Ohio Pilot Projects Using Corrosion-Resistant Prestressing Strands

The Ohio Department of Transportation explores the use of stainless steel strand and carbon-fiber-reinforced polymer strand to resist corrosion in adjacent box-beam bridges

by Omar Abu-Hajar, Ohio Department of Transportation

Deteriorating structures continue to challenge the Ohio Department of Transportation (ODOT). As in many northern states, a large portion of ODOT's annual funding is spent repairing and rehabilitating its aging bridge inventory.

Thousands of prestressed concrete box-beam bridges were built in Ohio after 1975, with more than 300 erected in 1990 alone. With an average age of 30 years, these structures are approaching the end of their 50-year design life (**Fig. 1**). There are 7860 prestressed concrete box-beam bridges in the state, 119 of which have condition ratings of 4 (poor) or worse using the National Bridge Inventory ratings (**Fig. 2**). Based on these data, ODOT predicts that most of these structures are destined to be replaced.

In an effort to reverse this trend, ODOT initiated a study to determine whether revised design and construction practices could head off future maintenance issues and result in a 100-year service life for adjacent prestressed concrete box-beam bridges. ODOT explored several tactics, including increased concrete clear cover over reinforcement, high-strength concrete with a corrosion-inhibiting admixture, and alternative materials for reinforcement and prestressing strand.

High-Strength Stainless Steel Strand

Ohio's concrete bridges are exposed to road salts and freezing-and-thawing conditions. Among the many bridges in Ohio, the focus of the pilot projects was narrowed to adjacent prestressed concrete box beams because they are degrading faster than other bridge types. One potential solution to overcome the early deterioration of these bridges uses high-strength stainless steel (HSSS) strand. HSSS strand has high corrosion resistance and is an alternative to normal carbon steel strand in extremely aggressive environments.

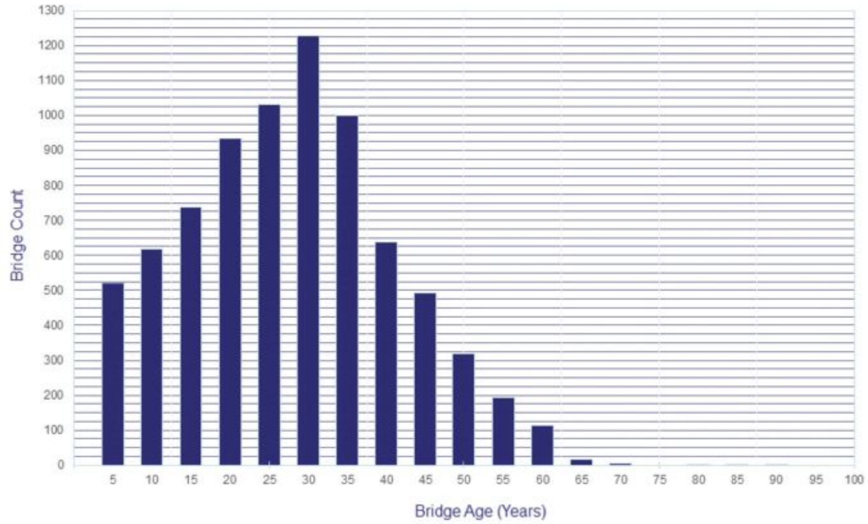

Figure 1. Age of in-service prestressed concrete box-beam bridges in Ohio based on 2019 data. All Photos and Figures: Ohio Department of Transportation.

When the ODOT program was launched in 2015, only limited relevant information was available. Several states had used HSSS strand in prestressed concrete piles, but not in beams. ASTM A1114/A1114M-20, *Standard Specification for Low-Relaxation, Seven-Wire, Grade 240, Stainless Steel Strand for Prestressed Concrete*,[1] published in 2020, was not yet available.

Compared with typical carbon or black steel, stainless steel is made from different alloys and the mechanical properties of stainless steel strand are fundamentally different (see "Structural Design Using Stainless Steel Strands" in the Spring 2018 issue of *ASPIRE*®). The most significant difference is in the ultimate strain: the minimum for stainless steel strand is 1.4%, compared with 3.5% for low-relaxation carbon steel strands.

The main concern when using HSSS strand in flexural components is its ductility. Because HSSS is a less-ductile material than carbon steel, the design must consider the strain capacity of the strand and must be balanced between flexural strength and ductility.

One of the benefits of using stainless steel strand as compared with carbon-fiber-reinforced polymer (CFRP) strand is that there are fewer constructability challenges with stainless steel strand. The prestressed concrete manufacturer can continue to use conventional tensioning methods and detensioning systems. Stainless steel strand is available domestically, but its use comes with some conditions that add to its premium price. For example, all mechanical connectors and other reinforcement should also be stainless steel. Stainless steel products should be stored and handled using tools that are not used on carbon steel, and stainless steel

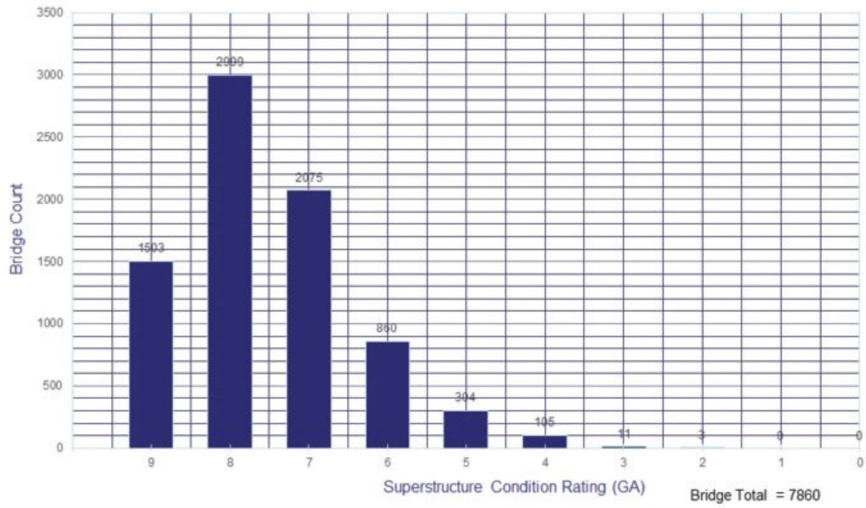

Figure 2. The superstructure condition ratings of prestressed concrete box-beam bridges in Ohio based on 2019 data.

products should not have direct contact with uncoated steel.

The first use of stainless steel prestressing and reinforcing steel in Ohio occurred in the SEN-19-14.34 bridge replacement project in Seneca County; this bridge opened to traffic on October 25, 2019. ODOT collaborated with precasters and consultants to design, fabricate, and construct the first prestressed concrete box beams using stainless steel prestressing strands in a bridge superstructure. Design software was also developed to streamline future ODOT projects with stainless steel strands in box beams.

At the time, commercial software did not allow the user to modify the strand elongation parameters. Carbon steel ruptures at a minimum of 3.5% strain, whereas stainless steel strands rupture at approximately 1.8% strain. The design value of strain rupture was set at 1.6% strain in the spreadsheet developed for stainless steel strands, so more strands were required. Additionally, commercial software did not allow the user to modify the initial stress to allow for compression-controlled or balanced-strain design methods.

The specifications for the project dictated 0.6-in.-diameter, 250 ksi stainless steel strands with an area of 0.216 in^2. According to data from the mill, the maximum elongation could range from 1.1% to 1.8%. The steel grade was 250 ksi, and the modulus of elasticity was 24,300 ksi. In the preliminary design, the jacking stress was set considering the maximum limit of 70% of the specified tensile strength of the stainless steel strand, but it was later lowered to 65% as recommended in the available literature.[2–4] The final design value was specified at 54% (29.2 kips per strand) to provide for a balanced-strain condition. ODOT set this limit to prevent strand from rupturing before reaching the ultimate compressive strain of the concrete. It was a balancing act, economizing the number of strands at an initial stress level while keeping stress limits in the beam at an acceptable level.

There was an approximate 13-week lead time for HSSS strand at the time of the project bid letting.

In addition to the stainless steel strands in the beams, stainless steel duplex alloy 2205 reinforcement with 75 ksi yield strength was used in the beams and in the composite concrete slab. Standard ODOT beam details were used for the strand layout and concrete cover to keep fabrication as typical as possible. Strands were placed 2 in. from the bottom of the beam, and beam shear reinforcement was placed below the strands for a concrete cover of 1.2 in. The Seneca County project also used transverse post-tensioning instead of the "snug-tight" tie rods that are standard in Ohio. To protect the 6-in.-thick, composite cast-in-place reinforced concrete deck, the specifications included using a 2½ in. concrete cover in the deck, sealing concrete surfaces, and installing a stainless steel drip strip at the slab's fascias.

Carbon-Fiber-Reinforced Polymer Strand

Testing data on flexural components using alternative prestressing strand materials were limited, so ODOT looked to other agencies for help with the alternative materials. Bridge engineers consulted with Michigan and Virginia Departments of Transportation as well as the American Association of State Highway and Transportation Officials' T-6 Committee on Fiber Reinforced Polymer Composites. At the time of design, AASHTO's *Guide Specifications for the Design of Concrete Bridge Beams Prestressed with Carbon Fiber-Reinforced Polymer (CFRP) Systems*[5] had not yet been published. Where there were no guidelines, sound engineering judgment was called on.

Examples of severe deterioration of prestressed concrete adjacent box-beam bridges built 35 to 45 years ago in Ohio.

Pilot project SEN-19-14.34 in Seneca County, Ohio, used stainless steel strand in a prestressed concrete adjacent box-beam bridge with a 6-in.-thick, composite cast-in-place reinforced concrete deck with stainless steel reinforcing bars. The completed structure is a 79-ft-long, 32-ft-wide single-span structure with a 30-degree skew.

When ODOT's CFRP pilot program began, CFRP strand was not available locally, and precast concrete producers were hesitant to use it. Unlike HSSS strand, CFRP strand does not closely mimic carbon steel strand when it comes to tensioning and detensioning. Whereas the process to cast beams with stainless steel strand required minimal changes from the standard process using carbon steel strand, accommodations and special procedures were necessary to cast beams with CFRP strands. For this project, ODOT used carbon-fiber composite cable (CFCC) strands that were 0.6 in. in diameter with an area of 0.179 in.^{2}, a modulus of elasticity of 22,481 ksi, and ultimate tensile strength of 337.2 ksi. The initial stress was set to 182.1 ksi with a tension force of 32.6 kips per strand.

Special equipment and procedures were needed at the precast concrete plant to install and tension the CFCC strands, a process that takes extra time and delays the turnover of the forms. Special couplers were rented from the CFCC manufacturer on a trial basis for this project. Additional protective gear was also required for fabricator personnel. Other differences in fabrication include preproduction planning, lifter and cage assembly, and strand tensioning. These processes differ from those performed for carbon steel strand. It typically takes a full workday to layout the CFRP strands and place the reinforcement. Beam fabrication is then finished by tensioning the strands and casting the concrete the following day. This essentially doubles the amount of time in the bed for beams with CFRP strands compared with traditional carbon or stainless steel strands.

Pilot project SEN-635-05.21 using CFCC was also located in Seneca County. The desirable features of CFRP strand include its noncorrosive qualities, high-tensile strength, and flexibility, and its light weight (CFRP strand is one-fifth the weight of steel strand). However, special care must be taken around the material

Pilot Project SEN-635-05.21 in Seneca County, Ohio, used carbon-fiber composite cable strands in a prestressed concrete adjacent box-beam bridge with a 6-in.-thick composite, cast-in-place reinforced concrete deck with stainless steel reinforcing bars. The completed bridge is a 54-ft-long, 32-ft-wide single-span structure with a 10-degree skew.

to avoid welding sparks and any sharp bending.

The two Seneca County pilot projects were simple spans of less than 80 ft. Both projects used 33-in.-deep and 48-in.-wide box beams. The total beam costs were $361,600 for eight 79-ft-span box beams using HSSS strand and $385,000 for eight 54-ft-span box beams using CFCC strand. Thus, the cost premiums for prestressed concrete box beams with HSSS and CFCC strand were 2.65 times and 6.25 times, respectively, the typical costs for box beams using carbon steel strand.

During the process, ODOT has evaluated whether the higher initial costs associated with these special materials are justified. Will the enhanced durability dramatically increase the service life? What are the long-term implications to maintenance and repair budgets? Economic comparisons of additional pilot projects are in the works as ODOT prepares final life-cycle cost analyses.

Future of Alternative Materials

ODOT will evaluate the use of innovative materials on a project-by-project basis. In particular, these materials may be considered along with more traditional materials for replacement projects of the high number of adjacent box-beam bridges built in the 1980s and 1990s, which account for one-half of the adjacent prestressed concrete box-beam bridge inventory in Ohio. ODOT's efforts with HSSS strand and CFRP strand on these pilot projects should prove to enhance both the durability and sustainability of these bridges. The new bridges in Seneca County are expected to provide safe access for northern Ohio communities for the next 100 years.

Although there was a significant premium in the initial cost of these pilot bridges, ODOT will continue to evaluate the life-cycle costs and look for potential savings as these materials become more mainstream. ODOT also intends to seek out improvements in conventional concrete construction methods for future projects.

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EDITOR'S NOTE

National Cooperative Highway Research Project 12-120, Stainless Steel Strands for Prestressed Concrete Bridge Elements, *is developing guidelines for the application of stainless steel strands for prestressed concrete bridge elements and proposing modifications to AASHTO design and construction specifications. The report is scheduled to publish in 2023.*

Whether carbon steel is at risk for galvanic corrosion when it is in contact with stainless steel has been debated. Research has indicated that even in the presence of chlorides, when carbon steel is coupled with stainless steel, galvanic coupling current density is very low and will not initiate the corrosion of the carbon steel. (See Qu, D., S. Y. Qian, and B. Baldock. 2003. "Effects of Galvanic Coupling between Carbon Steel and Stainless Steel Reinforcements." In Proceedings, NACE Northern Area 2003 Conference, Ottawa, Ontario, Sept. 14–17, 2003, 1-26. https://nrc-publications.canada.ca/eng/view/accepted/?id=73879711-a8c5-4ab6-a22e-80cd98919caa.)

Unique chucks are required to tension carbon-fiber composite cable strand, and the strand layout needed to accommodate the couplers wastes bed space. The couplers used for carbon-fiber composite cable strand require 11 pieces for strand preparation and assembly, compared with only three pieces for carbon steel or stainless steel strand.