CHAPTER 18

The Tohickon Aqueduct

I first became aware of the Tohickon Aqueduct project when contacted by William J. Collins, a landscape architect and timber framer from Point Pleasant, in Bucks County, Pennsylvania. We agreed to meet and discuss the proposed project at the annual meeting of the Timber Framers Guild of North America in Guelph, Ontario, in 1992. Bill Collins, a resident of Point Pleasant and a principal in the firm Simon Jaffe Collins Incorporated Landscape Architecture of Berwyn and Doylestown, Pennsylvania, had worked several years as project manager, landscape architect, and designer for the local sponsor, the Point Pleasant Community Association. The design concept he presented to me in Guelph was an aqueduct framed with Town lattice trusses, in keeping with the original 1834 construction.

The Delaware Canal was constructed in the early 1830s with the primary goal of transporting anthracite coal from northeastern Pennsylvania to cities on the eastern seaboard. The Tohickon Aqueduct is a vital link in the 60-mile-long Delaware Canal carrying the canal over Tohickon Creek in Point Pleasant, Pennsylvania. The canal climbs 164 feet between Bristol and Easton through a series of 23 locks, over nine aqueducts. The Tohickon Aqueduct, originally built as a timber-framed Town lattice truss structure was replaced in the 1890s with an iron riveted structure containing a wood-framed trunkway. This aqueduct collapsed in 1931. After World War II, the canal was transformed into a Pennsylvania state park and the aqueduct reconstructed with steel girders supporting a cast-in-place concrete trunkway. By 1990, the badly deteriorated concrete and steel structure needed to be replaced. As if to place an exclamation mark on the statement that the aqueduct needed to be replaced, a September 16, 1999, storm in Point Pleasant, caused a portion of the sidewall of the aqueduct to collapse.

Bill Collins was one of several community leaders who were very interested in replacing the aqueduct as a timber structure. The concept plans were presented at a meeting of community and elected officials and officials of the Pennsylvania Department of Conservation and Natural Resources, Bureau of Facilities Design and Construction. A unique agreement was reached, allowing the community to collaborate with the State Parks Department by providing engineering plans for the timber superstructure outside the normal procurement process.

Apparently, it was an easy agreement to broker, as the state would not have to pay for the engineering. Fortunately, there was an organization interested in having the Tohickon Aqueduct constructed of wood. The Wood in Transportation Program of the U.S. Department of Agriculture Forest Service came to the rescue, providing five small grants to successive phases of the project. The state would be responsible for administration of the project and design of the substructure and the interface of the trunkway with the canal. Initial funding for design of the superstructure was provided by U.S. Forest Service grants through the Wood in Transportation Program. Initial funding was minimal, so design proceeded slowly between 1992 and 1999. This was especially frustrating for the members of the Point Pleasant Community Association when I presented them with construction photographs of the New Covered Bridge in Old Salem, North Carolina, a similar project well underway, which had started at the same time. By contrast, the aqueduct project had gone nowhere.

During the extended design phase, the proposed Town lattice truss had evolved into a Burr arch-truss. The geometry of the aqueduct was governed by the existing stone piers, the canal grades, and location of the towpath. It was soon apparent that a trapezoidal shaped trunkway would be the most logical cross-section allowing sufficient space for the ten foot wide standard canal boat or barge while minimizing the total amount of weight to be supported. Grades required the trunkway to be supported on transverse beams supported by the bottom chords of two parallel trusses. Interior diagonal braces provided lateral stability to the top of the trusses, completing the trapezoidal shape.

The use of a Town lattice truss had strong historical precedence in Bucks County, with 11 covered bridges, so framed, remaining in 1989. Those covered bridges were built between 1832 and 1875, certainly within the active history of the canal. It is interesting to note that the counties in Pennsylvania that had been settled by the English usually built Town lattice–framed covered bridges, while the counties settled by the Germans mostly built Burr arch–framed bridges. We were about to upset the covered bridge continuum.

There were a number of good reasons for selecting a Burr arch-truss system instead of a Town lattice truss design for the superstructure. First, the original aqueduct was a Town lattice, which was replaced after 50 or 60 years with an iron aqueduct. We were not able to locate information about the original design, its configuration, or its record of service. As a result, a Town lattice design would be open to almost as much speculation as any other system.

In reality, the Town lattice would have been a difficult system to construct, because it would have to be built on site with many trunnels driven into a large number of lapped joints of chords and lattice. The aqueduct, by its nature, needed to be built of pressure treated wood for durability. The problems of treating and drying pressure-treated timber would be virtually insurmountable using waterborne treatment such as Chromated Copper Arsenate (CCA). The acquisition of trunnel stock, which usually is of White Oak (impossible to pressure treat) and southern pine pressure-treated lattice and chord material, would require a very long lead time to dry, treat, and redry. Any excess moisture in the trunnels or lattice would result in splits forming in the lattice and the trunnels loosening as the structure reached its equilibrium moisture content.

Although the goal was to design a bridge that timber framers could build, the assembly of a Town lattice structure requires specific experience and skills unique to certain bridgewrights. Although the Town lattice has a reputation for toughness, it contains many built up and intersecting members with a potential for decay between members on hidden surfaces. Boring or cutting through CCA pressure-treated material is problematic because salt crystals associated with the preservative tend to dull tools. Driving trunnels through salt-treated lattice and chords is also an issue because of the brashness of the treated wood and the roughness of the salt-treated surfaces, which must engage during the driving process.

The Town lattice truss is labor intensive and would have to be built continuous over three spans, extending beyond the abutments a distance equal to its depth. Although this would allow for the forces at the end supports to be distributed among a sufficient number of lattices, as opposed to an abrupt termination resulting in excessive stresses in the lattice, the total length of the trusses would increase by 24 feet. Repairing a Town lattice truss is extremely difficult and labor intensive because of the closely spaced and tightly held lattice sticks. Again, this work would require the services of a bridgewright with specific experience.

The Burr arch system was designed as a redundant system with either the arch or the truss able to support all loads, independent of the other. The nineteenth-century builders would proportion each and then simply “yoke the two together.” In this way, they could circumvent the question of whether the truss stiffens the arch, or the arch stiffens the truss.

In this case, the truss and arch were analyzed separately and then also together. Instead of superimposing the arch on the truss, in the computer we actually suspended the less stiff continuous truss from three two-hinged arch spans. The Burr arch structural system was designed to support a total weight of 8000 plf.

FIGURE 18-1
The aqueduct consists of three equal spans of 66 feet. (See color insert.)

Although the superstructure was covered and protected with a membrane liner in the trunkway, all wood was specified to be pressure treated to resist decay. The aqueduct, by its very nature and environment, is susceptible to decay caused by moisture derived from condensation, leaks, and splash.

The first design was as traditional as possible using timber-framed connections for splices and to build up the arches. The arches were detailed with mechanically fastened laminated members with shear blocks and stitch bolts with timber washers. The posts and braces were solid timbers, while the critical chord members were glued laminated timber members to ensure quality control and long continuous lengths. To minimize the amount of steel in the structure, posts and braces were notched to fit notches in the chord members. To provide continuity as the supports, the chords were connected with traditional bolt-o-lightning splices.

The trunkway was fitted with a membrane liner to ensure the water-tightness of the aqueduct. We suggested that a second layer of wood consisting of large panels be placed on top of the liner to conceal it and provide puncture protection.

An aqueduct is unique because it is uniformly loaded on a constant basis. A vessel traversing the aqueduct displaces an amount of water equal to its weight, and thus, does not increase the load to the structure. Aqueduct structures provide an opportunity to test the concept of load duration, which is central to the design of timber structures.

The Tohickon Aqueduct was bid in 1999 with J.D. Eckman, Inc. of Chester County, Pennsylvania, submitting the low bid of $3.1 million. Several timber-frame companies that were heavily courted by the designers declined to submit a bid. Because the low bid exceeded the state's proposed budget, the Department of Conservation and Natural Resources was directed by the state to develop an alternative design in concrete. Again, on behalf of the Point Pleasant Community Association, Bill Collins petitioned the Department of Conservation and Natural Resources to consider a timber aqueduct. This time it would be a "value engineered" version of the first design, bid as an alternative to a concrete structure designed by the department. Again, it agreed, on similar terms, that value engineering would proceed without funding from the state. As before, the Forest Service agreed to fund the engineering design with the condition that the project include fiber-reinforced polymers to reduce cost. Fiber-reinforced polymers were introduced as a research project of the Advanced Engineered Wood Composites Center at the University of Maine.

The structural system was value engineered to reduce costs by simplifying details, remove requirements for traditional timber framer qualifications, and introduce more glued laminated timber into the project, in particular, for the two-hinged arches.

FIGURE 18-2
The arches were replaced through "value engineering" by glued laminated timber.

Traditional hand-crafted joinery was deleted, including the complicated bolt-o'-lightning splices. The three spans were designed to be individual trussed systems identical in geometry. The use of Pennsylvania red oak was deleted as an alternative and the more easily obtained southern pine was specified.

The goal of the value engineering was to reduce construction costs by $500,000. The revised project bid in 2000, with J.D. Eckman, Inc. again emerging as the low bidder, was $2.1 million, approximately $1 million less than the original.

The aqueduct as built is a skewed structure, 201 feet, 10 inches in length with trusses that are 12 feet in height, out to out of the chords.

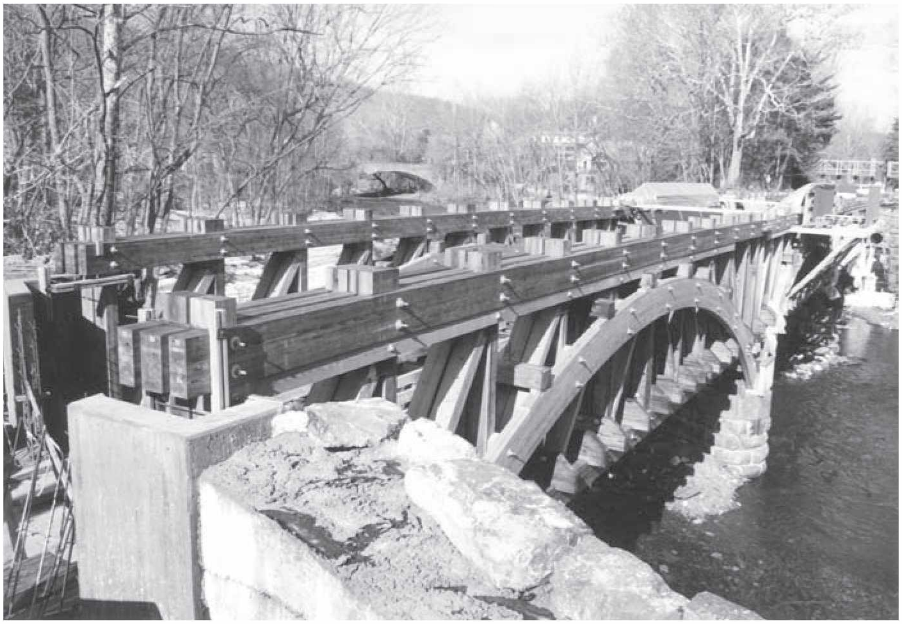

FIGURE 18-3
The skewed structure is 201 feet, 10 inches in length.

It includes three 66-foot spans with double 6¾ inch by 23⅜ inch glued laminated two-hinged arches yoked to a multiple kingpost truss with double 6¾ inch by 16½ inch and single 8¾ inch by 16½ inch glued laminated timber chords, top and bottom.

Although the Tohickon Aqueduct was formally reopened on September 15, 2001, and was eligible for nomination for the special Palladio Award Competition for Covered Bridge Restoration announced by *Clem Labine's Traditional Building* magazine, I was persuaded by one of the jurors not to enter it since it was a reconstruction and would not qualify.

The Palladio Awards program launched in 2000 by *Traditional Building* magazine and *Period Homes* magazine included "covered bridge repair, preservation,

FIGURE 18-4
The chords are pressure-treated glued laminated timber.

FIGURE 18-5
The superstructure was constructed of pressure-treated southern pine.

restoration, or reconstruction completed between 1998 and 2003."[1] It appeared that the twin dilemmas of whether the aqueduct would qualify as a covered bridge and whether a total reconstruction of the superstructure in an alternate system would render it unlikely to earn honors. Of course, there were historic examples

FIGURE 18-6
The Tohickon Aqueduct was reopened on September 15, 2001.

FIGURE 18-7
The completed aqueduct won a National Timber Bridge Award in 2002. (See color insert.)

of aqueducts with Town lattice and Burr arch structural systems included in Richard Sanders Allen's series of covered bridge books. Some structural engineers favor demolition of a historic covered bridge, only to reconstruct it new, as a viable preservation solution. They argue that the new rebuilt bridge is still historic because the original "idea" remains. Certainly, the reconstruction from scratch of the superstructure of a long-gone timber framed aqueduct does not trample on preservation sensibilities. In fact, prior to the Palladio Awards, the Tohickon Aqueduct had won a first place National Timber Bridge Award in 2002 for "Rehabilitation of an Existing Bridge."

The most remarkable aspect of the Tohickon Aqueduct project was the ability of Bill Collins to move a state agency toward a solution in which they had no initial interest, and then obtain, through negotiation, interested third parties to pay for the engineering.

REFERENCE

1. Cesa, Edward A., News Release USDA Forest Service, January, 2003.