Strengthening a stone arch bridge

New Technology helps maintain historic charm

By David B. Woodham, P.E.

The Newcomer's Mill Bridge in western Maryland is a historically significant remnant of the first federally funded roadway, The National Road, which Congress authorized in 1806. The roadway itself began in nearby Cumberland and proceeded west- ward. Before the bridges were built, passengers along this road had to climb up and down the muddy fiver banks and ford the fiver by wagon, horse, or foot.

In the 1800s, the stone masonry arch was the most common bridge type, as it was relatively simple to build under the direction of a competent mason. The construction was quite simple. The spandrel walls and arches were built of stone. The interior was then filled with rubble and covered with smaller aggregate and soil to form the roadbed.

According to the Maryland Historical Trust, the Newcomer's Mill Bridge was built around 1815. This single-span stone arch bridge crosses the Little Savage River. The semi-circular arch span is approximately 25 feet and is constructed of random stone, while the spandrel walls are constructed in coursed ashlar bond (Figure I). The bridge currently provides access for one property owner and typically carries only cars and light trucks. Even though these are small evidenced by a visible crack between the wall and the main barrel. In addition, we observed three additional longitudinal cracks in the arch at roughly eight foot intervals. Undoubtedly, the bridge required maintenance throughout its life; however, only the more recent repairs are documented. Most likely, the mortar joints were repointed periodically to maintain the structure. In an attempt to prevent mortar erosion on the underside of the arch barrel, a layer of shotcrete was applied. The shotcrete repair is unsightly, and it is not a long-term solution for this type of structure. As applied, it prevents the moisture from escaping from the arch baird. In 1991, the southwest wingwall collapsed and was subsequently repaired the following year. According to available records, the south abutment) of the arch were eroded one to three inches back from the exterior face of the stone. Near the southeast comer, a large void was present where stone and mortar had fallen away from the joint between the barrel and south spandrel wall, as shown in Figure 2.

In order to assess the bridge's capacity, Atkinson first needed the detailed geometry of the bridge. We retained a local surveying crew to collect this information. More than 600 three-dimensional points on the bridge deck and barrel were collected. The points were gathered on a variable grid spacing which was fairly coarse overall (three to four feet on center) but tightened to 18 inches-square in areas where the geometry was critical (i.e. the quarter points of the barrel arch and the future locations of the anchors).

Our firm converted the information to three-dimensional coordinates, then developed an AutoCAD file as an input file for the analysis program.

We sent the bridge geometry file to Gifford and Partners (U.K.) who performed the structural analysis of the bridge. Because of the many stone arch bridges in England, Gifford is accustomed to this type of analysis and has developed a discrete element model, which essentially models individual mortar joints and stones. The friction/contact laws were conservatively determined based on the type of stone and typical mortars from that period. This model provided an improved prediction of the inelastic behavior of the arch.

loads by modem standards, they are greater than those envisaged by the original builders. In 1999, Atkinson-Noland & Associates was contracted to bring the bridge back to its original condition. The major deficiency observed on the bridge was the detachment of the spandrel walls, a common problem in masonry arch bridges.

The south spandrel wall was dearly separating, and the north wall was also beginning to separate, as spandrel wall was also rebuilt in 1995.

Many mortar joints near the springing (the location where the arch meets the

Figure 1: View of south spandrel wall showing the location of repaired cracks and remedial spandrel anchors.

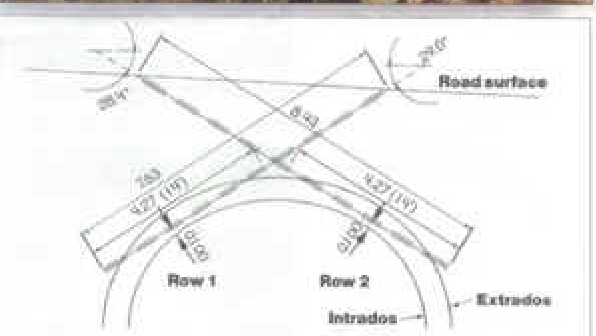

Figure 2: (top) Severe deterioration at Southwest corner showing separation of spandrel wall from arch barrel and resulting void. Figure 3: (bottom) Section through arch showing typical ARCHTEC strengthening anchors installed tangent to intrados at quarter span (dimensions shown are in meters).

the arch. The anchors were recessed two inches into the stone core, and the holes were patched once the anchor had been installed and grouted, Sixteen Cintec anchors (six feet to 10 feet in length) were installed on the south and north spandrel walls to tie the walls together with the arch barrel, making these elements act compositely. In addition, three, 29-foot anchors were installed connecting the north and south spandrel walls to prevent further separation. Four main ARCHTEC anchors were installed from the roadway of the bridge and designed to pass tangentially near the arch intrados at the quarter span (Figure 3]. For efficiency, the 14-foot anchors had to pass as close to the intrados as practically possible -- in this case, within four inches (10 an.) of the intrados. In order to achieve the proper placement of the reinforcing, we needed to layout the location of the anchor entry point and the vertical and horizontal angles carefully. According to Wayne Ruth of Masonry Solutions, "New masonry coring equipment both simplifies and accelerates the installation of the longer anchors." With nearly 300 feet of coring the new equipment made a method has been correlated with a number of laboratory experiments with good results. The bridge was analyzed with and without the anticipated repair anchors, This analysis indicated that four, one-inch diameter ARCHTEC anchors were needed to reach the required load capacity of the bridge and to pre- vent a hinge from forming in the arch barrel. ARCHTEC is a proprietary anchor system designed specifically for this purpose. Repairs began in November of 1999. The construction team first repaired major voids and rebuilt areas where stone had fallen away from the bridge. The voids near the springing of the arch were repaired using low-pressure grouting techniques. Injection ports were drilled on two-foot centers through mortar Dints in the masonry. A compatible cementious grout was injected, beginning at the lowest elevation, at pressures of 10 psi or less. This work continued to a height of approximately six feet above the stream bed. One localized area had to be stabilized before we could begin drilling the larger anchors through the structure.

We installed 20 small Cintec anchors (two feet long, 3/4 inch in diameter\} in the south spandrel wall. The Cintec system of reinforcement was developed in Europe beginning in 1965 and consists of stainless steel reinforcing bars that are surrounded by a fabric sock. The anchors are installed in oversized core holes and then injected under low pressure with a proprietary grout. The grout inflates the fabric sock around the anchor to provide both a chemical and mechanical bond with the interior of the core hole. Holes for these anchors were drilled on a grid of roughly two feet by two feet. The holes were drilled through the face of the stone in order to tie the large stones to the rubble above Client Maryland DOT Project management CLS Cintec America Masonry contractor Masonry Solutions Inc. Structural analysis Gifford and Partners Mr. Woodham is vice president at Atkinson-Noland & Associates in Boulder, Colo., a consulting engineering firm specializing in evaluation and repair of existing structures

big difference. We successfully demonstrated the strengthening of a historic structure using ARCHTEC anchors with minimal invasion. The use of internal reinforcement did not alter the appearance of the structure, nor did the installation cause major disruption to its use. An advanced structural analysis technique allowed the composite behavior of the reinforced masonry to be predicted accurately and therefore was a more efficient use of the reinforcement. We restored the appearance and durability of the bridge and prevented moisture from entering the masonry with crack repairs and mortar repointing. Also, we penetrated the shotcrete liner covering the arch barrel periodically allowing moisture to escape.

Credits	
Client	Maryland DOT
Tech. & site support	Akinson-Noland & Assoc.
Project management	CLS Cintec America
Masonry contractor	Masonry Solutions Inc.
Structural analysis	Gifford and Partners
Surveying	Specs Surveyors

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