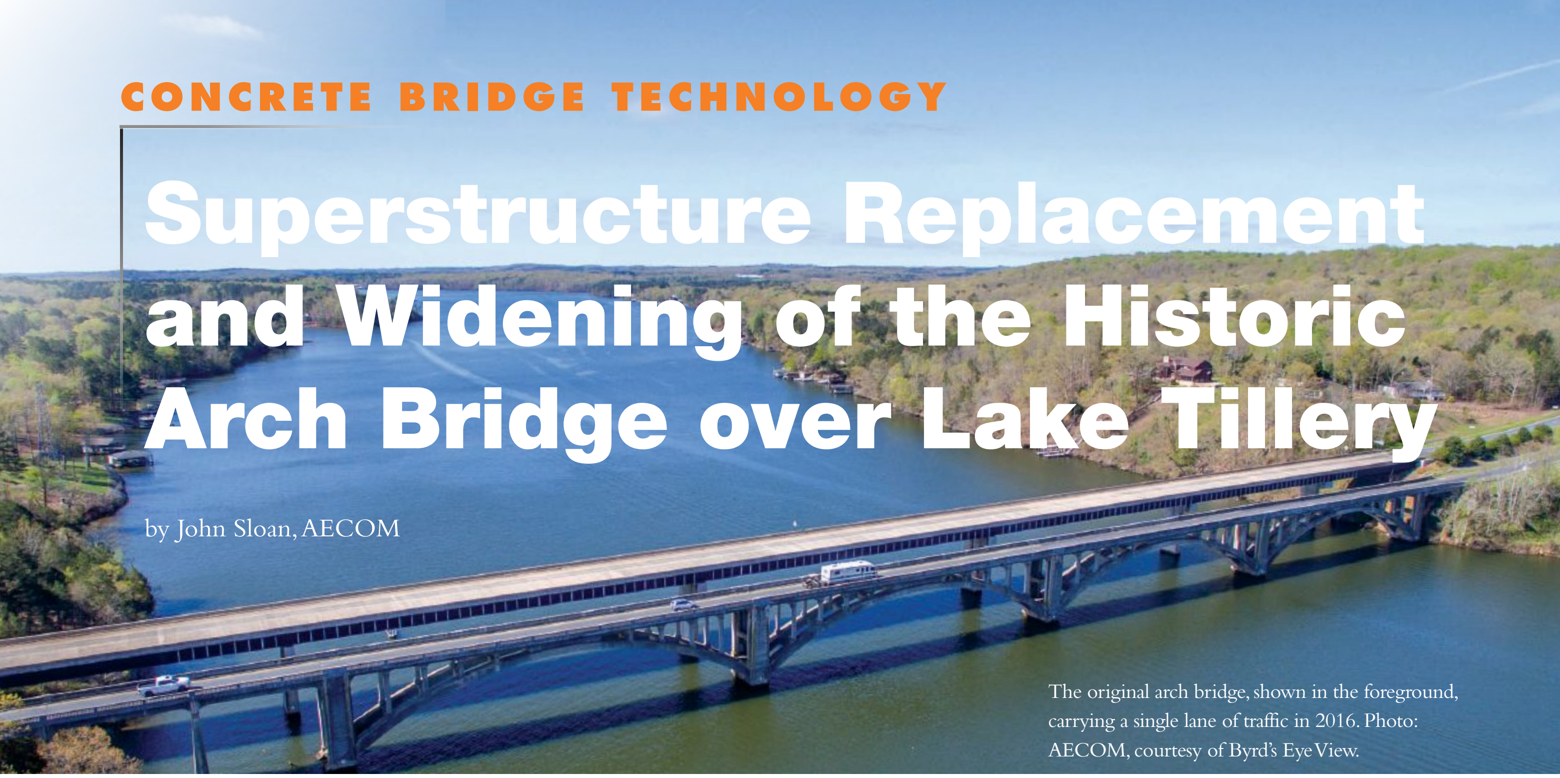
Superstructure Replacement and Widening of the Historic Arch Bridge over Lake Tillery

by John Sloan, AECOM



The original arch bridge, shown in the foreground, carrying a single lane of traffic in 2016. Photo: AECOM, courtesy of Byrd's Eye View.

The Lake Tillery Bridge was constructed northeast of Charlotte, N.C., in 1927. The open-spandrel arch bridge was originally intended for two-lane, two-way traffic. However, by 2015, the 20-ft-wide deck of the arch bridge was carrying only a single, westbound lane of traffic because adequate shoulder width was needed to improve safety. At that time, the historic bridge was within the limits of a larger road-widening project, and its owner, the North Carolina Department of Transportation (NCDOT), needed to decide what to do with it. Many options were considered, such as replacing the bridge altogether or turning the arch bridge into a bike and pedestrian facility while constructing a third bridge for additional vehicular traffic. NCDOT contracted with AECOM to perform a feasibility study to determine if the bridge could be widened to provide a 36-ft-wide roadway for vehicular traffic. The feasibility study evaluated whether the arches and piers could be preserved while replacing the superstructure to allow two westbound lanes with shoulders on the widened bridge. Other aspects of the Lake Tillery Bridge rehabilitation project were discussed in Project and Creative Concrete Construction articles in the Spring 2022 issue of *ASPIRE*®.

Feasibility Study

The feasibility study had four main parts. The first part involved a complete inspection of the structure, including above- and underwater portions. Although the inspection found significant deterioration of the bridge superstructure near the expansion joints, the arches and piers were in good condition, to the extent that even the grain imprint of the old timber formwork could be seen in some of the concrete.

The second part of the feasibility study was a material evaluation and service-life analysis. It was important to NCDOT that the arch bridge project result in a full 75-year service-life extension—the same duration as the service life for a new bridge. The material evaluation found the concrete to be in good condition, and the arches and piers were anticipated to achieve the desired service life of an additional 75 years.

The third part of the feasibility study included a two-dimensional load rating of the arches and piers under the original bridge configuration, and another load rating under the proposed configuration. This analysis demonstrated that the proposed configuration could work, and the load response of the arches could be improved by eliminating expansion joints and stiffening the superstructure.

In the final part of the feasibility study, the historic architecture of the bridge was evaluated. The team created renderings of the proposed structure for comparison with the original, and it was determined that the project would have no adverse effects on the historic structure, in accordance with the Historic Preservation Act. The superstructure replacement alternative was estimated to cost at least $4 million less than any other alternative, and NCDOT decided to move forward with final design of this alternative.

The new superstructure of the open-spandrel arch bridge in the foreground is wide enough to carry two lanes of traffic with shoulders. Photo: AECOM.

The original open-spandrel arch bridge had a 20-ft-wide deck. Photo: AECOM, courtesy of Byrd's Eye View.

The new superstructure of the rehabilitated bridge has a 36-ft-wide road surface. Establishing continuity of the prestressed concrete box beams from pier to pier before placing the concrete deck mitigated loadings on the arch ribs. Photo: AECOM.

Final Design

At the beginning of the final design phase, a laser survey was completed to confirm the geometry of the existing arch ribs and spandrel-column pedestals. Using the information from the survey, a four-dimensional finite element model of the bridge that included the nonlinear effects of the construction sequence was constructed. The team used this model for geometric control as the superstructure was removed and then replaced. The team also could account for geometric changes due to the removal and addition of loadings throughout the construction process. Because the dead load of the proposed superstructure was greater than that of the original, a detailed construction sequence was specified to prevent overstressing the arches during construction. This construction sequence ensured the new superstructure loads would be placed on the arches concentrically along the axis of the component. The arches are lightly reinforced compression components, so the concentric dead load improved their ability to resist live-load moments due to vehicular traffic. The model indicated that the arch ribs remained uncracked throughout the construction sequence and under live load; therefore, the design team used the full moment of inertia of the components without stiffness reductions.

The original superstructure had three reinforced concrete deck girders with steel plate bearings that bore directly on the spandrel bent caps, so this was a very rigid articulation. The superstructure had expansion joints at third points within each arch span, which created high moment demands in the arch ribs below these joints. In the final structure configuration, load was relieved from the arch ribs by establishing continuity of the prestressed concrete box beams from pier to pier before placing the concrete deck. This was achieved by providing continuity reinforcement and closure pours between the box beams over the spandrel bents. In addition, the stiffness of the proposed superstructure was significantly greater than that of the original. Tall elastomeric bearings with a much lower modulus of elasticity than the original steel bearings were used, which created a spring support at each spandrel bent, allowing the superstructure to flex and resist demands while further alleviating the demands on the arches. Collectively, these items created a greater level of redundancy in the proposed structure compared with the original articulation.

The original superstructure was removed during construction. A detailed construction sequence prevented overstress in the arches during construction. Photo: AECOM, courtesy of Aerial Photo Pros.

Concrete Preservation

Material preservation was an important aspect in the final design. Discrete anodes were used in concrete patches to mitigate the effects of chlorides in the concrete located below the expansion joints in the original superstructure. A cementitious jacket was specified for the piers at the waterline to repair wear and scaling caused by surface waves during the bridge's previous 90 years of service. A breathable sealer was applied to the entire structure to help preserve the original concrete and to create a uniform appearance among new, original, and repair concretes. The elimination of 15 expansion joints from the original bridge aids the preservation of the structure.

Construction

NCDOT hired PCL as the contractor for the Lake Tillery project, and AECOM served as NCDOT's engineer during the construction phase of the project. The team collaborated successfully to complete the rehabilitation and open the historic arch bridge to traffic in August 2022. With its efficient structural design and anticipated full service-life extension of 75 years, this project provided NCDOT with significant savings compared with other alternatives, improved connectivity within the region, and maintained the historic and architectural character of the original bridge.

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