Restoration of Meem’s Bottom Covered Bridge

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On October 28, 1976, the Meem’s Bottom Covered Bridge in Shenandoah County, Virginia, was set on fire. Listed as a historical landmark on the Virginia Landmarks Register, the structure is the longest covered bridge in the state and is one of two that still carry traffic. At the direction of the Virginia General Assembly, the Virginia Department of Highways and Transportation undertook the task of rebuilding the structure and restoring it to service in such a manner as to maintain its historical significance. The conclusions derived from a structural analysis of the Burr arch-truss design and the novel procedures undertaken by the department to restore the bridge are presented. In completing the task, the department successfully maintained the 80-year-old structure’s historical significance and satisfied the mandate of the General Assembly. Although completely destroyed, the load-carrying joints were rebuilt through extensive use of epoxy. Specially treated lumber, fire retardant varnishes, and stainless-steel roofing were used in the restoration to meet the need for fire protection and to minimize maintenance.

Preserving or modifying a historic bridge does mean expanding some extra thought or effort, but it does not always mean added expense. Upgrading an old bridge may, in fact, be less costly than building a new one, and converting an old bridge into commercially usable architectural space could even be profitable. Regardless of cost and other factors, ways can always be found to preserve selected historic bridges if there is sufficient commitment to that end.

ACKNOWLEDGMENT

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REFERENCES


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The direct link between Strathmore Mansion and the Valley Pike (now US-11), which were separated by Meem's Bottom and the North Fork of the Shenandoah River. The Whisler family, who owned the mansion and iron furnaces at Liberty and Columbia, probably engaged master bridge builder John W.V. Woods of Shenandoah County to span the river bottom, thus eliminating several miles from an otherwise circuitous route between their properties.

The Virginia Department of Highways acquired the bridge in 1932 and maintained it in good repair. It carried a 9-t (10-ton) traffic rating until it was set on fire in 1976. In spite of the efforts of a volunteer fire department, the bridge was severely damaged, as can be seen in Figure 2. The roof system, top lateral system, siding, and framing were totally destroyed. The nail laminated oak strip flooring, which had been installed on steel stringers to replace the original timber floor system in 1937, was burned beyond repair but would later serve as a work platform during repairs. Only the main structural members remained and these had lost as much as 3.8 cm (1.5 in) of material from all sides. The heat was so intense that three floor stringers buckled and their weldments to the floor beams were broken.

RESTORATION

At the urging of local officials and historic organizations, the Virginia General Assembly directed the Virginia Department of Highways and Transportation to restore and return the bridge to service rather than replace it.

When John Woods built the bridge 80 years earlier, he had no idea of the problems his masterpiece of bridge architecture would present to the bridge engineers of the department. Woods chose to erect a covered timber bridge of the Burr arch-truss system (Figure 3) that incorporated the same skills and craftsmanship in fitting the individual members together as master boatwrights used in building yesteryear's tall sailing ships. Ship lap-splice joints, mortise and tenon joints, and keyed-butt joints fitted together as tightly as joints do in the finest reproduction furniture available today.

STRUCTURAL ANALYSIS

A structural analysis of the bridge was necessary to determine if sufficient strength remained for restoring the bridge to service, assuming that

1. The interlocking joints of the arch and truss, which were completely destroyed by the fire, could be restored;
2. The necessary interaction of the jointed members could be regained and the bearing strength restored; and
3. The arch, which was buckling at its splice points, could be realigned and adequately braced to maintain its proper alignment.

Because of the extreme indeterminate nature of the Burr arch-truss structural system, it was necessary to engage Emory Kemp of West Virginia University as a consulting engineer. Kemp had available the ICES

Figure 1. Meem's Bottom Covered Bridge before the fire.

Figure 2. Meem's Bottom Covered Bridge after the fire.

Figure 3. Schematic of the Burr arch-truss.
STRUDEL II computer program that was adaptable to the analysis of this type of bridge.

Remnants of the roof structure and siding framework were removed to eliminate as much dead load from the weakened structure as possible. Char was removed from the members believed to be salvageable and measurements taken.

Kemp's analysis provided insight not only into the potential for restoration but also into the working relation between the arch and truss systems. Many bridge engineers believed that the truss carried the dead load and the arch sustained live loads.

Although Kemp's research did not invalidate this reasoning about the application of various loadings, it did reveal a superior stiffness characteristic of the arch-truss system because of the arch compared with a simple truss. Even in its burnt condition, the structure provided midspan deflections for H15-44 truck loadings well below the $1/800$ of the span limitation of the American Association of State Highway and Transportation Officials (AASHTO) specifications (2).

When the results of deflection analysis were compared with the stress calculations for the truss, which neglected the arch, it was found that the arch caused a reduction in stresses in the truss system and significantly reduced the total deflections for the truss that acted independently. The arch curtails deflections attributable to creep and shrinkage of the truss members under sustained loads and loosening of the joint system due to cyclical loadings.

The stress analysis of the truss system revealed that the truss verticals were the critical members. While the axial stresses were within acceptable limits, the analysis indicated the existence of large tension and compression stresses indicative of the presence of undesirable bending moments in the vertical members. Further investigation revealed that these were caused by two significant errors in the design.

The most crucial of these errors was the manner in which the diagonal members were framed into the truss verticals, as illustrated in Figure 4. The eccentricity of the diagonal with respect to intersections of the top and bottom chords and the vertical members created the significant bending moments. The fixed joints at the intersection of the
top chord and verticals contributed further to the bending in the verticals.

The fire damage sustained by the structural system was twofold. First, the overall effectiveness of the truss was reduced, which redistributed the stress in such a manner as to increase the importance of the function of the arch in the arch-truss system. Second, this redistribution of stress occurred without any members other than the already critical vertical members being overstressed. The overstressed verticals were further overstressed; thus, the fire aggravated an already critical problem.

**REPAIR PROCEDURES**

In planning the restoration, it was clear that the present structural system would be inadequate without taking steps to reduce the stresses to a tolerable level by removing or resisting the eccentric loadings in the vertical members.

The top chord of the truss was severely damaged and was later found to have large sections of rotting material and insect infestation. A new top chord was warranted and could be put immediately below the old one before it was removed so that the eccentric load of the diagonal would be eliminated (Figures 4 and 5).

The point of eccentricity at the bottom chord was at a position where the horizontal thrust of the diagonal could be transferred through the vertical into the floor system by welding a strut plate to the floor beam and the exterior stringer, as shown in Figures 4 and 6. Although all of the bending in the vertical at this point could not be eliminated, this procedure did reduce the undesirable bending to acceptable levels.

With the problem of the bending moment in the vertical truss members resolved and the design of the truss consequently improved, restoring the joints and gaining proper interaction of the joined members remained the big problems to resolve. The realignment of the arch could be determined only by work, and it was felt that the alignment could be held with the new top lateral system of the truss and with properly restored joints.

Originally, the vertical truss member had been shaped to lock into the top chord, arch, and bottom chord and was notched to provide a bearing seat for the diagonal members that passed cleanly through the arch (Figure 7). When a live load was placed on the verticals, the interlocking action of the joints transferred the load to the truss members and into the arch. These joints, which had been cut, shaped, and matched to bear the loads, had been destroyed by the fire, as shown in Figure 8. Large gaps were left where tight bearing surfaces had been. Only the splice joints in the arch escaped fire damage, perhaps because of the tight bearing caused by the dead load. In many places the gap around the vertical through the arch was large enough to pass an arm through the arch all around the vertical. Neat rectangular cross sections no longer existed.

To compound matters, areas in the arch were found to be severely damaged by insect infestation and rot. Exposed to the elements, this deterioration could only accelerate. The restoration of the joints was to become the major task in restoring the structure to service.
The initial repair effort was to bring the arch to as straight an alignment as possible. A combination of cable restraints and compression struts was used to force the warped arch back to its proper alignment. These restraints were left in place for the major part of the repair; the restoration of the joints, installation of the new top lateral system, and framing of the roof were completed before they were released.

Several ideas were considered in engineering the reconstruction of the joints, all of which incorporated the use of epoxy to some degree. Ultimately, a high modulus, low-viscosity epoxy resin system was used that, when mixed with a wood flour, gave the appearance of wood to the rebuilt areas, as can be seen in Figure 9. Several different flours were considered. Walnut shell, maple wood, and pine flours (the last called white tag) were mixed in the laboratory. The specification finally written left the type of flour open and only required that the epoxy and wood-flour mixture should closely resemble the color of the timber being repaired.

The consistency of the epoxy and wood-flour mix could be controlled to meet the demands of its placement in the repair process. Where structural details permitted, the mixture was poured. In other locations it had to be stiff and placed with a trowel. Where it was necessary to remove rot or insect-weakened areas along the arch, the epoxy and wood-flour mixture was used to fill the cavities left by the removal of the deteriorated timber. In exceptionally large cavities, blocks of wood were used for filler, and in one area a salt-treated...
The metal roof was installed by using the same standing seam method of construction used for the tin roof destroyed by the fire. The roof was of a special terne-coated stainless steel that has weathered to a uniform gray appearance. A stainless-steel roof was chosen to eliminate the hazards associated with having a tin one. A new 12.2-m (40 ft) above a rocky stream bed. The additional cost was about equal to the initial cost of an original tin roof and one maintenance painting. Additional long-term savings will also be realized.

During construction, insect damage to some of the members at the portals was discovered, as was hidden rot. The areas around the masonry abutments were treated against insect attack, and a covering of the abutment wings was fashioned by using siding and the stainless-steel roofing material to guard against the infiltration of water.

All new timber in the restoration was given a dual pressurized treatment of a preservative and a fire retardant that would not alter the appearance of the wood. The existing material left in place was given several coats of a clear fire-retardant paint that slightly darkened the old timbers. Oak plank wearing strips were placed over the deck panels and the bridge was once again ready for service (see Figure 13 and 14).

Three years after the fire the Meem's Bottom Covered Bridge was reopened with a 7.3-t (8-ton) load capacity at a final restoration cost of $240,000 and carried its first official vehicle, a farm wagon pulled by a team of horses.

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Now, if either the vertical or its joint with the arch were to fail, the live load and dead load of the floor system carried by each vertical would be transferred through the hanger directly into the arch. The hanger was not tightened enough to pre-load the rod but was brought up to a snug tightness that would permit the hanger to work along with the vertical as the truss deflected.

The new top lateral system was erected along with the framing for the new roof (see Figure 12). Stringers warped from the intense heat were replaced and the antithrust strut plates (Figure 6), which were to reduce the bending moments in the verticals at the lower diagonal connections, were welded in place.

The arch at this point was still braced and tied off to hold it in its proper alignment. With the epoxy compounds fully cured, all new structural members in place, and the floor system strengthening the arch to obtain satisfactory joints of the structural members, the restraints to the arch were released. With some minor transverse movement, the arch and truss maintained an acceptably straight alignment.

The charred remnants of the oak-strip deck were removed and a new deck of glued, laminated southern pine was installed. Framing for the siding and portals was erected and new 2.5×15.2-cm (1×6-in) pine siding was installed.