PROJECT

Sound Transit Light Rail

Site challenges provide an opportunity for concrete segmental construction solutions

by Angela Tremblay

Since its founding in 1993, the Central Puget Sound Regional Transit Authority, more commonly known as Sound Transit, has been committed to expanding transit options in the Washington state counties of Pierce, King, and Snohomish. The agency has expanded bus, commuter train, and light-rail service throughout the region with a focus on providing affordable access and environmentally friendly transit options. As part of Sound Transit's ongoing light-rail expansion, planning for the Federal Way Link Extension (FWLE) project began in 2012, followed by voter approval in 2016, and the final route selection in 2017. FWLE provides an 8-mile extension from Angle Lake to Federal Way. The project is Sound Transit's largest design-build contract to date, and, when it is completed in 2026, the extension will connect Seattle and Seattle-Tacoma International Airport to the communities of Des Moines, Kent, and Federal Way, attracting 18,000 to 23,000 passengers daily, up to 8000 of whom would be new to the system.[1]

The FWLE route has at-grade and elevated sections, as well as three new stations. Most structures along the route are simple-span precast, prestressed concrete girder bridges of varying span lengths (130 to 190 ft per span, up to 18 spans) supported by concrete columns and caps. The decks use various concrete solutions, including precast concrete deck panels, cast-in-place (CIP) decks, and CIP concrete rail plinths. The three stations are elevated platforms constructed using precast, prestressed concrete girders. This article describes the long-span CIP concrete segmental bridge, Structure C, which offered the best solution for a section of the route that passes through an extremely challenging site.

Difficult Site Conditions

The design-build team was selected in 2019, and design began based on the planning-level design and the draft environmental impact statement; subsurface exploration was limited at that point due to difficult access. As the design progressed for the elevated section in Kent, Wash., the team gathered more than 30 soil borings and discovered that site conditions for the Structure C bridges near South 259th Place and Interstate 5 (I-5) were considerably more challenging than the initial designs assumed. The planned route had unanticipated weak soil conditions, including undocumented landfill debris and wetland soils, as well as a large liquefiable layer. These findings ultimately led to the redesign of the bridges.

The Federal Way Link Extension Project provides an 8-mile extension of the light-rail system from Angle Lake to Federal Way, Wash. The project is Sound Transit's largest design-build contract to date. Figure: Sound Transit.

profile

FEDERAL WAY LINK EXTENSION STRUCTURE C / KENT, WASHINGTON

BRIDGE DESIGN ENGINEER: Kiewit Engineering Group, Denver, Colo.

OTHER CONSULTANTS: Construction engineer: McNary Bergeron & Johannesen, Denver, Colo.; independent reviewer and shop drawings: Systra/IBT, San Diego, Calif.

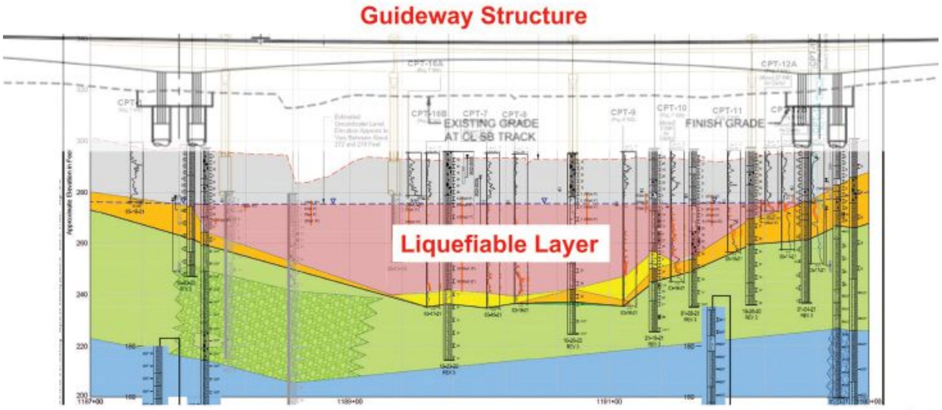
PRIME CONTRACTOR: Kiewit Infrastructure West Co., Federal Way, Wash.

CONCRETE SUPPLIER: Heidelberg Materials (formerly Corliss), Federal Way, Wash.

POST-TENSIONING CONTRACTOR: Schwager Davis Inc., San Jose, Calif.

The cast-in-place, concrete segmental Structure C allowed construction from above with the balanced-cantilever method and accommodated the long spans needed to avoid problematic soil conditions and mitigate impacts to wetlands. Photo: Kiewit.

The original design for Structure C used relatively short, 135-ft simple-span bridge units to support the light-rail extension. In November 2020, the design-build team notified Sound Transit that additional geotechnical investigations and analysis indicated that site conditions could not support the structure as originally designed. The team had analyzed a 2500-year design seismic event, as required by the *Sound Transit Design Criteria Manual*,[2] and determined that soil in the area would have the potential to liquefy, causing the adjacent slope to fail and slide into the FWLE guideway. These findings resulted in a substantial change order and redesign effort.



The main span of Structure C is located to clear a soil layer consisting of uncompacted fill. In an earthquake, this layer can liquefy and cause the embankment to slide downhill. Figure: Kiewit.

Other project-site concerns included McSorley Creek and wetlands, and the proximity and height of the adjacent I-5 roadway embankment. The design-build team proposed a rigid-pier bridge solution with a 190-ft-span precast concrete, post-tensioned girder superstructure designed to slide along seismic bearings, thereby keeping the system operable during the design seismic event, including a potential upslope landslide event. As the rigid-pier bridge design was being finalized, construction of a temporary access road commenced. According to the project history from Sound Transit, during the access road installation, the site experienced localized slope failures, and so the team designed and installed timber piles to stabilize the slope.[3] In July 2022, while the ground-improvement measure was being installed, a landslide briefly closed a southbound lane of I-5 and stopped all work at the site except for emergency slide repairs to stabilize the slope. While the design-build team reevaluated the bridge solutions, permanent slope repairs were performed in accordance with Washington State Department of Transportation (WSDOT) standards.

CENTRAL PUGET SOUND REGIONAL TRANSIT AUTHORITY, A PUBLIC CORPORATION ACTING UNDER THE SERVICE NAME OF SOUND TRANSIT, OWNER

OTHER MATERIAL SUPPLIERS: Reinforcing bar supply and installation: CMC, Auburn, Wash., and Nucor Rebar Fabrication, Tacoma, Wash.; disk bearings and expansion joints: RJ Watson, Alden, N.Y.; shock transmission units: Taylor Devices, North Tonawanda, N.Y.; drilled shafts: Michels Corp, Renton, Wash.

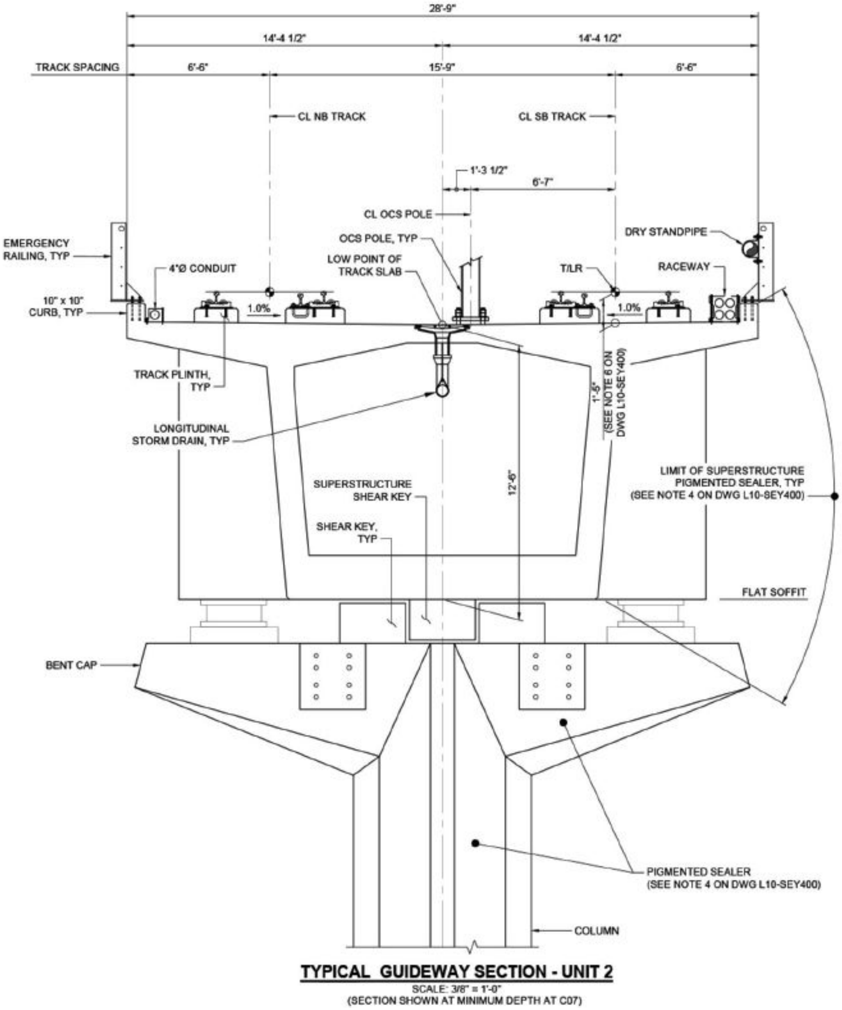
BRIDGE DESCRIPTION: 1097-ft 7-in.-long cast-in-place concrete segmental transit guideway bridge with 500-ft main span and 300-ft back spans

STRUCTURAL COMPONENTS: Cast-in-place concrete segmental superstructure with 62 segments. Two sections of the back spans were cast on falsework at either end of the structure for a length of about 50 ft. Cast-in-place concrete single-column piers supported by 12-ft-diameter, 110-ft-deep drilled shafts.

The 1100-ft-long cast-in-place concrete segmental box-girder Structure C is built adjacent to the heavily traveled Interstate 5, which is located on a 50-ft-high embankment. Photo: Kiewit.

Final Design

After some iterations and coordination with Sound Transit, the design of Structure C Unit 2 was finalized. This design featured an approximately 1100-ft-long CIP concrete segmental box-girder structure that would be built adjacent to the existing, heavily traveled I-5, which is located on a 50-ft-high embankment. The team chose to construct the CIP concrete segmental structure from above, using the balanced-cantilever method, to accommodate long spans, avoid problematic soil conditions, and mitigate the project's impact on the wetlands.



The constant-width, typical box-girder section of the concrete segmental bridge carries two light-rail tracks, emergency railings, and acoustic panels. Figure: Kiewit.

The Structure C bridge guideway design was performed in accordance with the *Sound Transit Design Criteria Manual*,[2] supplemented with the WSDOT *Bridge Design Manual*[4] and the seventh edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[5] Sound Transit requires that structures be designed for a 2500-year maximum design earthquake to promote resiliency in their system and ensure that operations can resume quickly after lesser seismic events. In addition, the design criteria for this project included concrete durability, corrosion control, and sustainability requirements to provide a 100-year design life, which was investigated and then documented in a project-wide durability report.

Structure C consists of two units. Unit 1 is the approach spans that comprise three spans of precast, prestressed concrete wide-flange girders for a structure length of 370 ft 2 in. Unit 2 delivers the innovative solution required to span the weak soils and sensitive environment along the FWLE route. Unit 2 is a three-span 1097-ft 7-in.-long,

AESTHETICS COMMENTARY

by Frederick Gottemoeller

"'Improving aesthetics always adds cost!' How many times have you heard that one?" About a year ago, I began a commentary on the Honolulu Authority for Rapid Transportation's transit system with those sentences (see the Winter 2024 issue of *ASPIRE*®). Well, the Federal Way Link Extension is another example where improved aesthetics came along with reduced cost. This example is also a transit project, but this time, the impetus to investigate an innovative approach was a wretched foundation situation.

When an innovative solution competes against a conventional one, the innovative solution is often penalized because the design and construction team are not familiar with it and therefore feel the need to tack on unnecessarily large cost margins for uncertainties and "contingencies." On this project, the design-build team recognized that danger, so they brought aboard experts in segmental concrete design and construction early in the project's life. The results were money-saving innovations such as dual travelers and integrated shop drawings.

The solution derived for this project addresses the difficult soil conditions and costs less than competing solutions. Also, as a bonus, the design gives the guideway a sleeker and more streamlined shape, which is more interesting because it reflects the forces on it. As a result, the structure is a more welcome component of the communities through which it passes.

As I said a year ago, "Such 'twofers' are available more often than most designers imagine. They should be the goal of all engineering refinement."

Cast-in-place concrete box-girder segments vary in height from 12.5 at the midspan to 25 ft at the piers and typically have a width of 28 ft 9 in. The bottom-slab post-tensioning ducts and web shear keys are visible. Photo: Kiewit.

Two sections of the back spans were cast on falsework at either end of the structure for a length of about 50 ft, while the remainder of the segmental structure was constructed using form travelers and the balanced-cantilever construction method. Photo: Kiewit.

Integrated shop drawings and three-dimensional modeling allowed the design team to spot conflicts before they happened, which was critical to the successful installation of the many reinforcing elements required in the superstructure. Photo: Kiewit.

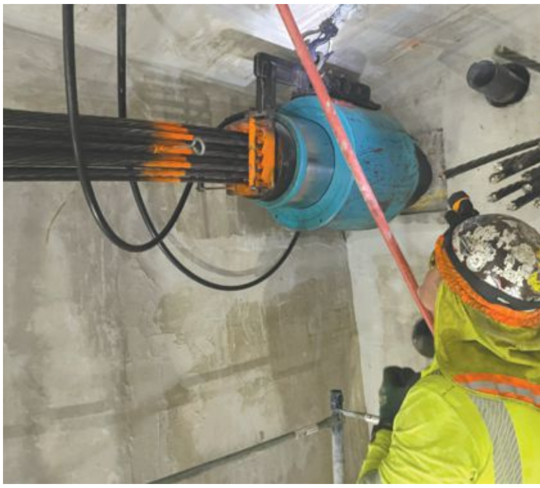
A view inside the box girder showing the internal continuity tendons before tensioning and the closure formwork in the background. The internal continuity tendons are ready to tension as soon as the closure pour (formwork in background) has reached the required strength. Photo: Kiewit.

CIP concrete segmental box-girder bridge consisting a main span of 500 ft and back spans of 300 ft and 297 ft 7 in. CIP concrete segments vary in height from 12.5 to 25 ft and have a constant width of 28 ft 9 in. The designers specified segment lengths of 11.5 ft for deeper sections and 15.5 ft for shallower sections based on the capacity of the contractor's form travelers. The typical section carries two light-rail tracks, emergency railings, and acoustic panels.

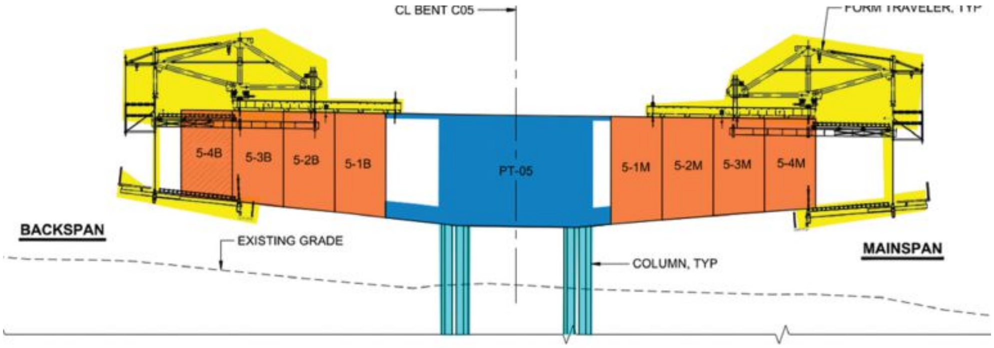
Lock-up devices (or shock transmission units) are provided to engage the two end columns of the Unit 2 structure during a seismic event. This type of system provides a temporary rigid link between the bridge superstructure and substructure under seismic or other fast-acting loads, while also allowing the bridge to expand or contract over time due to temperature changes, creep, or shrinkage.

Technical details of the bridge superstructure include concrete strengths for the CIP box girders of 6 ksi at 28 days and 8 ksi at 90 days. Mild reinforcing steel is uncoated ASTM A706,[6] Grade 60 or 80 ksi. Water-filled cooling tubes were used in the larger or thicker concrete sections, such as the thicker bottom slabs and diaphragms, to cool the concrete as it cured. During curing, the concrete temperatures could have reached well above 200°F; using the cooling tubes ensured that the temperatures stayed below 160°F, which is necessary to mitigate cracking.

Uncoated post-tensioning (PT) bars conforming to ASTM A722[7] Grade 150 standards were tensioned to a specified force and used to attach the shock transmission unit brackets to the bridge. The internal and external PT strands are 0.6-in.-diameter, seven-wire, low-relaxation steel conforming to ASTM A416[8] Grade 270 standards. The three-span structure has three types of PT, all running in the longitudinal direction: 128 bridge top-deck cantilever tendons with 10- or 11-strands per tendon, 26 bottom-slab tendons using 18- to 24-strands per tendon, and 12 internal (within the void of the box girder) continuity tendons that have 19 strands per tendon. The PT ducts—white plastic ducts for tendons encased in concrete or black high-density-polyethylene ducts for internal tendons—were grouted to provide a PL-2 tendon protection level, as described in the *Specification for Multistrand and Grouted Post-Tensioning* published by the Post-Tensioning Institute and American Segmental Bridge Institute.[9]



Tensioning the strands of a post-tensioning (PT) tendon. One advantage of the design-build delivery for this project was that the post-tensioning (PT) material supplier was chosen and engaged during the initial design phase. They worked with the design team as the bridge superstructure design was advanced. Photo: Kiewit.



Segments are being cast on both sides of one of the piers. Using four identical form travelers allowed segments to be cast on both sides of both cantilevers concurrently. Photo: Kiewit.

The Unit 1 superstructure is supported by single-column piers with tapered bent caps and a CIP concrete abutment—all with concrete design strengths of 4 ksi. The Unit 2 end supports also use single-column piers, while the interior/main-span supports use two columns with a pier table. For the two-column supports with the pier table, the design requires 6-ksi concrete, which can be achieved any time before the columns are loaded with the superstructure. The design team chose to list a 56-day time frame to reach 6-ksi strength in the plans as a matter of convenience. For the pier tables, the design team added the requirement of 7-ksi concrete strength at 90 days to accommodate stress checks on the structure that included the effects of live loads. This level of detail in the design took advantage of the predicted concrete strength at the time of operation. The foundation support for each pier column is provided by a single 110-ft-long, 12-ft-diameter drilled shaft for each column. The drilled shafts have a 5-ksi design concrete strength.

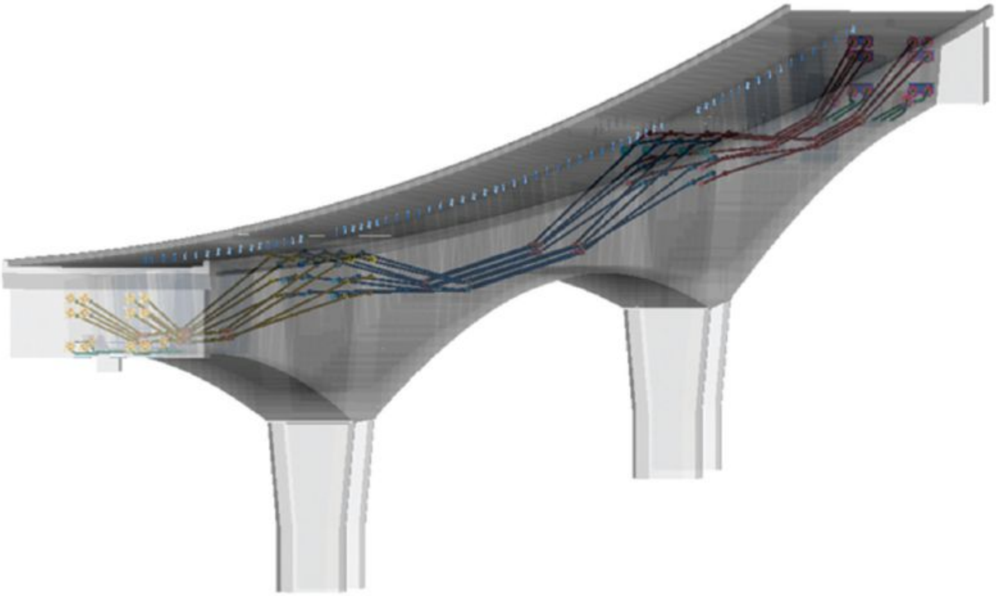
Construction Solutions

With the design-build delivery method, bridge engineers, construction engineers, suppliers, and contractors were able to work from the start as an integrated team to problem-solve and choose solutions that suited the project as well as the expertise of the team. For example, unlike many projects that perform the permanent concrete segmental bridge design with a generic PT system, the PT material supplier was chosen and consulted during the initial design phase and worked with the design team as the superstructure design was advanced. Similarly, the design and construction teams decided early in the project to design the pier table to be just long enough to fit two travelers back to back on a single pair of shared rails. This decision helped jumpstart the team's early designs for the pier table falsework and allowed the use of identical form travelers to cast all cantilevers concurrently.

One of the most significant efforts that involved both design and construction—producing integrated shop drawings for the concrete segmental bridge—started early in the project. This integration (inclusion of all embedded items) was not required by the project specifications, but the team elected to produce and submit the integrated shop drawings to limit interferences and thereby facilitate construction success and schedule certainty.

Using a previous project as a template, the design and construction team, including the reinforcing steel and PT subcontractors, brainstormed what needed to be included in the integrated shop drawings. Each segment was

A three-dimensional (3-D) model of the three-span concrete segmental structure showing the post-tensioning tendons. The 3-D model was used to create the two-dimensional integrated shop drawings for each segment. Figure: Kiewit.



modeled in three dimensions with a precision of ⅛ in. or better in size and location. All conflicts were noted and sent to the engineer of record for review and resolution. After the three-dimensional model was complete, a two-dimensional shop-drawing package that included reinforcing bar lists, PT data, and all other information for the specific segment was assembled. The 68 packages for the pier tables and box-girder segments were submitted to Sound Transit for approval before construction and will be used as the as-built drawings.

A key to the success of this endeavor was starting early—the team was assembled and started modeling, drafting, and reviewing before the bridge design was finalized. It took just over a year to complete the packages and stay ahead of construction.

Collaborative Success

This was a very challenging project, but selection of the long-span concrete segmental bridge and the integration of the experienced design and construction teams led to completion of the Structure C scope months early and within budget. The design-build delivery method for the FWLE helped the team make the creative adjustments needed to develop solutions for this project. Sound Transit and the design-build team collaborated in dealing with changing parameters and site conditions, and their collective problem-solving efforts led to a final design that meets the needs of Sound Transit and the communities that it serves. In recognition of the project's intentional focus on system resilience and sustainability, the project was awarded the Envision Platinum designation from the Institute for Sustainable Infrastructure.

Structure C was completed in October 2024, and Sound Transit will conduct systems integration testing along the extension next. The FWLE is scheduled to open to the public in 2026, and when it opens, it will provide the region with safe, reliable light-rail transit for years to come.

Structure C was completed in October 2024 and Sound Transit plans to begin systems integration testing along the extension as early as the end of 2024. Photo: Kiewit.

References

1. Lindblom, M. 2024. "The Light Rail Bridge Spectacle You've Eyeballed for So Long Nears the Finish Line." *The Seattle Times*, June 30. https://www.seattletimes.com/seattle-news/transportation/the-light-rail-bridge-spectacle-youve-eyeballed-for-so-long-nears-the-finish-line.
2. Sound Transit. 2018. *Sound Transit Design Criteria Manual.* Rev. 5. Seattle, WA: Sound Transit.
3. Sound Transit. 2023. Motion No. M2023-42. https://www.soundtransit.org/st_sharepoint/download/sites/PRDA/FinalRecords/2023/Motion%20M2023-42.pdf.
4. Washington State Department of Transportation (WSDOT). 2018. *Bridge Design Manual (LRFD).* M23-50.18. Olympia, WA: WSDOT. https://wsdot.wa.gov/publications/manuals/fulltext/M23-50/M23-50.18Complete.pdf.
5. American Association of State Highway and Transportation Officials. 2014. *AASHTO LRFD Bridge Design Specifications*. 7th ed., with 2015 and 2016 interim revisions. Washington, DC: AASHTO.
6. ASTM International. 2022. *Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement*. ASTM A706/A706M-22. West Conshohocken, PA: ASTM International.
7. ASTM International. 2018. *Standard Specification for High-Strength Steel Bars for Prestressed Concrete*. ASTM A722/A722M-18. West Conshohocken, PA: ASTM International.
8. ASTM International. 2024. *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*. ASTM A416/A416M-24. West Conshohocken, PA: ASTM International.
9. Post-Tensioning Institute (PTI) and American Segmental Bridge Institute (ASBI). 2019. *Specification for Multistrand and Grouted Post-Tensioning*. PTI/ASBI M50.3-19. Farmington Hills, MI: PTI.