By Jim Barker, P.E.

Restoration of a Covered Bridge over Troubled Waters...

And Underneath Calm Ones

In eastern Indiana, an unusual covered bridge has stood for 160 years. Its trusses are a variation of the Burr arch wherein the "vertical" members actually lean outwards, and lean at more severe angles the farther they are from midspan. This is sometimes called a Wernwag truss after legendary covered bridge genius, Lewis Wernwag. He built such trusses and may have patented the design; however, this is unknown since at least one of his patents was lost in an 1835 patent office fire.

The bridge was designed to carry a 16-ton vehicle. Yet when that vehicle passes across the bridge, it adds almost no stress to the truss members. The explanation for this behavior lies not in the unusual truss system, but in the unusual design vehicle, which is a boat.

The Metamora Aqueduct carries the Whitewater Canal across Duck Creek (*Figure 1*). The canal was built in 1839 as part of Indiana's massive internal improvements program. State bonds were used to fund transportation improvements based on the proposition that they would increase property values, resulting in greater tax revenue, which, in turn, would pay off the bonds. When this did not happen, the State defaulted on the bonds. The resulting scandal caused a prohibition against deficit spending to be added to the state constitution, the continuing effect of which can still be seen every time the legislature wheedles and whittles to pass a balanced state budget.

According to local lore, the present bridge was built to replace a two-span bridge that had been washed out during a flood. Since the canal was a private venture, there are few records. As for the bridge, its builder and construction date appear to be lost in the mists of time. But a surviving letter suggests that the present bridge was built in 1848 or 1849.

The Aqueduct faithfully carried the canal's commerce until the canal ceased operation in 1866, where after a railroad was built along the canal's towpath (*Figure 2*). In 1948, the bridge was rebuilt and incorporated into the Whitewater Canal State Historic Site. The original arch timbers were retained and reused, but other parts of the trusses were replicated from locally grown yellow poplar. By 2004, the restoration exhibited distress and, as a result, corrective work was initiated. The ensuing repair project illustrates some issues commonly encountered in historic preservation.

Figure 1: The Duck Creek Aqueduct carries the Whitewater Canal at Metamora, Indiana. The bridge spans 71 feet and has a nominal 28-inch water depth.

Determining the Project Scope

The design of a new bridge usually proceeds in an orderly fashion, in steps that have been repeated many times in engineering firms, and with design costs being relatively well understood. But in preservation design, the structure's owner usually comes to the engineer with an observed problem or deficiency, and asks for help on that limited concern. However, that may not be the only problem, or even the most serious one. The preservation engineer needs to quickly define the problem(s), at least in general terms. An initial, very preliminary inspection, evaluation and analysis of the structure is needed to permit setting a reasonable scope for the design contract.

In 2004, the State of Indiana approached the author requesting that a new flume be designed for the aqueduct. The flume, which is the part of the structure that actually holds the water, had been leaking for years (*Figure 3*), soaking the floor beams underneath and causing them to decay and break. In this bridge, the flume is made of wood planks suspended by steel rods from the trusses, which are entirely above water level. This arrangement is doubly clever because it protects the all-important trusses from splashes and leaks, and allows the flume to be easily raised or lowered to maintain the exact desired bed elevation

Figure 2: The aqueduct ca. 1935. The polygonal arch was added around 1865 and removed in 1948.

Figure 3: Leaks in the flume caused decay in its supporting structure.

The author suspected that the bridge had other defects that were as important as the decayed flume. Such timber trusses are usually built with a positive camber (upward crown), but these trusses sagged 10 inches at midspan. It was difficult to conceive of a mechanism that would allow such gross deformation without involving some sort of structural failure. An initial inspection discovered the cause to be connection failures, and led to a recommendation that the project scope be expanded.

The original truss design contained an odd and inefficient detail. Instead of pressing against the stone abutments, the heavy arch rings stopped 12 inches short of the stone, and notched into the lower chord timbers (*Figure 4*). Thus, the bridge was a tied arch rather than a true Burr Arch or Wernwag Truss. Scale drawings from the 1930s show that this was the original construction. The logic of stopping the arches 12 inches short of good bearing was perplexing.

The arch thrust, pressing on the 2-inch deep notches, had sheared off the ends of the lower chord timbers. Steel side plates and clamping bolts had been added in the past to reinforce those connections, but the shear failure, arch ring spreading, and midspan sag remained. The 79-foot long lower chord timbers were spliced at their third-points using scarf joints with side plates, and those splices were also examined. Steel side plates on the splices had been painted for rust protection, and some paint fell on the adjacent timbers. A tell-tale gap in the overspray paint (*Figure 5*) testified clearly that the splices were failing also.

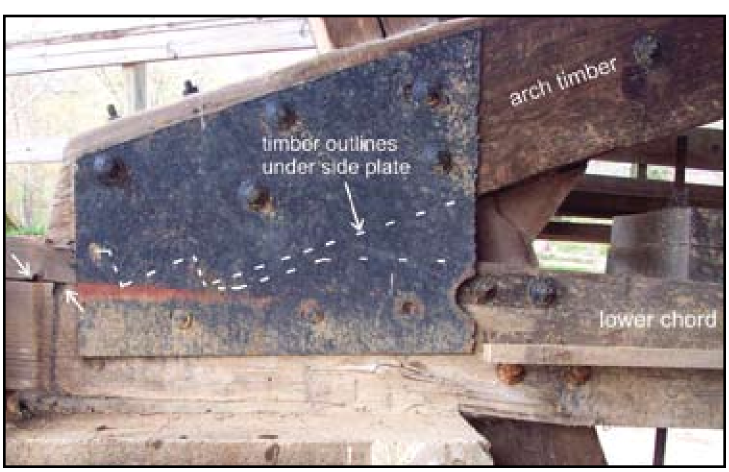

Figure 4: Typical bearing seat. Thrust from arch sheared top of lower chord, splitting a bolt hole (arrows). Lower chord crushed and curved as it passed the face of abutment.

A meeting was held at the bridge. The Curator of the Historic Site, engineers from the Indiana Department of Natural Resources (IDNR), and the author viewed the evidence, discussed the issues, and decided to expand the project scope.

Flume Replacement

Repairs were accomplished in the winter, when the water in the canal is lowered to be only a few inches deep. A low dam at the upstream side of the aqueduct kept the remaining water out.

White oak was chosen for the new material for the flume because of its superior performance in wet environments. In the American Midwest, the two most common varieties of oak are red oak and white oak. An important difference is that the longitudinal sap-carrying vessels in red oak are clear, while those in white oak eventually develop growths that plug them. Thus, white oak is less porous and lasts longer in wet environments. The new flume liner boards have tongue and groove edges, and a thin line of sealant was applied to the tip of each tongue just before the adjacent board was placed against it. In contact with water, the boards swell slightly, completing the seal.

Since the 6-inch by 16-inch by 24-foot long floorbeams supporting the flume could be subjected to wetting, they were also cut from white oak. IDNR wished to use traditional technology for the repairs, and avoid lumber treated with preservatives.

Sealing the connection between the wooden flume and the stone abutments had been problematic for decades. Carefully detailed caulked joints had been tried, but they quickly failed. Neoprene compression seals were installed, but partially failed and left wide gaps. For this project a new seal was designed, consisting of a 7-inch wide strip of 60 mil EDPM roofing, clamped down along both edges using ⅛-inch x 1-inch stainless steel bars. Although very simple, this design has sealed the gap with no leaks whatsoever.

Truss Repair

The arch-truss was analyzed using a 2-dimensional finite element model. The analysis indicated that the timbers were adequate to carry the dead load and live load with satisfactory margins of safety. But when member forces were routed though the connection details (done by hand analysis), the lower chord splices and arch-end connections appeared to be overstressed. This was expected, as the actual failures had already been noticed.

continued on next page

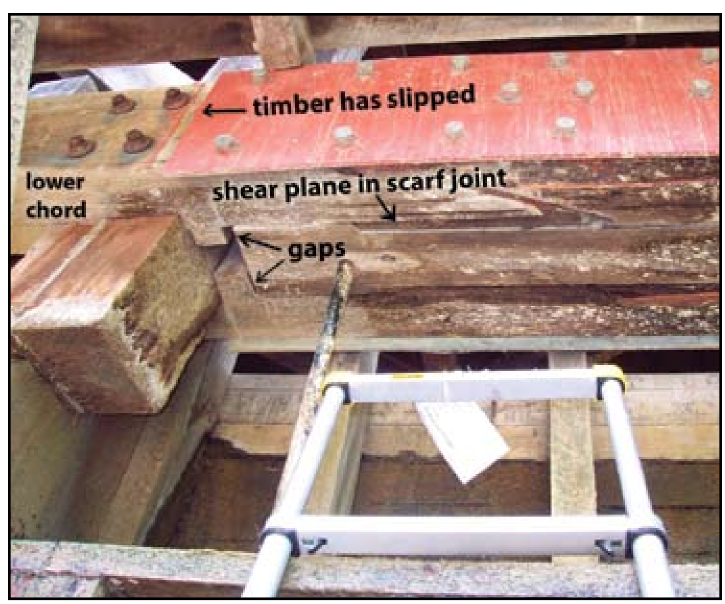

Figure 5: A failing splice in lower chord timbers. Unpainted strip at left shows timber has slipped.

Figure 6: IDNR engineers inspect the shored, but not yet jacked, trusses. They are standing on the walkway for the tow horses.

In preservation design, several considerations are involved that don't occur when designing new construction. These include: (1) does the repair respect the original designer and his intent, and avoid just lathering the current designer's work on top like a technological "Kilroy was here" defacement? (2) how can the needed strength, serviceability and reliability be attained with minimum change to the structure's appearance? and, (3) if modern materials are used, will they help enough and be unobtrusive enough to justify their introduction into an historic structure?

We should design with a light and respectful hand. However, we should not ignore the structure's problems, the public's safety, or the project's funding limits. Designers may have to ask that the funding be increased, but they should always respect that constraint. In preservation design, funding restrictions often limit the choices for "best practice" design.

With so many things to balance, it is important for an engineer who works in preservation to deeply respect the builders who created these structures, and to preserve their original vision as closely as possible. A designer who is concerned about our history, and who has taken the time to learn about Theodore Burr, Louis Wernwag, Stephen Long, Hardy Cross, and etc., will probably do a better job on a historic restoration than one who views the project as one more "profit center".

In this case, the solution called for the trusses to be shored and jacked to restore a positive camber (*Figure 6*). Then, the lower chord splices would be rebuilt, and two particularly splintered lower chord timbers would then be replaced in kind. The removed timbers, each 10-inch x 15-inch x 27-foot long, would be used as patterns. The new timbers were Douglas fir, which (unlike poplar) could be found well seasoned in the needed size. The new steel plates would be longer, but narrower, than the old (1948) plates, and would have keyways to help transfer the load (*Figure 7*). Epoxy adhesive would be used sparingly to assure equal bearing in all keyways.

Repairs were also needed at the ends of the arch rings over the bearing seats. As the truss was jacked, the sheared ends of the lower chords were pushed back to their original positions and fastened in place. Then, wood blocks were added between the end of each lower chord timber and the abutment to partially transmit the thrust of the arch ribs into the abutment, reducing the tension force in the lower chord. This changed the structural action from a tied-arch to more nearly that of a Wernwag truss. Such a significant change in structural behavior is rarely acceptable. But in this case, the benefit was so great and the visual impact so slight that it was viewed as a reasonable compromise between the competing goals of achieving a durable repair and maintaining the intent of the original designer.

The sustained weight of the canal water had started to crush the lower chords at the bearing seats. To counteract this, the existing steel side plates were replaced with ones that extended down to the

Figure 7: Scarf splice in lower chord. Keyways have just been cut in wood to match those on new side plate. Timbers that loosened when sag was jacked out were reseated and shimmed.

Figure 9: Completed project just before work-dam was removed. Butterfly gates in flume walls help regulate the water level.

abutment. If the wood continues to compress, the side plates will help carry the vertical load to the abutments, reducing the stress in the wood (*Figure 8*). A tension tie was added next to each bearing seat to help support the lower chord a short distance from the abutment. Photos from 1935 show similar tension ties in place.

Figure 8: Bearing seat area, new flume, and expansion joint seal after repairs were completed.

Conclusion

The bridge is now repaired and ready for additional decades of service. The contractor's craftsmanship was excellent, and the chronic problems of weak splices, sagging trusses, and a leaky flume are now fixed. The project's $207,000 total cost was a modest price to preserve the last historic timber aqueduct in America (*Figure 9*).

The bridge is an ASCE Historic Civil Engineering Landmark structure. Every hour during summer months a horse-drawn canal boat carries passengers along the canal and through the bridge, helping tens of thousands of tourists per year experience how much this county and its transportation system has changed in the last 150 years.▪

Project Credits:

Owner:
Indiana Department of Natural Resources, Whitewater Canal State Historic Site

Contractor:
CLR, Inc., Chad Reitmeyer, President
Amos Schwartz, master timber framer

Designer:
J.A. Barker Engineering, Inc.

James Barker, P.E. is President of J.A. Barker Engineering, Inc., Bloomington, Indiana. The firm specializes in the repair of historic bridges and barns. Mr. Barker may be reached at **jim@jabarker.com**.