In: American Society of Civil Engineers, Proceedings of the 2005 Structures Congress, April 20-24, 2005, New York, NY. 2005.

Kings Covered Bridge Rehabilitation, Somerset County, PA

Figure 1 – Kings Bridge eastern portal w/ temporary truss system

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Abstract

Kings Covered Bridge over Laurel Creek in Somerset County, Pennsylvania is approximately 114-foot clear span multiple Kingpost Truss with nail-laminated arches. This timber bridge is historically significant because it retains its original features of the 1860's since the 1930s when it was spared from modernization by the construction of an adjacent steel highway bridge for vehicular traffic. Since that time Kings Bridge has a colorful history, including use as livestock barn and a proposed new use as a part of a "twin covered bridge" municipal park. Kings Bridge remains a museum-quality artifact. The bridge is currently supported by a temporary steel queenpost truss system pending full rehabilitation. The rehabilitation strategy for Kings Bridge is to minimize interventions, repair in-place, and to replace deteriorated members in-kind where possible. This paper documents the rehabilitation of Kings Bridge as of November 1, 2004. An updated presentation of the existing timber conditions; structural analysis; and final rehabilitation design will be presented at the ASCE Structures Congress in April 2005. Rehabilitation construction will begin fall 2005. The rehabilitation funding for Kings Bridge is 100% federal through the National Covered Bridge and the Transportation Enhancements programs.

Introduction to Kings Bridge

Background

The Kings Bridge that exists today was constructed in at least two phases. The first phase was a multiple king post truss that probably dates from the middle of the nineteenth century (ca. 1860 or earlier). The arches were likely added to the truss in 1906. Arnold Graton offers this scenario,

"The two posts on each corner are circular sawn oak. The arches were probably installed before the corner posts were replaced and the bridge 're-builder' used the new arches to hold the bridge up while he was replacing the 8 corner posts and scabbing on timber at different locations where leaks had allowed the water to rot the chords."

Existing Structural System

<u>Trusses</u> – The length of truss bays between posts are not identical. See Figure 7. The spans between posts at the center of the bridge are unusually longer than the bays near both ends. Several hand-hewn posts remain in the trusses, but most members are sawn. Tie beams are dropped into slots at tops of posts and pinned. The outrigger ends of the tie beams bear rafter sills. See Figure 2. Knee braces are framed between the tie beams and posts. Horizontal x-bracing is alternately nailed and "let in" between the tie beams of each bent. Lower "needle" beams were added later to the posts, below the lower chords, suspended from the arches for supplemental support.

<u>Arches</u> – The circular-sawn, nail-laminated arches are not "let in," but are bolted to truss members – indicating that these members were not part of the original construction. The combined structure of trusses <u>and</u> arches was intended to carry the

live load, however the subsequent failures of both lower truss chords changed the distribution of the loading through the truss-arches in a dramatically visible way. See Figure 3.

Figure 2 – Assembly of truss posts and upper chords, tie beams, and rafter / sills

Figure 3 – View of interior trusses, arches, SJC Team

Perhaps the most interesting structural aspect of Kings Bridge is that the retrofitted laminated arch is a “tied arch” rather than a two-hinged arch. It is a tied arch because the arch is restrained by the bottom chord which is allowed to stretch. A two-hinged arch would bypass the bottom chord and bear directly against the abutments – imparting a great deal of thrust. Instead, struts were installed from the bottom chords to seats in the abutment faces – similar to arch extensions in appearance but able to carry much less force than arch extensions. This tied arch is less stiff than a two-hinged arch. Since the struts decayed at their abutment seats they have transferred no forces from the arch directly into the abutment face. After the chord breaches the truss/arches stretched and were resisted by the abutments – but not without damage to the substructures.

<u>Substructure</u> - The truss bears on stone abutments. “Seats” were carved in the face of the abutments to bear the timber struts to transfer loads from the arches through the lower chords to the substructures. See Figure 4.

<u>Joists / Floor</u> – Another interesting aspect of the Kings Bridge is the lattice form of the floor joists that combines the purposes of transverse beams, longitudinal stringer beams and under floor diagonal bracing into one system to both carry floor loads and provide lateral bracing. The floor joists form a lattice system of light, circular sawn 5x6s that bear on ledger blocks nailed to the inside face of the lower chords. The floorboards are laid longitudinally and appear to have been turned over. See Figure 5.

<u>Sheathing</u> – The bridge is clad with board and batten siding. The roof consists of deteriorated wood shingles on circular sawn nailers mounted on sawn rafters that are fastened at the apex with wood pins. A canted cap and wainscoting protects the lower area of the inside of the trusses from traffic debris. See Figure 5 and 6.

Figure 4 – Northern face of eastern abutment. (Note the separation of the wingwall face resulting from the horizontal thrust of the truss/arches after lower chords failed.)

Figure 5 – View of floor joist system from below. (Note the retrofitted tie beam fastened with canted rods that imposed enough horizontal force to damage the lower post relish.)

Figure 6 – Interior "wainscot"(Note retrofit rod and gates from previous "barn" use")

History

Kings Bridge has an unclear history. The dates above the portals claim "Built 1802" and "Rebuilt 1906". Observations of the existing structure and related covered bridge research suggest different versions of history. The structure was probably constructed originally in the mid-1800's with a major rebuilding around 1906. The abandonment as a state highway structure was in the first half of the 1930's, when the single span timber bridge over Laurel Creek was bypassed with a two-span, two-lane steel stringer bridge,

From that time until 2002, Kings Bridge was privately owned and maintained by the local farming family – the Kings of Middlecreek Township. "Kings" Bridge was retrofitted to serve as a livestock barn over the water. Gates and fences from its agricultural use still exist on the bridge. The remnants of rubber tire hinges still exist on the lower downstream chord where a "floating fence" was hung to prevent livestock from wandering up the creek in low flow periods.

<u>Earlier Repair Interventions</u> **–** If the bridge date of 1906 is correct for reconstruction, then it appears that the bridge was almost entirely rebuilt at that time. The lower chords show signs of partial replacement and some later scab and plating repairs. New replacement timber was mostly chestnut on the interior / exterior siding and new

oak for the planking. The replacement posts were oak or possibly chestnut and chords were oak. If the retrofitted arches were not used to support the bridge in place while it was rebuilt, then the entire bridge was probably supported with major bracing from the creek bed.

The bridge was probably stripped of all roofing and siding as well as plank flooring. The main exposed frame was then dismantled to a point where the major post and chord repairs could take place. Under this scenario nail-laminated oak arches with all contingent rods and blocks were installed after the major repairs. The sheathing was then reapplied. The good planks from the floor were flipped over and used. The good exterior and interior sheathing was reversed and reused in combination with adequate and similar new wood. A new roof was then installed on the entire bridge.

All siding was nailed with “round” or wire nails. The oak plank flooring was all flipped over, putting the worn side down, nailed off with round spikes and covered with another layer of newly sawn planks. The roof sheathing and all cedar shingles were all round nailed. Wire nails are common from the last 10 years of the 19th Century. The interior wainscot boards were made from newly sawn chestnut and reused and flipped over pine boards. The exterior siding showed the same usage pattern. The entire shell of the bridge, as well as the floor decking, appears to be done at one time. There was no evidence found that showed partial removal and replacements of the sheathing and flooring.

Some repairs were made to the bridge following its complete rebuild. These repairs occurred in the area of the failed chords and appeared to be temporary fixes to a major problem and not a solution. These repairs included bolting 3"x10" oak planks to the lower chords. The most recent repair appears to be the spiking of 3x10 oak planks to the posts and braces on both sides of the lower chord failure on the North (upstream) side of bridge. A series of retrofitted rods extend through upper chords, braces and posts on both trusses to help transfer the loads at the lower chord failures back through the trusses into the abutments. Most damage to primary frame appeared to be related to water damage from roof failures and decay continues during the rehabilitation design phase

Arnold Graton offers this theory as to why the Kings Bridge has a collection of up and down, and circular sawn timbers:

“It is possible that more than one person supplied the timber. There were probably times of the year where a person could contribute time rather than dollars to the bridge project. The Kings may have had access to the old fashioned up and down mill. To address the hand hewn members, most sawmills had 16' carriages. To cut 32' to 52' timber would require a carriage from a minimum of 24' with track twice the length of the timber plus 10' or so. Therefore a 32' lower chord stick would require a mill track and shed to be approximately 74' long. Over the last half century, I have run across a number of covered bridges that had sawn post and braces and hand hewn lower and upper chords. The shorter timber was sawn in the mill and the long

timber, which would be hew logs, (hard to get to the mill), would be hewed out in the woods and delivered to the covered bridge site as timber 32' to as long as 52'. This is one case that I remember. So, the King's Covered Bridge could have been built in the same time frame as most covered bridges were built."

Conservancy Intervention – The Southern Alleghenies Conservancy (SAC) and the Somerset Conservation District (SCD) began to assist the Rockwood Area Historical Society in 1996 to secure $90,000 in State Department of Economic Development (DCED) funds to rehabilitate Kings Bridge. At the time of SAC intervention the bridge was still owned by the King Family.

The state funds were used to engineer and construct a temporary suspension system to stabilize Kings Bridge in place over Laurel Creek. DCF Engineering Inc (DCF) of Cary, N.C. and Arnold M. Graton Inc. of Ashland NH designed and constructed the temporary system in fall 2000. State funds were also used to fund a comprehensive strategy that was developed by Simone Jaffe Collins Inc. Landscape Architecture of Berwyn, PA for SAC to secure the balance of $1M that was estimated to rehabilitate the entire bridge.

In 2000 SAC began to execute the funding strategy with the assistance of PennDOT and local, state, and federal legislators. By 2003 the project had received 100% federal funding for rehabilitation though PennDOT under two FHWA programs – $340,000 from the National Covered Bridge Program and $595,000 from the Transportation Enhancements Program. During this period SAC also negotiated the donation of the Kings Bridge and one acre of land from the King Family into the SAC land trust program for rehabilitation and public use as a municipal park. When SAC completes the rehabilitation, Middlecreek Township will take ownership of Kings Bridge and maintain it as a public park and the structural "cousin" to the Township's Barronvale Bridge located one mile upstream .

Stabilization – A stabilization system of two queenpost trusses was designed by DCF to be placed to the exterior of the bridge. Each truss bears on timber cribbing towers that rest on the stream banks below. The system was designed and installed with the expectation to temporarily hold the bridge securely in place during the shoring, engineering, planning, and fundraising phase. The inserted steel queenpost shoring system is inherently stable. Steel wide flange "needle beams" were placed transversely through the bridge, and bear on the upper chords of the temporary queenpost trusses and are positioned to suspend the timber bridge from its upper chords. The downstream truss was critical at the time shoring was installed. Only the bolts where the lower chord was repaired were preventing the bridge from collapsing into the creek. The abutment walls provide critical support to the bridge and were not be disturbed.

A subsequent "tuning up" of the trusses was performed by AMG for SAC in October 2004. The bridge suspension was "plumbed up" and straightened. This system was originally envisioned to be in place for 2 to 3 years during the fundraising period. Winter 2004-5 will be the fifth season for the temporary system.

<u>Structural Documentation</u> – DCF prepared CAD construction documents for the stabilization design that were used to map the existing conditions and actual dimensions of the bridge. See Figure 7.

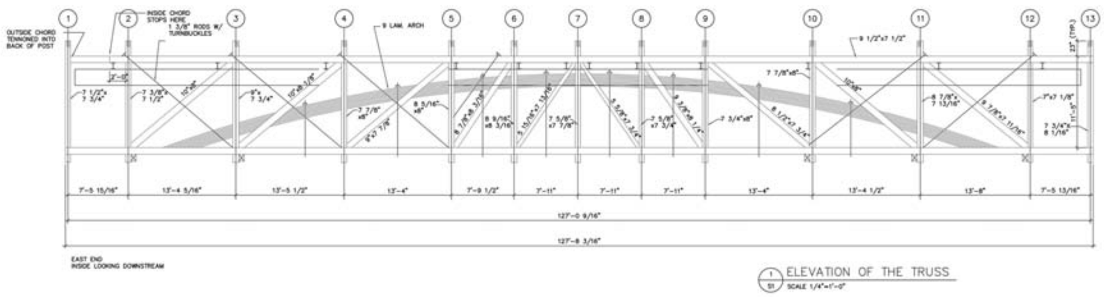

Figure 7 – CAD Drawings - Frame elevation (by DCF)

Rehabilitation Design

Investigation of Conditions

As part of the SAC rehabilitation design contract, members of the SJC team convened on-site for two days in October 2004 to assess the conditions of Kings Bridge. SJC and AMG assisted DCF as the project engineer of record, to map the structural dimensions of the bridge as well as "flag" visible locations of deterioration, and document former repairs. Preliminary findings follow

<u>Structural Issues</u> – Three issues that pose the greatest challenge to Kings Bridge rehabilitation result from water damage.

- Lower chords - The King Family did a remarkable job maintaining the roof during its ownership, but years of insidious leaks ultimately resulted in failures of both lower chords. The breaches occurred in the corresponding bay on opposite ends of each truss. The failures were recognized in time by the Kings and series of vernacular repairs including metal rods, wood splints and iron brackets were retrofitted to skillfully keep the bridge standing.

- Truss Posts – Leaks in the areas of lower chord failures also resulted in damage to several truss posts and shouldered truss braces. The joints in a covered bridge timbers are often the weakest points in the structure. The head of two posts had failed in shear at the joints due to excessive new loading patterns after the lower chord failures and repairs were installed by the King Family. See Figure 5.

- Arch Struts – These members are installed below the line of the lower chords and are not sheathed by the bridge siding – probably to avoid obstruction of the creek during flood levels. These untreated heavy timbers have long since lost structural integrity where the hearts have decayed at the bearing seats on the stone abutments.

This failure essentially changed the original intent of the two-hinge laminated arch to function more as a tied arch. The arches are visibly deformed above the locations of lower chord failures, exhibiting the transfer of loads from the adjacent truss posts through the arch and back into the trusses and lower chords to the foundations.

<u>Nondestructive Evaluation</u> – USDA Forest Service personnel from the FPL and WIT program performed a series of nondestructive evaluation tests on various bridge truss members that were identified as deteriorated or potentially deteriorated based upon a visual condition assessment.

- Moisture Content – Measurements were performed with an (Delmhorst model RC-1D) electrical-resistance type moisture meter and 76mm (3-in.) long insulated probe pins in accordance with ASTM D4444 (ASTM 2000) requirements. At each identified location, data were collected at pin penetrations of 25, 51, and 76 mm (1, 2, and 3-in.) into the bridge members. All moisture content field data is to be corrected for temperature and species in accordance with Pfaff and Garrahan 1984.
- Stress Wave – Measurements were performed with (Fakkop Microsecond Timer) stress wave timing equipment in accordance with established procedures (Ross and Others 1999). At each identified location, the width of the member was measured along with the wave transmission time. Calculated stress wave velocities (foot per micro-second) helped to identify potentially decayed locations in the bridge truss members. See Figure 8.
- Resistance Drilling. Measurements were performed with a micro-resistance drill (IML Resistograph model F400) that measures drill bit resistance that provides a good density profile of the wood member (Figure X) (Ross and Others 2004). True scale density profile plots were used to characterize the extent of internal deterioration in the bridge truss members. See Figure 9.

Preliminary NDE results of the truss members in the vicinity of Post no. 10 (South) are included in Figure 10 (Summary Table). All adjusted moisture content measurements were less than 16 percent, except for test location 10S-g, which was slightly higher at 19 percent. These results indicate that the truss members are currently drier than the threshold moisture content level which is required for decay. Stress wave velocities ranged from 180-220 ft/m-second and were near the threshold level for the presence internal deterioration.

Several micro-drill resistance measurements reported consistently low wood density and confirmed the stress wave measurements. A representative resistance plot shows relative density profile of both (inner & outer) top chord truss members at location 10S-c. See Figure 11. Both truss members had a relative drilling resistance below 15 percent, with the interface between members visible at approximately 7.5 inches drilling depth.

Figure 8 - Using a stress-wave timer to detect interior decay in a lower chord member"

Figure 9. Using a resistance-drill to locate interior decay in an upper a chord member.

Test location[a]	Member	Moisture content[b] (%) at penetration 1-in.	2-in.	3-in.	Stress wave Time (ms)	Distance (in.)	Velocity (ft/ms)	Refer to resistance drill plot[c]	Comments
10S-a	Inner top chord	13	16	15	151	9.63	188	--	
10S-b	Outer top chord	14	15	16	153	9.44	194	512	Low resistance - deterioration
10S-c	Inner top chord	12	12	12	171	9.38	219	513	Low resistance - deterioration
10S-d	Outer top chord	13	13	12	142	9.25	184	--	
10S-e	Inner top chord	12	12	12	--	--	--	--	
10S-f	Outer top chord	14	12	12	--	--	--	--	
10S-g	Inner top chord	19	14	17	156	9.63	194	516	Low resistance - deterioration
10S-h	Outer top chord	15	12	17	141	9.63	176		
10S-I	Inner top chord	--	--	--	148	9.06	196	517	Low resistance - deterioration
10S-j	Outer top chord	--	--	--	157	9.06	208	--	

Figure 10 - Summary table of field data at location of post number 10 South (10S). a—refer to schematics for actual test locations; b— adjusted for temperature, not for wood species; c— see appendices for actual resistance drill plot;

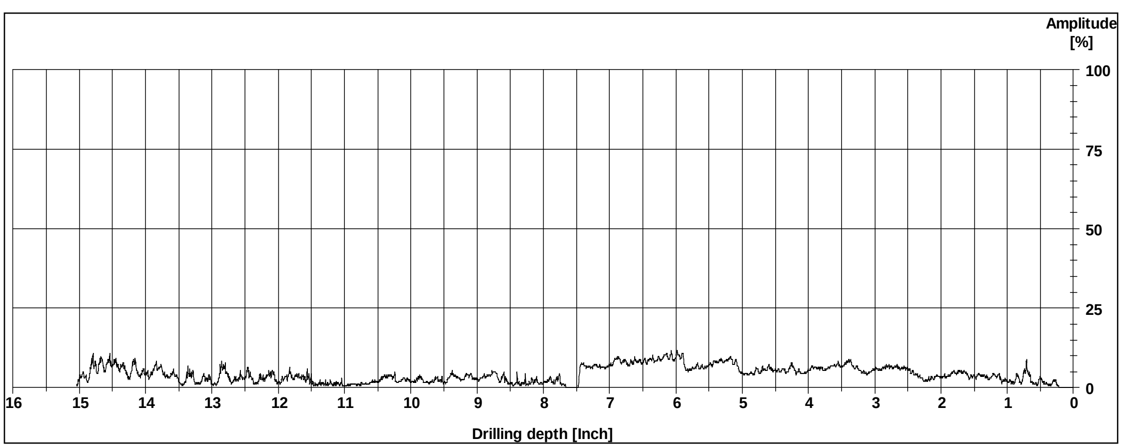

Figure 11. Resistance drill plot 513 (corresponding to test location 10S-c) The resistograph plot shows a typical low resistance at a suspected deteriorated location.

Off-site Timber Testing

- Species Testing – Small scale samples retrieved from the Kings Bridge were used to identify the species and provide a basis for determining engineering properties. This task is currently underway by FPL and WVU.

- Strength Testing – Large scale samples of lower chord material at the failure location were removed under separate contract and delivered to WVU for testing. The load carrying capacity of the samples will be established by setting a load limit, within the elastic range, that corresponds to approximately 120-150% of the maximum design live load. Failed floor joists were also collected and will be tested at WVU.

In addition to the on-site and off-site investigations, a complete structural analysis will be made to understand how the bridge behaves in terms of stresses and deflections. With this analytical information available, a final preservation plan will be developed. The following section presents preliminary preservation options.

Preservation Options

The intent for Kings Bridge after rehabilitation is for non-vehicular trail use. This end use increases the options for rehabilitation. The SAC preservation goal – to retain the maximum existing fabric in Kings Bridge after rehabilitation – suggests that the priorities for preservation treatment are: (1) to retain / repair, (2) replace in kind, or (3) replace with alternative materials and mitigations.

The rehabilitation of the bridge will be made using similar materials and technologies as similar as possible to the original construction. Timber to match existing will be locally obtained if possible. Through examination of the structure and rigorous engineering analysis, a rehabilitated bridge of known capacity will result that maximizes the amount of historic "fabric" (original materials, surfaces, etc.) that are retained. Construction will follow *The Secretary of the Interior's Standards for the Treatment of Historic Properties*, utilizing traditional timber details.

References

ASTM 2000. Use and calibration of hand-held moisture meters. ASTM D4444-92. Philadelphia, PA: American Society for Testing Materials.

Ross, Robert J.; Pellerin, Roy F.; Volny, Norbert; Salsig, William W.; Falk, Robert H. 1999. Inspection of timber bridges using stress wave timing nondestructive evaluation tools—A guide for use and interpretation Gen. Tech. Rep. FPL–GTR–114. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 15 p.

Ross, R.J.; Brashaw, B.K.; Wang, X.; White, R.H.; Pellerin, R.F. 2004. Wood and Timber Condition Assessment Manual. Madison, WI: Forest Products Society, 74p.