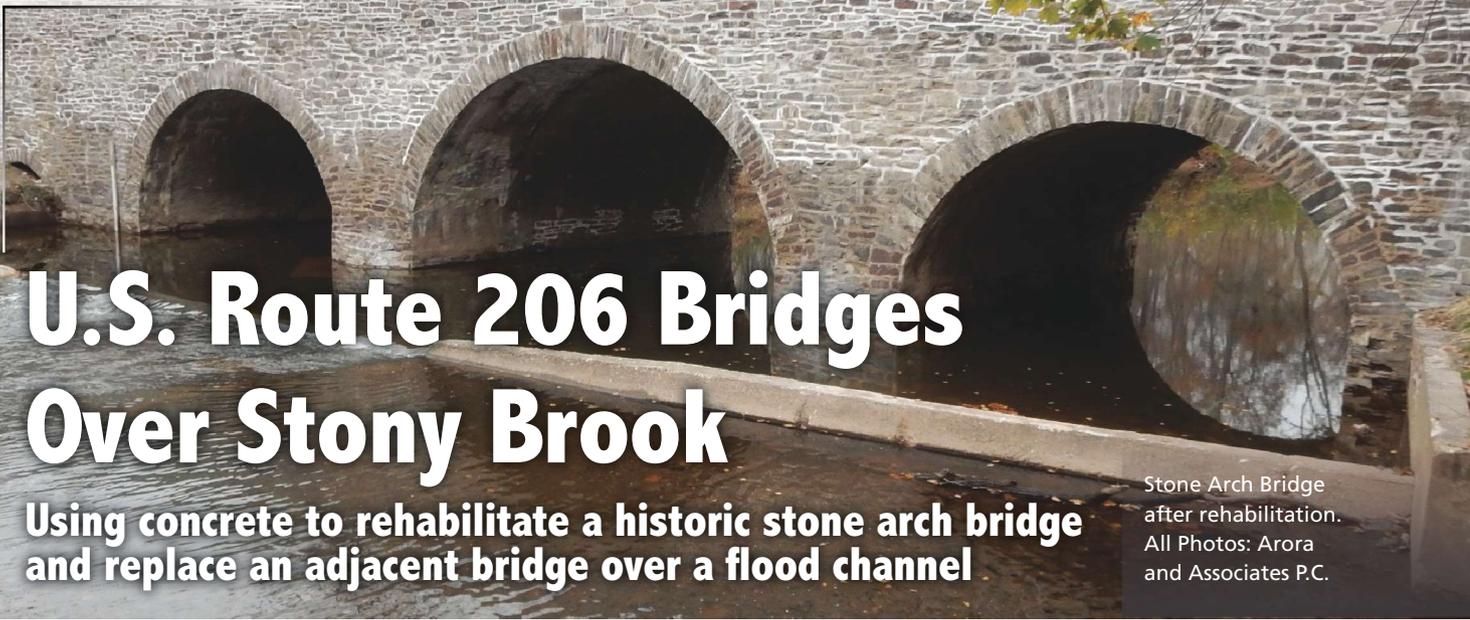


PROJECT



U.S. Route 206 Bridges Over Stony Brook

Using concrete to rehabilitate a historic stone arch bridge and replace an adjacent bridge over a flood channel

Stone Arch Bridge after rehabilitation.
All Photos: Arora and Associates P.C.

by David Hutchinson and Khairul Alam, Arora and Associates P.C., and Pankesh Patel, New Jersey Department of Transportation

Built in 1792, the Stone Arch Bridge over Stony Brook in Princeton, N.J., is the oldest still-in-use bridge owned by the state. The triple-arch stone bridge was built by local masons using stone from nearby quarries and currently carries U.S. Route 206 vehicular traffic in Mercer County. In 2016, after serving the public for more than two centuries, the historic bridge was nearing the end of its service life and was unsuitable to support traffic loadings in the 21st century. A rehabilitation project using

cast-in-place concrete within the fill of the arches effectively strengthened and added durability to the structure, while preserving the beauty of the original bridge.

Emergency Repairs

On February 22, 2016, the parapet and spandrel wall above the north arch on the upstream side of the structure partially collapsed, forcing closure of this section of Route 206. The failed area was stabilized, and an in-depth inspection of the bridge was performed, which revealed more areas that needed repair. The partial collapse was a sign that the bridge needed attention to address the underlying causes of the failure. The roadway was reopened to traffic on March 7, 2016. However, heavy truck traffic across the bridge was prohibited,

Partial collapse of the stone parapet and spandrel wall of the Stone Arch Bridge. The ruin wall of Worth's Mill is on the right. The Flood Channel Bridge is just beyond the ruin wall.

and the failed area and extensive leaning and bulging of the spandrel walls and parapets on the upstream face remained.

The emergency repair, including the installation of temporary concrete barriers to protect the collapsed area and other nonstable parapet areas, allowed for the continued use of the bridge while the project to retrofit the structure for strength, safety, and durability was undertaken.

Historical Considerations

The historic nature of the bridge and adjacent structures was an important factor in the rehabilitation project. The crossing where the Stone Arch Bridge stands was part of the early 18th-century King's Highway and an important crossing during the Revolutionary War. The original timber bridge, which dated to 1738, when the area was settled by Quakers, was damaged for strategic reasons in the Battle of Princeton. The Stone Arch Bridge was



profile

U.S. ROUTE 206 BRIDGES OVER STONY BROOK / PRINCETON, NEW JERSEY

BRIDGE DESIGN ENGINEER: Arora and Associates P.C., Lawrenceville, N.J.

PRIME CONTRACTOR: South State Inc., Bridgeton, N.J.

PRECASTER: Precast Systems Inc., Allentown, N.J.—a PCI-certified producer

built as a replacement for the first structure a decade after the end of the Revolutionary War. It originally had a cart-way width of 18 ft but was widened to 32 ft around 1916.

Next to the Stone Arch Bridge on the southern approach is the Route 206 Bridge over the Stony Brook Flood Channel (Flood Channel Bridge). Built in 1892, the original Flood Channel Bridge was a three-span bridge, which was later widened along with the Stone Arch Bridge. The Flood Channel Bridge was an important feature of the King's Highway historic district; however, at the time that the Stone Arch Bridge partially collapsed, the Flood Channel Bridge was in poor condition and in need of replacement. Therefore, the decision was made to replace the Flood Channel Bridge while the Stone Arch Bridge was rehabilitated. Undertaking both projects at the same time would accelerate construction and limit the duration of the Route 206 detour.

Another important aspect of the project was the treatment of the ruins of the Worth's Mill southern wall, which stands next to both the Stone Arch and Flood Channel Bridges. This ruin wall, which predates the Stone Arch Bridge, was determined to be in poor condition and in need of repair and stabilization. To ensure the stability of the wall during construction, electronic monitoring of the structure for vibration, displacement, and tilting was conducted.

Project authorization by the Historic Sites Council was required under the New Jersey Register of Historic Places Act. The project received approval with 18 mitigating conditions—such as recording the structures to the Historic American Engineering Record (HAER) standards, archaeological monitoring, construction of a minimum of two test panels for approval by stakeholders, and a long-term stabilization plan for



Excavation above the arches was accomplished by hand labor and small equipment.

the Worth's Mill ruin wall—which were incorporated into the project.

Design Concepts and Construction Methods

The rehabilitation of the Stone Arch Bridge involved removing the fill above the arches; rebuilding out-of-plumb walls with the same stone and a lime-based, historically appropriate mortar; and constructing reinforced concrete saddles and walls within the roadway fill to strengthen the arches. The replacement fill of the roadway above the arches was constructed with lightweight concrete to eliminate water infiltration. A reinforced concrete core was used for the parapets for crash worthiness and was faced with existing stone. The concrete core for the parapets extends up from the cast-in-place spandrel walls. The parapet maintains the existing draping pattern across the bridge but is raised to meet the American Association of State Highway and Transportation Officials (AASHTO) Test Level 4 crash rating.

Although the existing stone arch was not designed to be composite with the new saddle, some composite action is anticipated because the top of the stone arch has an irregular shape due to the original coursed stone construction. The saddle and spandrel walls are reinforced and are the structural system that takes the vertical and horizontal loads. The top of the existing stone arch was cleaned of all dirt and loose material. The original design called for the remaining fill above the arch to be filled with a lower strength lightweight flowable fill, but the contractor decided to use Class A lightweight concrete throughout the fill because it did not want to form out the spandrel walls. Because it was designed to current loads, the bridge is no longer posted.

The Flood Channel Bridge was replaced by a single-span, prestressed concrete adjacent-box-beam bridge with a total bridge length of 150 ft. The location of the north abutment was moved to



Construction of concrete saddles to strengthen the arches of the Stone Arch Bridge.

NEW JERSEY DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTIONS: Stone Arch Bridge: Rehabilitated three-span stone arch bridge (originally built in 1792) spanning Stony Brook with a 26 ft 6 in. center span and 20 ft 9 in. flanking spans; Flood Channel Bridge: Single-span, 65-ft-long structure constructed from adjacent prestressed concrete box beams

STRUCTURAL COMPONENTS: Stone Arch Bridge: Reinforced concrete saddle; Flood Channel Bridge: 27-in.-deep AASHTO Type BI-48 prestressed concrete box beams

PROJECT CONSTRUCTION COST: \$7.4 million

AWARDS: Professional Engineers Society of Mercer County Project of the Year; American Council of Engineering Companies NJ Honor Award; American Society of Highway Engineers Southern NJ—Honor Award; New Jersey Historic Preservation Award

avoid demolition and excavation near the Worth's Mill wall. The abutments were faced with a similar ashlar stone to blend in with the environment and connect the history of the two bridges and the ruin wall of Worth's Mill.

An accelerated 120-day construction schedule was set to complete the bridges and approach work; during this time, archaeological monitoring was conducted and documented. Collaboration among all stakeholders during design and construction was the key to the success of the project. Local and agency stakeholders included the New Jersey Historic Preservation Office and the Princeton Historic Preservation Committee, both of which contributed to specific design elements and were involved with the project from inception to completion.

For the Stone Arch Bridge rehabilitation, certain aspects of the 68-ft long and 33-ft 9-in.-wide structure needed to be changed. For example the parapets, which were only 10 in. high at the bridge ends, had to be raised. To address this issue, an alternative approach to the safety needs of the public was required to achieve stakeholder consensus. Other substandard features, including substandard shoulder width and superelevation, received design exceptions because correcting these features would have had significant financial, historical, and environmental impacts.

Benefits of Concrete

Cast-in-place concrete is a flexible and adaptive construction material that allows for field changes while maintaining the desired structural strength. There are many unknowns when removing the fill above an arch in a structure as old as the Stone Arch Bridge. As-built plans for the bridge did not exist, and methods to determine the fill depth and material (such as

The new prestressed concrete box-beam Flood Channel Bridge. Worth's Mill ruin wall is on the left.



Placing lightweight concrete for fill above arches. Note the epoxy-coated reinforcement for concrete core for the parapets.

ground penetration radar and pavement corings) can be inconclusive. The use of cast-in-place concrete allowed for quick adjustments to the reinforced concrete saddles and spandrel walls based on the actual field conditions after excavation. Much of the concrete that had been placed during the 1916 widening of the bridge was incorporated into the 2016 rehabilitation to avoid further impact on masonry areas that did not need to be reconstructed. Epoxy-coated reinforcing steel was used in the concrete saddle and spandrel walls to provide additional corrosion protection. The flexibility of cast-in-place concrete also proved beneficial for construction of the reinforced concrete collars, which were placed in the waterway to protect the footings against scour and doubled as a support for the framing system designed to temporarily support the arches during construction.

For the Flood Channel Bridge, adjacent prestressed concrete box beams with P-3 concrete were used to construct a single-span, 65-ft-long structure. Class P-3 concrete has a compressive strength of 7 ksi and is typically used for prestressed concrete members. High-performance concrete was used for the deck, parapet, suspended backwall, and sleeper slabs on the project. The shallow 27 in. depth of the box beams helped maximize the hydraulic opening. Removal of two piers within the channel allowed the new north abutment to be located in front of the existing abutment, portions of which remained in place to avoid demolition and excavation close to the ruin wall. The precast, prestressed concrete box beams

were quickly installed and, without the need for deck formwork, allowed the contractor to quickly traverse the new bridge and access both sides of the arch bridge to remove the fill and place concrete.

Conclusion

Rehabilitation techniques were developed to strengthen a historic stone arch bridge with structural concrete within the fill area of the structure and to leave the existing masonry in place by rebuilding out-of-plumb sections and repointing other masonry. Reinforced concrete saddling of the arches was designed for modern loading. Additionally, reinforced concrete spandrel walls were placed within the fill to resist horizontal loads and were extended into the parapets, which may not have met current crash-worthiness requirements. In a rehabilitation project like the Stone Arch Bridge, coordination with stakeholders throughout the design and construction stages was a key to the success of the project. When proper respect is paid to the environmental and historical aspects of a project, durable and beautiful structures that preserve valuable history can be delivered to the satisfaction of the owner and all stakeholders. ▲

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Downstream view of the rehabilitated Stone Arch Bridge and new Flood Channel Bridge.

