of a new bridge or tunnel.

At this early stage of the design process, many questions remain as to the final needs and requirements related to capacity and modes of transportation accommodated by the bridge. Additionally, required clearances for airplane paths and navigation channel requirements on the river will play an important part. Some concepts will be more conducive than others in accommodating the changes that may occur as the project unfolds further.

The following considerations impact the analysis for each concept under this criterion:

- To what extent does the bridge concept accommodate a range of bridge widths that would reflect the different possibilities for number of rail tracks to be provided?
- How well does the bridge concept accommodate possible pedestrian and bicycle facilities?
- Does the bridge concept accommodate potential changes to the anticipated main span length?
- How well does the bridge concept provide for anticipated vertical clearance requirements on the river beneath the bridge?
- Is there a potential for a change in vertical profile with this concept in order to provide necessary vertical clearance on the river?
- How well does the bridge concept allow for the maintenance of existing freight and passenger/commuter rail operations during construction?

It is important to note that a number of the criteria used to evaluate the alternatives are interrelated. For example, initial cost is directly influenced by many of the construction impact and constructability issues. Analysis of bridge types and tunnels should be examined with an eye toward identifying clear distinctions between alternatives.

3. Criteria Related to Airports and Potomac River Navigation Channel

One important consideration in the development of bridge concepts is any restrictions that might impact bridge height and the height of construction equipment. The Long Bridge is in the approach path to Ronald Reagan National Airport (DCA) along Runway 1-19 which is the primary runway at DCA and receives the vast majority of all commercial aircraft operations.

Airports and runways have imaginary surfaces that extend out from the end of the runway. The most restrictive of these surfaces is the Federal Aviation Regulation (FAR) Part 77 Imaginary Surface. The Part 77 surfaces extend out from the runway on all four sides and can be broken into five categories; primary, approach, transitional, horizontal, and conical surfaces. The approach path is the more restrictive surface based on the proximity of the Long Bridge to the airport.

The approach surface varies depending on the type and use of a runway. The approach surface is longitudinally centered on the extended runway centerline and extending outward and upward from each end of the primary surface. For DCA Runway 1-19, the inner edge width of the approach surface is the same width as the primary surface (1,000 feet) and it expands uniformly to a width of 16,000 feet at a distance 10,000 feet from the runway primary surface. The primary surface is 200 feet from the runway threshold. The inner approach surface slopes at 50 feet horizontal: 1 foot vertical (50:1) so that the height above the runway threshold, at the beginning of the inner approach, is 200 feet. The approach surface does extend further back from the runway for 40,000 feet at a slope of 40:1, for another 1000 feet above the inner approach starting elevation, for a total of 1,200 feet above the threshold elevation. In plan view, the approach surface is trapezoidal in shape. It is 1,000 feet wide as it starts 200 feet behind the runway threshold. At the end it is 16,000 feet wide 50,000 feet out. Figure 5 shows the plan view of the Part 77 50:1 approach surface. Note that the shape of the approach is not completely trapezoidal as the approach follows the Potomac River.

In addition to the approach surface, some portions of the transitional surface lie above the Long Bridge. Along the length of the runway surface, the transitional Part 77 surface starts at the edge of the approach surface and extends outward and upward from the runway, at a 7 horizontal to 1 vertical slope, to an elevation of 150 feet above the established airport elevation. The horizontal surface at DCA is 164.9 feet MSL based on the established airport elevation of 14.9 feet. Even with the transitional surface being considered, the approach surface remains the controlling surface for determining the maximum bridge height at Long Bridge.

Long Bridge is the closest of the four bridges at the 14th Street / I-395 crossing to the Runway 1-19 approach end at DCA, as shown in Figure 8. At its closest point at the Virginia waterfront of the Potomac River, the Long Bridge is approximately 4,310 feet from the runway threshold. Based on this distance, the maximum elevation of the bridge at this location is 81.5 feet. For the center of the bridge, at the navigational channel, the maximum height is 89.2 feet and at the right edge of the approach slope the maximum height is 94.7 feet.

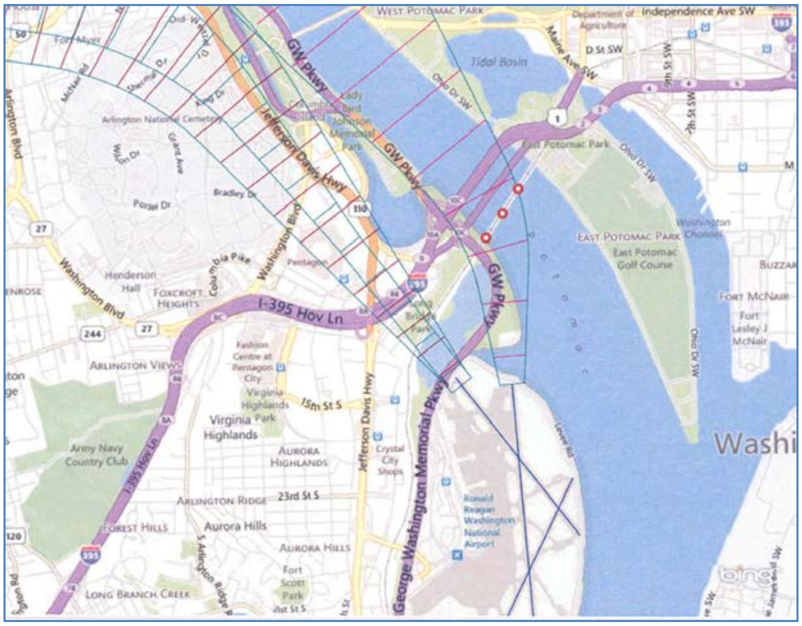

Figure 8 – Plan View of National Airport Approach Surface

During design and construction, coordination of bridge heights as well as any construction equipment, including cranes, would need to be communicated to DCA in order to file a *Notice of Proposed Construction or Alteration* with the Federal Aviation Administration (FAA). Current plans to extend Runway 1-19 would change this approach slope and would increase the maximum height allowed by an additional 5 to 10 feet. Specific measurements of this adjustment are not available until the runway expansion is completed and the new runway threshold is defined. Long Bridge concepts and bridge types were developed in consideration of this height restriction.

The dredged navigable waterway below the Long Bridge is identified as the Georgetown Channel between Hains Point to just above the Chain Bridge. The National Oceanic and Atmospheric Administration (NOAA) provided the data and navigation charts used by commercial, military and recreational vessels to navigate the Georgetown Channel. Figure 9, as provided by NOAA, shows a mid-channel controlling depth below the Long Bridge at 20 feet. Long Bridge has two swivel spans both of which are fixed in the closed position. Current U.S. Coast Guard navigation operations consider the minimum width of the channel at 110 feet and the minimum clearance at 20 feet. The Tidal Basin is on the northeast side of Potomac River 1.6 miles above Hain's Point. A fixed bridge, with a clearance of 11 feet, crosses the entrance and tide gates obstruct passage under the bridge.

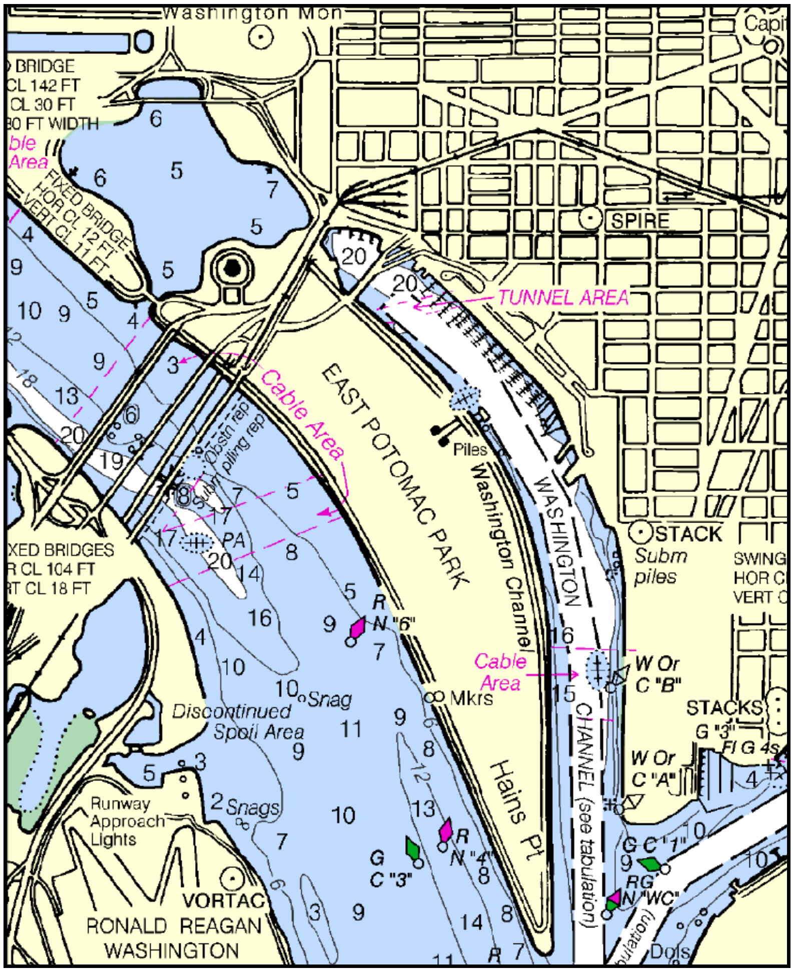

Figure 9 – NOAA Navigation Chart 12289

Rehabilitation or replacement bridge concepts for the Long Bridge will need to maintain the navigation channel and provide passage beneath the bridge, at or above the current clearances.

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4. Conceptual Bridge Alternatives

4.1 Rehabilitation or Reconstruction of Existing Bridge

Analysis was performed on the existing bridge to assess the current bridge condition and forms the basis of rehabilitation or reconstruction options. To execute a rehabilitation it would require a number of analyses including: underwater inspection; inspection of the superstructure; reassessment of train load ratings; and the completion of a fatigue life study.

One focus of the rehabilitation would be to extend the service life of the steel superstructure to protect from corrosion. The rehabilitation alternative takes into consideration the existing coating system which has failed with widespread surface corrosion which needs to be repaired or replaced. Coating option include over-coating techniques with typical success performance of 7 to10 years or 3-coat, zinc-rich primer paint systems, which would provide a performance of 15 to 20 years. During rehabilitation, any structural issues in the superstructure would be addressed and corrected.

Rehabilitation to the substructure would include the installation of additional vertical batter piles around the existing piers. This would increase the bridge capacity for heavier loads and greater braking forces allowing trains to run at full speed. Substructure rehabilitation would include installation of cofferdam, excavation, installation of piles, modifications to existing piers and connection between existing structures and new construction. The rehabilitation alternative assumes that at least one track must be in service during the rehabilitation.

Reconstruction of the existing bridge assumes a two track replacement of the current bridge structure that could be designed using one of the bridge type concepts in this report.

4.2 Steel Tied Arch

This alternative consists of a single steel tied arch main span of approximately 280 feet, and approximately 10 to 12 approach spans flanking the tied arch span. The approach spans could have varying span lengths but would likely be designed in the range of approximately 85 to 108 feet. The tied arch span would be located on the current navigable channel of the structure, roughly matching the main columns of the 14th Street Bridge. The tied arch could have a variety of configurations, including parallel arch ribs versus “basket-handle” arch ribs (arch ribs inclined inward); vertical cables versus networking cables; and a variety of different options for arch rib bracing.

The approach spans would likely consist of standard multi-girder construction. The girders could consist of either steel or precast, prestressed concrete beams. Approach piers could be constructed in a variety of styles, including cap-on-column or hammerhead/tulip configuration. Figure 10 shows a rendering of the conceptual steel tied arch alternative for Long Bridge.

Figure 10 – Steel Tied Arch Rendering of Long Bridge

Analysis of Aesthetics

The steel tied arch would represent a departure from the style of neighboring bridges, in the sense that all neighboring bridges are deck supported with all structural elements beneath the level of the deck. With the tied arch above the deck level, users of the bridge would pass through the structural elements as opposed to over them.

The tied arch would provide an opportunity to create a visual statement that could be seen from adjacent bridges as well as from the banks of the Potomac River. The steel arch ribs and bracing would provide opportunities for the inclusion of color or lighting to further make the tied arch span stand out, if so desired. However, since the tied arch is used in one relatively short portion of the bridge, the opportunity for a dramatic above-deck aesthetic statement is limited. Aesthetic treatments are also possible on the approach spans and piers.

This bridge type does not represent a particularly unique structure type, as there are many tied arches in service in the U.S. and around the world. However, it would represent a unique bridge type for the Washington, D.C. region. Uniqueness could also be added to the tied arch span by using basket-handle (inclined) arch ribs, networking (non-vertical) arch cables, and potentially unique approaches to providing lateral bracing of the arch ribs.

Analysis of Constructability and Construction Impact

The steel tied arch represents a fairly common structure type with which most major bridge contractors would be familiar. The majority of the structure would consist of typical multi-girder approach spans of reasonable length, which would represent standard bridge construction for contractors.

Assuming the span length of the tied arch span is limited to approximately 280 feet, construction of the tied arch span could either take place in its final location, or the arch span could be constructed off-site and moved into place using special lifting and moving equipment. If the span length remains in the 250 to 300 foot range, the need for temporary shoring for construction of the arch ribs (assuming the arch is constructed in its final location) would be somewhat limited.

Because the tie girder of a tied arch resists horizontal thrust loads from the arch ribs, the loads transmitted to the piers and foundations on the main span would be predominantly vertical loads, thereby making the design and construction of the piers and foundations somewhat more straightforward, and the expectation would be that the foundations for this alternative would be smaller and more economical than the other alternatives.

Of the bridge concepts being considered at this time, this alternative likely represents the shortest construction schedule. The approach spans could likely be constructed simultaneously with the main span, reducing construction time. As the approach spans are standard construction elements, we would expect construction of these spans to be quick relative to the other concepts. Additionally, construction of this alternative does not have high risk of being slowed down during cold weather months. However, this alternative has the potential to result in more piers in the river than the other alternatives.

Analysis of Initial Cost

The steel tied arch alternative is likely to be the least expensive alternative of those currently being considered, from an initial cost standpoint. The factors contributing to the initial cost of this alternative are:

- The majority of the bridge is standard construction that can be built with relatively small initial cost. The “unique” portion of the bridge that requires unique fabrication and construction of the tied arch itself is limited to a small portion of the bridge.

- There is little need for specialized construction equipment or an excessive need for temporary works. The tied arch span represents somewhat unique construction but with the span length being contemplated for this main span, the construction of the tied arch will be fairly straightforward.
- The foundations for the main tied arch span should be relatively smaller than the foundations for the other alternatives, since the main span is shorter and transfers smaller loads (and potentially significantly reduced lateral loads) to the subsurface.
- The tied arch alternative results in more piers in the water compared to the extradosed and through arch alternatives.

Analysis of Future Maintenance and Life Cycle Costs

The approach spans make up a significant percentage of the overall length of this structure, and these spans will have maintenance requirements that are standard for most conventional bridge structures. Specifically, the bridge bearings and expansion joints will need to be periodically replaced, as will any required drainage elements on the bridge. If the approach spans consist of steel girders, the girders may require repainting at some point in the future, unless weathering steel is utilized. Concrete elements such as the piers will need to be protected from chloride intrusion and will need to be inspected for cracking, spalling, and delamination.

The steel tied arch span will present additional maintenance requirements that could include future painting of the arch ribs and lateral bracing between the arches. The tied arch span will also have a steel flooring system consisting of floor beams and (potentially) steel stringers. These elements will need to be inspected and protected from corrosion. The tie girder, which connects the ends of the arch ribs, is a tension member that will need to be carefully protected from the possibility of any crack development. The tie girder represents a fracture critical element and accordingly, should be carefully inspected on a regular basis to ensure safety.

Inspection of the majority of the bridge (approach spans) will be standard and should not require any specialized equipment or techniques. Inspection of the arch ribs and hangers will require man-lifts that have the capability to access the top of the arch ribs.

Analysis of Adaptability

If this bridge type were constructed, it would have to be built adjacent to the existing bridge in order to maintain existing rail service. It would be possible to construct the approach spans in stages, which would involve:

- Constructing new girder lines and substructure supports adjacent to the existing bridge, with rail traffic on the existing bridge;
- Moving rail traffic to tracks on the new bridge; then
- Removing and reconstructing the tracks on the existing bridge alignment.

It would not be feasible to perform this operation on the tied arch span of the bridge. In order to maintain rail operations throughout construction, the new bridge would have to be built entirely on new alignment adjacent to the existing bridge. The tied arch span, with supporting elements above the deck of the bridge, provides very good vertical clearance beneath the structure for river navigation traffic. There would be little likelihood for the need to adjust the vertical profile of the bridge to accommodate vertical clearance.

The tied arch could accommodate a wide range of potential bridge widths, up to approximately 120 to 140 feet in width for a single structure. This represents a practical upper limit to the width of the bridge such that the floor beams can be cost-effectively fabricated and erected. This width accommodates most of the scenarios envisioned for a four track railroad on approximately 68 feet of the bridge width and other modal options beyond the 68 foot width. The widest alternative requires at least 137 feet. Diagrams 1 through 4 show the elevation, cross sections and construction sequence for the steel tied arch alternative.

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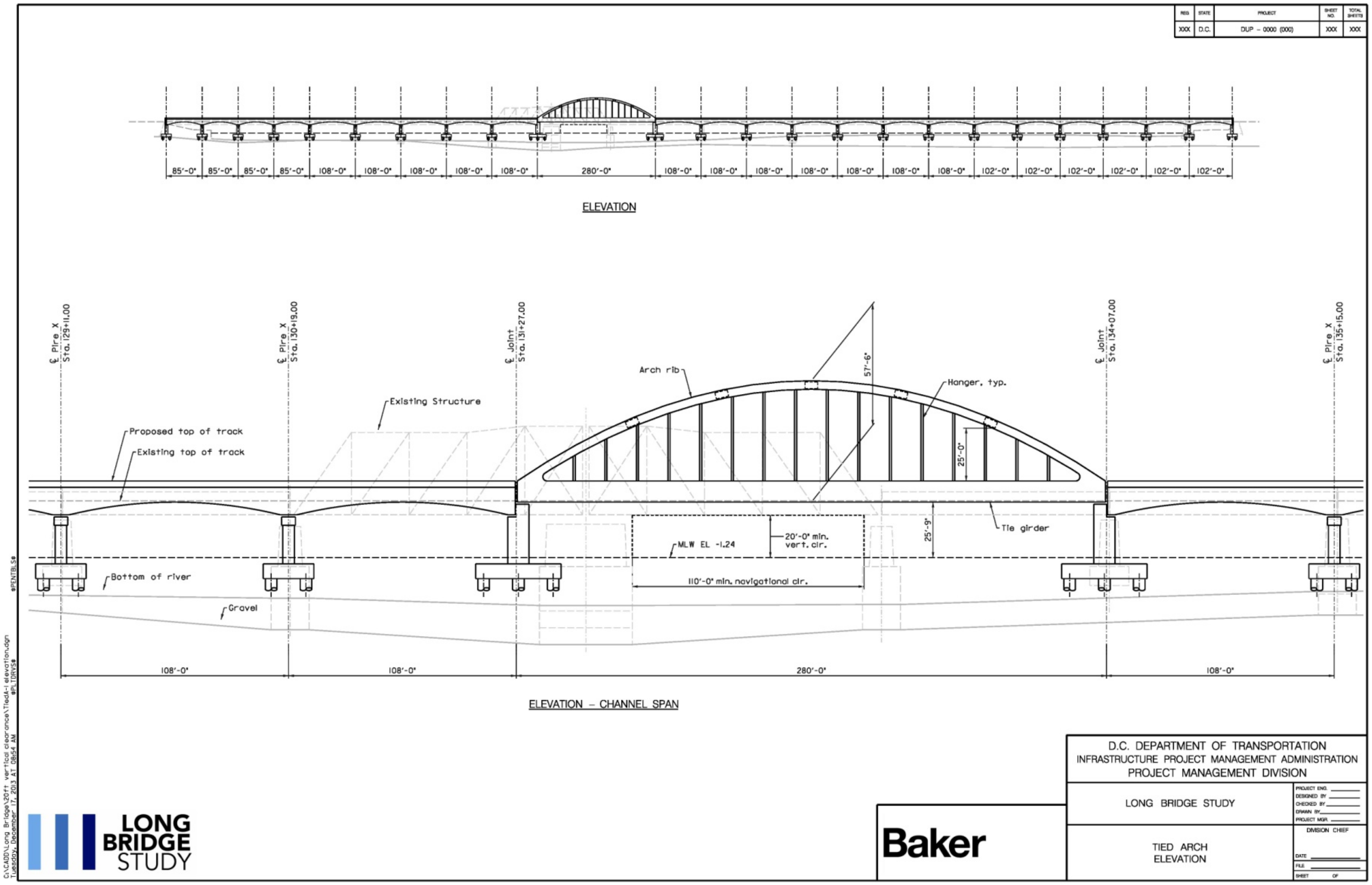


Figure 11 – Steel Tied Arch Elevation

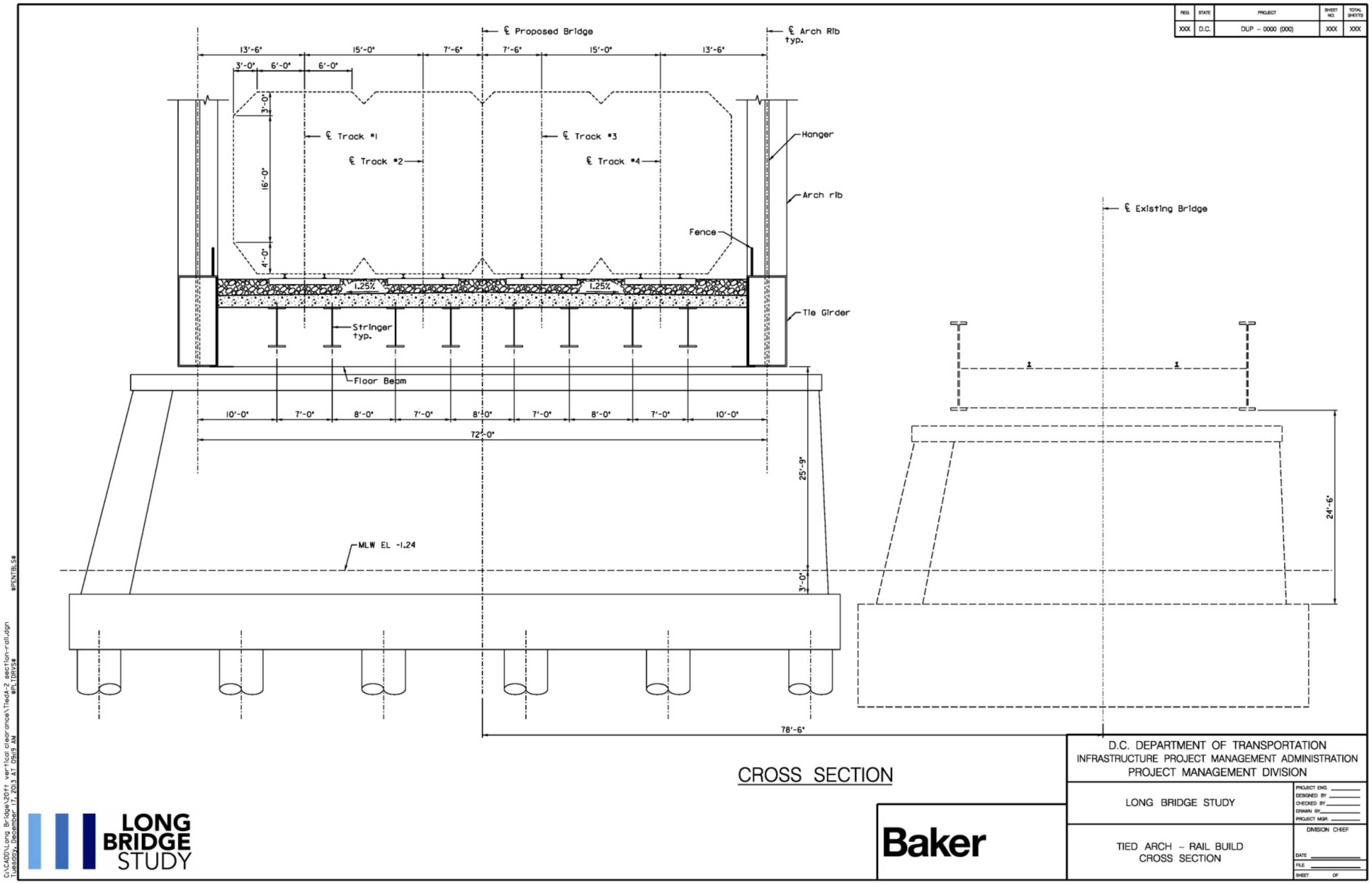


Figure 12 – Steel Tied Arch Cross Section - Rail

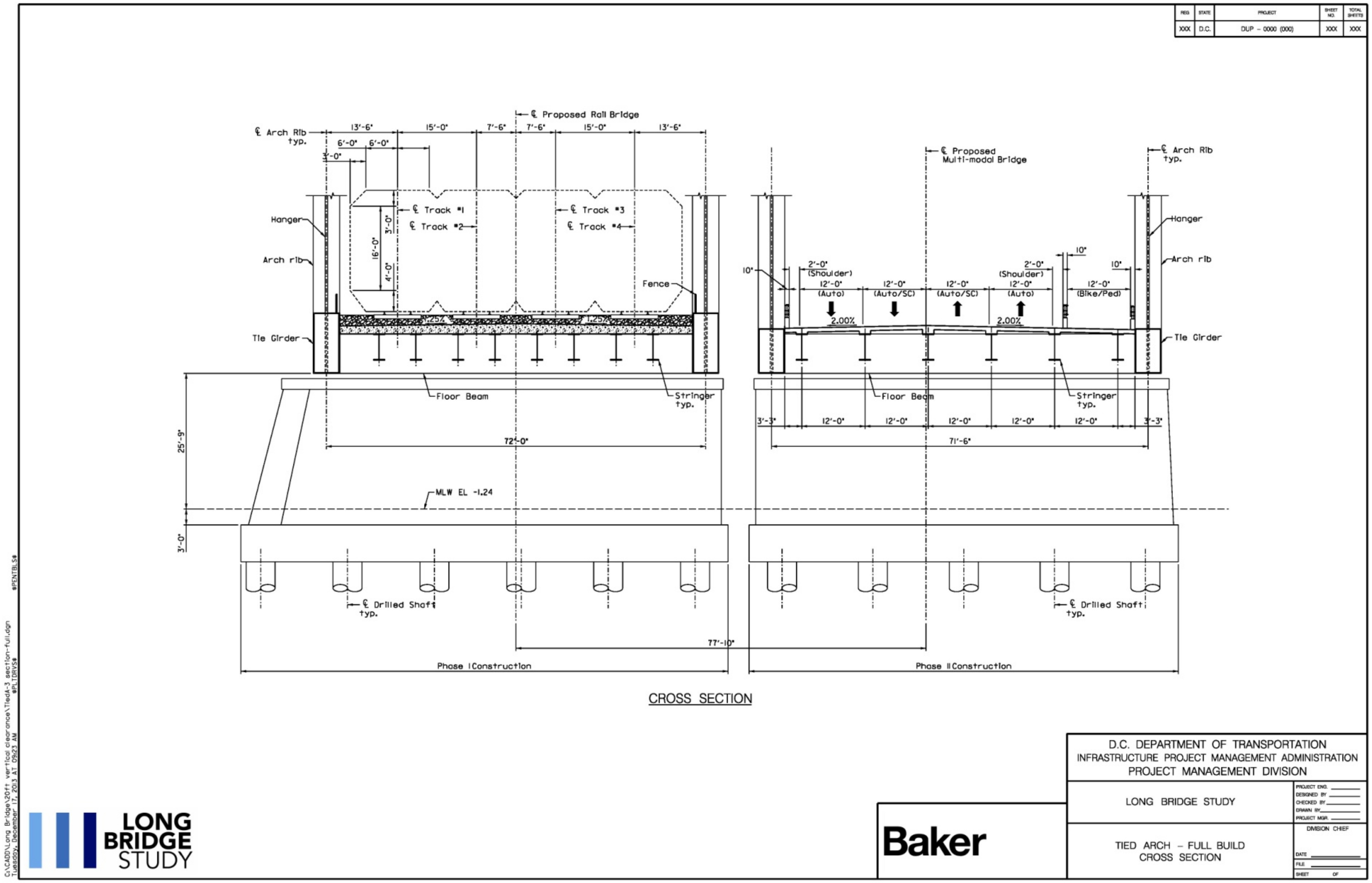
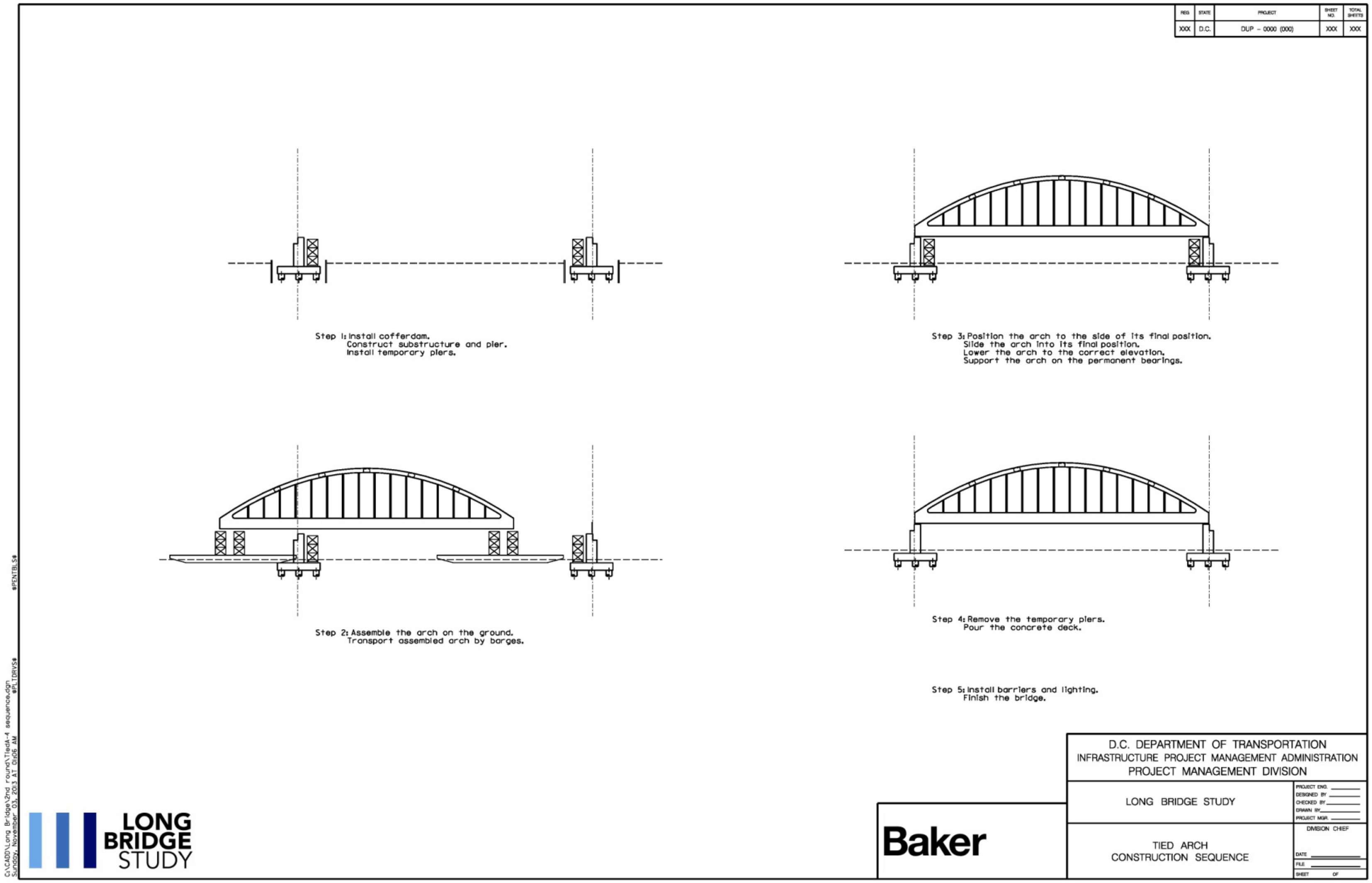


Figure 13 – Steel Tied Arch Cross Section – Full



Step 1: Install cofferdam.
Construct substructure and pier.
Install temporary piers.

Step 2: Assemble the arch on the ground.
Transport assembled arch by barges.

Step 3: Position the arch to the side of its final position.
Slide the arch into its final position.
Lower the arch to the correct elevation.
Support the arch on the permanent bearings.

Step 4: Remove the temporary piers.
Pour the concrete deck.

Step 5: Install barriers and lighting.
Finish the bridge.

Figure 14 – Steel Tied Arch Construction Sequence

4.3 Steel Through Arch

This alternative is very similar to the steel tied arch alternative described above. It consists of a significantly longer main span, with a span length of approximately 440 feet (in comparison to the 280 foot tied arch span). The arch ribs for the through arch alternative, unlike the tied arch, continue beyond the bottom of the bridge deck down to the river surface and frame into concrete thrust blocks.

The approach spans would likely consist of standard multi-girder construction. The girders could consist of either steel precast, prestressed concrete beams. Approach piers could be constructed in a variety of styles, including cap-on-column or hammerhead/tulip configuration. Figure 11 shows a rendering of the conceptual steel through arch alternative for Long Bridge.

Figure 15 – Steel through Arch Rendering of Long Bridge

Analysis of Aesthetics

Like the tied arch, the steel through arch would represent a departure from the style of neighboring bridges, by providing an above-deck support system where other bridges are supported from below the deck. With the portion of the through arch that is above the deck level, users of the bridge would pass through the structural element as opposed to over it.

Like the tied arch, the through arch would provide an opportunity to create a visual statement that could be seen from adjacent bridges and from the banks of the Potomac River. The arch for this alternative would be larger than the steel tied arch and would have a higher rise; therefore it would be more visible and could create a more dramatic visual impact. The steel arch ribs and bracing would provide opportunities for the inclusion of color or lighting to further make the through arch span stand out, if so desired. Aesthetic treatments will also be possible on the approach spans and piers.

The through arch is a somewhat more unique structure type than the tied arch throughout the U.S., and would be a unique bridge type for the Washington, D.C. region. Uniqueness could also be added to the through arch span by using basket-handle (inclined) arch ribs, networking (non-vertical) arch cables, and potentially unique approaches to providing lateral bracing of the arch ribs.

Analysis of Constructability and Construction Impact

Constructability and construction impact for this bridge type would be similar to the tied arch described in the section above. There are a few significant differences, however, that would make the evaluation of the through arch less favorable than the tied arch in this category.

Most importantly, the through arch requires the use of large foundations at the base of the arch ribs to resist the horizontal thrust of the arches. In contrast, the tied arch resists these horizontal loads by use of a tie girder. The large horizontal forces at the foundations need to ultimately be resisted by the subsurface material, and for this reason this bridge type is more practical in locations where a strong bedrock layer is close to the surface. In this location, a firm sand layer is 40 feet or more below the water surface. Therefore, potentially large and expensive foundations, supplemented with driven piles, will be required to carry the thrust loads down to the bearing layer.

Additionally, the span length proposed for the through arch is significantly larger than that of the tied arch. This complicates the erection of the arches and could result in a greater need for temporary supports in the Potomac River. It will also result in larger arch rib members, making fabrication, delivery, and erection of the arch ribs more difficult.

Like the steel tied arch alternative, a fairly large percentage of the bridge would consist of standard approach spans, which would require straightforward, conventional construction. In addition, with the longer main span, the through arch would likely have two fewer approach piers, somewhat reducing the amount of foundation work in the river. However, this advantage is more than offset by the need for large thrust blocks at the ends of the arches.

Analysis of Initial Cost

In comparison to the tied arch alternative, the through arch alternative will be somewhat more expensive, for the following reasons:

- A smaller percentage of the bridge will be conventional approach span construction.
- With the longer main span, the size of the arch members will be larger and costlier to fabricate, deliver and erect. Likewise, the floor system for the arch spans will be much more extensive and will add to the cost.
- The longer main span may also increase the likelihood of needing special erection equipment and/or temporary supports in the Potomac River. Erection equipment would have to come from southeast of the current structure. Depending upon whether the new construction is northwest or southeast of the existing structure, a determination will need to be made if the current moveable spans will need to be operational for movement of erection equipment to the northwest side of the current structure. This would require extensive coordination with the operational requirements of the bridge for rail traffic to maintain uninterrupted scheduled movement of freight and passenger trains.
- The need for large foundations at the ends of the arch ribs to resist horizontal thrust loads, given the depth of bedrock at this location, has the potential to add significant cost to the project.

Analysis of Future Maintenance and Life Cycle Costs

Evaluation of future maintenance requirements for this bridge type is very similar to that of the tied arch alternative. This alternative would potentially have slightly fewer bearings to inspect and replace, since it uses fewer approach piers. Inspection of this alternative becomes somewhat more difficult with the longer and higher steel arch and more extensive flooring system.

The approach spans make up a significant percentage of the overall length of this structure, and these spans will have maintenance requirements that are standard for most conventional bridge structures. Specifically, the bridge bearings and expansion joints will need to be periodically replaced, as will any required drainage elements on the bridge. If the approach spans consist of steel girders, the girders may require repainting at some point in the future, unless weathering steel is utilized. Concrete elements, such as the piers, will need to be protected from chloride intrusion and will need to be inspected for cracking, spalling, and delamination.

Inspection of the majority of the bridge (approach spans) will be standard and should not require any specialized equipment or techniques. Inspection of the arch ribs and hangers will require man-lifts that have the capability to access the top of the arch ribs.

Analysis of Adaptability

The analysis of the steel through arch for this category is very similar to that of the steel tied arch. This bridge type would present a challenge to provide ongoing rail operations while the new structure is being constructed.

One distinction is that this alternative, due to its longer main span, has the ability to provide a wider navigational opening than the tied arch. A drawback, however, is that because the arch ribs are brought down close to the water line, they become exposed to the risk of vessel impact unless properly protected.

Like the tied arch, this alternative should be able to provide vertical clearance below the structure without requiring a change to the vertical profile of the bridge. Diagrams 5 through 8 show the elevation, cross sections and construction sequence for the steel through arch alternative.

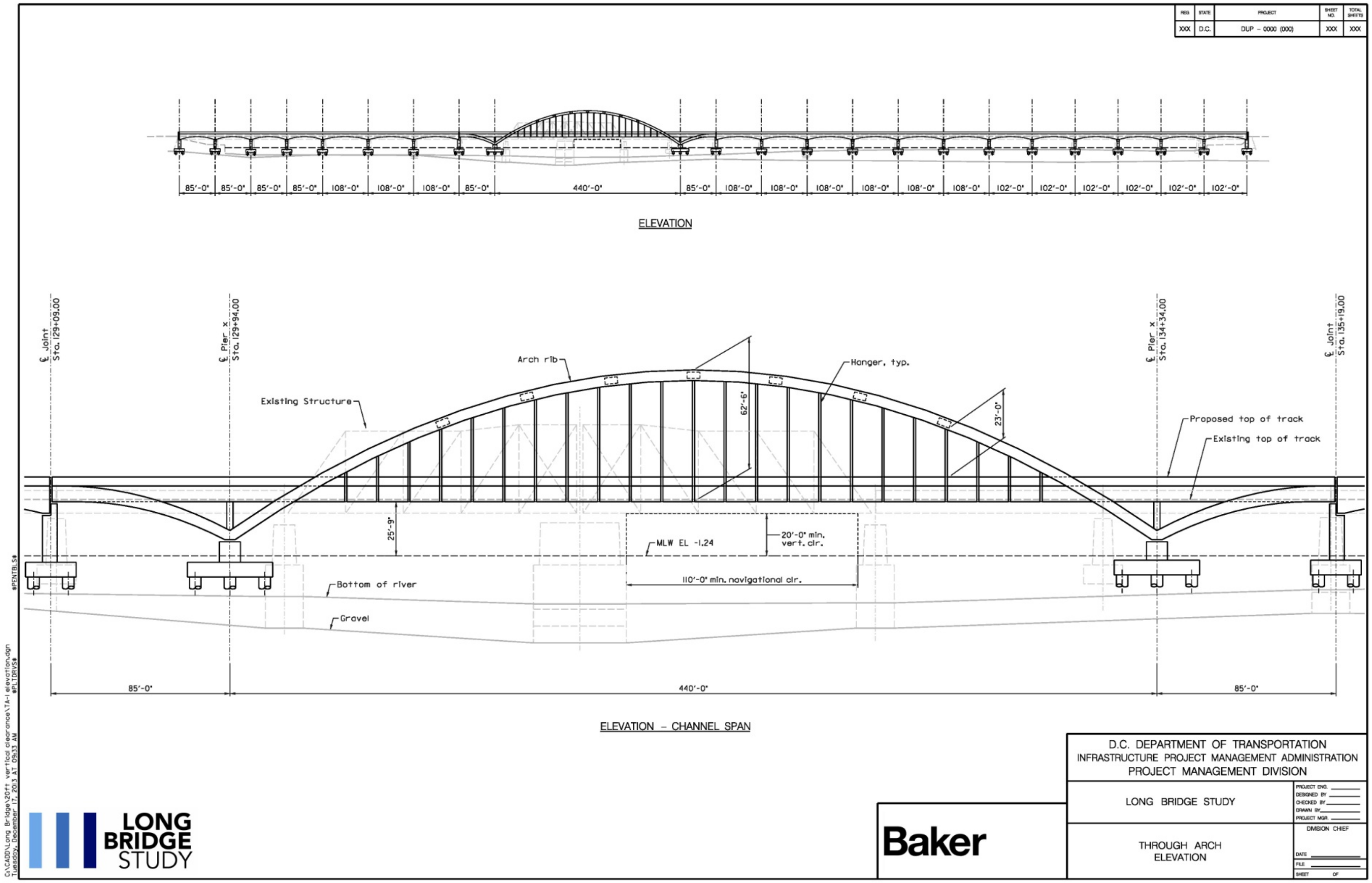


Figure 16 – Steel Through Arch Elevation

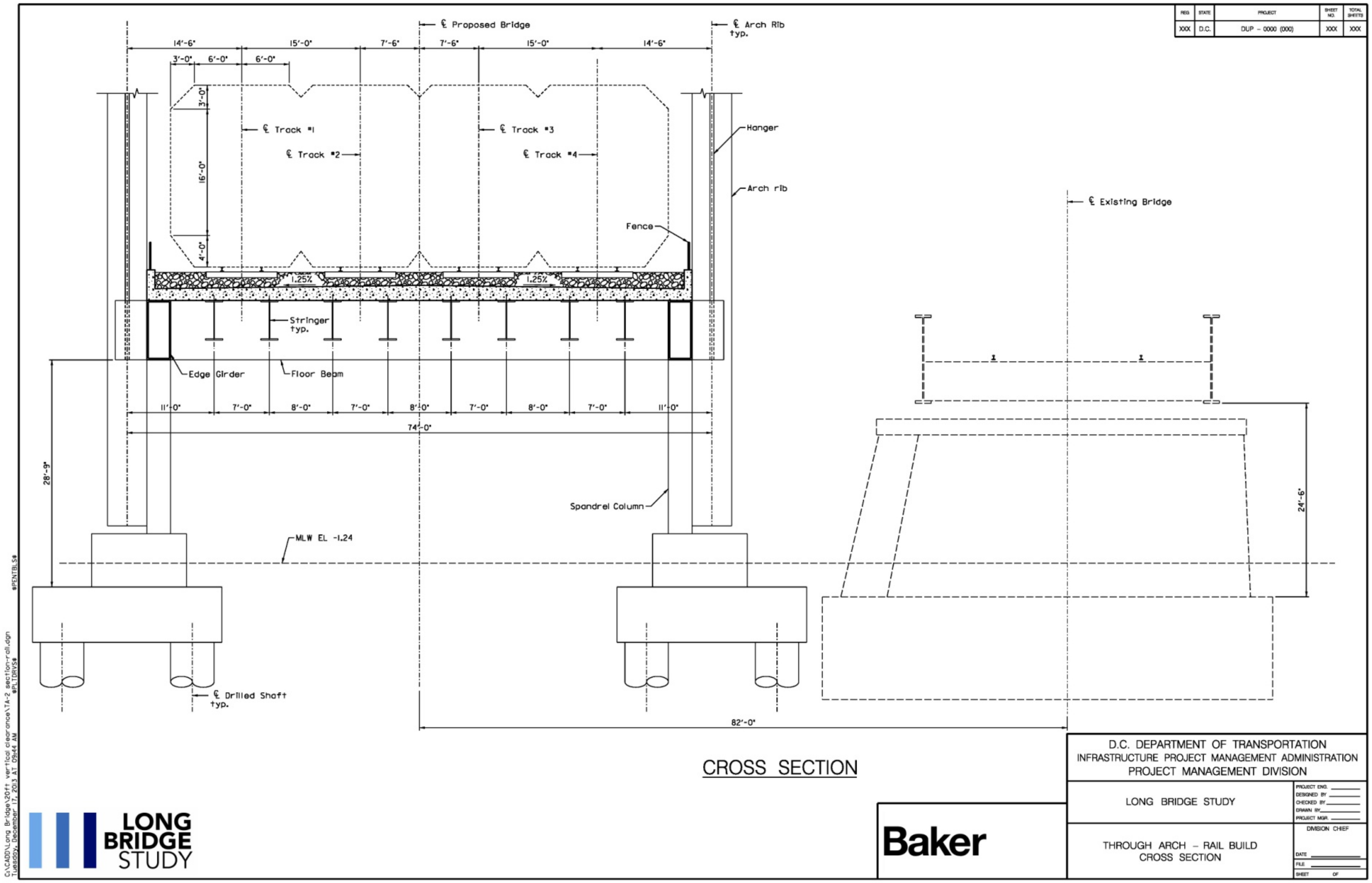


Figure 17 – Steel Through Arch Cross Section – Rail

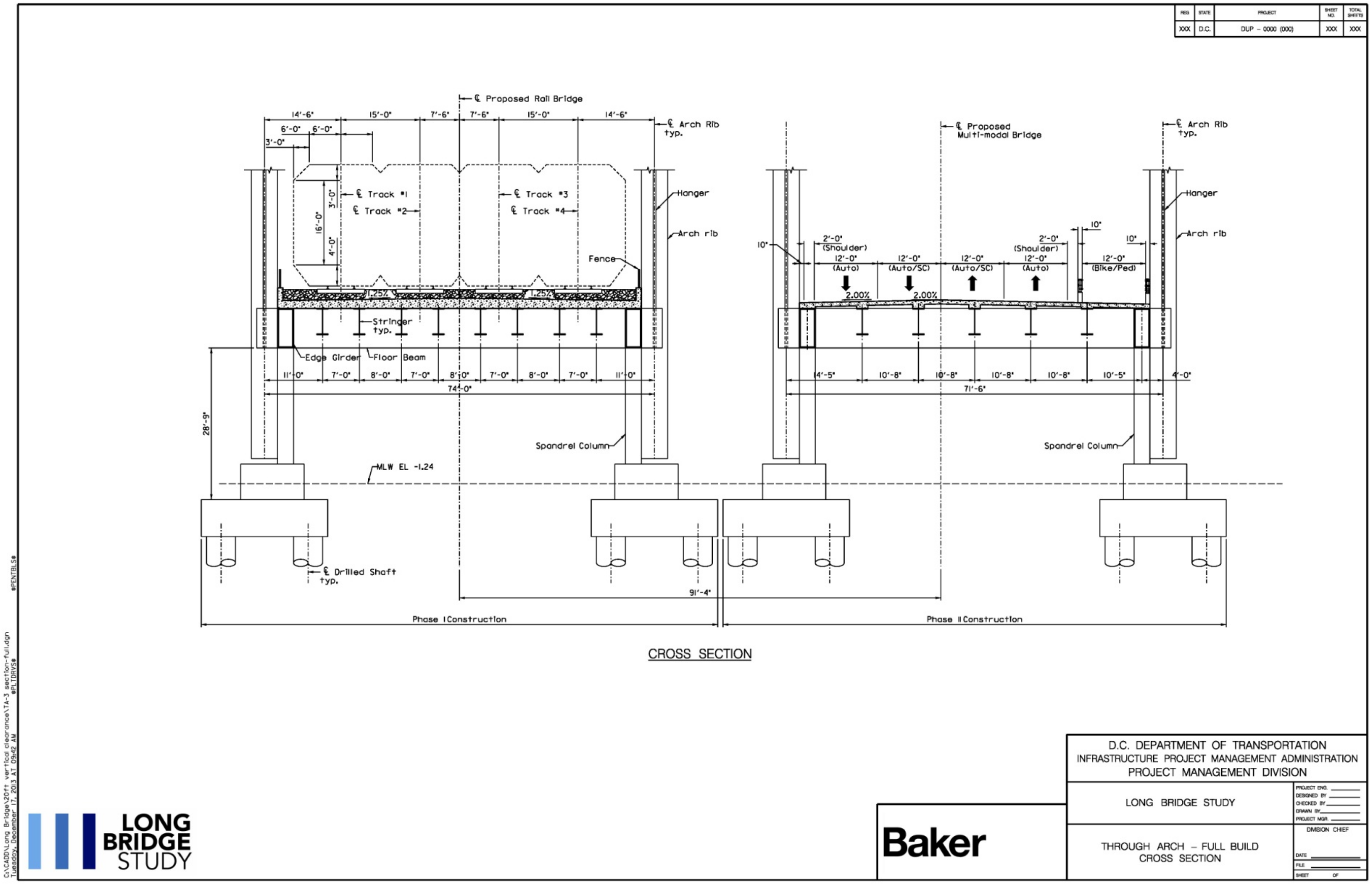


Figure 18 – Steel Through Arch Cross Section – Full

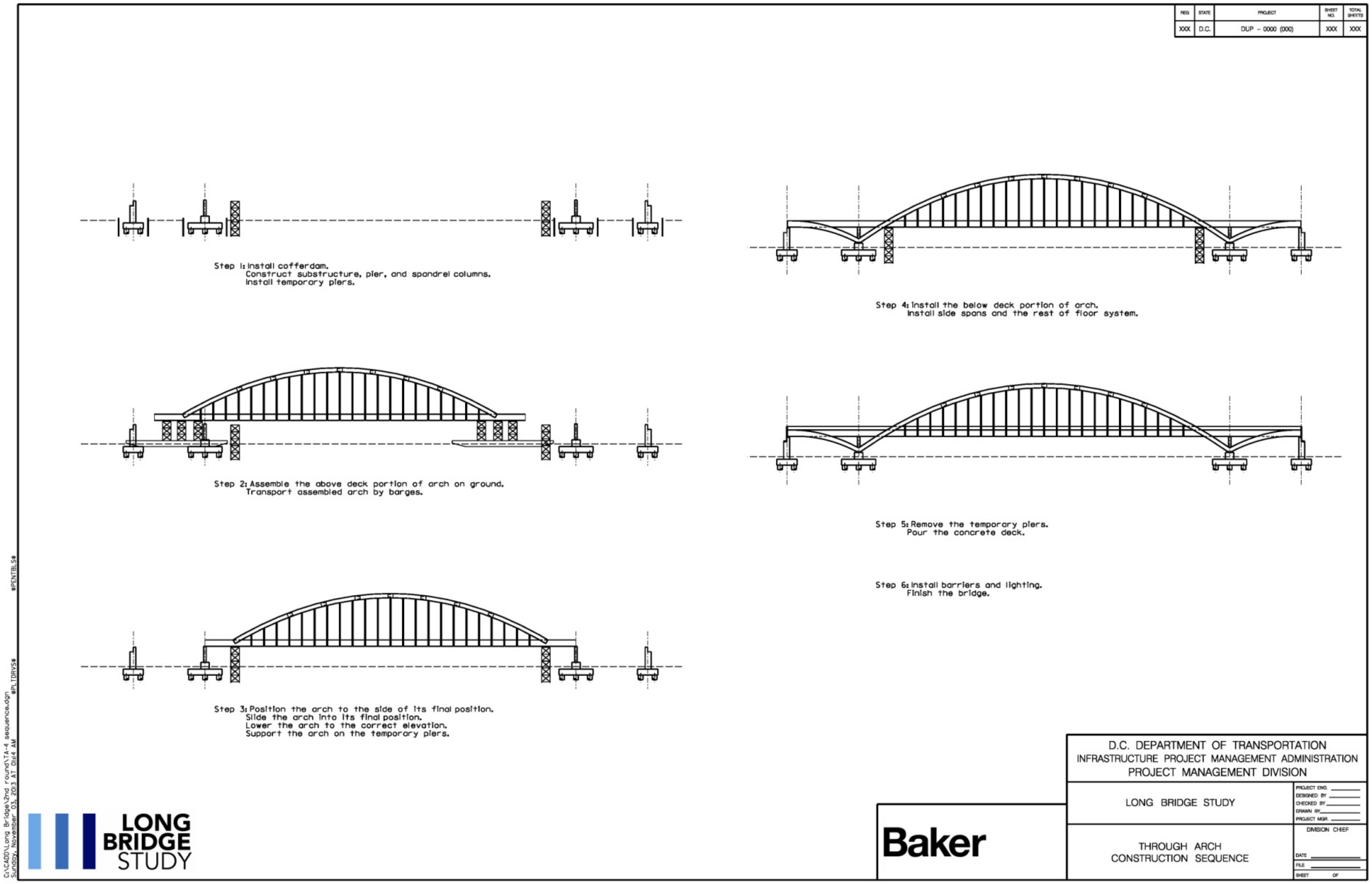


Figure 19 – Steel Through Arch Construction Sequence

4.4 Extradosed/Cable-Stayed

This alternative uses a series of cable-supported spans to cross the river with equal spans lengths of approximately 300 feet. The superstructure would be supported by cables above the deck, anchored at one end to a central pylon and at the other end to the edge of the deck. The towers or pylons would extend 48 feet above the deck.

The deck elements could consist of either steel or concrete edge girders, or could also consist of concrete box girders. With a span length of 300 feet, it is anticipated that variable depth (haunched) girder elements would be practical, and would provide optimal aesthetics.

The towers would consist of concrete elements located on the outside of the deck at the ends of each span. A variety of options are available for the arrangement of the superstructure cables. Figure 12 shows a rendering of the conceptual extradosed/cable-stayed alternative for Long Bridge.

Figure 20 – Extradosed / Cable-Stayed Rendering of Long Bridge

Analysis of Aesthetics

The extradosed bridge type is unique, as very few structures of this type have been built in the United States. This structure type would present an opportunity for an uncommon bridge type near the heart of the nation’s capital.

A number of opportunities would be available for aesthetic variety and enhancement with this bridge type. The cables could be arranged in a number of different manners, including fan arrangement, parallel arrangement, or harp arrangement. The concrete towers also present opportunities for aesthetic expression with the column shapes, sizes, colors and textures. The cables also present a unique opportunity for architectural lighting.

The proposed span lengths are 1½ to 3 times greater than the other alternatives considered; creating a more favorable view shed from the water and river banks. Navigation for smaller craft around the bridge will be enhanced.

While this structure type creates opportunities for aesthetic treatments, it should also be noted that this bridge type may not be viewed as compatible with surrounding bridges and the architecture of neighboring buildings. The extradosed/cable-stayed structure presents a very modern visual appearance and a bridge type reflecting recent technology, whereas other bridges in the Washington D.C. region tend to reflect the more traditional types of structures that include concrete arches.

Analysis of Constructability and Construction Impact

Of all of the bridge types discussed in this report, the extradosed structure represents the bridge type that would be least familiar to local contractors. This bridge type would likely require the expertise of a national contractor who had prior experience with the construction of cable-supported or cable-stayed bridges. Erection of the superstructure will require techniques and equipment that is out of the ordinary for conventional bridge construction.

One advantage of extradosed or cable-stayed construction is that it is possible to perform the construction in a top-down fashion using balanced cantilever erection. In this scenario, few if any temporary supports would be required in the Potomac River during construction. However, balanced cantilever construction results in significant unbalanced loads on the piers and foundations during construction, potentially resulting in larger and more expensive foundations. Also, by using 300 feet spans across the river, a significant number of piers that support this balanced cantilever erection are located in the river. Additionally, each pier will include a 48 foot tower which must be cast-in-place on the river, which will add cost and complexity.

The unique nature of the construction would result in this concept having the longest anticipated construction schedule. In addition, because of the nature of the step-by-step erection of this bridge type, special design and erection analysis expertise is required to ensure structural stability at each stage of erection, and that the final desired geometry of the structure is properly achieved.

Analysis of Initial Cost

Compared to the other bridge alternatives, the extradosed/cable-stayed bridge type represents the option with the highest initial cost. The factors that influence the initial cost of this bridge type include the following:

- The unique nature of the structure type and the relative lack of contractors able to build this structure type mean a less competitive bidding environment.
- A longer percentage of the overall structure consists of unique structure as opposed to less expensive conventional bridge construction.
- The overall schedule for construction is anticipated to be longer than any of the other alternatives.
- If balanced cantilever construction is used, the foundations are likely to be larger and more expensive than the other structure types.

Analysis of Future Maintenance and Life Cycle Costs

The maintenance activities associated with this structure type are non-typical and include the need to inspect and maintain the stay cables that support the deck. Durability issues have been reported on cable-supported structures where the cables have not been properly grouted and subsequently exposed to salt-laden moisture or water. Therefore, great care should be taken in the grouting of the cables and the cables should be regularly inspected.

If steel edge girders are used for the superstructure, maintenance activities would be similar to a steel girder bridge. Specifically, it would require periodic painting of the steel and maintenance or possible periodic replacement of bearings and expansion joints. If a post-tensioned concrete superstructure is utilized, the superstructure could be designed to minimize cracking and enhance durability.

Analysis of Adaptability

The extradosed/cable-stay option can be constructed to provide appropriate vertical clearance beneath the bridge without significant modification to the vertical profile on the structure. However, in order to do this, the superstructure depth will need to be kept to a minimum; this may require more cables supporting the superstructure, which could increase cost and complexity. The proposed 300 foot span provides adequate horizontal clearance for Potomac River navigational traffic.

Like the arch alternatives, this structure type will be difficult to construct while maintaining existing rail operations during construction. This structure type cannot be built with phased construction, and therefore if rail service is kept on the existing structure during construction, the new structure will have to be built on separate alignment next to the existing bridge.

This bridge type can accommodate a variety of bridge widths, however like the arch alternatives, a practical upper limit of approximately 120 to 140 feet in width should be considered. The narrowest alternative is 98 feet; the widest alternative is 152 feet for the extradosed option. Multiple structures would need to be considered for alternatives greater than 140 feet. Diagrams 9 through 14 show the elevation, cross sections and construction sequence for the extradosed/cable-stayed alternative.

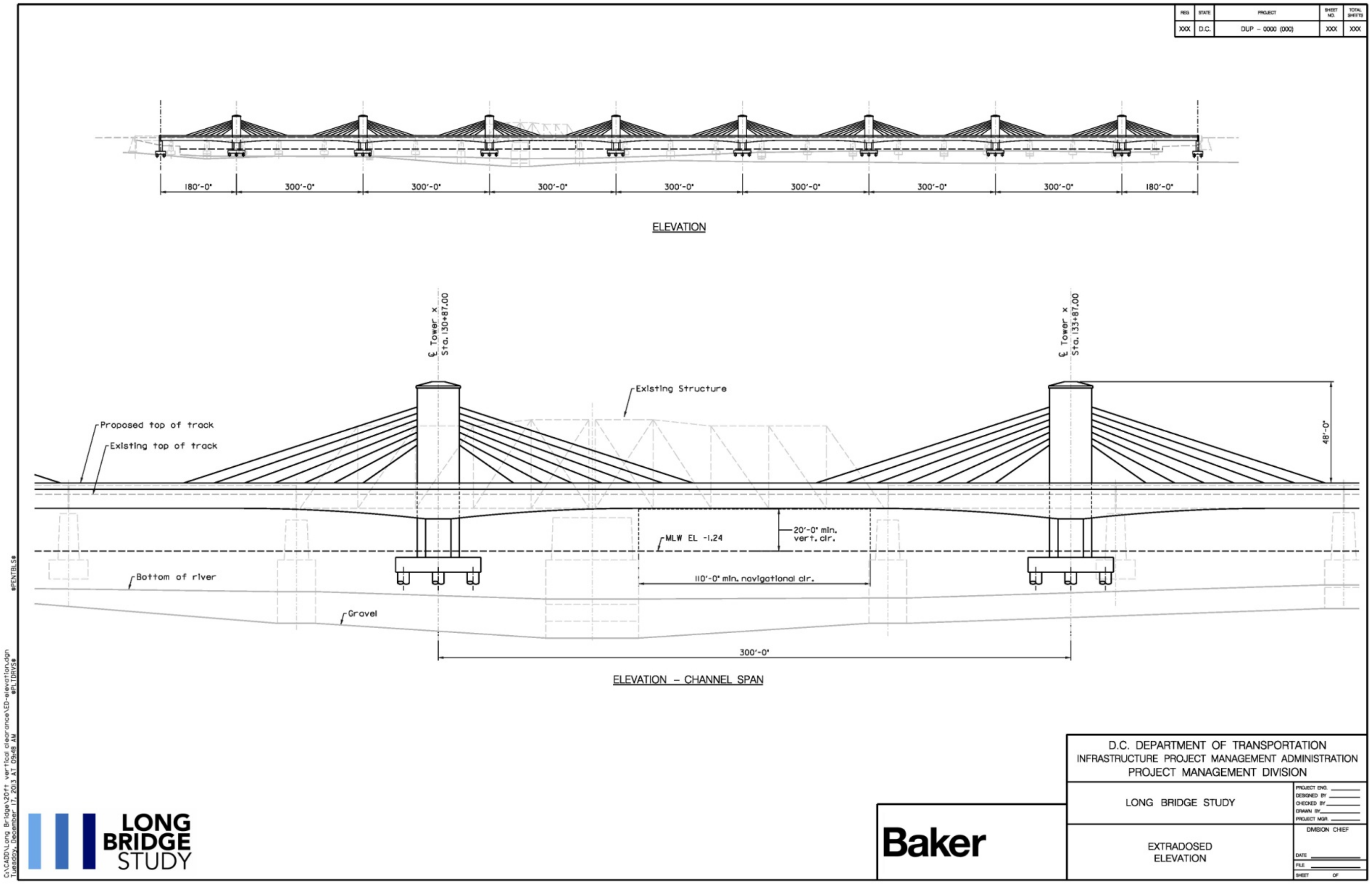


Figure 21 – Extradosed / Cable-Stayed Elevation

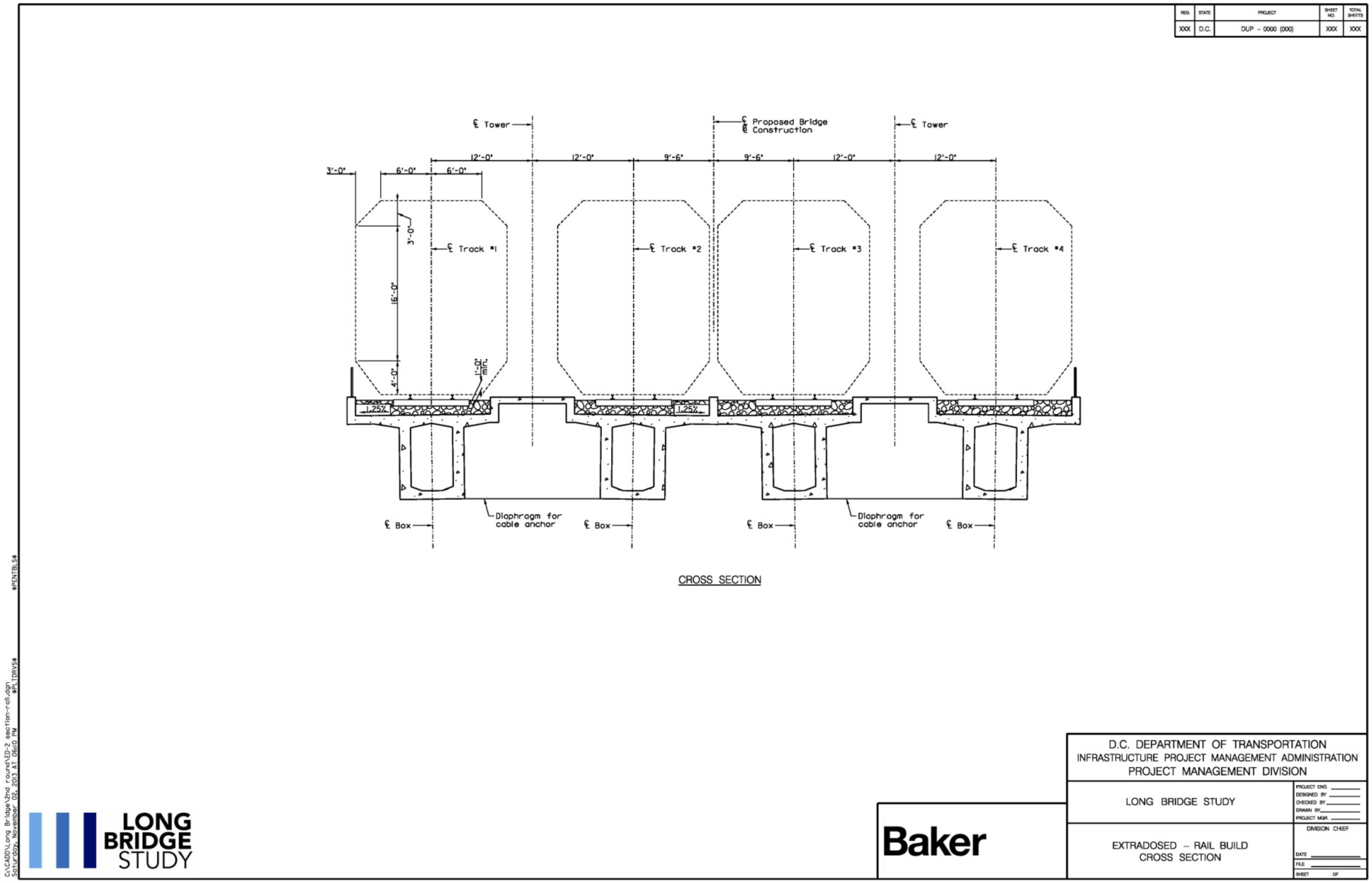


Figure 22 – Extradosed / Cable-Stayed Cross Section – Rail

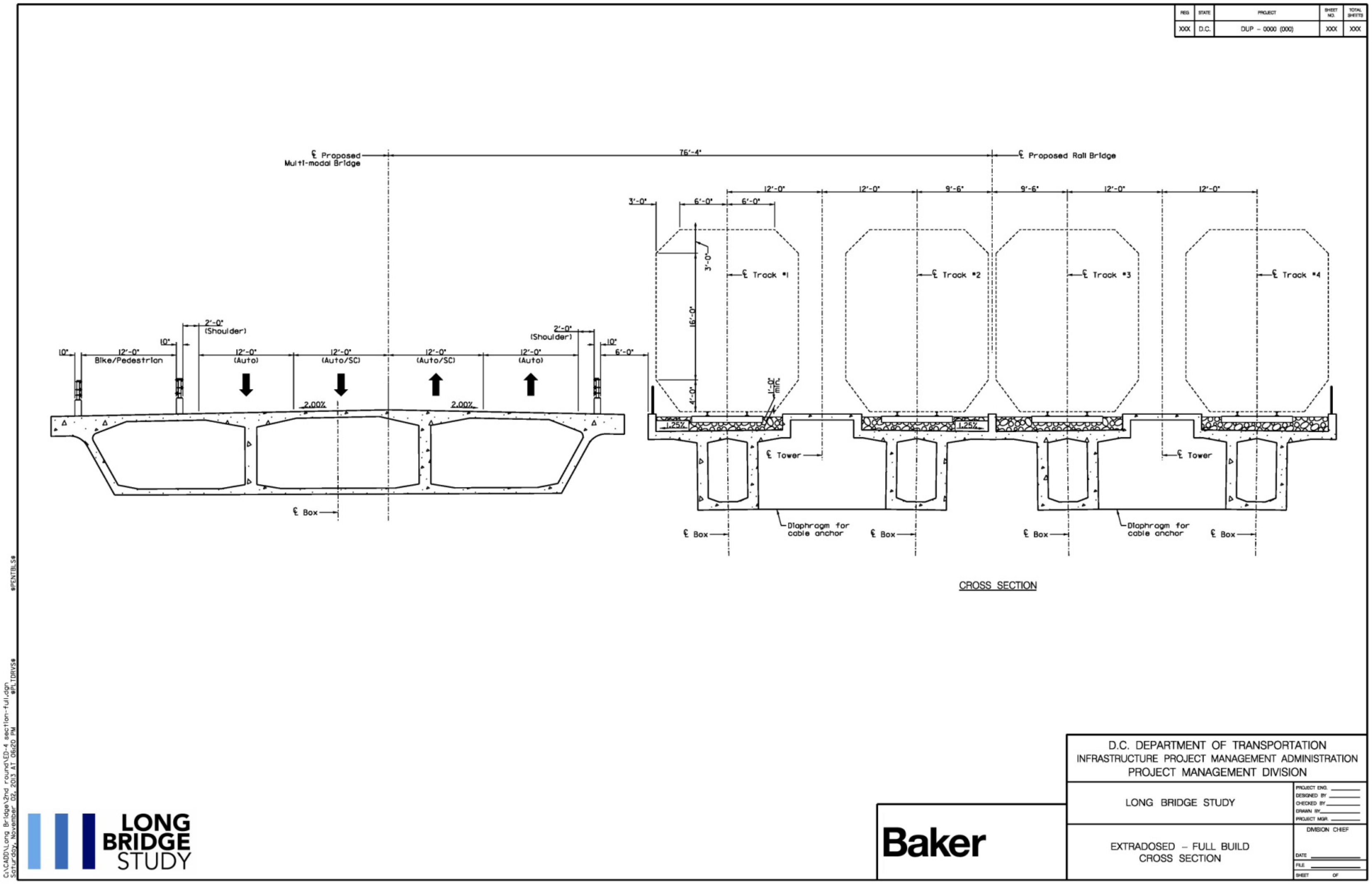


Figure 23 – Extradosed / Cable-Stayed Cross Section – Full

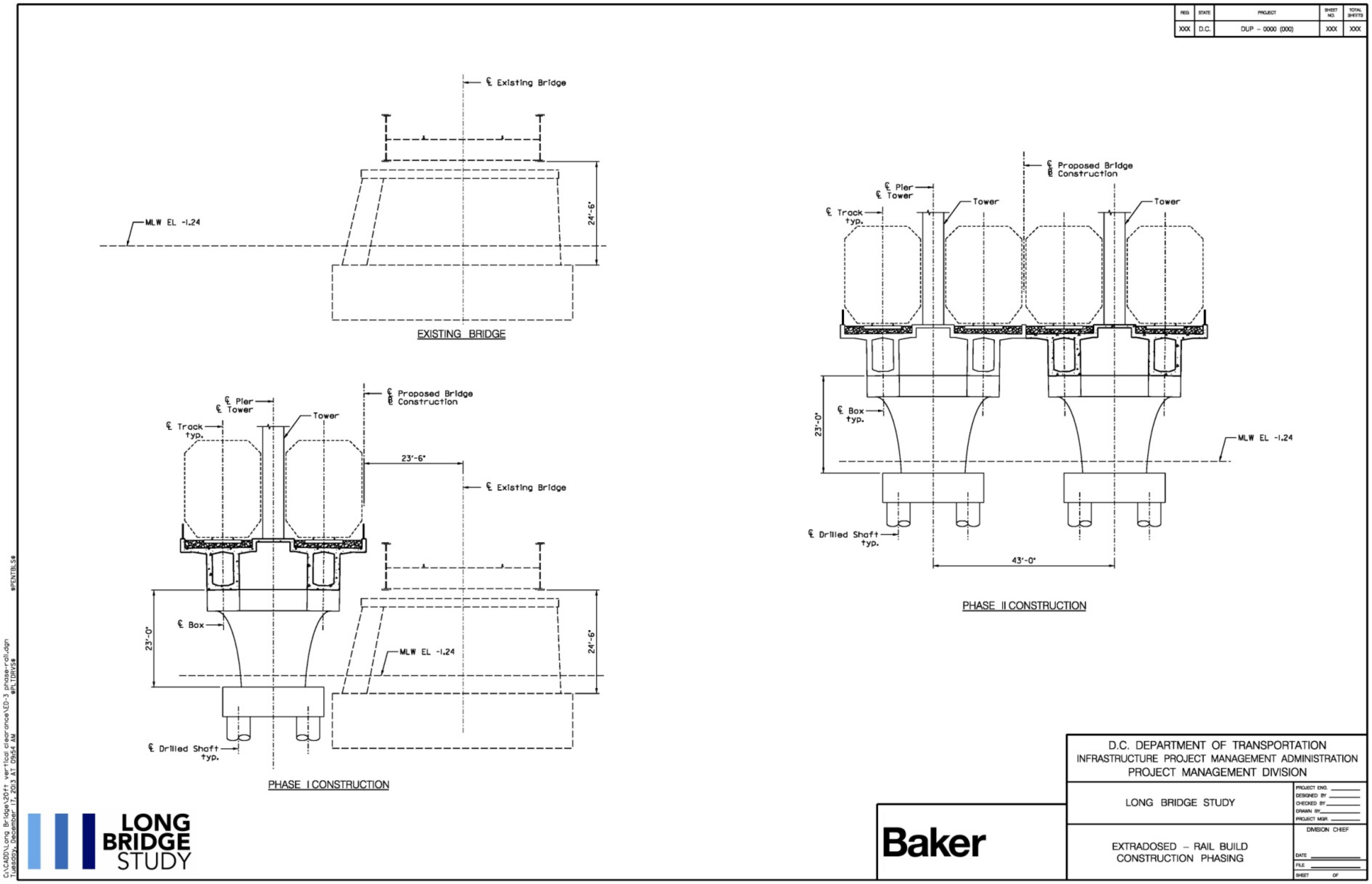


Figure 24 – Extradosed / Cable-Stayed Construction Phasing - Rail

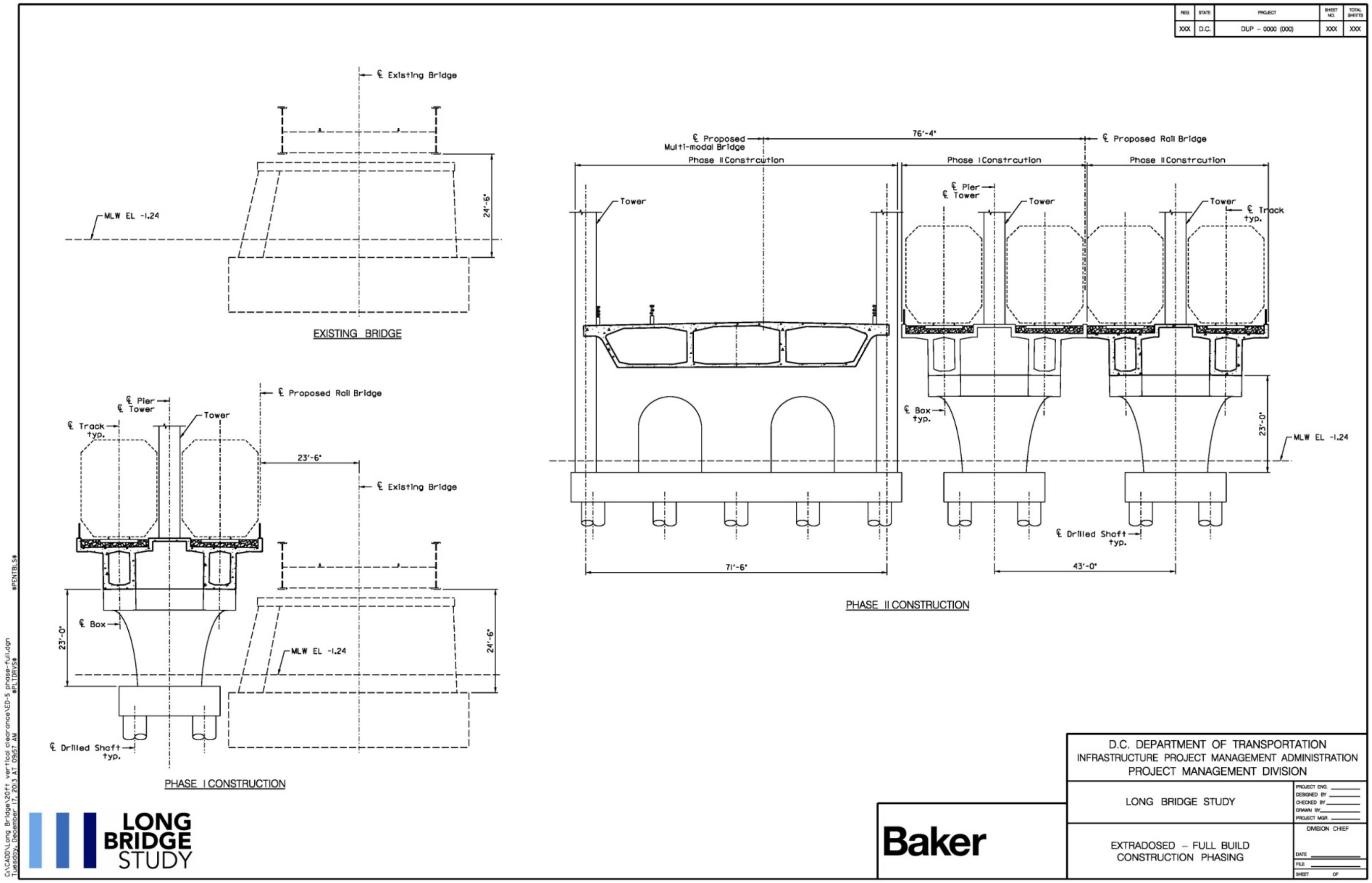
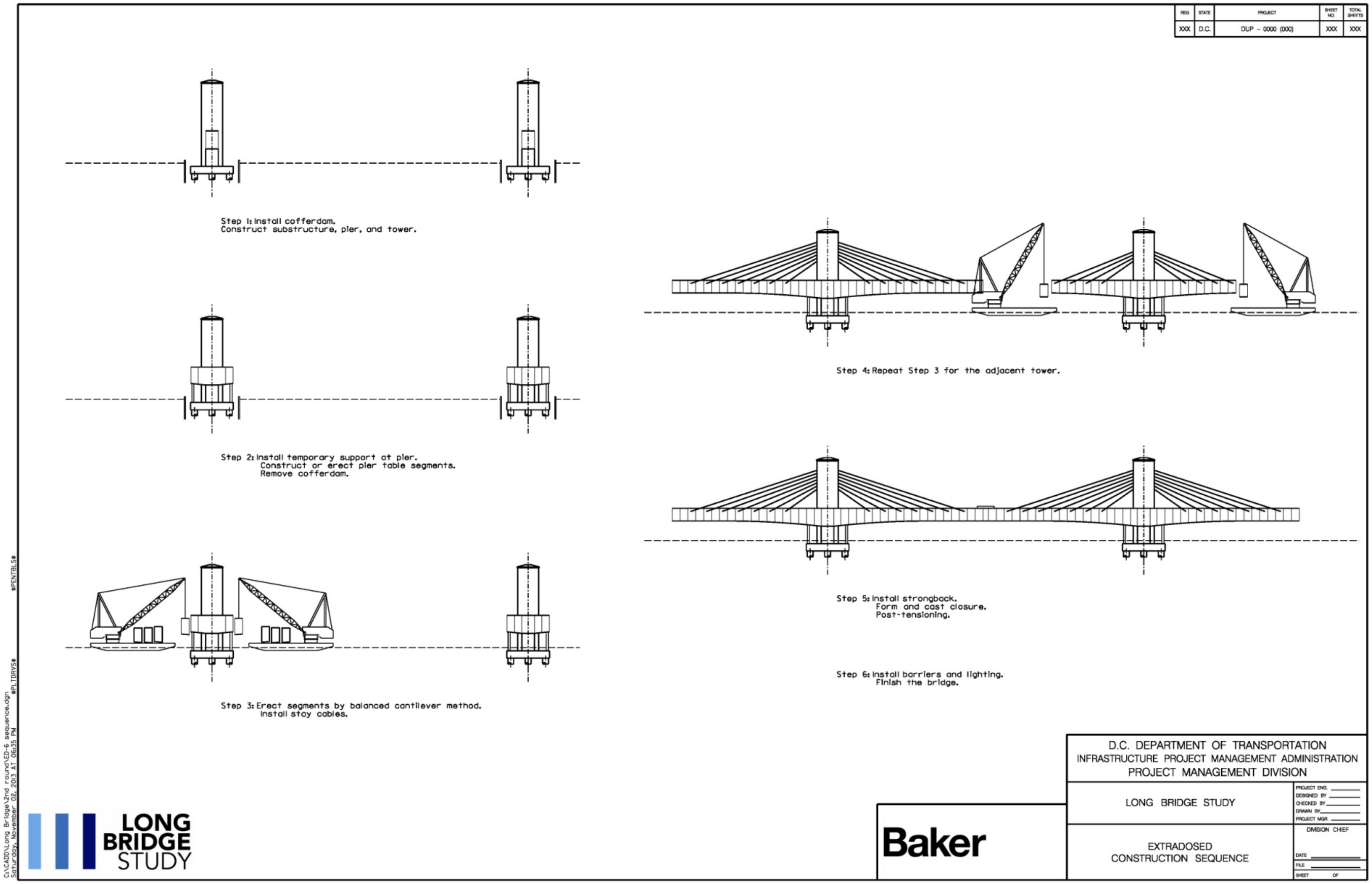


Figure 25 – Extradosed / Cable-Stayed Construction Phasing – Full Build



Step 1: Install cofferdam.
Construct substructure, pier, and tower.

Step 2: Install temporary support at pier.
Construct or erect pier table segments.
Remove cofferdam.

Step 3: Erect segments by balanced cantilever method.
Install stay cables.

Step 4: Repeat Step 3 for the adjacent tower.

Step 5: Install strongback.
Form and cast closure.
Post-tensioning.

Step 6: Install barriers and lighting.
Finish the bridge.

Figure 26 – Extradosed / Cable-Stayed Construction Sequence

4.5 Concrete Deck Arch

Description

This bridge concept would employ a series of concrete deck arch spans across the Potomac River, each with a span of approximately 170 feet. The arches for this alternative would support the superstructure from below the deck, as opposed to the other three arch type alternatives. Figure 13 shows a rendering of the conceptual concrete deck arch alternative for Long Bridge.

Several variations are available for this option that could include:

- An open spandrel deck arch, where the area between the arches and the deck is open.
- A closed spandrel deck arch, where the area between the arches and the deck is closed.
- An option that consists of steel or concrete I-girders for the majority of the cross-section, with precast concrete arch façade elements on each fascia. This structure type would be a multi-girder structure, with the precast façade elements emulating a closed spandrel deck arch.

Figure 27 – Concrete Deck Arch Rendering of Long Bridge

Analysis of Aesthetics

Many of the prominent bridges in the Washington, DC region consist of concrete arch members, including the recently constructed Woodrow Wilson Memorial Bridge. Thus, the concrete deck arch bridge type would be very compatible with the existing bridges in the area. Additionally, the use of concrete for the structure type fits in well with the local architecture of nearby buildings and facilities.

Other considerations related to the evaluation of aesthetics for this structure type include:

- With the main supporting elements of the bridge below the deck, views of the monumental core and the surrounding area will be unobstructed for users of the bridge.
- The absence of above-deck elements will provide clearer views from boats on the Potomac River and for users of the parkland on the banks of the river.
- The use of supporting elements, below the bridge deck, offers an opportunity to create a more prominent aesthetic impact for recreational users of the river beneath the bridge.
- If closed spandrel or façade panels are used, the opportunity exists for a wide variety of color or texture treatments on the arch spandrels areas.

Analysis of Constructability and Construction Impact

The following considerations factor into an evaluation of the constructability of this structure type:

- If standard girder superstructure with façade elements is chosen, this would represent the easiest and most straightforward construction with the shortest anticipated construction schedule of all of the bridge types under consideration.
- If post-tensioned arch construction is used, the arch sections will need to be comprised of precast elements, since casting-in-place on the river is not practical.
- Delivery and erection of large curved precast elements in this urban environment would need to be evaluated. Depending upon the locations available where precast elements can be constructed, it will be more practical to use segments to comprise the arch and post-tension the segments together.
- If precast arch ribs are used, there will be a potential for a significant amount of temporary shoring to erect the arch ribs. The erection of temporary shoring towers in the river could be difficult and expensive.

Analysis of Initial Cost

The analysis of initial cost for this structure type depends heavily on the type of construction used to build the bridge. A variety of options exist for arriving at the final desired architecture of a concrete deck arch, and some of these options are more economical than others. The most significant consideration is whether the bridge will be comprised of true arch members across the entire cross-section, or whether conventional girders are used in the cross section with precast arch façade panels on the outside of the cross-section.

If a decision is made to use precast post-tensioned segmental arch ribs, this would represent a somewhat unique construction type across the entire river and could be somewhat expensive. Economy for these types of structures is often dependent on having significant length of bridge and an abundance of repetition for fabrication and erection. Additionally, erecting and temporarily supporting large precast elements will require equipment and temporary supports in the river, which could introduce significant cost. The erection of precast elements will also require post-tensioning activities over the river, and the stressing of large post-tensioning tendons near the river could pose challenges and introduce additional cost.

This structure type does, however, offer the opportunity to employ a very cost-effective alternative that would likely represent the least expensive bridge type of those currently under consideration. This alternative would consist of standard steel or precast concrete girders on the interior of the cross section, with precast concrete façade elements on the exterior of the bridge. The use of conventional multi-girder construction for the majority of the bridge would save significant cost and represent the fastest and most economical type of construction. This method of construction has been successfully employed to construct aesthetically pleasing structures for a small aesthetic cost premium over the most economical girder-type construction as shown in the Figure 14 examples.

Figure 28 – Example of Precast Arch Facade Elements with Standard Girder Construction

Analysis of Future Maintenance and Life Cycle Costs

The following factors influence the rating of future maintenance and life cycle costs for this structure type:

- If post-tensioning is used in the precast arch ribs, the tendons and tendon ducts will need to be protected from water intrusion. Proper grouting of the tendon ducts will be critical to the long-term durability of the structure.
- If conventional girder construction is used for the majority of the cross-section, periodic inspection will be straightforward and inexpensive. Because the structural elements are below the deck, inspections for this bridge type can typically take place with little impact to traffic and on-going operations on the bridge.
- If girder construction is used and steel girders are employed, the steel girders will need to be repainted periodically. If concrete girders are used, there will be no need for future painting of this alternative, in contrast to some of the other bridge types under consideration.

Analysis of Adaptability

The most significant potential shortcoming of this bridge type is that it provides the least horizontal clearance for navigation below the bridge.

Because the supporting structural elements for this bridge type are all below the deck, this structure type will only be able to provide sufficient vertical clearance if the profile is raised, making the piers higher and increasing cost. This also could have aesthetic implications if the profile of this bridge is significantly higher than neighboring bridges. Raising the profile could also have impacts at the ends of the bridge and increase the amount of overall structure length, subsequently influencing cost.

In contrast to these factors, this bridge type does present a major advantage over the other bridge types by potentially allowing for phased construction. If an option were pursued that consisted of standard girder construction with precast façade elements to create the arch aesthetic, the bridge could be built in stages which would create an opportunity to maintain existing rail traffic throughout construction. Diagrams 15 through 21 show the elevation, cross sections and construction sequence for the concrete deck arch alternative. Diagram 22 shows elevation profile of the existing bridge and the four concepts.

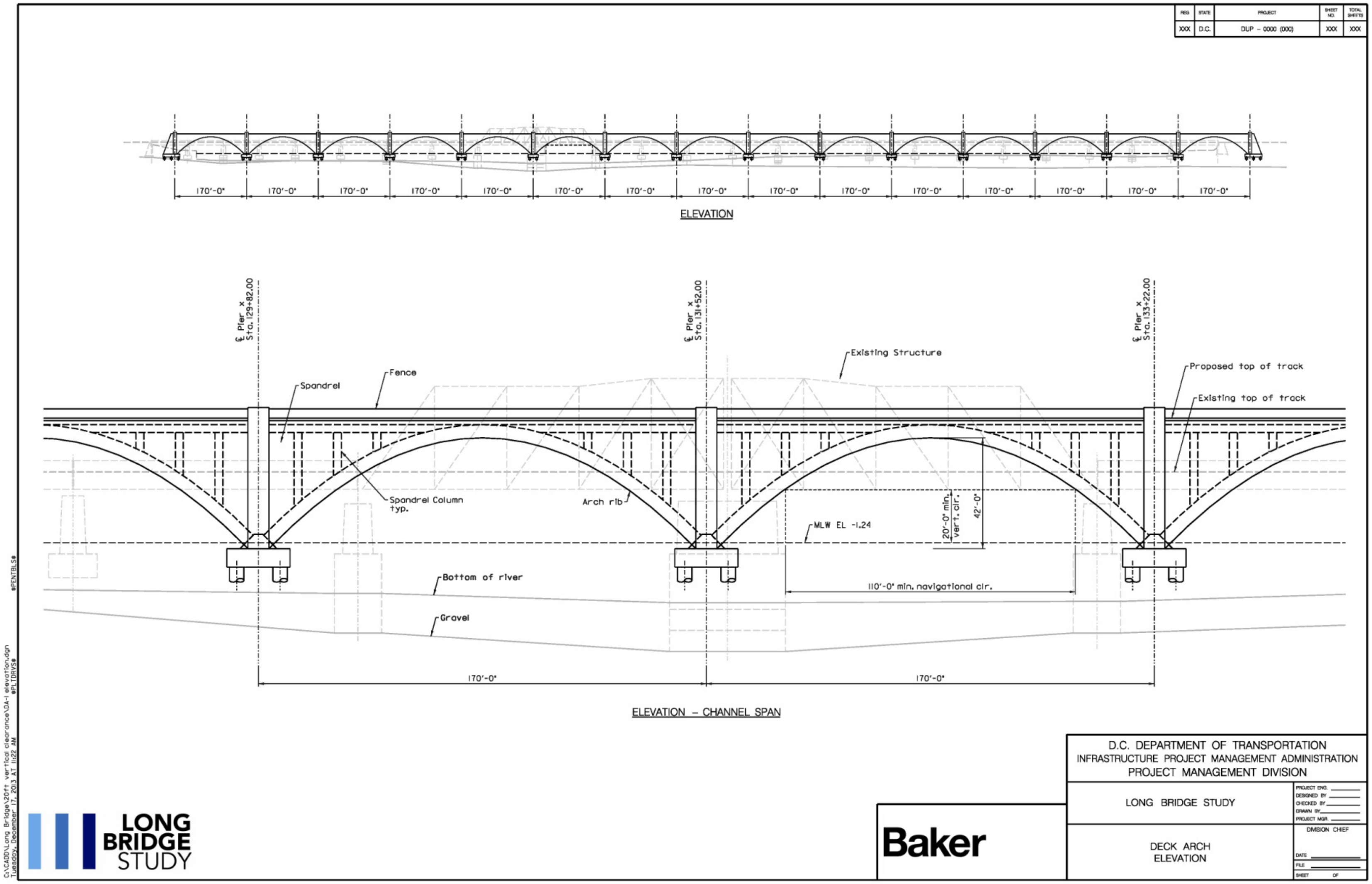


Figure 29 – Concrete Deck Arch Elevation

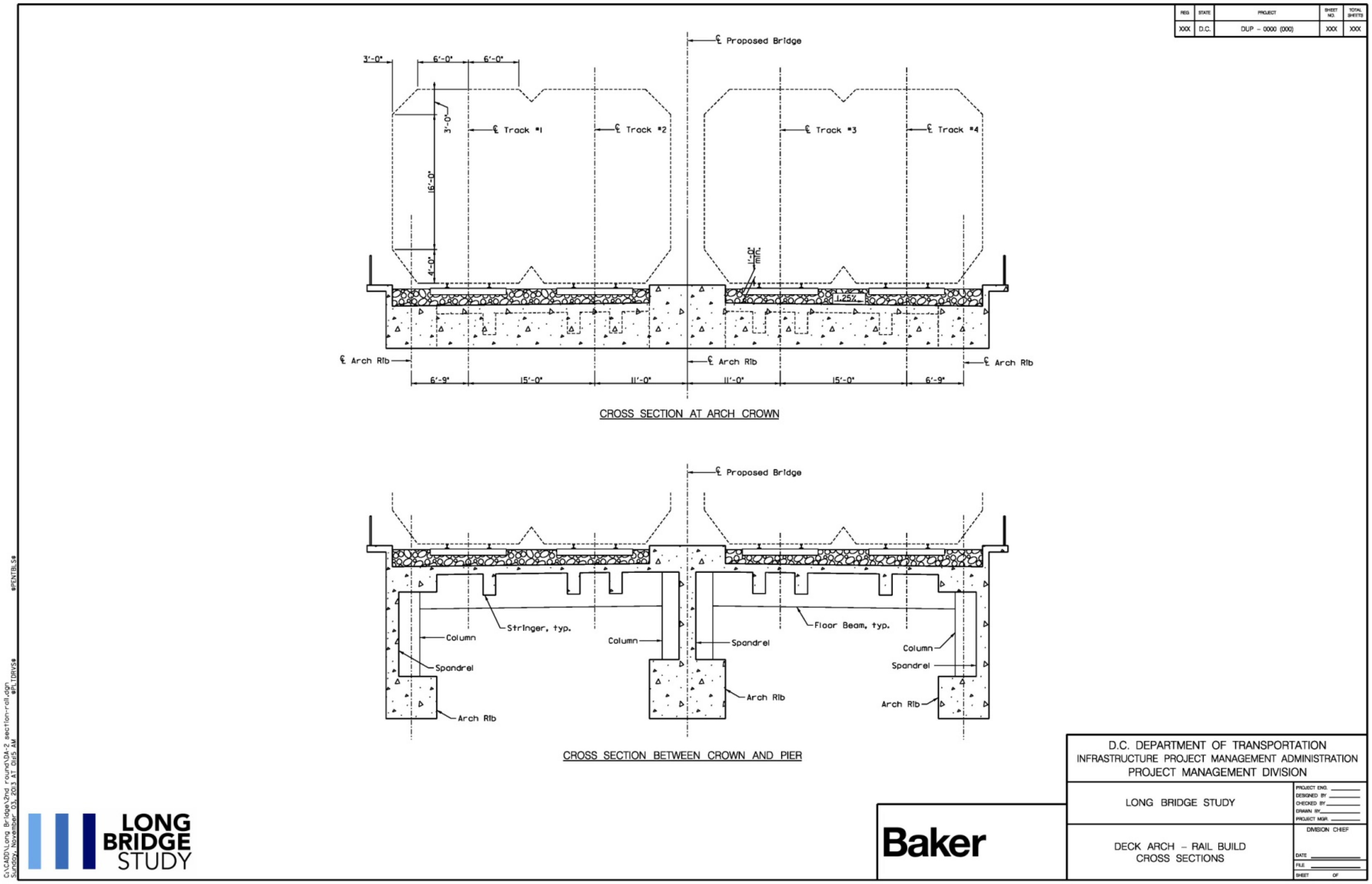


Figure 30 – Concrete Deck Arch Cross Section - Rail

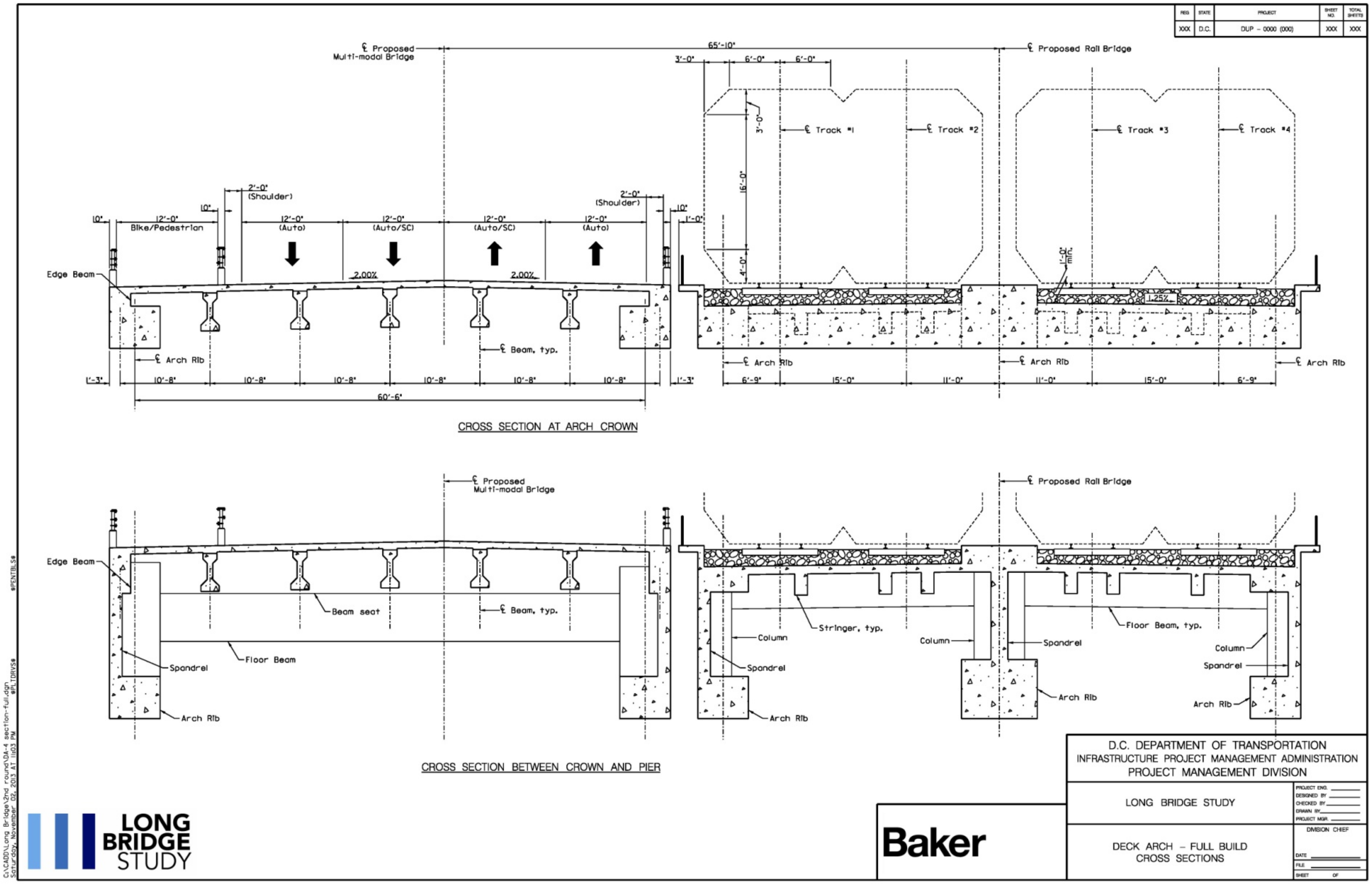


Figure 31 – Concrete Deck Arch Cross Section - Full Build

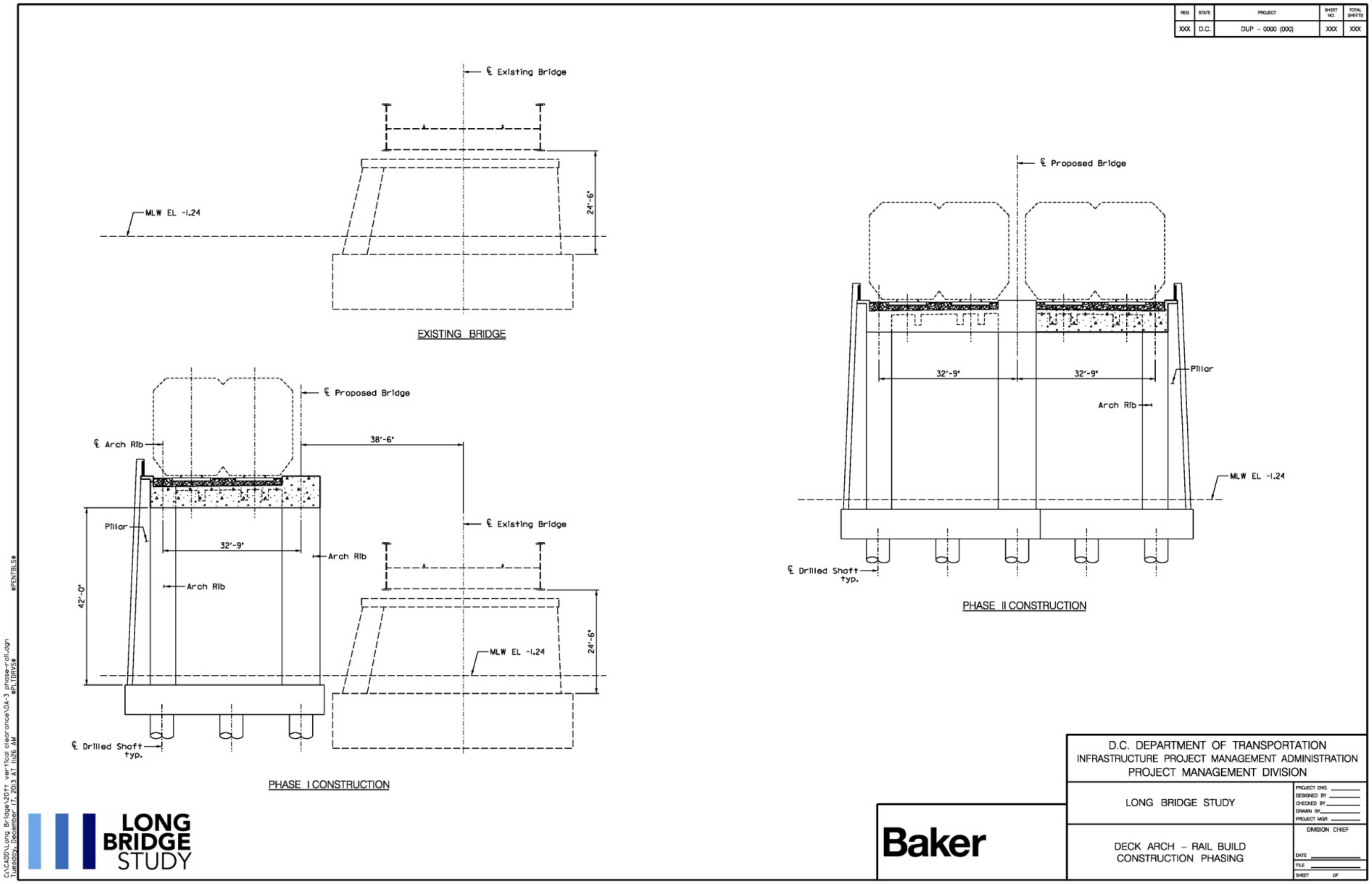


Figure 32 –Concrete Deck Arch Construction Phasing - Rail

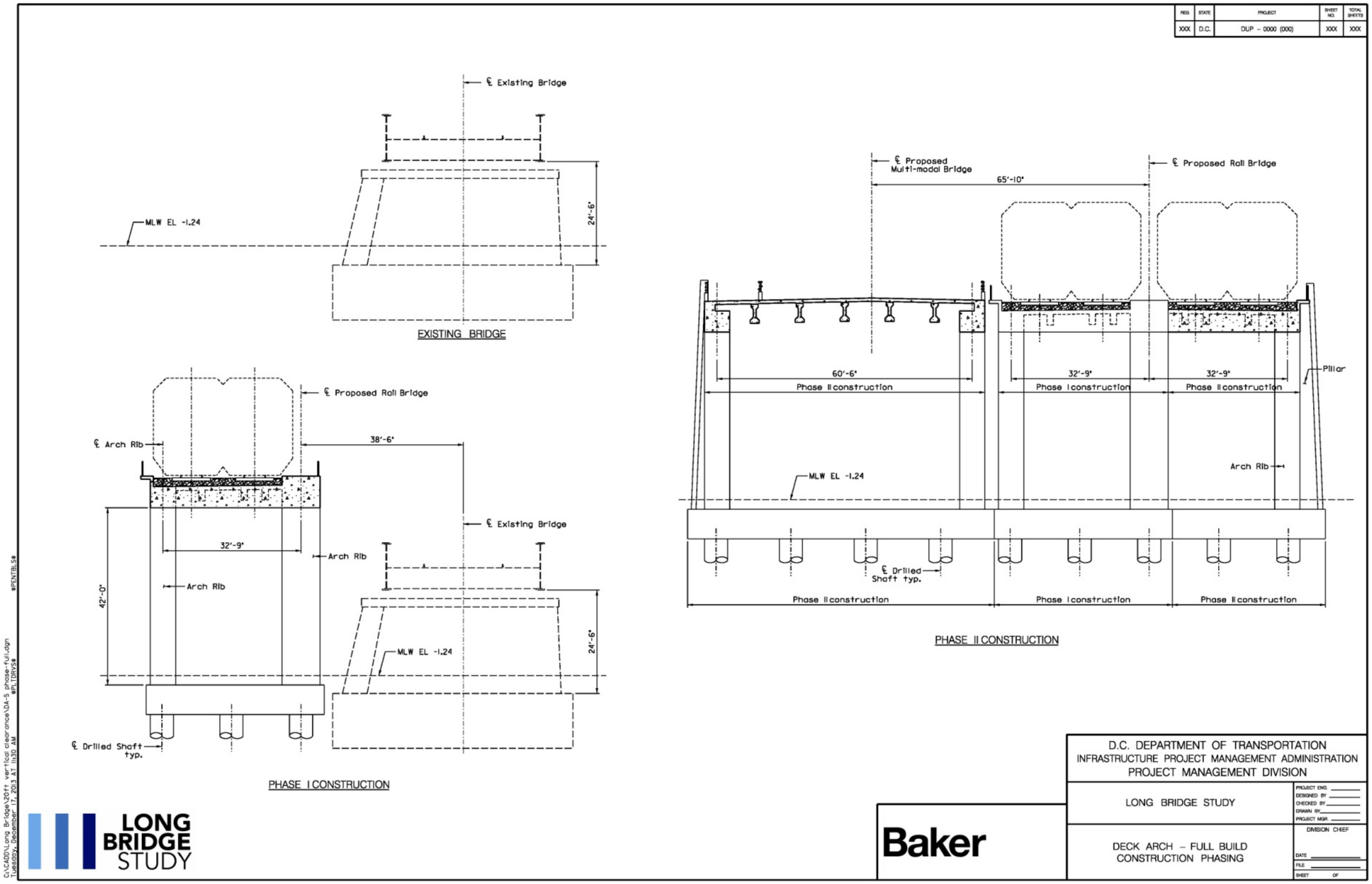


Figure 33 – Concrete Deck Arch Construction Phasing – Full Build

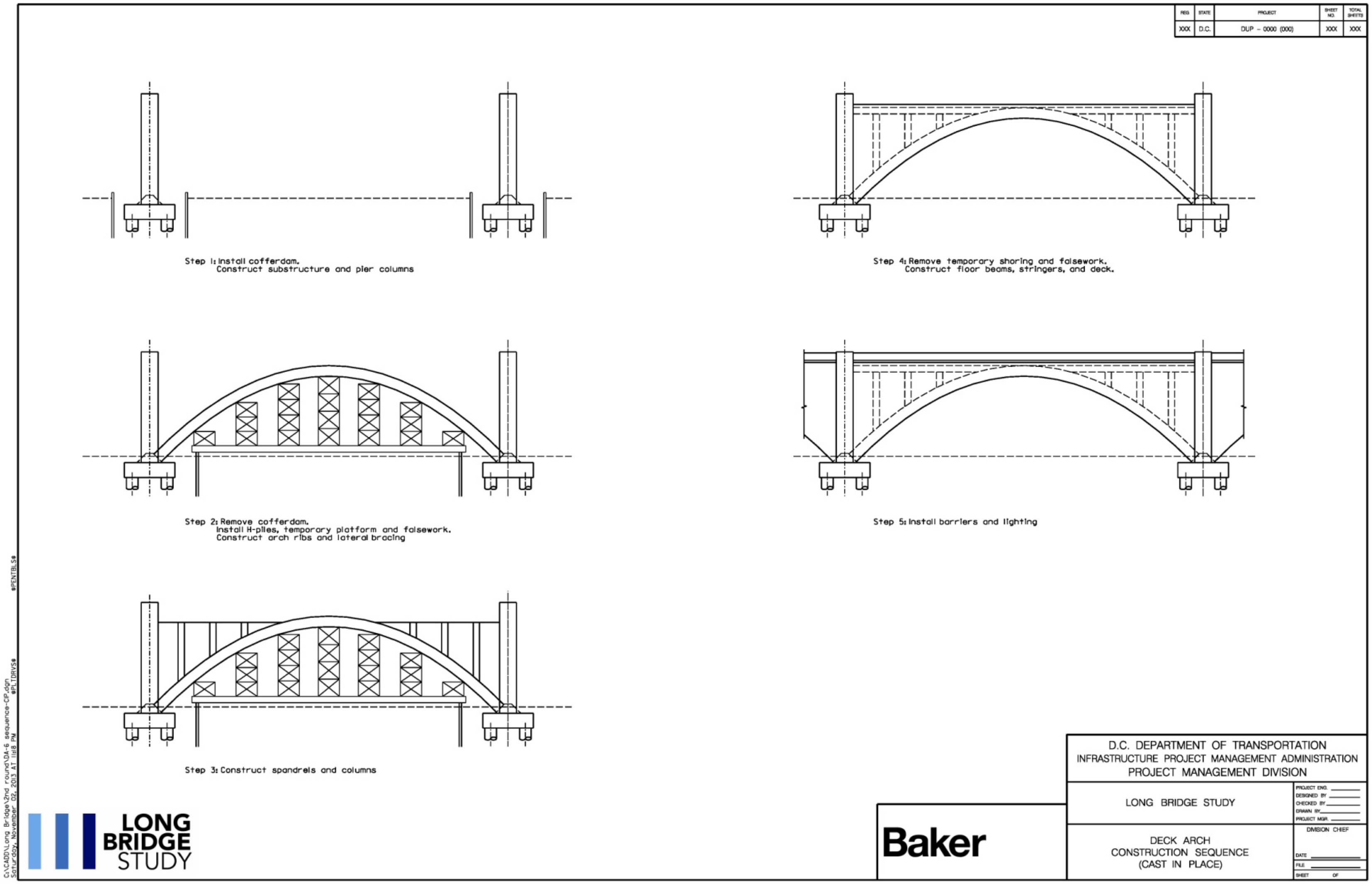


Figure 34 – Concrete Deck Arch Construction Sequence – Cast in Place

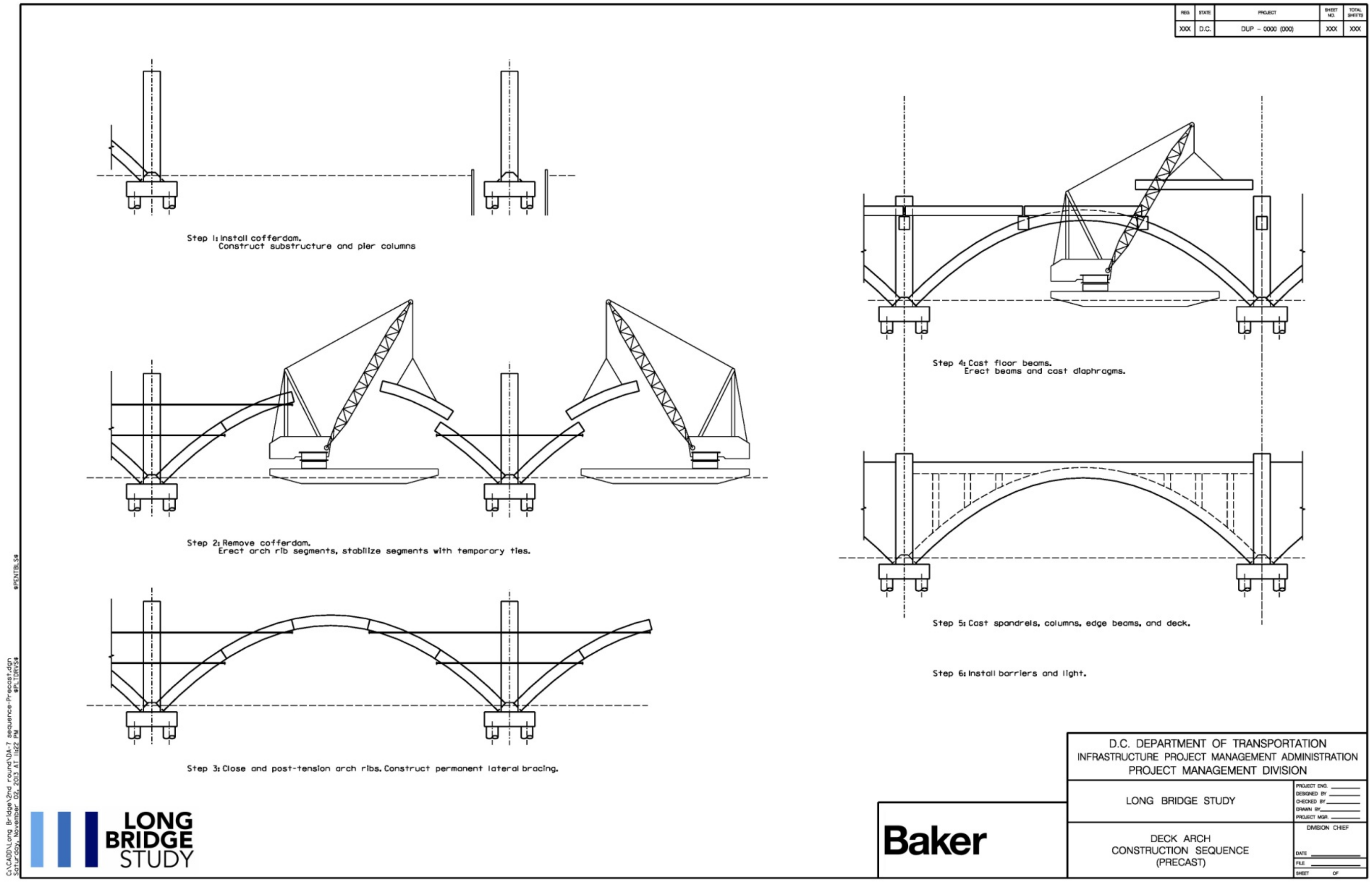


Figure 35 – Concrete Deck Arch Construction Sequence – Precast

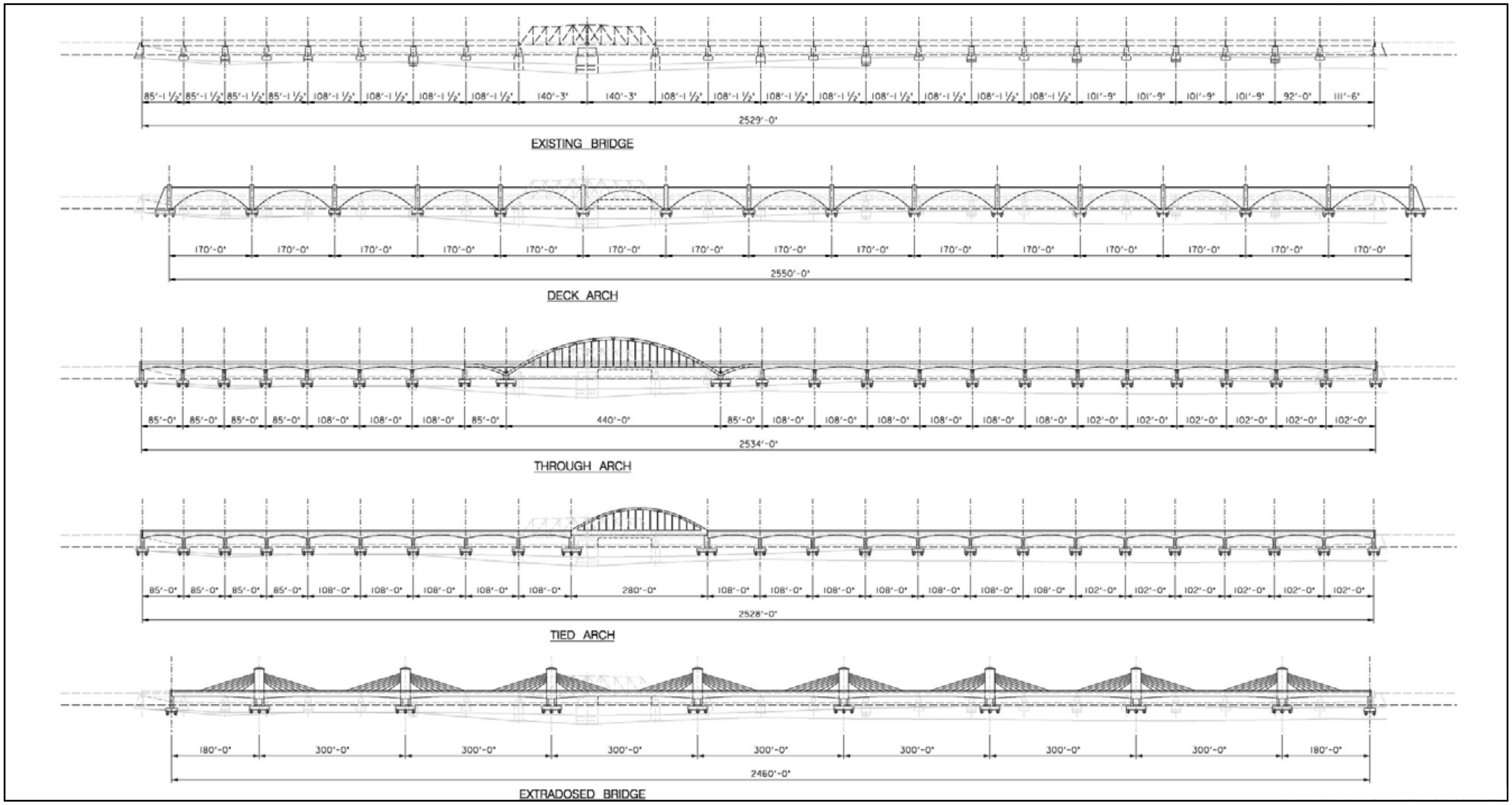


Figure 36 – Elevations – 4 Bridge Type Concepts

4.6 Tunnels

Tunnel options consist of several types of tunnel designs including: jacked segmental, submersed segmental, or twin bore. These designs are considered different means and methods for constructing tunnels and all require utility relocation and replacement in the areas of the assembly and retrieval shafts and tunnel approaches of several thousand feet.

Option A: Jacked Segmental Tunnel

The jacked tunnel option is utilized for near surface and soft ground tunnels. Tunnel precast concrete segments, 40 feet to 60 feet in length and up to 90 feet wide, are fabricated in a yard and delivered by truck to the jacking pit. The segments are placed into the jacking pit by crane and landed on rails. For the length of the tunnel, the soft ground will be improved with ground freeze, jet grout or other ground improvement techniques. These techniques will force the ground at the open heading of the tunnel to stand-up better for safe excavation. At the tunnel heading, a road header machine with a shield will grind out the improved ground in 4 foot drifts, immediately ahead of the precast tunnel segment. The excavated material is removed by either truck or conveyor belt to the assembly chamber and stockpiled at the surface for later removal by truck. Once the 4 foot drift is excavated and the tunnel segment is clear of surrounding obstruction, the tunnel segment is advanced with hydraulic jacks the full 4 feet. The roadheader (Figure 15) then moves back into position in the tunnel heading and excavates the next 4 foot drift and the operation is repeated until the tunnel reaches the retrieval chamber. Upon completion of the jacking operation, the annulus between the precast segment liner and excavation is grouted. The precast segmental tunnel is watertight.

Figure 37 - Roadheader Excavator

Option B: Submersed Tunnel

Submersed tunnels are precast concrete segments placed in a trench excavated in the river bottom. Segments are 60 feet long and up to 90 feet wide and delivered to the placement point by barge. Typically, the river bottom is dredged to a depth that will accommodate segment submersion by barge crane and rock cover for protection from a ship strike. From the shore line, the tunnel can be sheeted, cut/cover to the portal of the assembly and retrieval chambers. The submersed tunnel does not require waterproofing and is a water-tight structure.

Option C: Bored Twin Tunnels

Bored tunnels can be constructed using tunnel boring machines (TBM – Figure 7.9) that can range in outer diameter size from approximately 23 feet to as large as 57.5 feet and begin by assembling the TBM in an assembly chamber. The TBM begins excavation by grinding up the rock and removing the grindings by truck, train or conveyor belt to the assembly chamber. The TBM advances into the rock an average of 50 feet per day.   Tunnel analysis as part of this study estimated the need for two 44 foot outer diameter bores for each of two tunnel bores to accommodate the requirements of freight and passenger service. Depending upon the length of the tunnels, it may be economically beneficial to use either one or two TBMs. For a single TBM, the machine would be disassembled at the retrieval chamber after the first drive under the river, reversed position and reassembled, then driven back under the river for the second bore to terminate at the original assembly chamber.

Figure 38 - Tunnel Boring Machine

Depending upon geologic conditions – whether the tunnel is bored through hard rock or soft ground – there are two methods. A hard rock tunnel would be excavated by a TBM, waterproofed with a membrane and lined with cast-in-place fiber reinforced concrete. If conditions are soft ground, then an Earth Pressure Balanced Machine (EPBM) will excavate and line the tunnel with a precast segmental lining that is bolted with gaskets for water tightness. The lining of the tunnel is installed from the rear of the EPBM while the machine is excavating and there is no additional concrete lining operation after the EPBM is finished excavating – as there is with a lined hard rock tunnel.

Analysis of Aesthetics

Aesthetic implications of tunnel options are confined to where the tunnel emerges from underground. Typically these openings (portals) are simple in appearance showing the basic outline of the tunnel in concrete or a more decorative façade covered in stone or sculptured concrete. These openings would not be visible from the existing bridges or from the banks of the Potomac River.

In an urban environment, tunnel venting systems can be unsightly above ground. Two methods of ventilation are considered for the construction of a tunnel: the installation of vent shafts with fans along the length of the tunnel; and the separate ventilation requirement at underground passenger stations, which would require some type of above ground ventilation plant. Above ground venting structures are often blending into the surroundings and signing structures and other vertical structures are often used as vent shafts.

Analysis of Constructability and Construction Impact

All options will require excavation of assembly and retrieval shafts in crowded urban environments. An assembly chamber is a box excavation dimensioned at 400 feet long, 60 feet wide and 30 feet deep. Support of earth would likely be soldier pile and lagging down to the top of bedrock, then excavation by roadheader and excavator using shotcrete and rock bolt support for the walls. At the invert of the box a structural slab is poured for the working surface. Typically, the excavation break-out from the assembly chamber and break-in to the retrieval chamber will be through the chamber wall (portal) with a seismic safety device – such as an earthquake ring – and then through a large block of improved ground outside the chamber wall – usually jet grout or secant pile block. The interface of the jet grout block and the chamber wall provides a watertight connection and eliminates ground loss when the excavation breaksout of the chamber. This break out/in ground improvement is not necessary with the hard rock bore tunnel.

Tunnel construction requires large above ground staging areas in close proximity to the construction location. The location of tunnel portals and temporary construction shafts will need to be considered due to the length of the bore tunnels and possible impacts to existing above ground structures.

A number of constraints and specifications are required to develop the passenger and freight rail tunnel profiles. Requirements for the size of the tunnel and the critical measurement of top-of-rail to prepare the profiles are taken from the American Railway Engineering and Maintenance-of-Way Association (AREMA) Design Manual and recommended clearance envelopes from the Association of American Railroads (AAR). AREMA and AAR provide industry standards and define the required railway widths for passenger and freight rail as well as height required for single and double-stack trains and associated guide wire and catenary requirements for electrified passenger rail. Table 1 provides specifications for the different elements that will need to be considered in tunnel design.

Table 1 - Criteria for Tunnel Design

Tunnel Element	Specification
Height for double stack freight train	20’-3” maximum
Spacing from top of train to catenary guide wire	1’ – 6”
Outside diameter of tunnel	44’
Distance between track centers	16’
Spacing between tunnels or other underground infrastructure	10’ to 20’
Maximum grade for freight train operations	1%
Maximum grade for passenger train operations	3%
Length of vertical curve minimum operations speed	40 mph (V)
Maximum vertical acceleration	0.10 feet/sec (freight)
Minimum length of vertical curve	3 x V
Passenger platforms	800’ minimum
Spiral transition at each end of platform	100’ to 150’
Rail interlockings	1,200’ to 2,500’

Other considerations for tunnel construction include catwalks for maintenance and evacuation as well as life/safety escape portals with vertical ladders. Underground obstruction and existing infrastructure need to be avoided when considering a tunnel alignment including: existing Metro tunnels, roadway foundations, utilities and building foundations. Tunnel concepts need to assume that all tracks can be electrified in concept with the catenary and guide wire above the maximum height requirement for double stacked freight trains. The availability of electrification also necessitates the availability of switching (interlocking) between all tracks. Figure 17 shows the cross-section used for the purposes of assessing tunnel alignments and the location of tunnel portals.

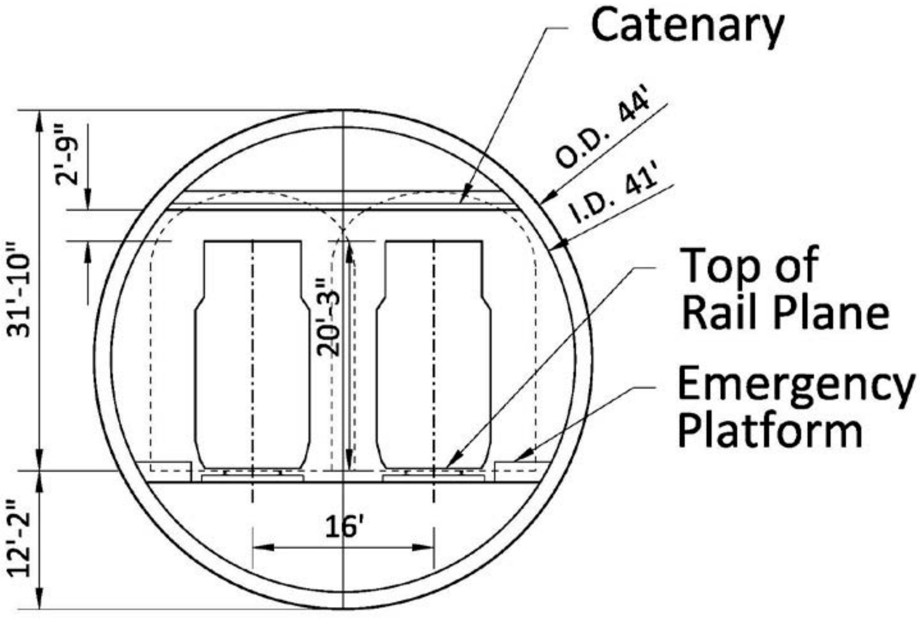


Figure 39 - Typical Tunnel Cross-Section

Plans and profiles for the freight and passenger tunnels require controlling criteria to determine the length of each tunnel and the portal locations where a tunnel would reach the surface at its earliest point. The channel in the Potomac River was the control point at 80’ to the bottom of the tunnel below the river mud line with the top-of-rail at 12’-2” above that, which started the profile at 67’-10” below the river mud line. Separate plans and profiles are developed for the freight and passenger tunnel concepts. The difference in maximum grade limits results in varying tunnel lengths and the location of portals and connections back into existing tracks. Diagram 23 shows the plan and profile for a freight tunnel alignment and Diagram 24 shows the plan and profile for a passenger tunnel alignment. An important consideration for constructability was to hold the grade of the passenger tunnel to 1% through the L’Enfant area in the

Southwest waterfront. This would be important for considering passenger stations and the location of interlockings to allow for switching between tracks. The estimated length of the freight tunnel is approximately 25,950 linear feet with 2000 foot portal egress in both Virginia and District. The estimated tunnel length of the passenger tunnel is 14,225 linear feet. A 1000 foot egress portal is assumed in Virginia. There is no passenger tunnel portal in the District as the tunnel continues and connects to the existing underground tunnel to Union Station.

Assessment of the vertical alignment and anticipated profile of a tunnel with the stipulated depth requirements to avoid existing underground structures makes it unlikely that a jacked tunnel or submersed tunnel will be constructed. A jacked or submersed tunnel is practical only for a relatively short distance. The grade restrictions for a freight tunnel and the tunnel length require long approach tunnels to the Potomac River crossing. This leaves the hard rock tunnel bore as a practical solution for the linear feet of tunnel that has been estimated.

Fire/life safety protection for passenger rail facilities is governed by the National Fire Protection Association (NFPA) standard, NFPA 130: *Standard for Fixed Guideway Transit and Passenger Rail Systems (2014 edition)*. This standard provides criteria for fire/life safety elements in passenger rail tunnels and stations including ventilation, emergency walkways, emergency exits, fire suppression, alarms, lighting, emergency communications and other elements. These elements have not been evaluated in detail for the Long Bridge tunnel concepts and are not depicted on the plans, profiles and typical sections. A line item for fire/life safety elements is included in the cost estimates. This estimate is based on tunnel ventilation using jet fans and for providing emergency exits, emergency walkways, fire suppression, alarms, lighting, emergency communications, and other fire/life safety elements provided in accordance with NFPA 130. Because the tunnel concepts provide the ability for passenger and freight trains to use all tracks, all tunnels are assumed to have the same level of fire/life safety protection. Ventilation for diesel exhaust is less robust than that needed for emergency smoke management and therefore can be handled with the smoke management ventilation equipment assumed for the ventilation costs for this study.

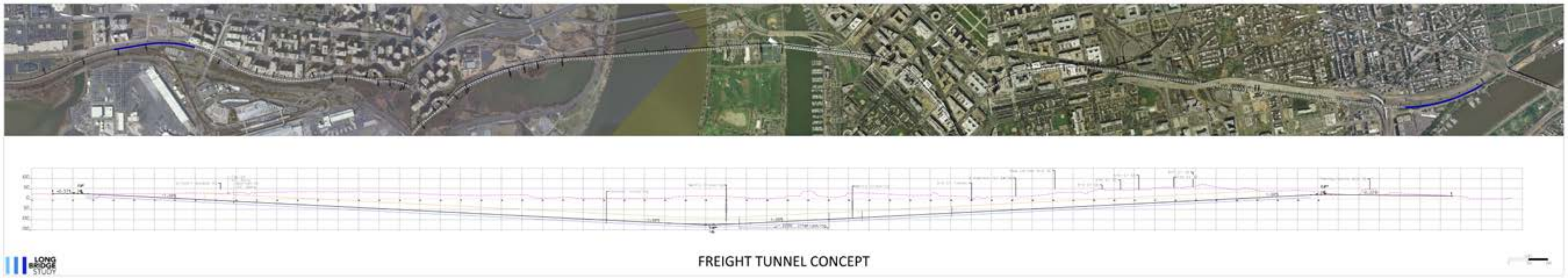


Figure 40 – Freight Tunnel Plan and Profile

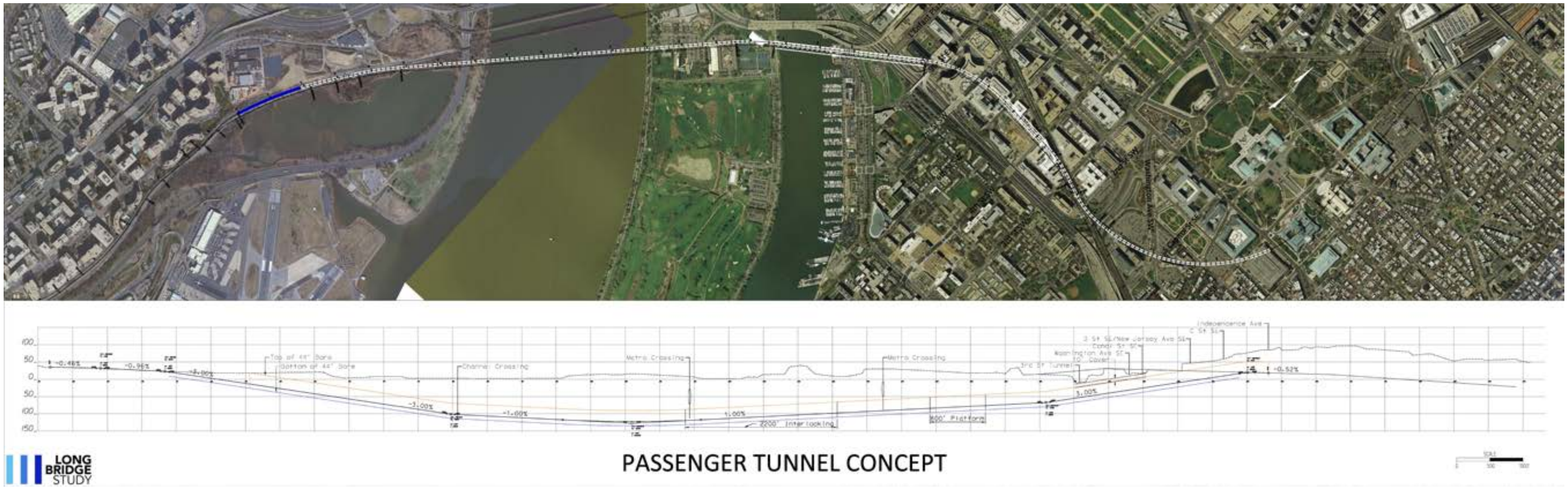


Figure 41 – Passenger Tunnel Plan and Profile

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Analysis of Initial Cost

In comparison to the bridge alternatives, a tunnel under the Potomac River would be the most costly alternative. Independent of the costs associated per linear foot of construction, the tunnel requires specialized equipment and the construction of chambers and pits to accommodate the equipment. Tunnels also require venting plants that are built to accommodate airflow from the venting shafts inside the tunnel to the outside. These complicated venting plants are expensive and require above ground land for construction.

Tunnels also present considerable costs for relocating existing utilities. A detailed underground utility assessment is required to determine what types of utilities will be encountered and the associated costs of relocating each utility. Often all utilities are not clearly marked and add cost during construction as they are encountered and addressed for relocation.

Analysis of Future Maintenance and Life Cycle Costs

Future maintenance and inspection costs are a function of leakage and deterioration prevention. Tunnels are lined with precast segmental concrete or cast-in-place final liner with waterproofing that is inspected regularly.

Analysis of Adaptability

The tunnel option presents no impacts to the existing Long Bridge structure, the federal park lands at the bridge approaches or the Southwest waterfront by virtue of being underground. Above ground considerations will need to be made on the treatment of the tunnel portal opening where the tunnel connects back into the existing rail system. Portal for the freight tunnel in the District would be close to the Anacostia River east of 11th Street SE and the portal in Virginia would be just south of the National Airport access road. The portal for the passenger tunnel in Virginia is at the west end of Long Bridge Park. There is no portal in DC as the passenger tunnel ties directly into the current passenger tunnel portal at New Jersey Avenue and the entire length at this end could remain underground to Union Station.

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5. Construction Costs

This report and the bridge and tunnel types discussed herein are conceptual in nature, and therefore evaluations of cost at this stage of project development must be considered as preliminary. None of the alternatives described in this report have been engineered to determine true costs based on estimated structural quantities, anticipated erection methods, right-of way implications, expected schedule durations, or potential effects of inflation based on the anticipated timing of the beginning of construction, among other determinations.

At this stage of development, a preliminary level of cost evaluation can be made that differentiates the alternatives on the basis of anticipated construction cost of the bridge structure and associated rail components. Specifically, it is reasonable at this point in the engineering development to define which structure and tunnel types are likely to be the most expensive and which are likely to be the least expensive for the construction of the bridge structure, bridge deck and approach areas, tunnel sections and associated tunnel requirements. It is customary at this stage of development to provide expected ranges of cost, based on typical historical per-square-foot costs, associated with each structure type. As engineering development proceeds and the bridge types become further defined, more reliable cost estimates will be developed that will provide better definition to the cost differences between the structure types.

Costs associated with the construction of rail relate to element of track work, earthwork and the placement of track bed ballast. Track estimates include the construction of linear feet of track and the associated turnout and crossover costs. Additional costs are estimated for signal requirements and the construction of interlockings at different locations along the length of the construction. Alternatives that included streetcar include linear costs for track work and catenary.

Utility costs are estimated from the surface utility survey completed for the project and detailed in Appendix B. A complete knowledge of underground utilities was not developed for this study.

Right of way costs were a function of the width of the bridge expansion and the portion of the bridge and associated elements that traversed over land. The portion of the bridge construction that was considered to be over land was approximately 4,450 feet. This was the linear measurement used to multiple by the bridge width expansion to arrive and square footage above land. This square footage was then multiplied by $200 per square foot to arrive at right of way costs. This cost was applied uniformly for all right of way including the federal park lands along the Potomac River. Additional costs are developed as a percentage of the bridge and rail construction costs. These include: drainage, signage, landscaping, maintenance of traffic, mobilization, staking / surveying, design of plans and construction services.

Several of the bridge types discussed in this report actually consist of a mix of structure types – for example, the steel arch alternatives consist of one or more spans of arch structure combined with spans of standard girder construction. This is an important distinction to be made between alternatives, since the expected cost of conventional girder construction is likely to be significantly lower than the more unique bridge types proposed. Therefore, alternatives that have a higher percentage of standard girder construction are likely to prove more economical than those that consist primarily of a unique structure type. Other bridge type variations include a partial extradosed cable-stayed bridge and a standard girder structure with concrete arch façade elements which is similar in style and look to the concrete deck arch.

Table 2 shows preliminary anticipated costs for each of the bridge concepts and tunnel types discussed in this report. These alternatives only include the reconstruction of the existing two track bridge (Alternative 2) or alternatives that only include freight and passenger rail options. Bridge concept costs are provided for Alternatives 2 and 3 for six bridge type options and for Alternative 4 for three tunnel options. The cost estimate for rehabilitation of the existing Long Bridge was estimated at $68 million. Table 3 shows the preliminary anticipated costs for alternatives that include passenger and freight rail options with other modal considerations. A complete set of individual cost estimates is provided in Appendix A.

The numbers shown on these tables should only be used as a basis of comparison between different bridge or tunnel alternatives, and should not be considered a complete estimate of final cost. All costs are shown in 2013 dollars with no inflation. A 35% contingency cost has also been added based on the sum of structure, rail and “other” costs of each option.

Table 2 – Construction Costs for Rail Only Alternatives

(2013 Dollars) - Order of Magnitude Costs*

Structure Type	Alternative 2	Alternative 3	Alternative 4
1. Steel Tied Arch	$137M - $197M	$355M - $464M	(A) Shallow Jacked Segmental Tunnel $6.222 Billion
2. Steel Through Arch	$151M - $217M	$378M - $494M	
3. Extradosed	$291M - $393M	$598M - $762M	(B) Shallow Submersed Segmental Tunnel $6.243 Billion
3a. Partial Extradosed	$205M - $289M	$458M - $594M	
4. Concrete Deck Arch	$160M - $225M	$402M - $521M	(C) Twin Bored Tunnel $5.728 Billion
4a. Standard Girder Structure with Concrete Arch Façade Elements	$154M - $210M	$365M - $467M	

*These costs and the bridge and tunnel types discussed herein are conceptual in nature. A 35% contingency is included in the cost of the bridge and tunnel options.

Table 3 – Construction Costs for Rail with Multimodal Alternatives

(2013 Dollars) - Order of Magnitude Costs*

Structure Type	Alternative 5	Alternative 6	Alternative 7	Alternative 8
1. Steel Tied Arch	$424M - 556M	$607M - $794M	$623M - $816M	$733M - $963M
2. Steel Through Arch	$450M - $590M	$638M - $837M	$655M - $859M	$770M - $1.012B
3. Extradosed	$700M - $893M	$917M - $1.169B	$941M - $1.200B	$1.104B - $1.410B
3a. Partial Extradosed	$535M - $695M	$709M - $919M	$727M - $943M	$849M - $1.104B
4. Concrete Deck Arch	$483M - $628M	$664M - $862M	$686M - $890M	$815M - $1.062B
4a. Standard Girder Structure with Concrete Arch Façade Elements	$431M - $555M	$587M - $758M	$604M - $781M	$710M - $923M

*These costs and the bridge and tunnel types discussed herein are conceptual in nature. A 35% contingency is included in the cost of the bridge and tunnel options.