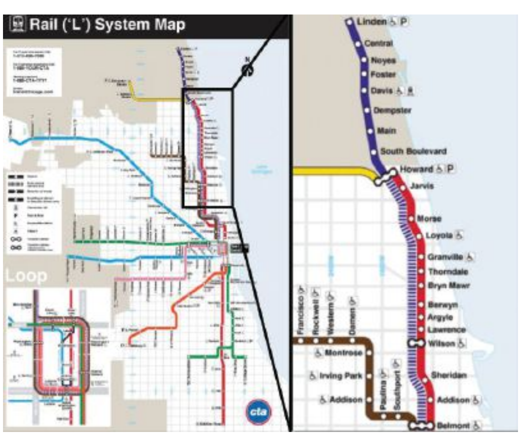
Precast Concrete Segmental Box Girders for the Red-Purple Modernization Program

by Erin Schultz and Kevin Buch, Walsh-Fluor Design-Build Team, and Ben Soule, SYSTRA International Bridge Technologies

The $1.2 billion Red-Purple Modernization Phase 1 design-build project is the largest capital project in the history of the Chicago Transit Authority (CTA). In its entirety, this project affects 9.6 miles of the Red and Purple lines, which carry 20% of CTA's rail traffic and run 24 hours a day, 7 days a week. The request for proposal was issued at the end of 2017 and awarded in 2018. In February 2019, notice to proceed was given to the design-build team.

A major section of Phase 1 is the Lawrence to Bryn Mawr modernization project, which includes replacement of 1.3 miles of four tracks currently supported by aging retaining walls with a new viaduct structure. The alignment snakes through a highly congested area on the north side of Chicago, sandwiched between a city alley and buildings built against the project right-of-way. Most of the new viaduct consists of two separate parallel structures that carry two tracks each. In one area the structures are connected by a fifth middle (pocket) track with crossovers to facilitate train movement (reversing direction) and storage. Construction is staged, with trains running on two tracks while the adjacent two are constructed, resulting in an extended construction schedule that does not interrupt service.



Location of the Lawrence to Bryn Mawr Modernization project within the Chicago Transit Authority system. Figure: Chicago Transit Authority.

Precast Concrete Segmental Box-Girder Solution

CTA's original base design consisted of 60 ft steel spans supported by two drilled shafts at each concrete bent. The request for proposal for the project stated:

> *The Contractor will not use through girders, steel box girders, trusses, tied arches, prestressed concrete beams, prestressed precast voided slabs, deck bulb-tee girders (including thin flange deck bulb-tee girders), prestressed or post-tensioned concrete U-beams, tri-beam sections, double tee girders, post-tensioned members or non-prestressed precast slabs for permanent structures.*

During the pursuit phase, the design-build team brainstormed innovative solutions to mitigate the challenges and risks inherent with the tight work-zone access restrictions. When evaluating potential alternative structure types, a simple-span precast concrete segmental box girder supported by single drilled-shaft bents emerged as the best-value solution. Major benefits of this solution included implementing a span-by-span erection with a launching girder, reducing the number of foundations, minimizing on-site craft labor by using an off-site precaster, and lessening the project's impact on the surrounding community by minimizing the duration of construction. The staging of the project, with two main phases of demolition and construction, provided excellent opportunities to advance precast concrete fabrication activities while limiting the investment in forms.

CTA has used steel as its preferred building material throughout the agency's long history (see the Authority article

profile

LAWRENCE TO BRYN MAWR GUIDEWAY / CHICAGO, ILLINOIS

PRIME DESIGN ENGINEER: Stantec, Chicago, Ill.

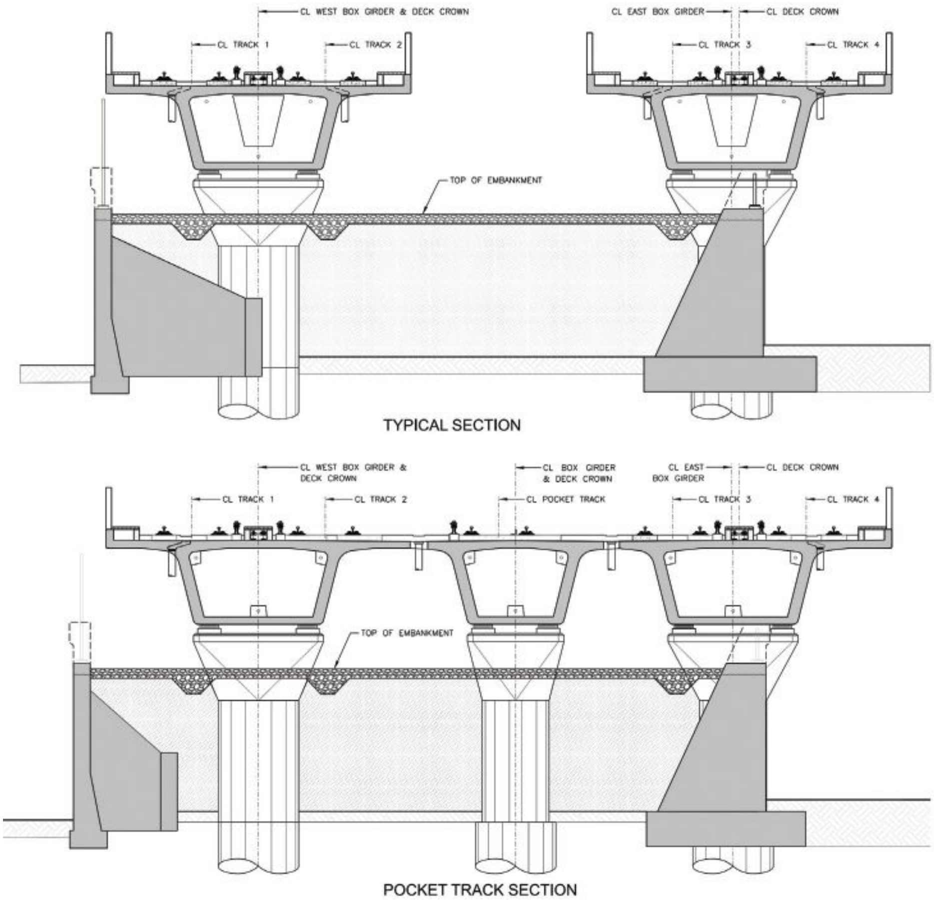
BRIDGE DESIGN ENGINEER: SYSTRA International Bridge Technologies, San Diego, Calif.

OTHER CONSULTANTS: Prime construction engineer: Collins Engineers Inc., Chicago, Ill.; segmental construction engineer: SYSTRA International Bridge Technologies, San Diego, Calif.

PRIME AND POST-TENSIONING CONTRACTOR: Walsh-Fluor Design-Build Team (a joint venture), Chicago, Ill.

CONCRETE SUPPLIER: Ozinga Ready Mix, Chicago, Ill.

PRECASTER: Utility Concrete Products, Morris, Ill.—a PCI-certified producer



Typical four-track and pocket-track configurations. Figure: Walsh-Fluor Design-Build Team.

on page 44 of this issue). CTA relies on the predictability of its steel structures and how they respond to the corrosive weather conditions as well as to stray current from the third-rail, 600-volt direct-current traction power system. Moreover, while prestressed concrete beam structures are common in the Chicago metropolitan area for highway structures, precast concrete segmental box-girder structures are not. Only a handful of precast concrete segmental bridges exist in Illinois, and none are found in Chicago.

The design-build team knew that a segmental box girder would be a significant alternative technical concept (ATC) for CTA, so the concept was introduced early during the first mandatory one-on-one meeting that was held with each prospective team during the pursuit phase. CTA was interested, but its representatives had several technical concerns, chiefly the effects of stray current within a concrete structure, replaceability of the structure without adversely affecting revenue service, and overall maintainability of the structure. Over the next five months, the team worked with CTA through their one-on-one meetings to develop solutions and commitments that would address CTA's concerns, leading to approval of the ATC and ultimately a successful bid.

Upon receipt of the notice to proceed, the team began detailed design work in earnest. As the design of the post-tensioned, precast concrete segmental viaduct progressed, it became clear that the effort could be grouped into two distinct areas: structural design and interdisciplinary coordination.

Design Challenges

At first glance, the structural design appears to be straightforward. The entire viaduct is composed of 100-, 110-, and 120-ft-long simple spans. The alignment is straight, and the structure is low to the ground. Furthermore, the foundations and substructure are repetitive and simple, with a monoshaft foundation and a single-column pier. The seismic demands are low, and the wind environment is not exceptional. However, this simplicity masked multiple project-specific requirements that kept the design team fully engaged.

Much of the effort stemmed from the design criteria. While many metro projects have design criteria based on the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*,[1] CTA has a history of designing in accordance with American Railway Engineering and Maintenance-of-Way Association's (AREMA's) *Manual for Railway Engineering*.[2] Critical differences are the higher load factors associated with AREMA (one load factor design combination has a factor of 1.8 on dead, live, and impact loads, which is significantly higher than typical AASHTO load factors) and an outdated segmental design section in the AREMA manual. As the design progressed, CTA adopted modernized design criteria: the

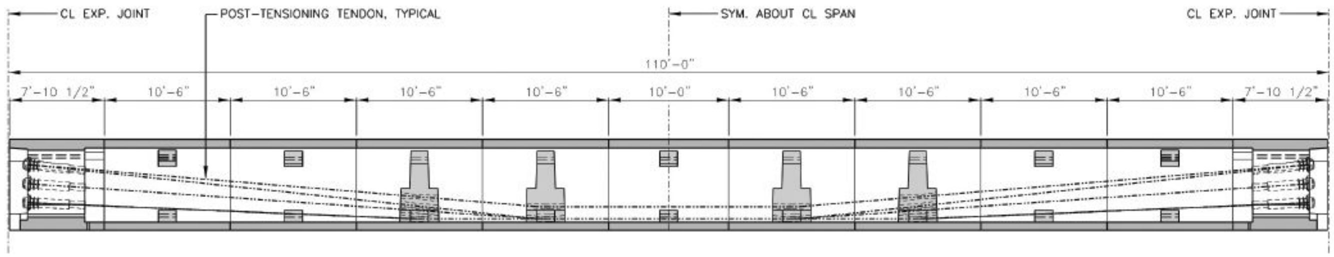
CHICAGO TRANSIT AUTHORITY, OWNER

OTHER MATERIAL SUPPLIERS: Erection equipment and segment molds: DEAL, Bay Harbor, Fla.; post-tensioning: Tensa (a Rizzani-DEAL company), Miami, Fla.; bearings: Scougal, McCarran, Nev., and RJ Watson, Buffalo, N.Y.; temporary post-tensioning: Dywidag Systems Inc., Bolingbrook, Ill.; epoxy for segmental joints: Sika Corporation, Lyndhurst, N.J.

BRIDGE DESCRIPTION: Twin 1.3-mile-long guideway bridges, each carrying two tracks of the Chicago Transit Authority's Red and Purple lines

STRUCTURAL COMPONENTS: Post-tensioned, precast concrete segmental box-girder spans varying from 100 to 120 ft, supported by reinforced concrete columns and reinforced monoshaft foundations

OVERALL PROJECT CONSTRUCTION COST: $1.2 billion



TYPICAL 110' SPAN

Elevation view showing the trajectory of the post-tensioning tendons of a typical 110-ft-long, simply supported span. Figure: Walsh-Fluor Design-Build Team.

agency retained the AREMA loads but based the capacity of segmental girders on AASHTO LRFD specifications. In this way, CTA benefits from two decades of specification development while continuing to target the original goals for reliability.

As a condition for approval, CTA required tendons that are replaceable under live load. This requirement led the team to design external tendons with custom anchorages. Because the design coupled high load factors with external tendons, the amount of post-tensioning was greater than the amount that would be required for a comparable transit structure. The extra amount was recognized and included in the bid-phase quantities.

Interdisciplinary Coordination

A transit viaduct interacts with several different systems and designs, all of which are vital to the functionality of the finished product. The interactions can involve something as obvious as the trackwork to details like lighting the signage at stations. CTA is also one of the oldest transit systems in the United States, and the new viaduct must remain compatible with the legacy hardware in operation adjacent to it.

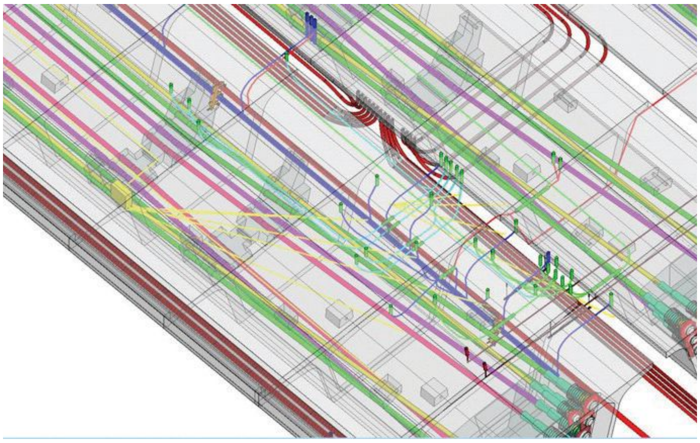
As the project progressed, the team incorporated building information modeling (BIM) into the interdisciplinary efforts and found it to be an effective tool. The stakeholders in the major disciplines—structures, track, signals, communications, and traction power—often struggle to coordinate through independently developed two-dimensional plans. BIM allowed these stakeholders to develop a common language and better understanding of each other's needs. For complex areas such as the pocket track, weekly meetings were established so that every element of the design could be accurately drawn. The real-time collaboration was critical to identifying and resolving the many potential conflicts. The modeling was also useful in creating a holistic system for managing stray-current and grounding mitigation.

Construction Phase

Given the site restrictions, erection with an overhead gantry was an obvious choice. However, the logistics for assembly of the 285-ft launching girder and delivery of the precast concrete segments to the viaduct posed their own set of challenges.

Precast Concrete Segment Casting

The project schedule afforded a unique opportunity to advance the casting of the precast concrete segments with a limited number of forms. However, significant space would be needed to store precast concrete segments until erection. The design-build team enlisted the help of a



Building information modeling (BIM) was implemented on the project to improve interdisciplinary coordination. BIM was an effective tool that allowed stakeholders in the structures, track, signals, communications, and traction-power disciplines to develop a common language and better understanding of each other's needs. Figure: Walsh-Fluor Design-Build Team.

Clearances were extremely tight during erection. The precast concrete segments are shown hanging from the launching girder. Later, epoxy adhesive was applied at the segment joints, the segments were temporarily pressed together, and the post-tensioning tendons were installed and tensioned. Photo: Walsh-Fluor Design-Build Team.

Precast concrete segments in storage at the precaster's rural facility. Photo: Walsh-Fluor Design-Build Team.

A precast concrete segment is hoisted from a haul truck on the street onto a completed viaduct span before being moved into position by a segment transporter. Photo: Walsh-Fluor Design-Build Team.

qualified, established precast concrete producer located in rural Illinois, approximately 80 miles southwest of Chicago. With a sophisticated facility and large storage yard, the precaster was able to supply the project using only three forms: two for typical segments and one for pier segments.

Segment Delivery

Because only 5 of the 11 cross streets along the alignment could be closed for extended periods, options for segment delivery locations were limited. For this reason, the launching girder was designed to accommodate segment delivery from the rear. Precast concrete segments were delivered at the various cross streets, hoisted onto the newly constructed viaduct, and then brought to the launching girder with a segment transporter.

Launching-Girder Assembly

Assembling the 285-ft launching girder between two buildings on a small neighborhood street required an innovative (but not necessarily efficient) solution. The design-build team worked

A rubber-tired segment transporter delivers a segment to the launching girder. Photo: Walsh-Fluor Design-Build Team.

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

When discussing aesthetics, designers often hear the question, "But won't it cost more?" The Chicago Transit Authority's Red-Purple Modernization is an example of a project that achieves improved aesthetics while costing less. The design decisions that were most significant in making this viaduct attractive were made not just for aesthetic reasons. They were made to improve durability, reduce costs, facilitate construction staging, and reduce construction impact on the surrounding urban area. Many were made by the owner before design even started. The aesthetic improvement was a by-product, but a very important and welcome by-product.

Let's start with two predesign decisions: to raise the height of the tracks above the streets and to substitute a viaduct for the existing embankment. The first decision allowed more light to penetrate the under-bridge area. The second created more space for other uses in this crowded urban area.

Then the concrete box girders simplify the appearance of the structure while eliminating overhead nooks and crannies that accumulate dirt and shelter avian critters. Plus, the girders' light-gray surfaces not only appear relatively bright and clean but also bounce the light around so that it penetrates even more completely through the crossing. Finally, the mass of the concrete girders absorbs noise, making the passage of trains less disruptive. All of these design choices will make the act of crossing under the elevated tracks or living in their vicinity more attractive, especially for pedestrians.

The Chicago Transit Authority is to be congratulated for its willingness to consider, think through the technical requirements of, and apply this new (to them) technology. The neighbors of the Lawrence to Bryn Mawr Guideway will benefit, and so will the neighbors of future modernizations.

The launching girder assembly. Photo: Walsh-Fluor Design-Build Team.

Erection of a precast concrete segment. Photo: Walsh-Fluor Design-Build Team.

with construction engineers to develop an assembly scheme that allowed the main girder of the launching girder to be preassembled directly over the cross street, then relocated onto the first span by self-propelled modular transporters. At this point, a gantry system was erected underneath the main girder to lift the launching girder to the final elevation, where final supports were installed.

A pocket-track girder slides laterally into position. The post-tensioning hardware is visible in the box girder. Photo: Walsh-Fluor Design-Build Team.

Typical Erection Sequence

All precast concrete segments were delivered to the rear of the launching girder and hung in position. Next, epoxy adhesive was applied at the segment joints, and the segments were temporarily pressed together. Then the post-tensioning tendons were installed and tensioned. Post-tensioning tendon assemblies were prefabricated off site and delivered as needed. Each span contained eight tendons with 19 to 27 strands per tendon.

The eastern alignment (consisting of 63 spans) was constructed first, along with the 11 pocket-track spans.

Upon completion of the first phase of erection, the launching girder will be removed from the alignment and stored. Once the next construction phase commences, the launching girder will be reassembled on the west alignment and the remaining 63 spans assembled.

Pocket Track Erection Sequence

The 11-span pocket track is supported by a third, narrower box girder. The pocket track and east alignment spans were erected during the same construction phase. Each pocket-track span was erected with the launching girder on the east alignment and slid transversely into its final position using a shallow-depth beam that was temporarily set on the two adjacent piers. Upon completing the erection of all precast concrete segments in that phase, the eastern and center box girders were connected transversely with a cast-in-place concrete stitch pour. A similar connection will be used to connect the center and western box girders in the next phase.

Project Status

The design-build team reached a major milestone at the end of 2022 with completion of the precast concrete segment erection and post-tensioning for the first of two construction phases. After the new system's equipment is tested and commissioned, train traffic will be diverted to the new viaduct, the existing structure will be demolished, and the next construction phase will begin. The project is expected to be complete in the summer of 2025.

References

1. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications.* 9th ed. Washington, DC: AASHTO.
2. American Railway Engineering and Maintenance-of-Way Association (AREMA). 2022. *Manual for Railway Engineering*. Lanham, MD: AREMA.

Erin Schultz is chief engineer and Kevin Buch is the Lawrence to Bryn Mawr Modernization construction manager with the Walsh-Fluor Design-Build Team in Chicago, Ill. Ben Soule is technical director with SYSTRA International Bridge Technologies in San Diego, Calif.