ORTHOTROPIC BRIDGE SAVES OLD COVERED BRIDGE

Robert F. Victor, P.E., Connecticut Department of Transportation

When inspection of the Old Covered Bridge at West Cornwall, Connecticut revealed extensive deterioration of its floor system and trusses, a new bridge was proposed to be built just upstream. The old bridge, dating from 1841, would have been left open to pedestrians only. This proposal angered local residents who wanted the old bridge restored. Because of tight vertical clearance restrictions, structure depth was severely limited. Preliminary computer analyses showed that a slender orthotropic steel deck bridge could be independently built within the old bridge and designed for AASHTO HS20 and alternative loadings. The construction consisted of building a parallel temporary bridge, raising the old structure 61 cm (2-ft.) higher to clear future floodwaters, painting, reshingling and whitewashing the interior and, erecting the steel deck bridge within. A timber floor was bolted to the steel deck plate. The total project cost $360,000 which is a savings of more than $1,500,000 over the cost of the proposed upstream bridge. More importantly, a historic nineteenth century structure was preserved as a heritage for the twenty-first century.

When inspection revealed deterioration of the floor system and trusses of the Old Covered Bridge at West Cornwall, Connecticut (Figs. 1 & 2), a new modern two-lane bridge was proposed to be built just upstream, bypassing the village of West Cornwall. The old bridge, dating from 1841, would have been left open to pedestrians only. This proposal angered local residents, who insisted that some way be found to strengthen the old structure without changing its appearance in any way!

Since any new floor had to remain at the existing grade to hold the existing vertical clearance of 3.35 m (11'-0") and since reconstruction would have to include a strong bottom lateral bracing system, only 76 cm (30 inches) was available for structure depth and vertical deflections. An orthotropic steel deck bridge, which is only possible through the use of extensive arc welding, can be made the most slender of all bridges. Preliminary computer analyses showed that a lightweight, economical, orthotropic bridge could be built within the covered bridge (Fig. 3).

To thoroughly analyze this highly redundant structure, a curved girder matrix grid analysis computer program (1) was modified to more easily handle the many members and loading conditions. The AASHTO (2) HS20 and alternative loadings were used to load the structure and design the various members.

Description

The deck plate of the bridge is 9.5 mm (3/8-in.) thick (based on L/300 deflection criteria between rib walls for an HS20 wheel) (3) and 4.27 m (14 ft.) wide (Fig. 4). Five trapezoidal ribs are 61 cm (2 feet) o.c. Brake press formed, the ribs are 23 cm (9-in.) deep, 8 mm (5/16-in.) thick, 31 cm (12-in.) and 17 cm (6½-in.) wide at the top and bottom respectively. The ribs are hermetically sealed between field splices and the end floorbeams. Since tests have shown that fillet welds would develop fatigue cracking (4), due to the transverse bending of the deck plate, the ribs were joined to the deck plate by 80 percent partial penetration groove welds.

The two main girders are 3.35 m (11 ft.) apart and each consists of 32 mm x 457 mm (1¼" x 18") bottom flange plate and 9.5 mm x 559 mm (3/8" x 22") web, fillet welded to the deck plate. Two edge plates 9.5 mm x 152 mm (3/8" x 6") are welded to each edge of the deck by partial penetration groove welds.

The steel bridge is two-span continuous (28.35 m - 22.86 m spans) (93' - 75') with each end cantilevered out from the bearings to form a total deck length of 52.61 m (172.55 ft.). In the longer span, floorbeams are 4.73 m (15.5 ft.) o.c.; in the shorter span 4.57 m (15 ft.) o.c.

A 13 mm x 152 mm (½" x 6") bottom flange and a 9.5 mm x 559 mm (3/8" x 22") web (castellated to fit tightly around the ribs) form the floorbeams which are fillet welded to the deck plate and ribs. The floorbeam web is fillet welded directly to the girder webs and the bottom flange is butt welded to the girder bottom flange. Trapezoidal plates 9.5 mm x 559 mm deep (3/8" x 22") stiffen the deck plate outside the floorbeams.

At each end of the bridge, the ribs are seal welded to the last floorbeam. Trapezoidal plates 9.5 mm x 559 mm (3/8" x 22") support the end of the deck plate. An edge plate is welded to the end of the deck plate. All steel conforms to ASTM A588 (Weathering Steel).

Design Data

Since the bridge is so lightweight (2.1 kPa-(44 psf) steel dead load, 2.5 kPa-(52 psf) total dead load) the live load stresses and deflections are large. The maximum computed live load deflection is 95 mm (3.75-in.) or L/300. This deflection was viewed as satisfactory since speeds are low and the largest vehicles using the bridge regularly would be school buses, fire trucks and other two-axle trucks.

In the actual bridge, the deflections, with the passage of a heavy vehicle are noticeable but not disturbing, since deck accelerations are small and vibration frequencies high (5). This is due to high stiffness-to-weight ratio and the mounting of the bridge on elastomeric bearings.

With the overall section determined by deflection criteria (as in most orthotropic bridges) (6), the meeting of fatigue criteria was easily accomplished. Most of the AASHTO fatigue categories (2) are present in this structure. Stress ratios and ranges vary considerably, depending upon the member and its location in the structure. At the section of maximum positive moment in the 28.35 m (93 ft.) span, the stress range in the bottom flange is 138 MPa (20 ksi) (from 159 MPa (23 ksi) max. to 21 MPa (3 ksi) min.) Dead load stress is 41 MPa (6 ksi). Thus live load stress plus impact is nearly three times greater than dead load stress. The deck plate, with its threaded welded studs for the timber decking, has a fatigue allowable stress of 114 MPa (16.5 ksi). Its maximum design stress is 105 MPa (15.3 ksi).

Construction

The construction started with the building of a 61 m (200-ft.) one-way temporary bridge adjacent to the covered bridge (Fig. 5). It was constructed from salvaged steel beams supplied by the Department and timber decking supplied by the contractor. This arrangement yielded a bid price of about $107 per sq. meter ($10/s.f.) which is very economical considering that the price included hauling, erecting and dismantling the three span (@ 20.4 m - (67 ft.) each) structure. It also included two river piers and two abutments.

With traffic thus diverted, the floor system of the covered bridge, consisting of steel floorbeams and a two-layer wood decking, was removed. The covered bridge was then jacked to an elevation 61 cm (two feet) higher in order to clear possible debris from design floods. New stone rubble masonry was added to the abutments and concrete to the pier (matching the existing appearance as much as possible). At the same time, new abutments consisting of a crossbeam, column and footing were built and buried inside the old abutments. The old abutments are thus relieved of much dead weight and all live load.

Fabrication

While construction proceeded apace in the field, the fabrication of the three full width orthotropic bridge sections was well underway (Figs. 6 & 7) in the shop. The specifications required that the fabricator, as part of the shop plan submission, submit a list showing the shop fabrication sequence. The designer was then able to review the proposed welding procedures in conjunction with overall fabrication methods with the view of minimizing distortion and shrinkage stresses.

The fabrication procedure evolved was as follows: (1) the top surface of the deck plates was sandblasted near-white and a weldable inorganic zinc-filled primer was sprayed on to provide a dry film thickness of 25 microns (one mil). This was done for environmental considerations at the bridge site. A clean surface was needed for stud welding and the high-build primer. Field sandblasting would have raised clouds of dust and a large quantity of debris which could be lethal to the trout in the stream. (2) Placed upside down (the entire bridge was fabricated upside down), half the square-edged longitudinal butt weld was made between the 1.83 and 2.44 mm (six and eight foot) wide deck plates. (3) All plates were then assembled and tacked (the floorbeam and girder web-to-flange fillet welds having previously been made). (4) The ribs were then welded to the deck plate. The fabricator had previously requested and received approval for a change in the partial penetration weld in which the ribs now would be supported on 2.4 mm (3/32") weld wire at 1.5 m (5 ft.)± intervals and rib edges left square-edged (giving a 17° root angle). Macroetch tests required by the qualification procedure showed that 100 percent penetration was achieved. (5) Upon completion of the underside welding, the bridge sections were turned over, the deck plate and ribs cut to length, and the longitudinal butt weld completed. Turned over again, the girder web and flange were cut to length. The bridge was then completely assembled and the holes for the bolted field splices drilled in the ribs and girders to assure proper assembly in the field.

Steel Erection

The three sections (measuring 18.6, 18.6, and 15.4-m; 61, 61, and 50.5-ft.) were trucked to the bridge site where they were assembled on the east bank of the river. The contractor had previously erected skid beams spanning from the abutments to the pier, over which the steel bridge would be pulled to the west abutment. Heavy duty machinery skates were attached to the bottom flange at the west end of the west section and another pair were set upside down at the east abutment. After each splice was completed, the steel bridge was pulled by a bulldozer winch on and over the skates (Fig. 8). Another set of skates were positioned at the pier while making the second splice in order to keep stresses within allowables during erection.

The two transverse field splices consisted of high-strength bolted ribs and girders (Fig. 9) and a welded deck splice and edge plates (Fig. 10). The welded deck gave a smooth surface for the deck planking. The sections were first aligned and the bolts placed without tightening. After fillet welding the backup strips to one side, the transverse groove weld was made. With this procedure, weld stresses were minimized. The transverse welds were inspected by the ultrasonic method (as were all butt welds in this bridge). This bridge required 1229 m (4030 feet) of welded joints, only 9.1 m (30 ft.) of which were required in the field.

A strong lateral bracing system composed of W6x20's was attached to the bottom chord of the old wooden trusses to complete the steel erection (Fig. 11). This bracing, made of weathering steel, required that nearly all of the fillet welds be made in the overhead position.

Other Operations

Each of the 625 cadmium plated threaded studs which hold the diagonal timber plank decking in place, had to be welded in exactly the right location in order that the pre-drilled holes in the planks fit over them. The planks had been pre-cut and drilled in order that they be properly preservative treated.

The contractor first positioned all the planks on the deck plate. Then the location of each hole was marked on the steel plate with a felt-tipped marker. The planks were consecutively numbered and removed from the bridge. The studs then were welded at the marked locations. After the deck was painted, the planks were brought back and bolted in position.

After stud welding, a self-curing inorganic zinc-filled coating was applied to a dry film thickness of 76 microns (three mils) (threads of studs were taped). Two coats of a high-build low-temperature curing epoxy-polyamide topcoated the zinc-filled coating. Total thickness of all coatings is 305 microns (12 mils). Although the deck is A588 weathering steel, it was felt that pitting corrosion on the bare steel could take place, under the planking, with road salt solution brought in by vehicles.

To put finishing touches on the bridge, timber curbing was installed and the interior whitewashed (Fig. 12). Outside, the roof was reshingled with white cedar shingles and the siding painted barn red (Fig. 13). Temporary approaches were constructed and the bridge reopened with appropriate, colorful ceremonies. Later the temporary bridge was removed, new approaches built and the area restored to its former condition.

Total construction cost for the project was \$360,000 which is a savings of more then \$1,500,000 over the cost of a new bridge, originally proposed to be built upstream. Total cost of all steel was \$101,750 (\$1.91 per kg., \$0.87 per lb.). More importantly, it is now possible to enjoy an old covered bridge well into the twenty-first century.

Acknowledgments

Photography: Joseph Rummel, Louis Sugland

Drawings: Ronald Gessay

Typist: Judith Gilistro

References

1. J. G. Bouwkamp and G. H. Powell. Structural Behavior of an Orthotropic Steel Deck Bridge. Department of Civil Engineering, University of California, Berkeley, Rept. SESM 67-27, 1967.
2. Standard Specifications for Highway Bridges. American Association of State Highway and Transportation Officials, Washington, D.C., 1977.
3. American Institute of Steel Construction. Design Manual for Orthotropic Steel Plate Deck Bridges, New York, 1963.
4. H. L. Davis and A. A. Toprac. Fatigue Testing of Ribbed Orthotropic Plate Bridge Elements. Center for Highway Research. University of Texas, Austin, Research Report No. 77-1, May 1965.
5. R. N. Wright and W. H. Walker. Vibration and Deflections of Steel Bridges. Engineering Journal, American Institute of Steel Construction, Volume 9, No. 1, New York, January 1972, pp. 20-31.
6. M. S. Troitsky. Orthotropic Bridges Theory and Design. James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, 1967.

Figure 1. Bridge Before Restoration

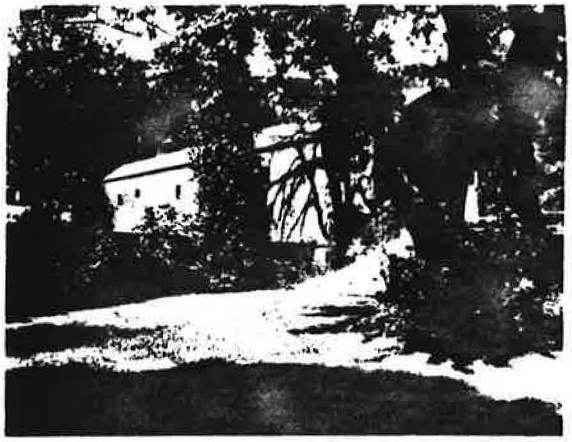

Figure 2. Floor System Before Restoration

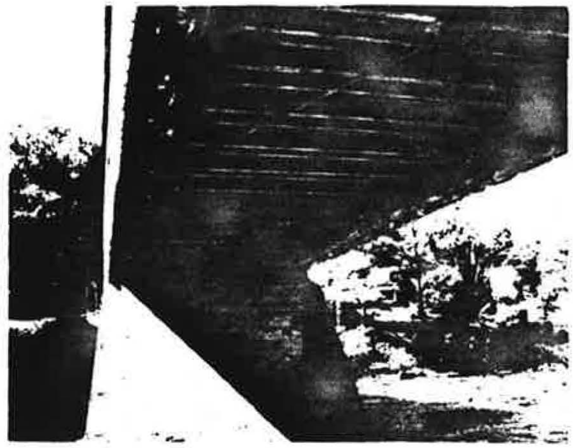

Figure 3. Bridge Elevation

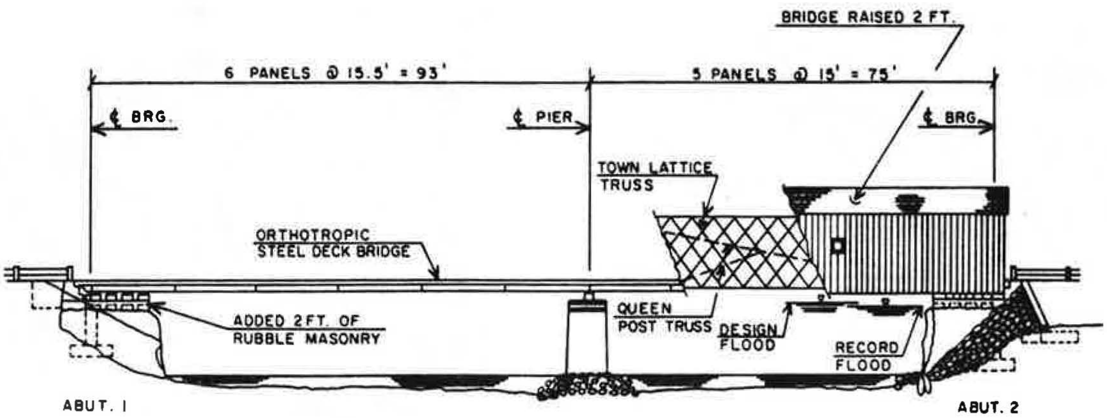

Figure 4. Bridge Cross-Section

Note: 1 ft. = 0.3 m

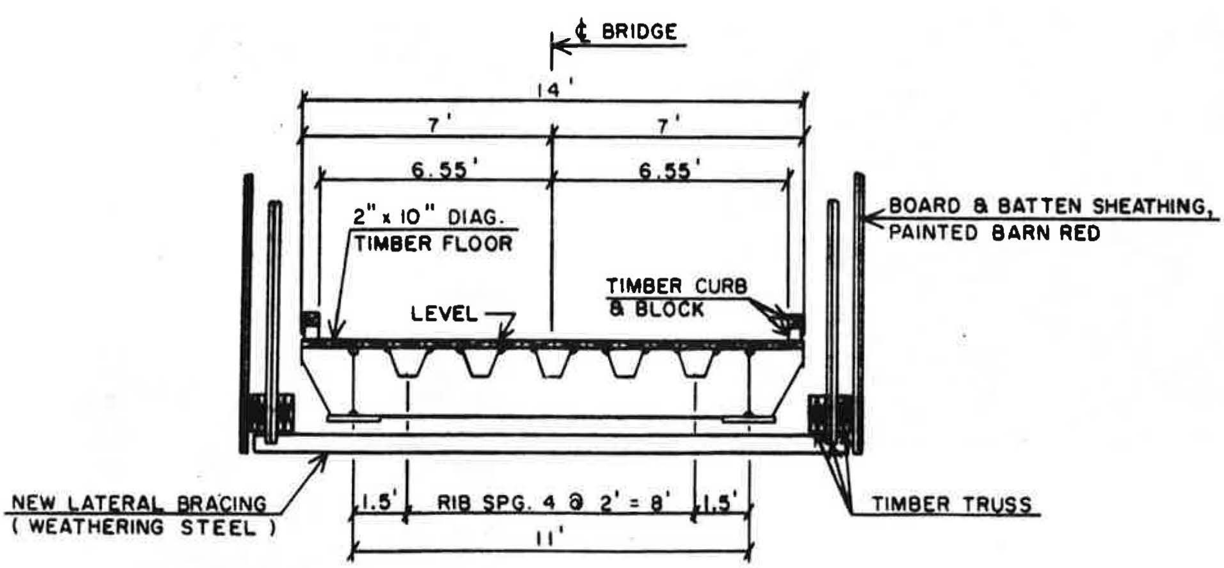

Figure 5. Temporary Bridge

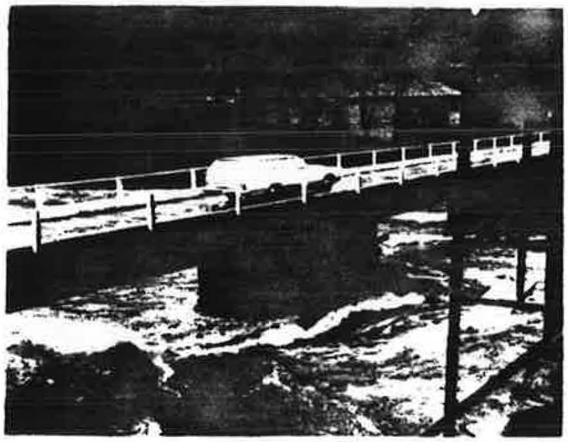

Figure 6. Orthotropic Bridge Fabrication

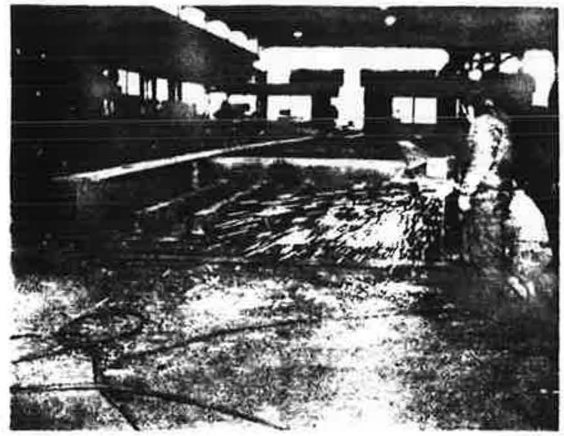

Figure 7. Completed End Section

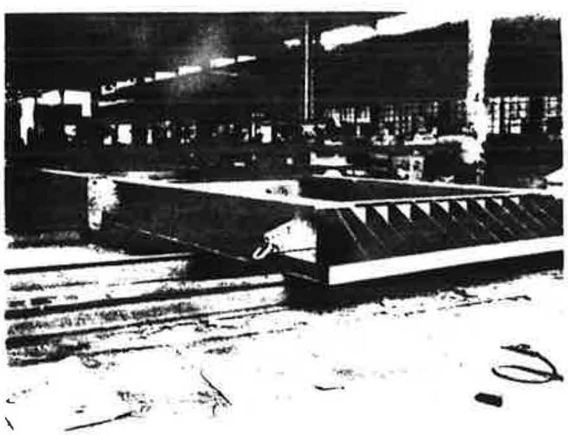

Figure 8. Bridge Site (Bulldozer Foreground)

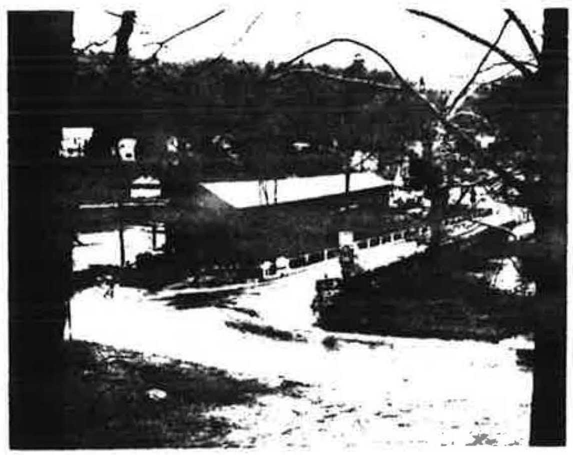

Figure 9. Bolted Girder Splice

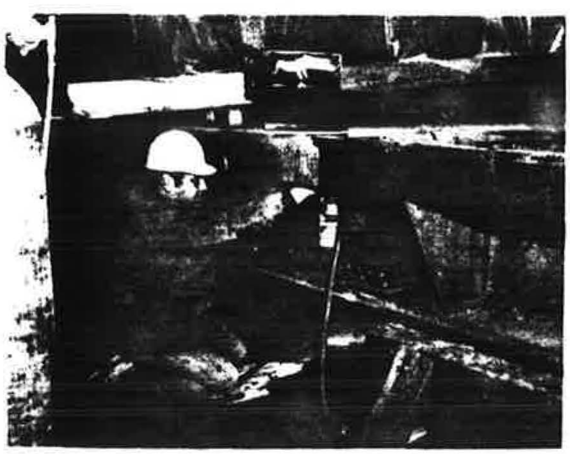

Figure 10. Deck Plate Weld

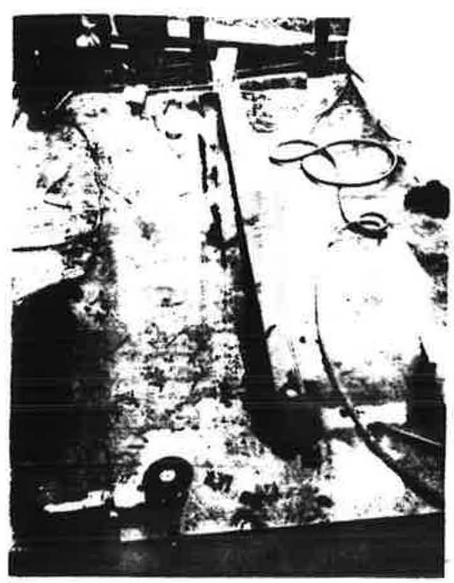

Figure 11. Completed Orthotropic Bridge and Lateral Bracing

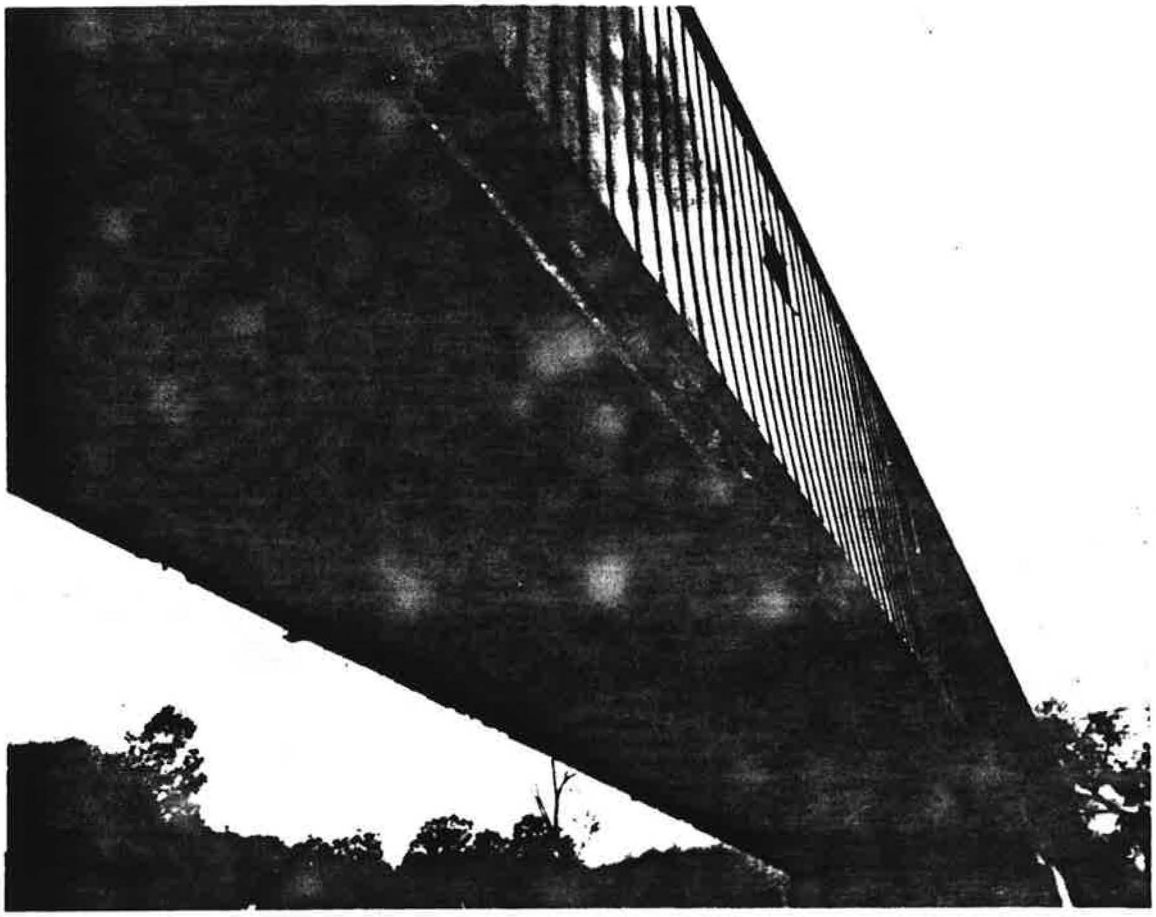

Figure 12. Restored Interior

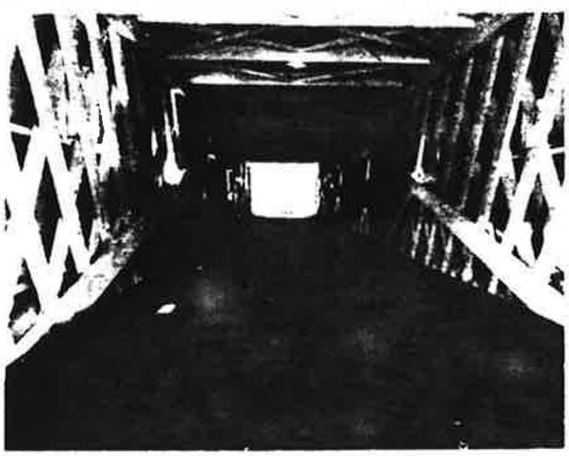

Figure 13. Bridge After Restoration