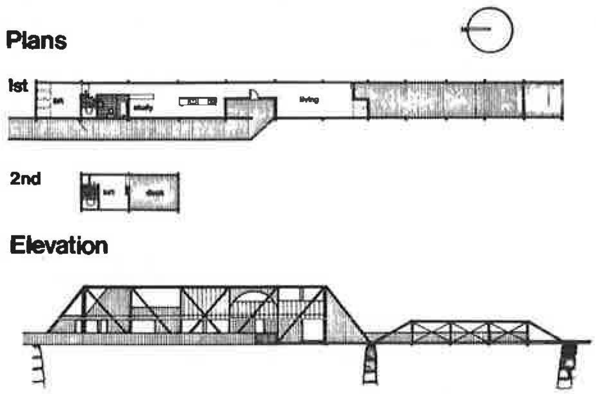
Figure 12. Bridge on VA-615 over Pamunkey River as housing.




another site of a less-demanding nature where it can continue to function as a bridge for light vehicles, bicycles, or pedestrians.

4. If no vehicular use of the historic bridge can be foreseen, it could be converted into some architectural use, such as those described in this paper.

5. In situations where none of the preceding four solutions are possible, the structure should be set off as a historic ruin. Several examples are described in this paper. This arrangement allows the structure to remain standing at a minimal cost.

6. If, of necessity, the structure can no longer be left standing, it should be match-marked, carefully dissembled, and stored in a protected environment with the hope that at some future time and place it could be rebuilt.

7. Further down on the scale of desirability, from a preservation point of view, is to save only selected components of the bridge that would otherwise be totally destroyed. These components could be made into exhibits, as in museums, or even be incorporated as ornamental elements into a new bridge built on the site of the old one.

8. As a minimum, whenever a historic bridge is to be razed, it should be documented with drawings and photographs, and such documents should be preserved in some archive.

Preserving or modifying a historic bridge does mean expending 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

An interdisciplinary study of this kind is not possible without the cooperation and assistance of many people. To them, we express our appreciation. In particular, Howard Newlon, long active in historic preservation, was the motivating force behind this study. Reid Reames and George Kirby also greatly assisted in many of the technical aspects of the project.

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# Restoration of Meem's Bottom Covered Bridge

KENNETH M. SMITH AND JOHN E. ANDREWS

**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.**

Approximately two miles south of the town of Mount Jackson in Shenandoah County, Virginia, the longest remaining covered bridge stretches nearly 61 m (200 ft) in a single span to bridge the North Fork of the Shenandoah River at Meem's Bottom.

The Meem's Bottom Covered Bridge, shown in Figure 1, was built on private property in the mid-1890s. Little concerning its history can be found in public records. Emory Kemp and Charles E. Daniels of the Department of Civil Engineering, West Virginia University, gave some of its history in a report (1) compiled following its near destruction on October 28, 1976.

The bridge apparently was built to provide a 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.

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

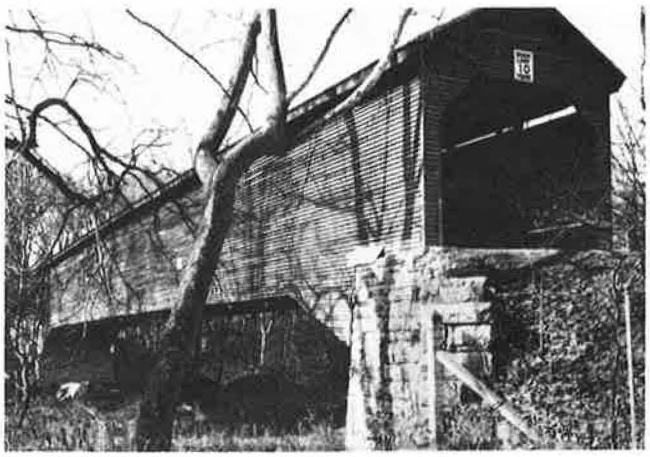
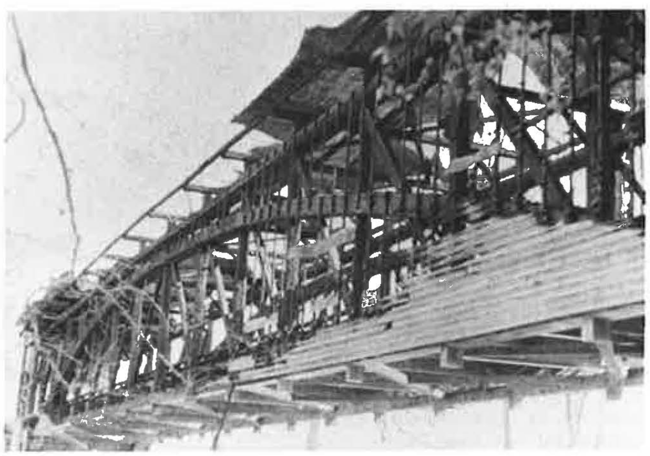


**Figure 2. Meem's Bottom Covered Bridge after the fire.**



## 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 3. Schematic of the Burr arch-truss.**

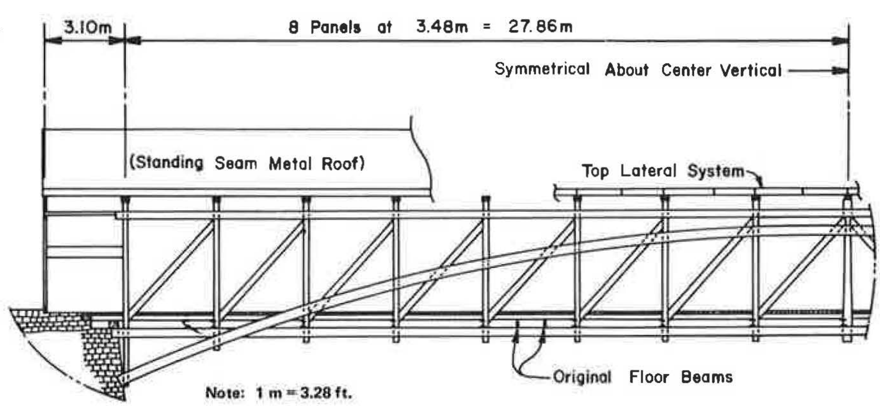
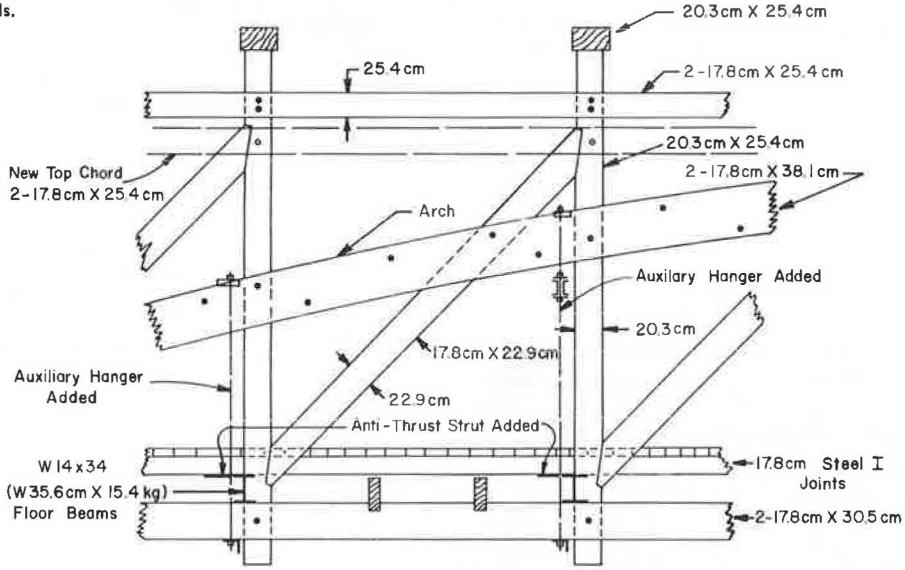


Figure 4. Typical panel details.




Note: 1 m = 3.28 ft.

Figure 5. Installation of new top chord.

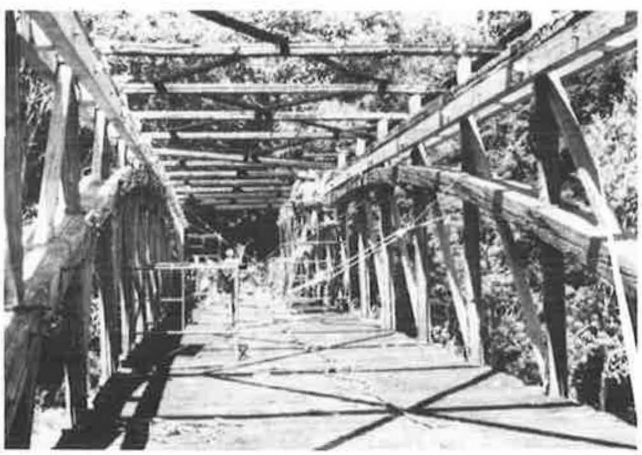
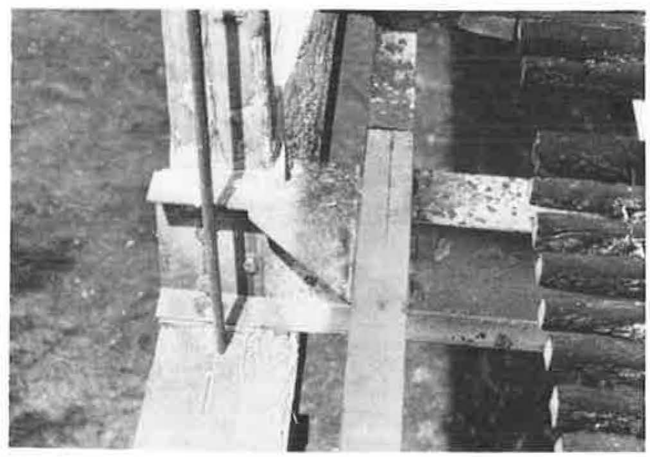


Figure 6. Installation of antithrust strut plate.



STRUDL 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.

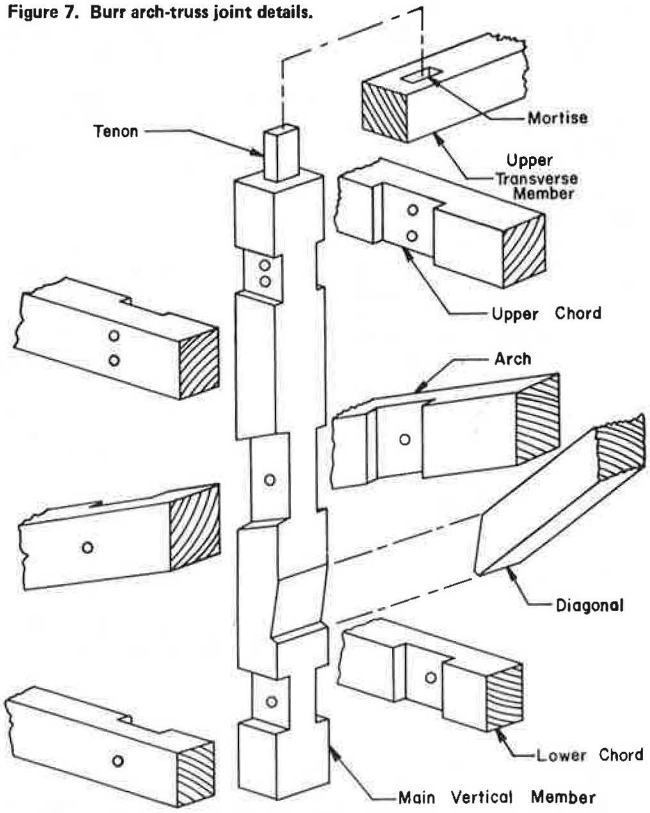
Although Kemp's research did not invalidate this reasoning about the application of various loadings, it did reveal a superior stiffness characteristic of the arch-truss system because of the arch compared with a simple truss. Even in its burnt condition, the structure provided midspan deflections for 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

**Figure 7. Burr arch-truss joint details.**




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.

**Figure 8. Typical joint destruction.**

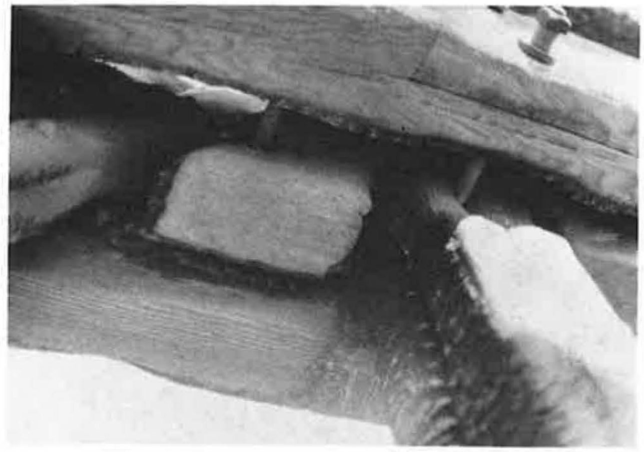


**Figure 9. Typical joint restoration.**

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

**Figure 10. Auxiliary hanger system.**

**Figure 11. Auxiliary hanger system at middle verticals.**

**Figure 12. Installation of top lateral system.**

**Figure 13. Interior of bridge after restoration.**

**Figure 14. Restored Meem's Bottom Covered Bridge.**

10.2x10.2-cm (4x4-in) timber was placed and wedged tight in a 2.4-m (8-ft) length of the arch before the mixture was placed.

Wherever truss members jointed with or passed through the arch, the epoxy and wood-flour mixture was used to restore bearing, fill a void, or restore a shape to obtain satisfactory joints of the structural members. With the weakened joints strengthened and restored with the epoxy and wood-flour compound, it was felt that the structure would again carry traffic, provided a method could be devised to safely transfer live loads to the arch. In the original structure this was accomplished at the vertical-to-arch connection by the interlocking joint that provided the transfer through bearing on the arch.

The epoxy-restored joints were considered satisfactory where they were in pure compressive bearing, but there was still doubt about the adequacy of the vertical-to-arch connection. The fire had destroyed these bearing surfaces and the epoxy restoration could not be trusted at this location because its purpose was to fill the void, not to transfer load by shear and tension forces. Consequently, an auxiliary hanger system, shown previously in Figure 4, was devised (see Figure 10). To serve as a stirrup, a structural angle was placed close to the floor beam and under the bottom chord. The stirrup angle was then suspended from the arch by a threaded, high-strength rod that passed through the bottom chord and the arch. Above the arch the rod was attached to a structural steel bearing plate, which was seated in the epoxy and wood-flour compound on a chamfer cut across the arch in such a manner as to ensure that the hanger load was applied uniformly across the arch members.

A slight variation of this device, shown in Figure 11, was necessary at the three middle verticals due to the framing of the diagonal at the top of the arch. At these locations the hanger rod was supported by a bracket composed of two small channels. This bracket was suspended from the arch by two rods that passed through the arch on either side of the diagonal truss member. Individual bearing plates seated on a chamfer and bedded with the epoxy and wood-flour compound on both sides of the diagonal to support the two rods completed this variation of the hanger system.

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 preload 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 lower vertical and diagonal member connections, 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 deck panels was installed. Framing for the siding and portals was erected and new 2.5x15.2-cm (1x6-in) pine siding was installed.

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 to paint a tin roof 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 used 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 varnish 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 Figures 13 and 14).

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

ACKNOWLEDGMENT

The contributions of Emory Kemp and Charles E. Daniels of the Department of Civil Engineering, West Virginia University, are gratefully acknowledged. Without the services provided by these consulting engineers and the information in their report (1), much of our report would not have been possible. The assistance of Ray Schutz, formerly with Sika Chemical Corporation, in developing the epoxy and wood-flour compound used in the repair is gratefully acknowledged. The assistance of the Virginia Highway and Transportation Research Council in the preparation of this report is also greatly appreciated.

This restoration project has received the first-place award for the Environmental Preservation and Enhancement category of the U.S. Department of Transportation's Federal Highway Administration biennial awards program for Excellence in the Design of Highway Facilities.

Without the outstanding assistance of the personnel of the Bridge Design Section and the Edinburg Residency of the department's Staunton District, the successful restoration of the Meem's Bottom Covered Bridge would not have been possible. We wish to dedicate this paper to the engineers and their staffs who worked so diligently to bring about the successful completion of a most perplexing and difficult project.

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