PROJECT

A Challenge of Geometry

Value-engineered shift from steel to concrete saves $19 million on a complex Interstate 20 bridge project

by Natalie McCombs, HNTB, and Micah Dew, Mississippi Department of Transportation

The Mississippi Department of Transportation (MDOT) had deemed a heavily traveled stretch of Interstate 20 (I-20) in Jackson, Miss., to be in need of replacement. The existing structure had three steel straddle-bent cap beams that classified the bridge as fracture critical. The goal was to replace a deteriorated section of I-20 eastbound with a larger bridge at the interstate's confluence with Interstate 55 (I-55) and U.S. Route 51 (U.S. 51). Once complete, the new bridge would handle eastbound I-20 traffic.

The project's complex geometry and long, elevated spans seemed to dictate the use of steel girders for the bridge superstructure. However, such a design would be costly, so examining the budget and identifying ways to reduce costs became key discussion points early in the design process. MDOT engaged a design consultant to perform a formal value-engineering study to identify specific ways to reduce the overall project cost.

A Consequential Shift in Direction

Original preliminary designs called for a 1789-ft-long bridge consisting of three units: unit 1 with three spans, unit 2 with one span, and unit 3 with four spans (**Fig. 1**). However, the 360-ft-long span in unit 3 required rather substantial 144-in.-deep steel girders, which in turn mandated a taller overall bridge structure to achieve required vertical clearances. More specifically, designers specified steel plate girders on radial bents supported by drilled shafts and pile footings. The bridge units each consisted of welded plate girders with 80- or 144-in.-deep web plates, flange thicknesses up to 3¼ in., and multiple grades of weathering and high-performance steel.

Aerial view of completed bridge before opening to traffic, looking west. Photo: Mississippi Department of Transportation.

The roadway varied in width from 60 to 72 ft. Additionally, the design of the east end of the bridge addressed the embankment stability by using a pile-supported relieving platform and reticulated micropile walls.

The steel girder component had a cumulative effect on cost, primarily due to the expense of erection and longer fabrication lead times. The initial cost estimate for the entire project was $50 million, with the bridge portion totaling $37 million.

Prestressed concrete beams are common in the state of Mississippi and are easy to fabricate and erect. The largest cost savings would come by using innovation

profile

INTERSTATE 20 EASTBOUND BRIDGE OVER INTERSTATE 55 SOUTH, INTERSTATE 20 WESTBOUND RAMP, U.S. ROUTE 51, AND CN RAILROAD / HINDS COUNTY, MISSISSIPPI

BRIDGE DESIGN ENGINEER: HNTB Corporation, Kansas City, Mo.

CONSTRUCTION ENGINEER: Huval & Associates Inc., Lafayette, La.

PRIME CONTRACTOR: Key Constructors LLC, Madison, Miss.

PRECASTER: Gulf Coast Pre-Stress Partners Ltd., Pass Christian, Miss.—a PCI-certified producer

POST-TENSIONING CONTRACTOR: Structural Technologies Inc., Fort Worth, Tex.

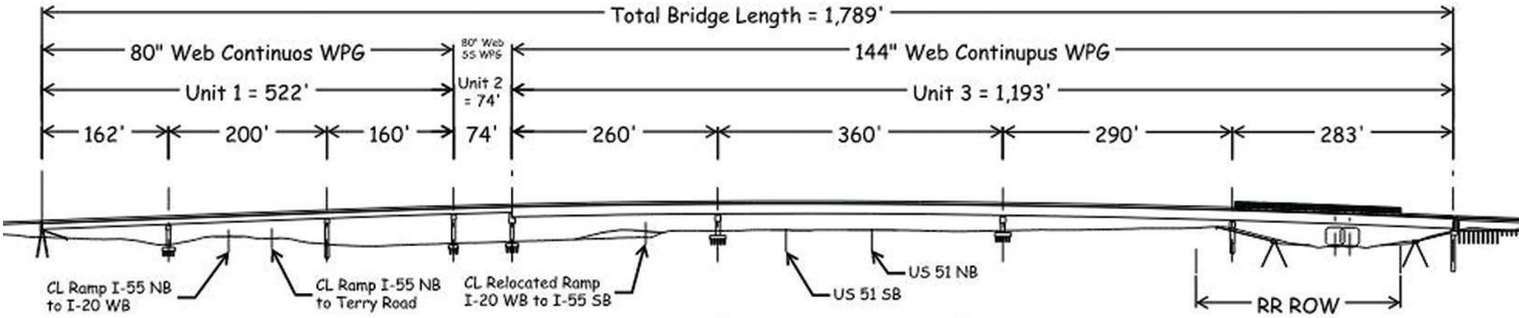


Figure 1. Original preliminary design with steel girders. Span 1 is at the west end (left). All Figures: HNTB Corporation.

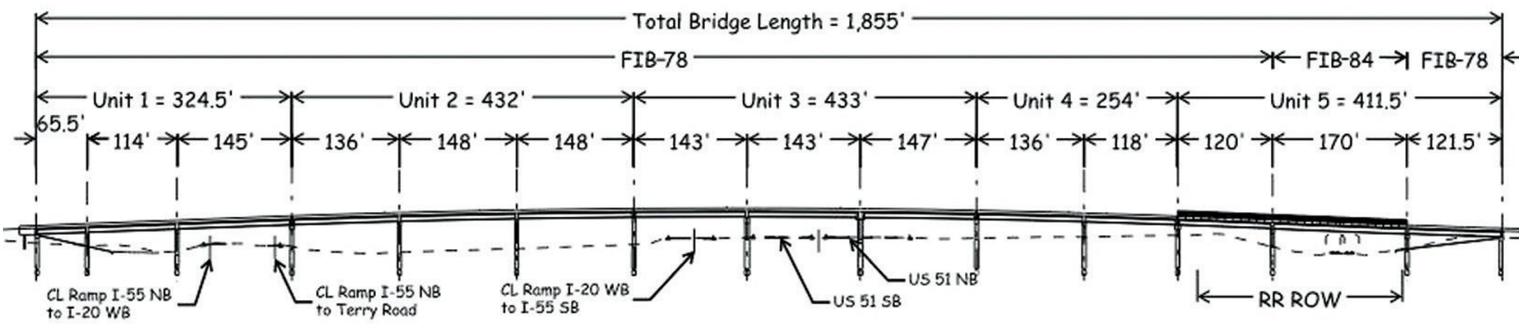


Figure 2. Value-engineered solution with prestressed concrete beams. Span 1 is at the west end (left).

Aerial view of the bridge under construction looking west toward bent 1. Prestressed concrete beams have been erected and stay-in-place deck forms and deck reinforcement have been placed. Photo: Mississippi Department of Transportation.

in bent placement and nontypical bent designs. The goal was to get the span lengths down to within prestressed concrete beam limits, which the design consultant was able to achieve. The value-engineering study revealed the following 10 items could bring the project cost within budget:

- Keep an existing I-55 southbound ramp in its existing location beneath the bridge.
- Place some foundation elements in the median of U.S. 51.
- Incorporate straddle bents where necessary.
- Incorporate drilled shafts for the entire bridge substructure.
- Skew bents to accommodate various ramps and roadways.
- Use post-tensioned inverted-tee cap beams where appropriate.
- Use precast, prestressed concrete beams.
- Innovatively reduce the length of the span over a 200-ft-wide railroad right-of-way.
- Lengthen the span on the east end of the bridge by 62 ft to avoid the need for a pile-supported relieving platform and reticulated micropile walls.
- Flatten the horizontal curve where possible.

An overhauled design with a longer 1855-ft bridge and roadway widths ranging from 60 to 72 ft was recommended. Most significantly, the bridge incorporated more, albeit shorter, spans. Apart from a 170-ft-long span over the railroad at the project's easternmost end, none of the other spans exceeded 148 ft along the centerline.

To accommodate the curved horizontal alignment and skewed substructure units, the prestressed concrete bulb-tee girders are on chords between bents and are flared with spacings varying from 9 ft to 11 ft 4 in. Of the girder spans, there are 13 spans of 78-in.-deep prestressed

MISSISSIPPI DEPARTMENT OF TRANSPORTATION, OWNER

OTHER MATERIAL SUPPLIERS: Reinforcing steel: Magnolia Steel Co. Inc., Meridian, Miss.; girder lift assistance: Barnhart Crane & Rigging, Jackson, Miss.; bearing devices: R.J. Watson Inc., Alden, N.Y.; expansion joints: Watson Bowman Acme Corp., Amherst, N.Y.; deck drainage system: C.L. Dews & Sons Foundry & Machinery Company Inc., Hattiesburg, Miss.

BRIDGE DESCRIPTION: 1855-ft-long, 5-unit, 14-span prestressed concrete Florida I-beam bridge

STRUCTURAL COMPONENTS: 12,202 ft of prestressed concrete beams with 86 FIB-78 and 7 FIB-84 beams, 8-in.-thick cast-in-place deck slab with metal stay-in-place forms and concrete continuity diaphragms supported on cast-in-place concrete multicolumn bents, two of which have post-tensioned straddle cap beams, all supported on drilled shafts

BRIDGE CONSTRUCTION COST: $19.3 million concrete Florida I-beam (FIB-78) girders and one span of 84-in.-deep prestressed concrete Florida I-beam (FIB-84) girders in the railroad right-of-way. These are the longest and deepest precast concrete girders to ever be used in the state.

The outcome of the study (**Fig. 2**) was significant and consequential, as it lowered construction costs, improved traffic management, and minimized long-term maintenance. Ultimately, approximately $19 million in project savings were identified. The as-bid construction cost for the bridge was $19.3 million.

Complex Geometry

Challenges of geometry are not uncommon on interstate bridge projects, and the I-20 project was no exception. For example, spans 1 through 10 (**Fig. 3**) are on a 1488-ft-radius horizontal curve and have a cross slope up to 9.2%, whereas spans 11 through 14 are on a tangent alignment. Additionally, much of the bridge is in a 1130-ft-long vertical curve with 3.7% grades. The width of the bridge also varied—the east end of the bridge was 60 ft wide, whereas the west end was 72 ft wide along the curve.

To make the bridge geometry work, the bents were creatively situated in roadway medians and shoulders and skewed by as much as 40 degrees to accommodate the railroad, roadways, and ramps.

Bents 8 and 9 were particularly challenging because the roadways beneath them precluded a typical multicolumn bent design. These bents were supported by only two columns to allow traffic below to pass under the cap beams. The cast-in-place concrete straddle cap beams spanned 65 ft and two stages of post-tensioning. The first stage was for the self-weight of the cap beam and the second occurred after the girders were set. Each cap beam has four tendons with thirty-seven 0.6-in.-diameter strands tensioned from only one end, with two tendons tensioned in each stage. The locations of the columns were tied to the clear zone of the roadway below. The layout required one end of the cap beam to cantilever beyond the column to support the exterior girder, resulting in a nonstandard drape of the post-tensioning tendons. The unique

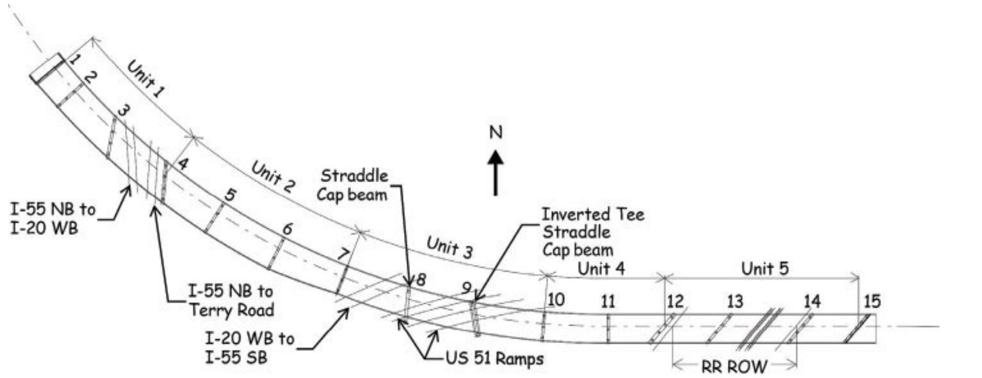
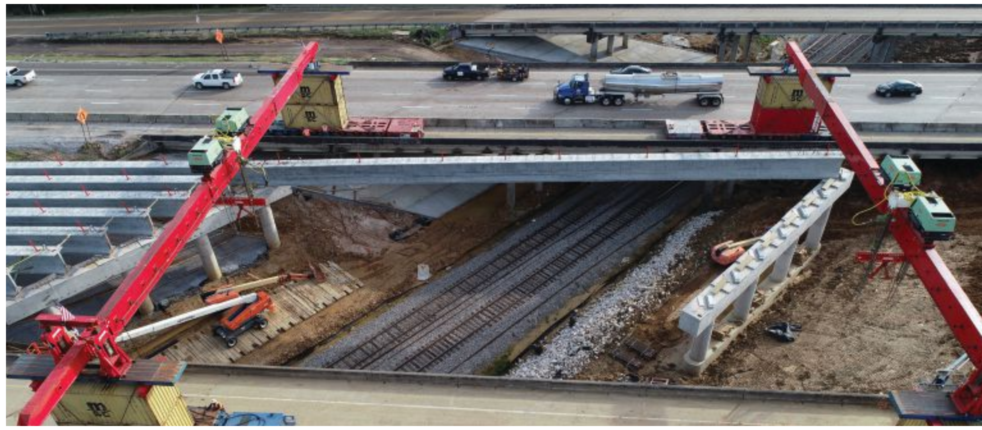


Figure 3. The schematic plan view of the structure illustrates the project's complex geometry and the challenging pier orientations. Bent numbers are shown on the figure.



Setting the 170-ft-long, 84-in.-deep prestressed concrete Florida I-beams over the railroad tracks was a challenge. These 200,000 lb girders were erected with an innovative gantry system using self-propelled modular transporters (for details, see the related article in the Summer 2021 issue of *ASPIRE*®). Photo: Mississippi Department of Transportation.

post-tensioning and loading led to a maximum post-tensioning jacking force of 1735 kip (80% of the ultimate tensile strength of the prestressing tendon, $0.80 \times f_{pu}$), with a maximum effective post-tensioning force of 1474 kip ($0.68 \times f_{pu}$).

While most columns have a 4-ft diameter with 4.5-ft-diameter drilled shafts, the columns at straddle bents 8 and 9 are 5.5-ft in diameter and supported by 6-ft-diameter drilled shafts. Bent column heights vary from 12 to 50 ft. Column configurations are as follows: bents 2 through 6 and 12 through 14 are four-column bents; bents 7, 10, and 11 are three-column bents; bent 8 is a two-column straddle bent with a post-tensioned cap beam; and bent 9 is a two-column straddle bent with an inverted-tee post-tensioned straddle cap beam made integral with the superstructure. For bent 9, the beams were set on the corbel of the inverted-tee cap beam and then a full-depth cast-in-place concrete diaphragm was placed around the beams to make the fully integral connection.

Looking south at the installed 178-ft-long, 84-in.-deep prestressed concrete Florida I-beams crossing the railroad. These are the longest girders used in Mississippi to date. Photo: HNTB Corporation.

Bent 8 has a 65-ft-long straddle cap beam that required two stages of post-tensioning. The first stage was for the self-weight of the cap beam (already completed); in the second stage, tendons were tensioned shortly after the girders were set (not yet completed). Photo: HNTB Corporation.

Prestressed concrete girders sit on the inverted-tee straddle cap beam at bent 9 before placement of the full-depth continuity diaphragm. Each of the two straddle cap beams has four tendons with thirty-seven 0.6-in.-diameter strands that were tensioned from only one end. Photo: HNTB Corporation.

Unquestionably, prestressing in the concrete girders was integral to achieving necessary span lengths. Twenty different strand-pattern designs were needed to accommodate span lengths from 60 to 150 ft for the FIB-78 girders and the longer-span FIB-84 girders, while also achieving loading and camber criteria. Of the 14 spans, only four had girder lengths with less than 5 ft difference between the shortest and longest girders per span. For all other spans, the difference in girder lengths from shortest to longest per span varied between 5 and 55 ft.

Innovating Along the Way

On the project's eastern end, lengthening the bridge was proposed to accommodate a long-standing slope stability issue in the railroad right-of-way and to allow installation of slope stability piles and monitoring of the slopes throughout construction.

The railroad right-of-way was 200 ft measured perpendicular to the track, which then required a longer span along the alignment. As with the original design, the railroad would allow only one pier in their railroad right-of-way; also, this pier had to be a minimum of 54 ft clear from the nearest track, and there were two tracks. These criteria set the maximum span length for the entire project. This resulted in the placement of the longest concrete girders in Mississippi's history, seven of them reaching 170 ft and weighing 200,000 lb each. These large girders, as well as the girders in the two adjacent spans, were erected with an innovative gantry system using self-propelled modular transporters. For details of the system, see the Creative Concrete Construction article in the Summer 2021 issue of *ASPIRE*®.

Standard 78-in.-deep Florida I-beams typically have a maximum span length of 150 ft. To increase the span length of this section, thickening of the 4-ft-wide top flange was considered.However, this solution would have added a significant amount of weight for very little structural gain. The solution that was ultimately chosen was to simply use the FIB-84 section, which is the next larger standard size in the Florida I-beam family of sections. The 6-in. additional web depth provided the required increased structural capacity at a fraction of the additional concrete weight.

There were other creative solutions. To decrease the number of expansion joints in the curved bridge from 15 to 6, the team used full-depth diaphragms to make the girders continuous for live load. By embedding the beams into concrete diaphragms at the piers, the design (nonstandard for MDOT) closes the joint and forces water to travel down to the next expansion joint. In effect, locations where the water will drain onto the substructure are limited; this design decision will result in less long-term maintenance and more durability in the substructure.

Material specifications for major components were as follows:

- The cast-in-place, 8-in.-thick concrete slab had a 28-day concrete compressive strength of 4 ksi.
- For bents 8 and 9, the concrete in the bents and drilled shafts had a minimum 28-day concrete compressive strength of 6 ksi.
- For all other bents, concrete in the bents and drilled shafts had a minimum 28-day concrete compressive strength of 4 ksi.
- Prestressed concrete beams had a minimum concrete compressive strength at transfer of 6.5 ksi and 8.5 ksi at 28 days.
- Mild steel reinforcement was Grade 60 ASTM A615.[1]
- For pretensioning and post-tensioning, ASTM A416[2] Grade 270 0.6-in.-diameter strands were used.

Conclusion

Creative value engineering and innovative construction techniques saved MDOT $19 million on this complex project. The bridge was open to traffic July 22, 2021, with other tasks continuing through the end 2021.

References

1. ASTM International. 2020. *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*. ASTM A615/A615M-20. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/A0615_A0615M-20.

2. ASTM International. 2018. *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*. ASTM A416/A416M-18. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/A0416_A0416M-18.

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