Three Bridges at I-64/Mercury Boulevard Interchange in Hampton, VA

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ABSTRACT: This paper describes three innovative steel bridges recently designed by Alvi Associates for the Virginia DOT. Magruder Boulevard over I-64 features challenging geometry and high-performance steel box girders. I-64 over Mercury Boulevard features high-performance steel and counterweight abutments. Flyover J over Ramp B features fully-integral construction with curved steel girders.

PROJECT OVERVIEW

This project is located in the City of Hampton, Virginia. The project involves improvements to the interchange of I-64 and Mercury Boulevard (RT 258). The existing interchange is a full cloverleaf. The interchange improvements consist of replacing the two loop ramps in the eastern quadrants with directional flyovers, widening 4.4 km (2.7 miles) of I-64, and constructing six new bridges (two replacements) and one bridge widening, all using staged construction to maintain traffic.

The project owner is the Virginia Department of Transportation. The Prime Consultant is SITE-Blauvelt Engineers, who performed roadway design, design of four bridges, retaining wall design, and geotechnical engineering. Alvi Associates designed three bridges. SAIC provided traffic engineering services. Downing Surveys provided surveying services. McDonough Boylard Peck performed a constructability review of the project.

At present (May 2002), the project is under construction. The General Contractor is E.V. Williams and the Bridge Contractor is McLean Contracting. Structural steel is being detailed by abs Structural Corporation and fabricated by Carolina Steel.

This paper describes the three bridges designed by Alvi Associates.

MAGRUDER BOULEVARD BRIDGE OVER I-64 (B622)

DESIGN SITUATION. The design situation for this bridge was as follows (Figure 1):

General

< Magruder Boulevard (located west of Mercury Boulevard) currently overpasses I-64 as a two-lane flyover ramp via a four-span steel girder bridge on pile foundations.
< Existing I-64 has three lanes in each direction. The proposed widening consists of an additional median and outside lane in each direction, resulting in a total of ten lanes.
< Widening of I-64, and the need for improved vertical clearance, required bridge replacement.

Geometry

< The proposed bridge needed to be on the same horizontal alignment as the existing bridge, which consists of a curve with a radius of 249 m (818 ft). The skew between Magruder Boulevard and I-64 varies from about 30° to 50°.
< The deck has a constant superelevation of 8%.
< The proposed bridge width is 15.4 m (50.5 ft), including two lanes and a 4.8 m (15.7 ft) inside shoulder to meet horizontal sight distance requirements.
< Raising the profile of Magruder Boulevard was constrained by the need to maintain vertical sight

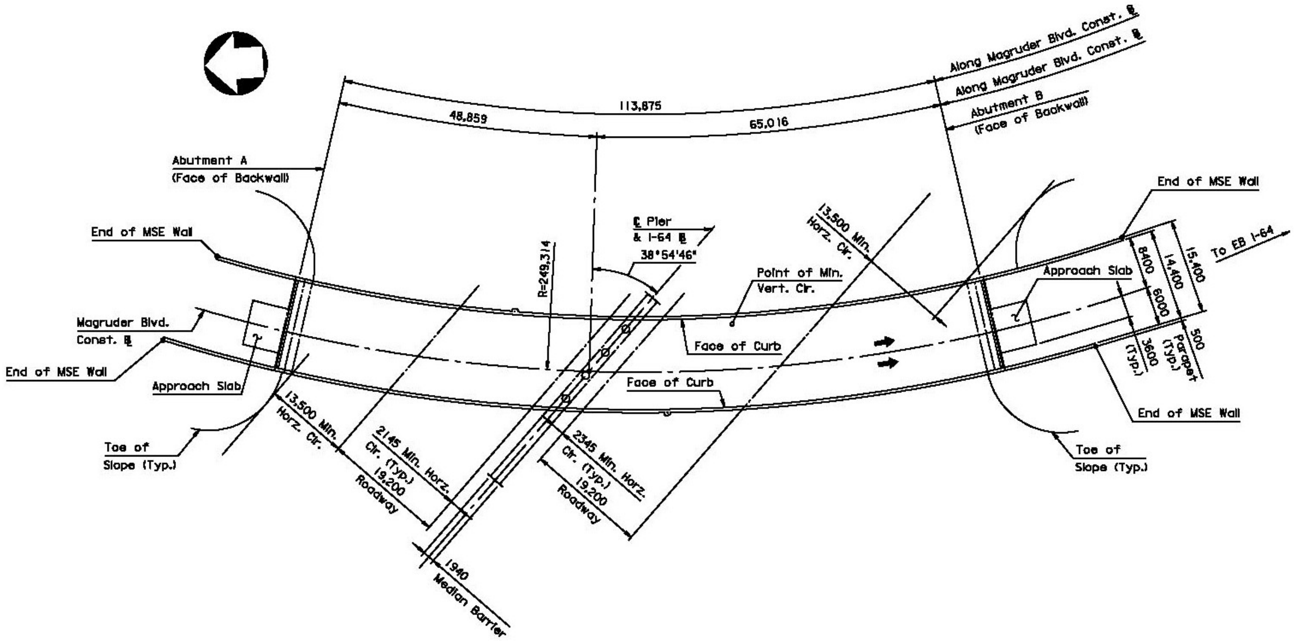

Figure 1. B622 General Plan

distance and prevent excessive approach construction. The structure depth was therefore limited to about 2.1 m (6.9 ft).

< The narrowness of the proposed I-64 median prevented a radial pier, instead requiring a pier skewed 39°. An integral radial pier was found infeasible due to the width of the bridge and the need for staged construction.

< Except for a skewed median pier, radial substructure was used for all alternatives due to the significant horizontal curvature and the skew of the alignment.

< The clear zones (edge of pavement to face of substructure) are 13.5 m (44.3 ft).

< The combination of skew, wide roadway, and wide clear zones resulted in minimum span lengths of about 49 m (160 ft) over WB I-64 and 65 m (213 ft) over EB I-64.

< The corresponding middle ordinates for each span were about 1.2 m (4.0 ft) and 2.1 m (7.0 ft), resulting and significant torsion and making curved girders mandatory for all alternatives.

Construction Constraints

< One lane of traffic had to be maintained on Magruder Boulevard, thus requiring two-stage construction for the proposed bridge.

< Proposed foundations had to avoid the existing piles.

< Traffic impacts to I-64 needed to be minimized due to an average daily traffic of about 140,000 vehicles.

ALTERNATIVES. The alternatives considered for this bridge consisted of two and four-span continuous superstructures using either six steel I-girders, two steel box girders, or four steel box girders. In addition, for the four-span layout, a precast concrete segmental twin box girder alternative using balanced cantilever construction was considered.

The two-span layout using four steel box girders (Figures 2 and 3) was selected as the preferred alternative, primarily because it has the lowest cost. The pier for this bridge consists of a single round concrete column under each box girder, with a column

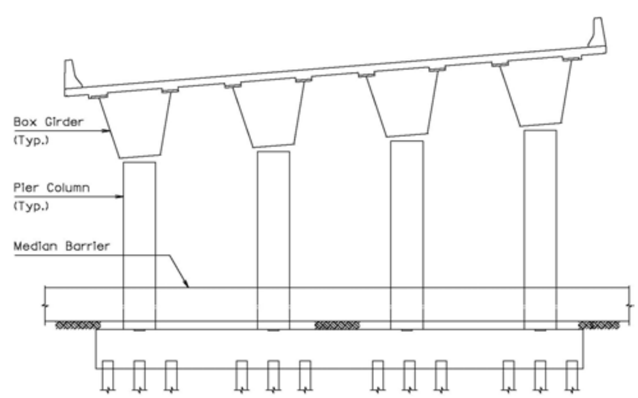

Figure 2. B622 Typical Section at Pier

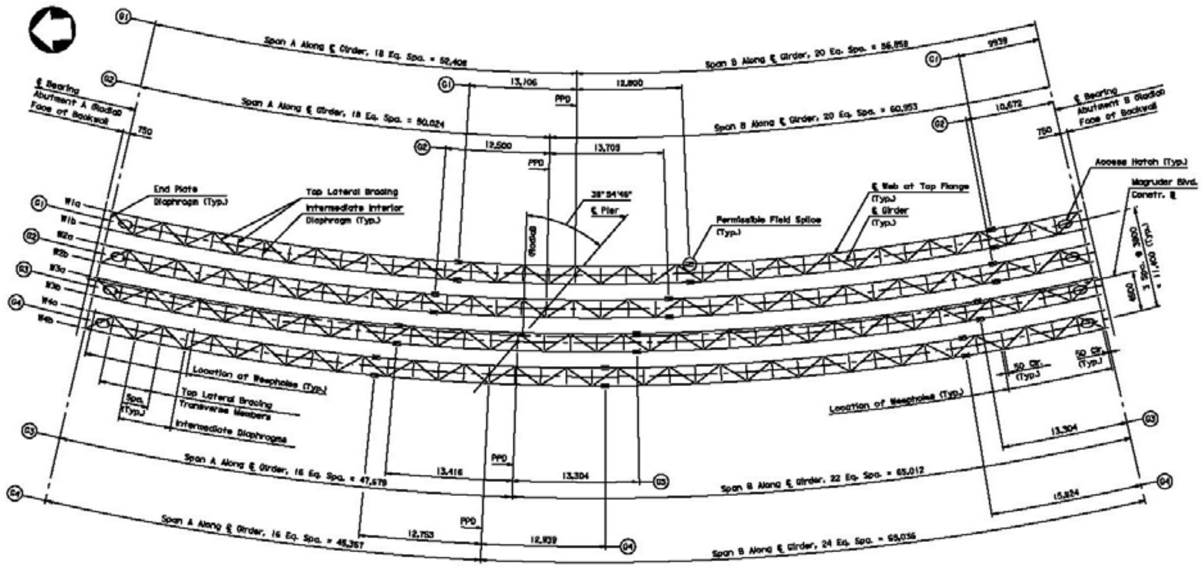

Figure 3. B622 Framing Plan

diameter of 1.22 m (4.0 ft). There is no pier cap, and the pier foundation consists of prestressed concrete piles (Figure 2). The abutments are MSE abutments on two rows of steel pipe piles.

KEY DESIGN FEATURES. The key design features of this bridge, and the resulting benefits, include the following:

- No steel diaphragms external to the boxes except at the abutments (Figure 3) - This simplifies construction and eliminates structural complications due to the skewed pier. However, it should be noted that box girders must be used carefully with skewed substructure due to compatibility-induced torsion.
- Increased transverse deck reinforcing, particularly at the pier - This compensates for the lack of external diaphragms.
- Box depth of 1.74 m (5.7 ft) - This depth enables inspection and maintenance.
- Insides of box girders painted white and provided with lighting - This enables easier inspection and maintenance.
- 485 MPa (70 ksi) High-performance steel (HPS) used in the girder flanges, hybrid with 345 MPa (50 ksi) steel in the webs - This reduces flange sizes, girder weight, and cost. This is one of the first box girder bridges in the US to use HPS.
- Fiberglass box girder access hatches provided next to the abutments (Figure 3) - This access location is far away from the roadway for safety, and at distance from abutment face which allows access by ladder. In addition, use of fiberglass greatly reduces hatch weight, enabling easier use by inspectors.
- Single elastomeric bearing under each box at each support - A single bearing reduces cost compared to dual bearings, and elastomeric bearings substantially reduce construction problems, cost, and maintenance compared to pot, spherical, and other metal bearings.

I-64 BRIDGE OVER MERCURY BOULEVARD (B623)

DESIGN SITUATION. The design situation for this bridge was as follows (Figure 4):

General

- I-64 currently overpasses Mercury Boulevard via a four-span steel/prestressed concrete girder bridge on pile foundations.
- Existing I-64 has eight lanes. The proposed widening results in eleven total lanes. Existing Mercury Boulevard has eight lanes. The proposed Mercury Boulevard construction provides a raised median and widens the overall roadway.
- Widening of I-64 and Mercury Boulevard required replacement of the existing bridge.

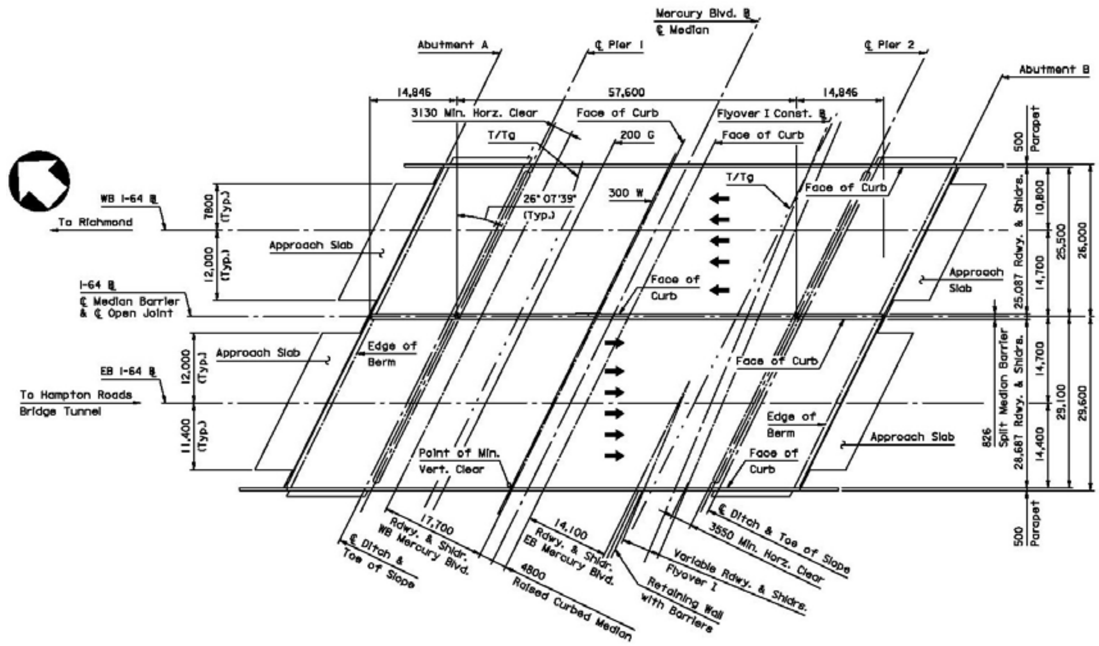

Figure 4. B623 General Plan

Geometry

- The proposed bridge needed to be on same tangent horizontal alignment as the existing bridge. The skew between I-64 and Mercury Boulevard is about 26°.
- There are superelevation transitions on the bridge.
- This overall bridge width is a relatively wide 55.6 m (182.4 ft).
- Raising the profile of I-64 was constrained by the need to maintain vertical sight distance and tie-ins with adjacent ramps. The structure depth was therefore limited to 1.5 m (4.9 ft).

Construction Constraints

- Three lanes of traffic in each direction had to be maintained on I-64, thus requiring three-stage construction for proposed bridge.
- The proposed foundations had to avoid existing piles.
- The proposed foundations had to avoid impacting an existing water line in the median of Mercury Boulevard, and two existing phone lines under Mercury Boulevard, none of which could be relocated.
- Due to the lack of existing shoulders on Mercury Boulevard, construction of a median pier would have significantly impacted traffic, thus requiring diverting traffic under the end spans of the existing bridge by excavating the existing fill and constructing retaining walls at a cost of about $1 million.

ALTERNATIVES. Five steel I-girder alternatives were considered for this bridge with the following span layouts:

- One span of 60 m (200 ft) minimum - This was found infeasible due to excessive structure depth.
- Two continuous spans of 38-47 m (125-154 ft) - This was found to be the best "conventional" alternative, but cost about $1.2 million (20%) more than the selected alternative, mostly due to the need for diverting traffic under the existing end spans.
- Three continuous spans with conventional end spans, using spans of 37-58-37 m (120-190-120 ft) - This alternative cost about $1.3 million (22%) more than selected alternative.
- Three continuous spans with short end spans, using spans of 14-58-14 m (47-189-47 ft) - *This was selected as the preferred alternative, primarily because it has the lowest cost (Figure 5).*
- Four continuous spans of 18-26-32-21 m (59-85-105-69 ft) - This alternative cost more than two continuous spans.

The abutments for the selected alternative consist of concrete cantilever abutments on two rows of steel pipepiles (Figure 6). The piers consist of multicolumn concrete pier bents on steel pipe piles.

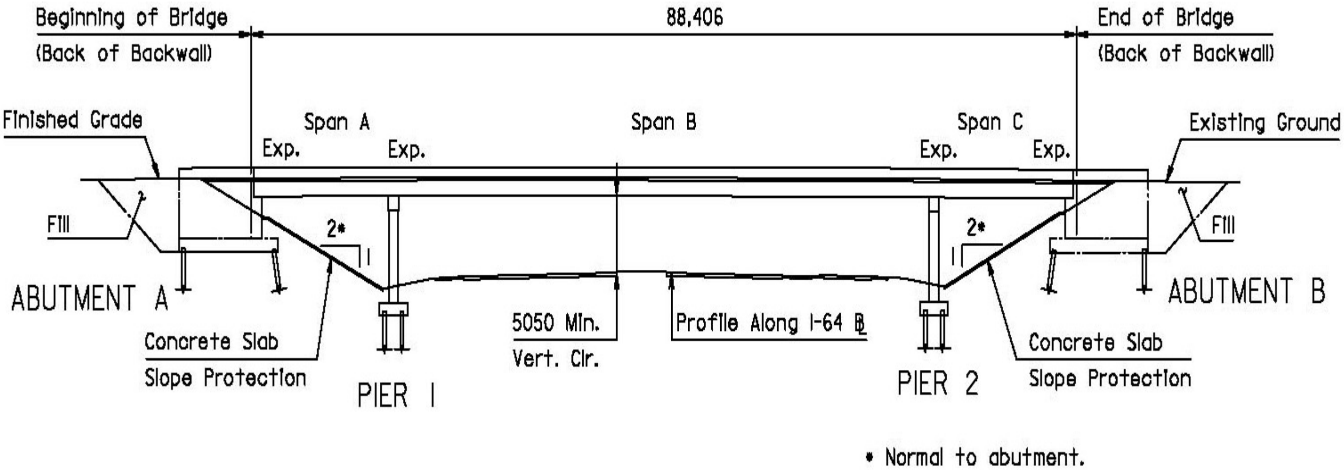

Figure 5. B623 Elevation

KEY DESIGN FEATURES. The key design features of this bridge, and the resulting benefits, include the following:

< No median pier (Figure 5) - This greatly reduces traffic impacts during construction. It also improves traffic safety, particularly considering the narrow median width, avoids impact to the existing water line, and improves aesthetics by creating greater openness.

< Short end spans (25% of the main span) combined with counterweight abutments (Figures 5 and 6) - This greatly increases superstructure stiffness, thus enabling a relatively long span with shallow structure depth. It also reduced cost by about $1.3 million (22%) compared to conventional end spans. This bridge is believed to be the first structure of this type in Virginia.

< Post-tensioned threadbars anchoring the superstructure to the abutments (Figure 6) - These enable the weight of the abutments and backfill to serve as a counterweight against uplift.

< Reinforcing steel welded to the tops of the steel pipe piles and developed into the concrete abutment footings - This enabled the piles to provide reserve uplift capacity in case of overload.

< Lightweight backfill behind the abutments - This reduced lateral earth pressure and thereby reduced the number and cost of piles.

< 485 MPa (70 ksi) High-performance steel (HPS) used in the girder flanges, hybrid with 345 MPa (50 ksi) steel in the webs - This reduced bridge cost by $330,000, which is an 18% reduction in steel cost and 6% reduction in bridge cost. This also enabled use of reasonable flange sizes to accommodate the large negative moments acting on the shallow girder depth.

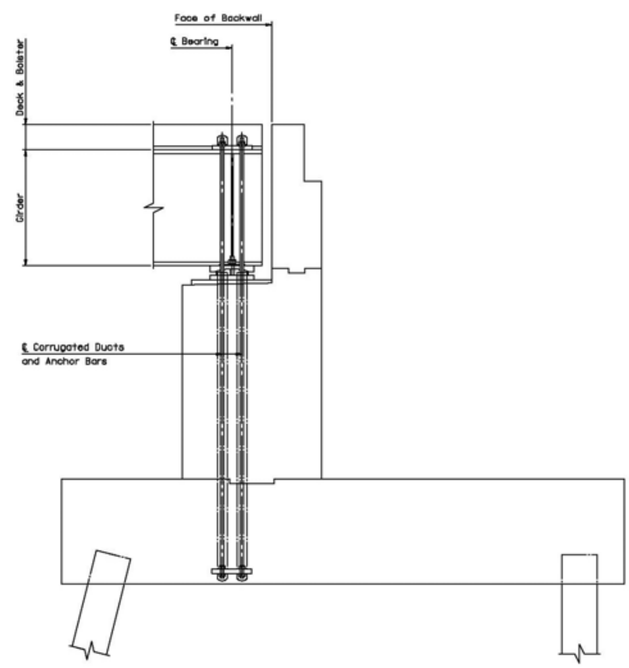

Figure 6. B623 Typical Abutment Section

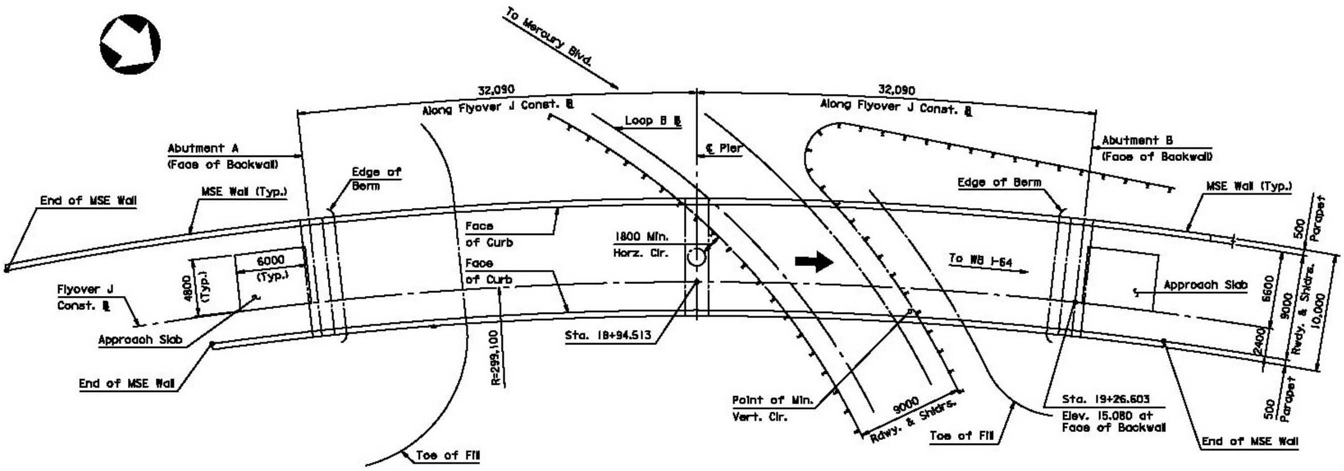

Figure 7. B627 General Plan

FLYOVER J BRIDGE OVER LOOP B (B627)

DESIGN SITUATION. A new bridge was required to carry a proposed one-lane flyover ramp over an existing one-lane loop ramp. The design situation for this bridge was as follows (Figure 7):

- The horizontal alignment consists of a curve with a radius of 299 m (981 ft).
- The skew between Flyover J and Loop B is about 47°.
- The deck has a constant superelevation of 4.5%.
- The overall bridge width is 10.0 m (32.8 ft).
- The profile of Flyover J could be raised as needed to provide desired structure depth.
- Radial substructure was used for all curved-girder alternatives due to the significant curvature and skew.

ALTERNATIVES. One and two-span alternatives were considered for this bridge. For a single span, both skewed and radial abutments were considered, with the span ranging from 23 m (75 ft) to 60 m (200 ft). The superstructure types considered included straight and curved steel I-girders, straight precast prestressed concrete girders, and a curved cast-in-place post-tensioned multicell concrete box girder.

For the two-span alternatives, continuous curved steel I-girders were considered, with each span ranging from 32 to 38 m (105 to 124 ft), with either conventional or integral abutments, and with either a hammerhead or integral pier.

Each of the single-span alternatives was eliminated from further consideration due to some combination of excessively large and costly abutments, a narrow and unsafe opening for traffic passing under the bridge, construction complications associated with erection of single-span curved girders, and/or higher cost than the selected alternative.

The selected alternative has two equal spans of 32 m (105 ft) (Figure 7) and uses curved steel I-girders with both an integral pier (Figure 8) and integral abutments (Figure 9). This alternative was selected primarily because it has the lowest cost, along with providing improved aesthetics.

KEY DESIGN FEATURES. The key design features of this bridge, and the resulting benefits, include the following:

- Integral abutments (Figure 9) - These eliminate deck joints and bearings, thereby reducing cost and maintenance requirements.
- MSE abutments wrapping around the integral abutments (Figure 9) - These complement the integral abutments by allowing minimal height of the integral abutments.

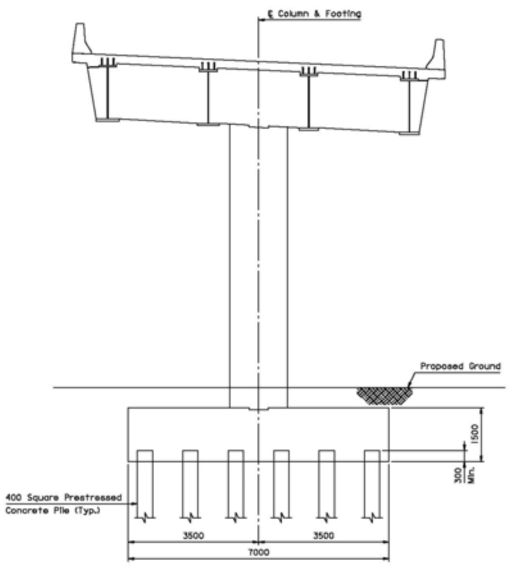

Figure 8. B627 Pier

- Integral post-tensioned pier cap (Figure 8) - This allows reduction of cost due to reduction of the structure length, and reduction of superstructure loads through frame action. This also improves structural redundancy, eliminates bearings and thereby reduces maintenance requirements, and improves aesthetics.
- Equal span lengths (Figure 7) - This span layout eliminates dead load torsion in the integral pier cap.
- Lightweight backfill behind the abutments - This reduces fill settlement and downdrag on the piles, and also reduces lateral earth pressure, thereby reducing the structural consequences of combining integral abutments with curved girders.

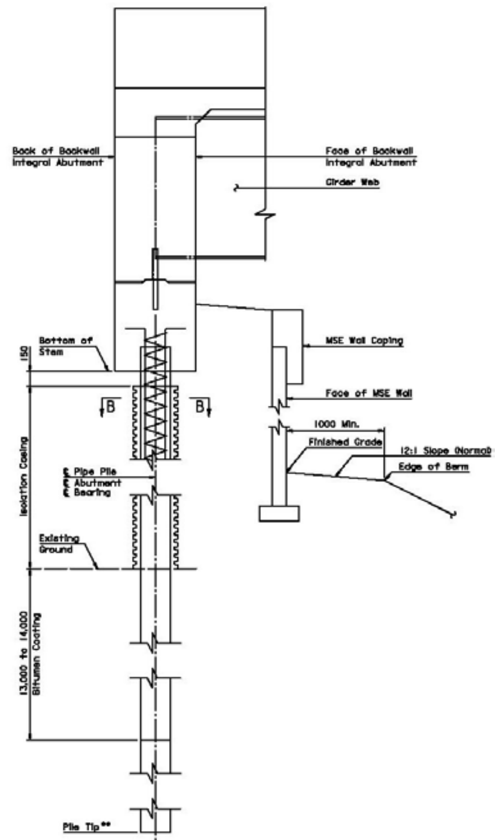

Figure 9. B627 Typical Abutment Section

- Isolation casings and bituminous coating around the steel pipe piles (Figure 9) - These reduce downdrag on the piles.

GENERAL RECOMMENDATIONS AND LESSONS LEARNED

This project involved three bridges in challenging, but not atypical, design situations. To address these challenges, an effort was made to incorporate state-of-the-art and innovative design concepts in order to develop bridge solutions with lower cost, improved durability, and pleasing aesthetics. Many of these design concepts should be applicable to a wide variety of bridge projects, and recommendations in this regard are provided below.

Structure Layout, Joints, Bearings, and Substructure

- When the main function of end spans is to provide continuity to interior spans, study shortened end spans with counterweight abutments.
- Eliminate joints and bearings by using integral construction wherever feasible, but expect complexity of structural analysis to increase due to higher degree of structural indeterminacy.
- Use integral pier caps where radial support, improved horizontal clearance, improved vertical clearance, and/or improved aesthetics are desirable.
- Use integral abutments wherever feasible, including curved girder bridges.
- When using integral abutments with curved girder bridges, carefully consider all resulting load effects.
- Consider MSE abutments as an alternative to conventional concrete abutments.
- If bearings are required, use elastomeric bearings instead of metal bearings wherever feasible.
- With box girders, use single bearings instead of dual bearings if the flange width is narrow enough.

Girders

- For curved girder bridges with significant span length and curvature, consider using box girders instead of I-girders, especially when difficulties associated with fit-up of diaphragms can be reduced.
- Use a minimum box girder depth of 1.5 m (5 ft), preferably 1.8 m (6 ft).
- Paint box girder interiors white and consider providing lighting.
- With box girders, use fiberglass hatches instead of steel, particularly for larger hatches.
- With curved box girders, ensure that sufficient deck reinforcing is provided to compensate for lack of external diaphragms.
- Use high-performance steel wherever the additional strength of the steel can be efficiently utilized.

Construction and Geotechnical

- Where construction access is limited and size of pile-driving equipment is limited, consider using steel pipe piles.
- When uplift capacity of piles can provide useful reserve strength, detail foundations to utilize this capacity.
- When lateral earth pressure behind abutments is a significant issue, consider using lightweight fill.

ACKNOWLEDGEMENT

The Project Owner, Virginia DOT, through liaison with Mr. Mir Ali, P.E., and the Prime Consultant, SITE-Blauvelt Engineers, were receptive to innovative cost-saving ideas throughout the design process and provided helpful review comments. Without this receptive approach, the innovations incorporated into the three bridges described in this paper would not have been possible.