

PROJECT

Paducah & Louisville Railway Bridge J23.7

New railroad bridge pushes the limits of typical rail construction to replace a 120-year-old, 120-ft-tall trestle structure

by Scott Wojteczko and Michael O'Connor, Alfred Benesch & Company

Paducah & Louisville (P&L) Railway Bridge J23.7 was originally constructed in the 1880s as a curved, 700-ft-long, 120-ft-tall steel trestle structure. It was built along land that would eventually become the Fort Knox Army Base. Less than ½ mile down the track is P&L Railway Bridge J23.3, a structure of similar age and construction to P&L Railway Bridge J23.7, though shorter and on a tangent. These two historic freight rail bridges, known together as the Muldraugh bridges, allow the P&L to

- transport commodities across Kentucky, and
- maintain rail access for military shipments to Fort Knox Army Base (as the only rail line servicing the base).

The age and condition of the existing trestle structures had necessitated numerous repairs and strengthening measures over the past 20 years to maintain continual rail service. With repair costs mounting each year and both structures beyond their expected service lives, P&L made the decision in 2009 to move forward with the replacement of both P&L Railway Bridge J23.3 and P&L Railway Bridge J23.7.

The P&L initiated a two-phase program that would commence with the replacement of P&L Railway Bridge J23.3 and culminate with the replacement of P&L Railway Bridge J23.7. After the financial commitment

that had been made in replacing P&L Railway Bridge J23.3, the P&L was awarded a Transportation Investment Generating Economic Recovery (TIGER) Grant in 2011 towards the replacement of the more-complex P&L Railway Bridge J23.7. Construction on P&L Railway Bridge J23.7 began in the fall of 2012 and was completed in the summer of 2014.

Railway Re-Alignment

The original P&L Railway Bridge J23.7 was built on a 5-degree horizontal curve spanning a valley that contained a creek, hiking trail, and Fort Knox private-access road. A large fill had been constructed on the west side of the valley to minimize the overall bridge length. Reconstruction of P&L Railway Bridge J23.7 on the existing alignment would have been highly constrained by

the location of the existing steel trestle towers, with rail closures required to systematically remove and replace sections of the existing structure.

The project team elected to construct P&L Railway Bridge J23.7 offset north of the existing structure, with span lengths maximized to minimize the number of substructure units required. Piers could not be located within the existing creek, trail, and roadway. Additionally, the topography of the region is highly irregular through the valley, with vertical exposed rock faces in some locations and 50 ft of overburden material in others. The final bridge layout includes 14 spans, with maximum span lengths of 85 ft and an overall bridge length of 1031 ft. Piers reach elevations 120 ft above grade in the deepest portions of the valley. The horizontal curve across

Aerial view of completed P&L Railway Bridge J23.7, looking north. Photo: Alfred Benesch & Company.



profile

PADUCAH & LOUISVILLE RAILWAY BRIDGE J23.7 / WEST POINT, KENTUCKY

BRIDGE DESIGN ENGINEER: Alfred Benesch & Company, Chicago, Ill.

CONSTRUCTION ENGINEER: GEM Engineering Inc., Louisville, Ky.

PRIME CONTRACTOR: Haydon Bridge Company, Springfield, Ky.

PRECASTER: Prestress Services Industry LLC, Lexington, Ky.—a PCI-certified producer

OTHER MATERIAL SUPPLIERS: Reinforcement: Gerdau, Muncie, Ind.; and Bearings: D.S. Brown, North Baltimore, Ohio



Chorded beam layout at the east end of the bridge. Photo: Alfred Benesch & Company.

the bridge has been reduced from 5 to 4 degrees to reduce track maintenance and enhance sight distances. The bridge is within a vertical curve, with a maximum grade of 1.3%.

Substructure

Each typical pier consists of two 7-ft-diameter circular reinforced concrete columns spaced at 21 ft on center. Transverse concrete struts that are 5-ft square are in place every 30 ft of height to increase the transverse stiffness of each pier and reduce the unbraced length of the columns. Each pier column is supported by a single 8-ft-diameter, drilled-shaft foundation, with 7-ft 6-in.-diameter rock sockets. Minimum rock socket depths of 2.5 times the shaft diameter were considered, with greater lengths installed where weak or fractured rock was encountered.

The American Railway Engineering and Maintenance-of-Way Association (AREMA) design requirements for longitudinal force due to traction and braking are significant when compared to traditional highway design, with force magnitudes greater than 5% of the total superstructure dead load. Compounding the challenge of resisting longitudinal force, AREMA limits the allowable longitudinal deflection from these forces to 1 in. To meet the deflection criteria with the two-column

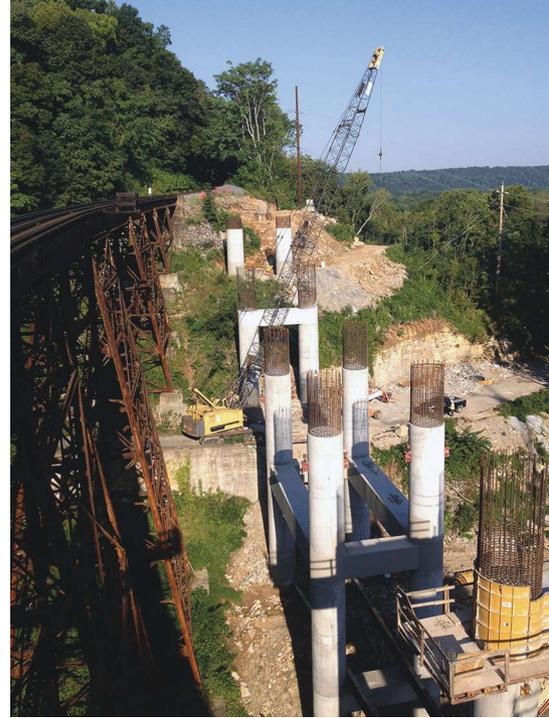
pier approach would have required the sizing of columns and drilled shafts to be increased dramatically.

Instead of increasing the size (and cost) of all pier columns and shafts, the concept of central “rigid braced piers” was introduced to the system. The rigid braced piers were created by reducing the spacing between Piers 5 and 6 and between Piers 10 and 11 to 47 ft 6 in. and adding 6-ft-square, reinforced concrete longitudinal struts between the pier columns. These rigid braced piers provide substantial longitudinal stiffness, with the capacity to absorb the majority of the longitudinal force while meeting AREMA deflection requirements.

To ensure the longitudinal load could be distributed to the two rigid braced piers without first imposing excessive deflections on the slender piers, multiple spans were designed with fixed-fixed end conditions. This is atypical for railroad design, where spans are typically of fixed-expansion layout. The introduction of double fixity allowed the bridge to be divided into four units, with each rigid braced pier providing more than 90% of the longitudinal stiffness within their respective bridge units.

Superstructure

New railroad bridge construction commonly uses standard precast



Pier construction at the west end of the bridge. Photo: P&L Railway.



Walkway hatches provide ladder access to pier caps for inspection of beams ends and bearings. Photo: Alfred Benesch & Company.

concrete box beams and slabs for span lengths up to 36 ft. When span lengths are in excess of 36 ft, it is most common to utilize steel rolled beams or plate girders with two to four beams/girders per track. Precast, prestressed concrete I-beams are not used regularly in the design of railroad bridges subject to

PADUCAH & LOUISVILLE RAILWAY INC., OWNER

BRIDGE DESCRIPTION: A 1030-ft-long, single-track ballast-deck railroad bridge with heights up to 130 ft over a deep valley on a 1432-ft radius horizontal curve, with 14 spans with lengths varying from 47 to 85 ft and a 14-ft-wide deck

STRUCTURAL COMPONENTS: Type IV, 54-in.-deep, precast, prestressed concrete I-beams; Kentucky Type 7 modified, 72-in.-deep, precast, prestressed concrete I-beams; a 10-in.-thick, cast-in-place concrete deck; piers with 7-ft-diameter columns; and 8-ft-diameter drilled shafts socketed into rock

BRIDGE CONSTRUCTION COST: \$10.6 million (\$10,290/linear ft)



Erection of 72-in.-deep precast, prestressed concrete I-beam in an 85-ft span, using a dual crane lift. Photo: Haydon Bridge Company.

freight loads but are more common to American Association of State Highway and Transportation Officials (AASHTO) highway bridge designs, primarily due to loading and schedule. However, precast, prestressed concrete I-beams can provide an economical solution for long-span railroad structures under the right conditions.

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By reducing the concrete beam spacing beneath the track, the concrete beams can meet capacity and serviceability requirements for longer spans. Additionally, reconstructing a railroad bridge on an offset alignment allows more time within the construction schedule for a cast-in-place concrete deck to be built and cured on the precast, prestressed concrete I-beams.

Evaluation of standard Kentucky beam sizes determined that the 72-in.-deep, Type 7 modified precast, prestressed concrete I-beams could provide sufficient capacity and stiffness for the maximum 85-ft span lengths with

four beams supporting the track. The beams are spaced at 3 ft 6 in., chorded along the horizontal curve. The specified compressive strength of concrete in these beams was 5.5 ksi at transfer of prestress, with a 28-day strength of 7 ksi.

Each beam has 16 straight prestressing strands in the bottom flange and six draped strands. Two additional partially debonded straight strands were included in the top flange of each beam to account for high initial stresses during shipping. These strands were detensioned before placement of the deck and diaphragms.

In addition to the 72-in.-deep precast, prestressed concrete I-beams, the 47-ft 6-in. spans within the rigid braced piers utilize four 54-in.-deep precast, prestressed concrete I-beams, also at 3 ft 6 in. spacing.

The concrete beams in each span support a 10-in.-thick, 14-ft-wide, cast-in-place concrete composite deck and parapets with a concrete compressive strength of 4 ksi. All spans are simply supported with joints in the deck at the end of each span, as is typical of railroad bridge construction. To accommodate the close beam spacing, stay-in-place forms were used for the deck.

Seismic Considerations

P&L Railway Bridge J23.7 is located in an outer ring of the New Madrid Seismic Zone; thus seismic guidelines in Chapter 9 of the AREMA manual were followed. Based on the significance of the structure, the project approach was to design P&L Railway Bridge J23.7 to behave elastically under Level 2 ground motion, with appropriate detailing measures to prevent failure in the event of a Level 3 ground motion.

Because of the multi-span irregular configuration, the code required a modal analysis to be performed. The designers used 3-D finite element modeling software to generate controlling mode shapes and natural frequencies of the structure for the design response spectrum of each level of ground motion. The modes were then combined to generate the design seismic loads for all substructure elements.

Appropriate AREMA detailing provisions were incorporated into the structure to meet performance requirements for Level 3 ground motions. Notable design and detailing provisions to improve ductility included

- no lapping of vertical reinforcement within column plastic hinge zones,
- butt-welded confinement hoops used in all columns and shafts, with maximum spacing reduced in plastic hinge zones,
- continuous welded rail specified across the structure to provide load path redundancy and increase bridge damping,
- transverse and longitudinal pier struts designed to yield prior to column yielding, forcing the initial plastic hinges to form within the secondary members, and
- foundations designed for the lesser of 1.3 times the column strength or the Level 3 ground motion load.

Summary

Reconstructing the P&L Railway Bridge J23.7 posed many significant challenges, not the least of which was how to span a 130-ft-deep, narrow, irregularly shaped valley. The project team successfully looked beyond typical railroad bridge design methods and construction materials to develop a highly maintainable, cost-effective bridge solution.

The new concrete structures in place at markers J23.3 and J23.7 provide aesthetically pleasing bridge solutions that blend well with the rocky, irregular local topography. With both new structures now in service on the new rail alignment, trains can operate at higher speeds and carry greater loads, effectively reducing travel times and increasing the efficiency with which the P&L Railway can serve its clients. 

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