U.S. ROUTE 460 PHASE I CONNECTOR OVER GRASSY CREEK AND ROUTE 610

Durable and cost-effective cast-in-place segmental design-build project in Virginia

by Leo Spaans, Janssen & Spaans Engineering Inc.

Located in western Virginia near the state line with Kentucky, the U.S. Route 460 Phase I Connector over Grassy Creek and Route 610 in Buchanan County spans a deep valley. Due to the need for such tall, flexible columns, geometry control for the superstructure became quite challenging. This article describes the project and further explains how critical geometry control for both the substructure and superstructure was maintained.

Description of Project

The project consists of twin, cast-in-place, segmental concrete superstructures with one prestressed concrete I-beam approach span at each end. The total length of the structure is 1725 ft. Span lengths for spans 1 through 6 are 110, 268.5, 489, 489, 268.5, and 103 ft. The pier heights measured from the bottom of the footing to the top of the superstructure for piers 1 through 5 are 109.5, 227, 261.5, 158.75, and 72.5 ft.

Piers 1 and 5, which support the prestressed concrete I-beam spans and the end spans of the cast-in-place segmental structure, are a more common pier type. This type consists of a concrete footing supported by either micro-pile or directly founded on rocks (spread footing). The column consists of two circular columns that are 6 ft in diameter with a 42-ft-wide cap.

Piers 2 through 4 have a spread footing founded on rock, with an H-shaped column integrally connected to the cast-in-place concrete superstructure.

Cost-Effective Solution

Since the project used a design-build contract, it provided the designer with unique opportunities; it allowed the designer to evaluate the different options, such as the best solution for the project based on the capabilities of the specific contractor with which the designer is working. With contractor's team input, the design options/alternatives were directly evaluated for cost effectiveness as well as utilizing the contractor's experience and capabilities.

The pier table was 50 ft long to accommodate two form travelers. All Photos: Mark's Photo.

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U.S. ROUTE 460 PHASE I CONNECTOR OVER GRASSY CREEK AND ROUTE 610 / BUCHANAN COUNTY, VIRGINIA

BRIDGE DESIGN AND CONSTRUCTION ENGINEER: Janssen & Spaans Engineering Inc., Indianapolis, Ind.

INDEPENDENT QUALITY CONTROL: Entran PLC, Lexington, Ky.

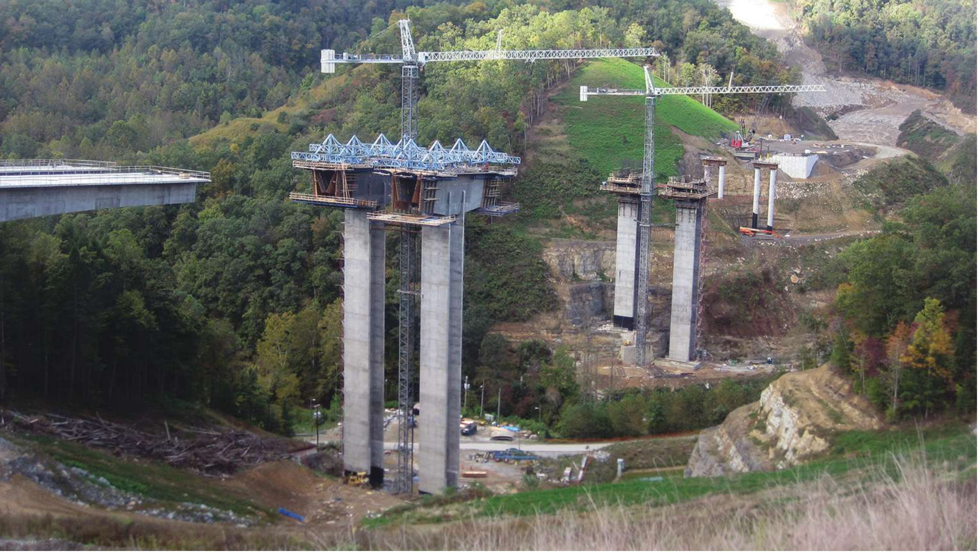
PRIME CONTRACTOR: Bizzack, Lexington, Ky./CJ Mahan, Columbus, Ohio

PRECASTER: Prestress Services Industries Inc., Melbourne, Ky.—a PCI-certified producer

POST-TENSIONING CONTRACTOR & FORM TRAVELER: VSL, Dallas, Tex.

EXPANSION JOINT & BEARING SUPPLIER: D.S. Brown, North Baltimore, Ohio

OTHER SUPPLIERS: MMFX, Irvine, Calif.



The tallest pier is 261.5 ft tall from bottom of the footing to top of the superstructure.

During the pre-bid phase, several options were studied including both steel and concrete superstructures and different span lengths in the range of 250 to 500 ft.

In developing cost curves, where both substructure and superstructure were figured in cost per square foot of deck area, it became apparent that longer spans were more cost effective. For example, the tallest pier already required 1700 yd^3 of concrete. The estimates clearly indicated that fewer piers with longer spans were more cost effective.

Structure height and the difficult site conditions made crane erection not cost effective for superstructure erection. The preliminary designs considered steel plate girders and steel box girders using a launching system, and cast-in-place segmental box girders constructed with form travelers.

Again, erection with overhead launching trusses for such a short structure (1725 ft) was not cost effective.

In the final analysis, the cast-in-place concrete segmental option turned out to be the most cost-effective solution for this contractor team.

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Superstructure Design

The cast-in-place concrete segmental superstructure consists of a variable depth, single-cell box girder which is 12.5 ft deep at midspan and 30.25 ft deep at the pier. The overall width of the box girder is 43 ft 4 in. The typical segment length is 16 ft 6 in. and the pier table is 50 ft long. This allowed two form travelers to be placed on the pier table at the same time without too much interference with each other.

For durability, the superstructure used an 8.0 ksi compressive strength concrete, as well as non-prestressed reinforcement meeting ASTM A1035. The deck of the box girder is transversely post-tensioned with four 0.6-in.-diameter strand tendons at 2 ft centers. The design was based on zero allowable tension in the top of the deck at full-service-load conditions.

The longitudinal analysis used the same zero-allowable-tension criteria. The cantilever tendons consisted of nineteen, 0.6-in.-diameter strands. Twelve 0.6-in.-diameter strands were used for the continuity tendons. Both groups of tendons used the bonded system, with ducts placed in the concrete section. External unbonded tendons were provided for future use. The design provided anchor points and deviation blisters to allow for 10% of the permanent post-tensioning to be added at any time in the future.

Based on the as-built structure, the following quantities were used for the superstructure:

- 14,590 yd^3 of concrete, providing an equivalent thickness of 3 ft
- 2,590,550 lb of nonprestressed reinforcement, based on 178 lb/yd^3
- 2,239,000 lb of post-tensioning tendons, with 2.5 lb/ft^2 in the transverse direction of the deck and 17 lb/ft^2 in the longitudinal direction

Piers 1 and 5 used two columns with a cap beam.

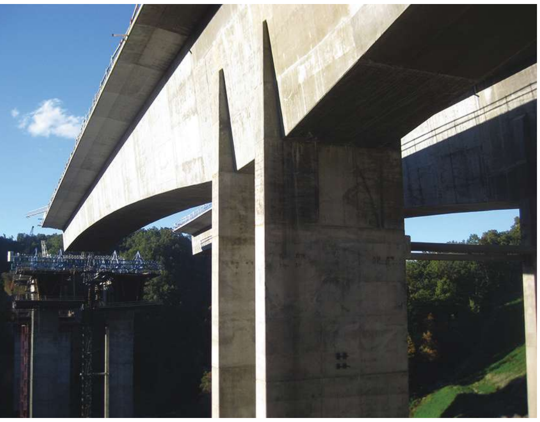
COMMONWEALTH OF VIRGINIA DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: Twin, 1725-ft-long, post-tensioned, cast-in-place, segmental box girder bridge

STRUCTURAL COMPONENTS: Each bridge consists of five cast-in-place concrete pier columns supporting four spans of cast-in-place single-cell box girder and two spans of precast, prestressed concrete I-beams

BRIDGE CONSTRUCTION COST: $47 million ($314/ft^2)

AWARDS: *Roads & Bridges* magazine Top Ten Bridges, Number 1



The walls of the H-shaped pier columns continue into the box girder to provide an integral connection.

The single-cell box has a depth of 30.25 ft at the pier.

Substructure Design

The tallest pier column from the bottom of the footing to the top of the superstructure is 261 ft tall, which created some interesting design challenges. To make connections integral with the superstructure and eliminate bearings, an open section was used. This, as opposed to a typical box section, avoids the steel staircase, eases future inspection, and simplifies forming.

Switching from a box section to an open H section has significant consequences for the stiffness of the column, especially during the construction of the free cantilever superstructure. Dead loads, construction loads, an unbalance moment at the top of the column, and additional wind loads on the cantilever are significant, requiring a delicate balance between the needed stiffness and the acceptable deflections.

The reduced moment of inertia compared to that of a closed box section created issues with the torsional stiffness. This also required the designer to address local buckling of the flanges, horizontal rotation, and torque in the pier columns.

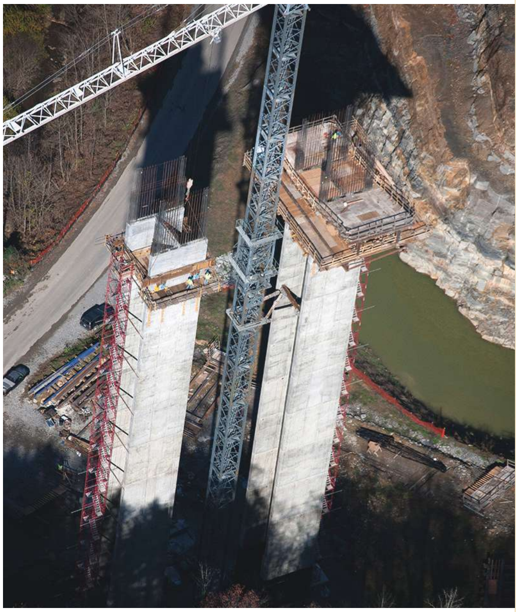
The H-shaped pier column is ideal for making an integral connection between the column and superstructure. The walls of the H column continue into the box girder and act as diaphragms in the box. Because the width of the wall actually widens the bottom slab, the shear forces in the webs of the box girder flow directly into the pier column. There is no need to have complicated reinforcement and/or transverse post-tensioning to push or pull the superstructure reaction forces onto a bearing support. These forces simply go into the column. This type of integral connection greatly simplifies the design and translates into simpler, easier, and more cost-effective construction.

Geometry Control

Geometry control of both the substructure and superstructure was critical. The columns were cast in segments about 20 ft tall with a climbing form system. The tallest column was 222 ft 2 in. tall and required 11 separate concrete placements.

The typical H-shaped pier has wall thickness of 2 ft except for the bottom 34 ft, where the minimum thickness is 3 ft. Upon completion of each concrete placement, the contractor performed a survey similar to that used for the segmental superstructure. These survey results were included in the information for setting the formwork for the next concrete placement. Using this method, the contractor was able to keep the geometric deviation within ½ in. for the entire column.

Upon completing the weekly cycle of casting superstructure segments, a survey was taken of the as-cast segments. These data were then incorporated into the setting of the form travelers for the next casting cycle. The contractor and the designer both performed the calculations, with the designer serving as an independent check.



The H-shaped pier column provided a flexible column, which made geometry control very important.

The geometry control for the superstructure became important with such tall, flexible columns. Not only did the loads cause rotation of the cantilever, they also caused horizontally movement up or down station of about 4 in. depending on which direction the unbalance moment acted. The end of the cantilever also moved about 12 in. up or down. These displacements were just due to dead load and did not include wind load, construction load, and/or movements caused by differential temperatures.

In theory, geometry control is quite simple if the engineer knows the exact properties of the column. However, the actual modulus of elasticity of the concrete and differential temperature of column play a big role in the behavior of the column. For geometry control during the erection, theoretical and actual behavior were fine-tuned so that the predictions for geometry control matched the actual behavior of the structure.

Leo Spaans is chairman of Janssen & Spaans Engineering Inc. in Indianapolis, Ind.

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