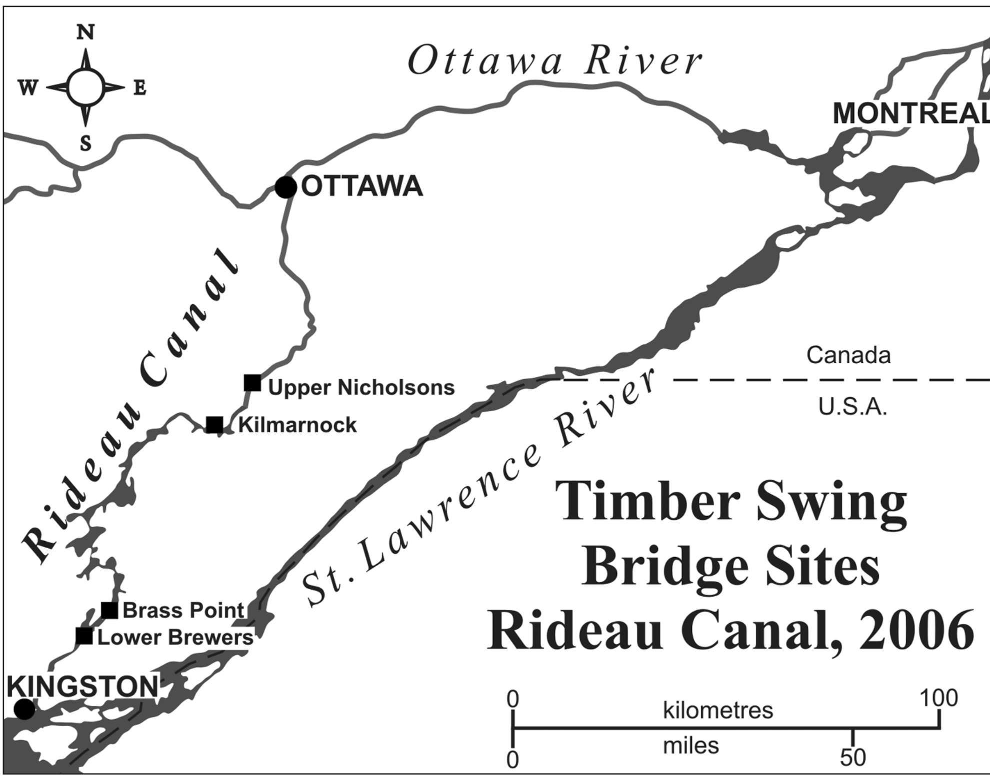

The four timber swing bridges extant on the Rideau Canal today were reconstructed by Parks Canada at Brass Point (December 1978), Lower Brewer's (June 1984), Upper Nicholson's (March 1986), and Kilmarnock (May 1986). (K. Watson, 2006)

Reconstructing Timber Swing Bridges at Parks Canada

Robert W. Passfield

In reconstructing historic timber bridges a critical problem is the increasingly heavy loads imposed by modern vehicular traffic. Bridge engineers are often forced to upgrade the reconstructed structure through modifying the sizing and spacing of the structural members and/or introducing more modern structural materials to meet higher loading standards, thereby diminishing the accuracy of the reconstruction. However, another approach is the substitution of a different species of wood of greater strength to increase design values. During the period 1978–1986, both approaches were used by Parks Canada on the Rideau Canal in reconstructing four timber swing bridges. After an initial reconstruction during which a historic bridge was reconstructed and upgraded through augmenting the dimensions and decreasing the spacings of its structural components, Parks Canada opted to introduce "ekki," a West African hardwood, to obtain higher design values, thereby achieving a more accurate reconstruction for three additional historic timber swing bridges.

This article traces the reconstruction of four timber swing bridges by Parks Canada in the period 1978–1986. It sets forth the two different approaches that were followed in reconstructing and upgrading the evolved form of the historic timber swing bridges on the Rideau Canal; identifies and examines the several departures introduced during the four reconstruction projects; and elaborates on the efficacy of "ekki" hardwood in facilitating a highly accurate reconstruction of three of those heritage bridges.

Introduction

In 1972 when Parks Canada acquired the newly designated Rideau Canal National Historic Site with a mandate to preserve its historic structures, the older bridges crossing over the waterway were not considered nationally significant heritage structures as none dated from the period of construction of the waterway. Among a wide variety of different types of bridge structures were five reconstructed timber swing bridges on the waterway that were of an unequal arm, centre-bearing type that had proliferated at the bridge crossings during the 19th century. They had been preserved through a practice of replacement-in-kind reconstructions carried out over the course of more than a century, at 12 to 15 year intervals, following the introduction of the original design prototype on the Rideau Canal in 1866.[1] When the canal was acquired there was a program in place to eventually replace the timber swing bridges with high level, by-pass bridges. However, it was discontinued when Parks Canada, in keeping with its heritage conservation mandate, decided to continue the traditional cultural practice of preserving timber swing bridges through replacement-in-kind reconstructions. The extant timber swing bridges had been reconstructed earlier at Jones' Falls (1960); Brass Point (1964); Lower Brewer's (1967); Kilmarnock (1970); and Upper Nicholson's (1971).

When the first of the reconstructed timber swing bridges reached its projected life span as of the late 1970s, Parks Canada had no intention to try to replicate the original 1866 design prototype in a reconstruction. The design of the prototype structure was known by then through research in federal government archival records. However, the reconstructed timber swing bridges were an evolved form of the original design prototype that had been upgraded and modified to meet evolving traffic needs through a succession of reconstructions carried out over the course of more than a century; that historical evolution was recognized and accepted. It was decided that Parks Canada would seek to reconstruct the evolved form of the historic structure extant at each particular bridge site, rather than arbitrarily rejecting the extant artifact in favor of an effort to achieve a pristine reconstruction of the design prototype.

The extant timber swing bridges on the Rideau Canal posed a particularly acute heritage preservation problem. Parks Canada would have preferred to conserve the existing spans and to have kept them in service, but that was not a viable option in terms of either local traffic needs or their physical condition, as evidenced by the two oldest spans. At Jones' Falls, the decay and deterioration of the historic swing bridge was so severe that the structure had to be swung open, and the road crossing closed, while the county proceeded with the construction of a modern high-level by-pass bridge just upstream of the lock station; and at Brass Point, core samples taken from the swing span revealed extensive interior rot in the timbers, so much so that a restricted two-ton load limit was immediately imposed. It was evident that the timber swing bridges would have to be reconstructed if they were to be preserved; the first Parks Canada reconstruction was undertaken at Brass Point.

Brass Point Swing Bridge Reconstruction, 1978

At Brass Point, there was a low-level, multi-span bridge structure of 467' length overall that carried a county road across a 30' deep arm of Cranberry Lake on a river section of the Rideau Canal. The bridge consisted of a timber swing bridge of 72'-6" span, last reconstructed in 1964, and four riveted steel truss fixed spans of a Warren pony truss configuration, dating from 1903. The steel spans had a 16' width (15' clear roadway) and a 6-ton highway loading capacity, whereas the timber swing bridge had a 12' width (11' clear roadway) and a 5-ton highway loading capacity when new. (Figure 1)

At Brass Point, the traffic problem was particularly acute, and could not be alleviated simply by reconstructing the evolved form of the historic timber swing bridge. The five-ton load capacity of the timber swing bridge precluded the passage of school buses, fire trucks, and heavy trucks, necessitating a detour of several miles to the nearest alternative bridge crossing; and in winter snow ploughs could not cross a timber swing span unless it was temporarily reinforced with trestle bents erected beneath the structure following the navigation season. Moreover, it was impossible to enforce load restrictions 24 hours a day. The existing bridge structure was being continually over-stressed by heavy trucks that continued to cross the canal at Brass Point, despite the posting of the greatly reduced load limit. It was clear to Parks Canada that the Brass Point swing bridge needed not only to be reconstructed, but also dramatically upgraded.[2]

Following a study of the traffic situation, Parks Canada's canals engineering staff were directed to triple the load carrying capacity of the timber swing bridge span, and to bring the entire bridge crossing up to a 15-ton highway loading capacity. In addition, the swing bridge was to be widened four feet to attain a 15' clear width roadway. Moreover, this was to be done while maintaining the his-

Figure 1. Brass Point Swing Bridge, Rideau Canal, showing the extant swing span reconstructed in 1964 by a canal carpentry crew. (Photo by author, July 1974)

toric appearance of the timber swing span, and the four fixed steel truss spans, in keeping with Parks Canada's heritage preservation policy governing the reconstruction of historic structures.[3]

Under Parks Canada's *National Historic Sites Policy* (1968), reconstructions were to be undertaken only as a last resort when the conservation of the original structure or its restoration were not possible; and in any reconstruction, it was declared essential to maintain "the line, level, and fabric ... as true to the original as possible." Modern materials and construction techniques could be introduced into a reconstruction, if the original materials were unprocurable, prohibitively costly, and/or modern materials were required to attain a reasonable life expectancy. Even then, however, such substitutions were acceptable only if the modern materials could be concealed by the historic fabric. Otherwise a reconstruction could not be justified.[4]

In undertaking to reconstruct the Brass Point Bridge, the first concern was to analyze the behavior of the historic timber swing bridge, and to calculate the stresses in the structure. Parks Canada engineers had no idea how the five-ton load capacity standard came to be applied to the reconstructed timber swing spans. It was known, however, that severe problems had been experienced earlier with an upgraded timber swing bridge formerly in service on a multi-span, low-level bridge at Rideau Ferry on the Rideau Canal. The Rideau Ferry swing span had been widened from 12' to 16', and upgraded to a six-ton load capacity during a 1947 reconstruction; yet on occasion the passage of heavy trucks had caused severe maintenance problems. The heavy live loads, and impact loads, had resulted in the occasional breaking of a cast-iron balance wheel, the breaking of a casting of the pivot assembly, the partial crushing of the pivot beam, and even the crushing of an end of the cap beam over the top of a mainpost of the gallows frame. Moreover, it was not clear what stresses were acting on this type of historic timber structure, and unfortunately the record of the maintenance problems at Rideau Ferry, from well over a decade earlier, was of little use. It was not known what loading had caused a particular problem; whether or not a casting was defective; whether the stay rods had been properly adjusted; and/or whether the live load on the beam bridge was carried wholly on the pivot beam and abutments in keeping with the design intent, rather than borne in part by the balance wheels.

On the other hand, the upgraded timber swing span in the Rideau Ferry bridge crossing had remained in service, with periodic repairs and replacements of damaged or decayed members until 1969, when it was replaced by a modern high-level bridge of reinforced concrete. The new bridge was built to a 20-ton highway loading capacity whereas previously the swing bridge had been carrying all highway traffic without restrictions in an era when a 15-ton loading capacity was generally in force for highway bridges. Obviously, on any number of occasions the timber swing bridge at Rideau Ferry had been significantly over-stressed.[5]

In July 1976 the Building Structures Section, National Research Council (NRC), Government of Canada, was contracted to test the behavior of the Upper Nicholson's swing bridge. Strain gauges were attached to the stay rods and the strains were measured under the dead load and live loads (a car and a 5.5 ton truck). It was found that almost all of the live load moments were carried by the two bridge girders. Under a moving load a maximum deflection of 0.51" was recorded in the girders at mid-span on the long arm, with the stay rods anchored at mid-span experiencing a load-slack cycle. In effect, it was the girders and floor system that would have to be strengthened if the timber swing spans were to be upgraded to carry heavier loads. To that end, the NRC report suggested that steel beams be substituted for timber in future reconstructions to minimize the deflection under heavier loads.[6]

Initially consideration was given to constructing a steel frame swing span with a timber façade, but this proved impractical as it would have produced an unwieldy hybrid structure with a heavy dead weight. Hence, it was decided to employ the historic structural material, Douglas fir, but to increase the size of the bridge girders and to modify the sizing and spacing of the interior structural members, to upgrade the carrying capacity of the 72'-long swing span.[7]

At Brass Point a substantial upgrading of the historic timber swing span introduced changes in four main areas: heavier, larger-dimensioned Douglas fir structural timbers were introduced throughout in the mainframe, corbel frame, and gallows frame; the floor beams and floor joists were increased in size and spaced closer together; the pivot beam and pivot assembly were totally redesigned; and the design function of the stay rods truss system was greatly modified.

In the bridge superstructure, the two girders of the mainframe and the corbel frame beams below were constructed of 15" x 18" timbers, rather than the traditional 12" x 16" timbers of the evolved form of the timber swing bridge; and a central 15" x 18" longitudinal girder was added to strengthen the swing span, which was widened to 16'. In addition, the corbel frame attained a length of 53', thereby providing support under each girder for 7/10s of the total span length. This ratio of length of corbel frame to length of mainframe matched the ratio of the evolved form of the post-war timber swing bridge, rather than the 5/10s ratio of the original design prototype. On the long arm of the mainframe, the underslung floor beams were increased to 8" x 14" from 6" x 12", and the

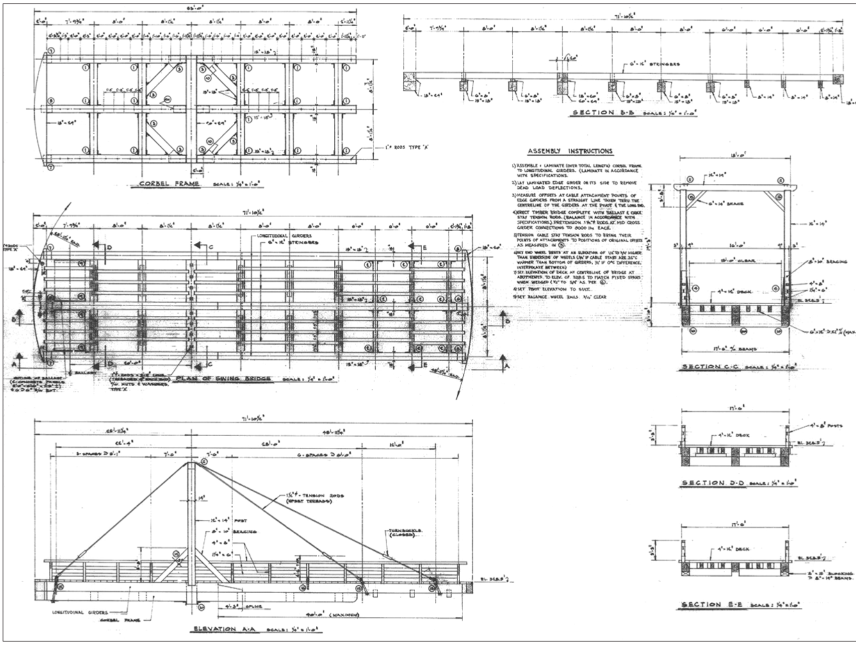

Figure 2. Drawing of the Brass Point swing bridge as reconstructed by Parks Canada in 1978. (Parks Canada, "Brass Point Bridge, Swing Bridge, Detail 1", Drawing 10-737, Sheet 112, n.d.)

floor joists were of a larger size and more closely spaced: 6" x 12" joists spaced at 1'-9" centres, rather than the former 4" x 12" joists on a 2' spacing. In the heel section of the swing span, the transverse beams of the corbel frame were also enlarged to15" x 18" from 12" x 16", and acted as floor beams for the deck joists, as was the case on all of the extant timber swing bridges. The swing span was planked with 4" x 12" planks in keeping with the historic structure it replaced. (Figure 2)

The pivot beam had the same cross-sectional dimensions, 26" deep by 20" wide, as on the existing historic timber swing bridges. However, it was no longer fitted up between the corbel beams for their full depth, with a 10" deep shoulder protruding below and extending out under the corbel frame to support the superstructure of the swing span. In contrast, on the reconstructed Brass Point Bridge the pivot beam passed through the 15" x 18" timbers of the heavier corbel frame, across the entire width of the swing span, and the pivot beam being of a greater depth, simply protruded downwards 8" beneath the corbel frame to the level of the pivot assembly. Thus, the corbel beam on each side of the span no longer constituted a cantilevered support beam for the bridge girder in resting on a shoulder of the pivot beam. In the modified configuration the corbel beams were simply abutted against each side of the pivot beam, to which they were connected by heavy steel angles lagged in place in the interior of the superstructure. In effect, the corbel frame was divided into two separate halves by the pivot beam of the reconstructed Brass Point Bridge, and on each side of the pivot beam, the corbel frame beams constituted separate support brackets for the bridge girders. Otherwise, the corbel frame timbers continued to be bolted to the bridge girders along their entire length of contact to form a single laminated beam, as was the case in the traditional swing bridge design, but now with a closer bolt spacing—1" diameter bolts at 2' centres.

Over the pivot beam, the centre beam of the mainframe consisted of two components, each 20" x 18" (width to depth), inserted on either side of the central longitudinal girder and bolted to the pivot beam, with 1" diameter bolts at 18" centres. The ends of the longitudinal floor joists were notched down into the two spacer beams over the pivot beam, as well as into the toe and heel beams at each end of the mainframe. On the long arm, the underslung 8" x 14" floor beams were notched at their ends to seat 6" up inside the mainframe girders so that the longitudinal floor joists could rest directly on the floor beams. In the heel section of the mainframe, there were no transverse floor beams framed to the girders; the floor joists were supported by the transverse beams of the corbel frame beneath the mainframe. Spacers, 6" x 8" (depth to width), were laid along the top of the floor beams in the corbel frame to compensate for the difference in depth between the 15" x 18" mainframe girders and the 6" x 12" floor joists. The floor joists ran straight through the long arm and heel section of the mainframe with lapped ends at every second floor beam.

All of the heavy framing timbers were joined with butt joints and fastened with modern steel angle connectors lagged into the interior corners, in keeping with the innovation introduced eight years earlier by the Department of Transport in reconstructing the Kilmarnock swing bridge. In effect, the mortise-and-tenon joints of the extant Brass Point bridge of 1964 were not replicated. Where steel angles could not be hidden, such as in the framing of the gallows frame members, steel dowels were used to make the connections.

As was the case on the existing historic swing bridges at Kilmarnock and Upper Nicholson's, the cap beam of the gallows frame was connected to the mainposts by means of a steel dowel, in conjunction with the traditional timber cap beam braces, which were no longer mortised into place. Rather, the beveled ends of the braces were simply inset slightly into the heavy timbers and fastened with a lag screw, in keeping with a modified practice introduced some years earlier. Similarly, the mainposts were connected at their base to the two outer bridge girders by means of a steel dowel, and were strengthened in the traditional manner with timber side braces and a large steel bracket on the interior of each mainpost. The steel bracket was similar in its configuration to the cast-iron bracket used previously, and performed the same function. However, all of the braces and brackets were of an increased size. The two cast-iron brackets from the extant bridge were salvaged and stored in the Smith's Falls Yard of the Rideau Canal.

The gallows frame was constructed in the traditional manner, but the 10" x 12" timbers forming the mainposts and the cap beam were replaced by heavier 12" x 14" members with a single heavy 6" x 14" cap beam brace in each upper corner. At Brass Point none of the old metalwork was re-used, or replaced in kind. The extant 1¼" stay rods were replaced with larger 1½" diameter steel stay rods, and the regulator, on the cap beam over each mainpost, was eliminated. It was replaced by a fixed plate saddle to which the stay rods were welded. In effect, the modified saddle connection bore no resemblance at all to the historic mechanism, and negated its historic design function.

In the historic structure, the stay rods were attached to a flexible regulator, which could rotate in a longitudinal direction about a horizontal axis in the saddle. It had two design functions. It served as a guide in adjusting the tension in the stay rods on the long arm and heel section to equalize the pull on the mainpost, thereby keeping the compression forces of the truss directly over the mainpost of the gallows frame, and through rotating the regulator could act to relieve stress in the stay rods on the long arm whenever the girders deflected under a heavy moving load. However, with the new fixed saddle arrangement the swing bridge was a rigidly stayed structure incapable of flexing.

The stirrup anchors for attaching the stay rods to the bridge girders were also greatly modified in detail. The traditional stirrup, which could flex under any deflection caused by a moving load, was now discarded. The lower stay rods ends were simply welded to a steel anchorage that approximated a stirrup anchor in appearance, but formed a rigid connection, totally inflexible. In sum, there was no longer any movement possible in the stay rods truss system to relieve the stay rods of increases in tension under moving loads, either at the saddle on the gallows frame, or at the girder anchorages. The general appearance of the stay rods truss system was preserved, but its significant hardware components and the historic design function and purpose of the truss system was compromised.[8]

The far heavier timbers of the reconstructed Brass Point bridge greatly increased its weight, and reduced the vertical clearance on the pivot pier. In consequence, the existing pivot assembly and balance wheels were removed, and replaced with totally different components performing the same function. The traditional 17" diameter cast-iron balance wheels were replaced with 8" diameter steel rollers with lubrite bushings; the new pivot assembly consisted of a lubrite spherical seat of 18" radius resting on a chrome-plated sphere seat of 17" radius, encased in a ¼"-thick bronze ring.[9]

The working plans were prepared by Canal Engineering Division, Architecture & Engineering Branch, Parks Canada, and the swing span was reconstructed under contract by the Dineen Roads and Bridges Co. Ltd. of Rexdale, Ontario, in October 1977. The reconstructed Brass Point timber swing span and the four steel-truss replacement spans were completed as of December 1978.[10] (Figure 3)

The swing bridge was balanced through adding concrete ballast panels within the heel section, and the new turntable track of 16' diameter was shimmed in keeping with the traditional practice, to provide a 3/16" clearance between the top of the pivot pier rail and the balance wheels. According to the specifications, the stay rods were tightened, or tensioned, until the ends of the swing span lifted ¼" off the rest stops on the abutments. In effect, this introduced a heavy post-tensioning into the stay rods, which was a departure from the traditional seating method of tightening the stay rods to take up any slack, and then adjusting shims under the pivot assembly to ensure that the girders of the continuous beam structure rested on the pivot assembly and the end rests at the abutments.[11]

During the initial design phase of the Brass Point swing bridge project some consideration was given to fully post-tensioning the stay rods. In effect, the idea was to convert the continuous-beam bridge structure to a fully stayed structure with the rods post-tensioned to a greater loading than any potential moving load crossing over the bridge. This would have ensured that the structure remained rigid, eliminating any live load deflection, and would have minimized the enlargement required in the girders to upgrade the swing span to a 15-ton

Figure 3. Brass Point Swing Bridge, showing the swing span crossing as reconstructed by Parks Canada in 1978. (Photo by author, October 2006).

load carrying capacity. This approach, however, was quickly discarded owing to the perceived difficulties in heavily post-tensioning a span that was not fixed at its ends.[12]

At Brass Point the functional design and behavior of the traditional Rideau Canal timber swing bridge was changed dramatically in the upgraded span. The stay rods truss no longer acted simply to keep the outer ends of the swing span from sagging when the swing span was swung open, off its abutments. In the original design, which had been maintained to that time on the Rideau Canal, the timber swing bridge girders carried both the dead load and the live load. However, in the upgraded Brass Point design, the stay rods were heavily post-tensioned to carry part of the dead load, and to stiffen the swing span by preventing any appreciable deflection of the girders under a 15-ton live load. In effect, the post-tensioned stay rods of the truss system contributed to the upgrading of the loading capacity of the swing span; and the swing span was converted from a beam structure to a composite beam bridge/partially stayed structure.[13]

Previously all timber swing bridges had been swung manually by means of either a simple push bar on the heel of the span, or a manually operated, mechanical-assist mechanism composed of a crab, endless chain, and chain blocks assembly. However, at Brass Point the massive weight of the upgraded and widened timber swing span proved difficult to swing manually. Consequently, in 1984 an electro-hydraulic power-assist unit was installed to operate the endless chain/chain blocks system in opening and closing the swing span.[14]

At Brass Point, Parks Canada succeeded in maintaining the historic appearance of the traditional timber swing bridge, as well as the line and level of the river crossing, while widening the structure four feet and upgrading the crossing to a 15-ton loading capacity. For the most part traditional materials were used, and the structural modifications and new connectors were hidden from view, and the modification in the design principle and function of the stay rods truss system was not readily noticeable. The increased loading capacity was sufficient to pass school buses, fire trucks, service trucks, and snow-ploughing equipment in winter time. Only heavy trucks were restricted from using the reconstructed bridge, but none of these were frequent users of the Brass Point crossing. The reconstruction and upgrading of the crossing not only largely removed a traffic bottleneck, but promised to dramatically increase the life span of the timber swing bridge previously subjected to severe overloading. The durability of the replacement bridge was also increased through pressure treating all of the heavy timbers with chromated copper arsenate (CCA), a chemical wood preservative. However, the upgraded Brass Point structure was not a very accurate reconstruction.

The Brass Point timber swing bridge reconstruction differed appreciably from the traditional Rideau Canal timber swing bridge in its timber dimensions, its metal hardware, its working components, and its structural design principles, as well as in its large scale and electro-mechanical mode of operation. It marked a significant departure from the traditional cultural practice of preserving the historic swing bridge structure "as was," through replacement-in-kind reconstructions, encompassing the re-use of the historic metal hardware of the structure being reconstructed. At Brass Point, the reconstruction succeeded in preserving a timber swing bridge in service through upgrading the load carrying capacity of the swing span to 15-tons, and the reconstruction preserved the historic appearance of the historic timber swing bridge. However, much of the historic character, design integrity, and many of the defining elements—the heritage values—of the historic Rideau Canal timber swing bridge were lost in the process.

In undertaking three subsequent historic swing bridge reconstructions on the Rideau Canal, a different approach was adopted. Efforts were made by Parks Canada to increase the accuracy and integrity of historic timber swing bridge reconstructions through introducing a different species of a traditional material to increase design values.

Ekki Hardwood

Prior to undertaking a second timber swing bridge reconstruction on the Rideau Canal—at Lower Brewer's lockstation in 1983–84—Parks Canada engineers began to investigate the possibility of using a stronger wood to increase the design values of the historic structure while respecting its structural integrity. In the early 1980s, Parks Canada became aware that a West African hardwood, ekki, was available in large dimensions through Canadian distributors acting for European commercial timber houses. The price was roughly twice the cost of pressure-treated, custom-sawn Douglas fir, but so was the reputed strength of ekki. Moreover, first-quality structural Douglas fir was unobtainable in clear large dimensions whereas large-dimensioned ekki timbers of any length required could be supplied defect-free. Ekki could also be procured in any desired finished sizes, machined, milled and drilled, ready for assembly.[15]

Ekki (*Lophira alata*), also known as Azobé and Bongossi, is the most common of the six principal large tree species of the West African tropical rainforest. Mature ekki trees attain heights of 160', with a long clear cylindrical bore or trunk of upward to 100' in length, and diameters ranging from five to six feet or more without buttressing. The wood is remarkably hard, highly resistant to termites and marine borers, extremely durable in wearing quality, and exceptionally resistant to water penetration and decay, so much so that it does not require treatment with a wood preservative. Other physical properties include a very heavy weight for its mass (60 to 70 lbs. per cu. ft.), and a high resistance to fire, much more so than softwoods heavily treated with fire retardants. It has a high strength in compression and static bending, and a high impact resistance, far exceeding the best North American hardwoods in its mechanical properties and durability.[16]

By the 1960s ekki was widely used in western Europe in applications demanding durability, although not for general construction purposes. In the building industry flooring, paneling, stairs, windows frames, door sills, outside doors, and balconies were often of ekki, and it was used for public walkways, wharves, stop logs in waste weirs, bridge decks, railway ties, and sleepers in mines, as well as for piling. Only in the late 1960s, following exhaustive testing of its mechanical properties by the Timber Research and Development Association in Britain, did ekki come into extensive use in Europe as a structural timber.[17] However, in 1983 when Parks Canada engineers began investigating the employment of ekki for bridge construction purposes, they were aware that it was used in decking bridges crossed by heavy lumber trucks in the forested interior of British Columbia but, to their knowledge, ekki had yet to be used in a structural capacity in North American bridge building.

According to the information provided to Parks Canada, ekki could be ordered in timbers 12" x 12" and larger, of defect-free heartwood, in lengths from 30' to 40' and more if required, and free of any sapwood or wane. Moreover, the African hardwood had a minimum modulus of rupture in static bending of 22,000 p.s.i. and a minimum crushing strength of 10,000 p.s.i. The hardness and interlocking grain of ekki made it extremely difficult to work with hand tools, but it could be easily machined and milled with high-carbon-steel cutting tools, and carbide- or tungsten-tipped power saws, planers, routers, and drills. Timbers could be ordered pre-cut, drilled, milled, and machined to tolerances of ± 3/32". Newly sawn ekki was a dark reddish brown color, but if left in its natural state would weather to a fawn grey color matching North American woods.[18]

Studies of various woods, comparing their natural (untreated) resistance to decay and biological attack in temperate climates, had established that ekki far exceeded the durability of North American hardwoods and softwoods. Ekki has an unimpaired life span of over 25 years, as opposed to 15 to 25 years for white oak, Western red cedar, or California redwood, and 10 to 15 years for Douglas fir, and most pine species.[19]

Lower Brewer's Swing Bridge Reconstruction, 1983–1984

In 1983 when a badly deteriorated reconstructed timber swing bridge at Lower Brewer's required renewal, a priority was given to reconstructing the 16-year-old structure as accurately as possible in all details, while upgrading the 5-ton loading capacity of the swing span to a more acceptable highway loading standard. To that end, an "as-found" measured drawing was prepared to record the existing structure (Figure 4) and a study was made of employing ekki for some structural members to introduce higher design values, while retaining the use of the traditional material—wood. In contrast to the earlier reconstruction project at Brass Point, it was decided that the swing bridge need not be upgraded to a full 15-ton highway loading standard simply to accommodate occasional users such

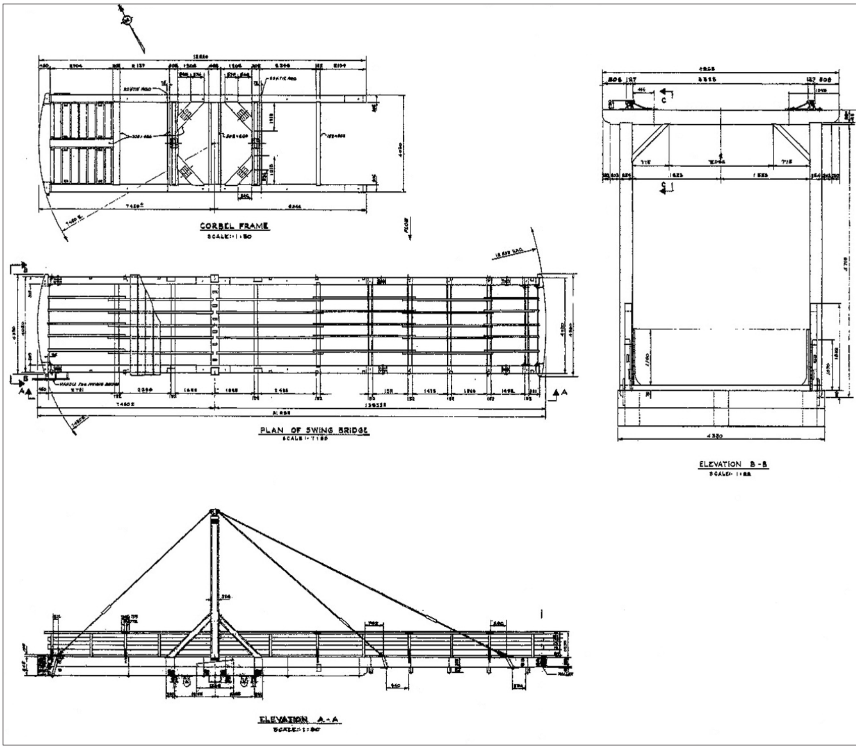

Figure 4. "As-found" record drawing of the extant Lower Brewer's swing bridge reconstructed in 1967 by a canal carpentry crew. (Parks Canada, "Lower Brewers, Existing Bridge." detail of Drawing 10-891, Sheet 103, January 31, 1984)

as county snow ploughs and heavy trucks. The traditional 12' wide timber swing bridge, if upgraded to a 10-ton load limit, would suffice to meet most local traffic needs. At the Lower Brewer's canal crossing a restricted load limit could be placed on the timber swing bridge to preclude heavy trucks and snow-ploughing equipment from using the crossing without entailing any long detours. There was a modern high-level bridge crossing of the Rideau Canal just a short distance upstream near the Upper Brewer's lock station.[20]

Moreover, henceforth within the Rideau Canal National Historic Site, heritage preservation would take precedence over optimum traffic capacity in the planning of the swing bridge reconstructions. This altered approach reflected a new *Parks Canada Policy* (1979), which stipulated that reconstructions could be undertaken under certain conditions, but only where sufficient data existed to permit an accurate reproduction. In contrast to the previous policy (*National Historic Sites Policy*, 1968), modern materials could no longer be readily substituted in the interior of a reconstructed historic structure simply to increase its life expectancy, to save costs, or because the historic material was difficult to procure. Reconstructions were henceforth to be as accurate as possible in all details, visible or otherwise, to preserve the historic character and design integrity of the historic resource in the reconstructed structure. If an accurate reconstruction could not be achieved, and/or the cost justified in terms of its historical significance and interpretive potential, then it was not to be undertaken. This did not rule out all compromise, but any departure from a totally accurate reconstruction had to be justified, and all alternatives investigated, before a departure could be authorized.[21]

The Design Brief for the Lower Brewer's swing bridge reconstruction reflected the new heritage preservation policy standards. It specified that:

> The intent of this project is to reproduce the existing bridge as closely as possible. Existing hardware is to be inspected ... and re-used whenever possible. Replacement hardware is to be identical to the existing, except for minor items such as bolts. Timber sizes are to match the existing.
>
> The only modifications to be considered are to the timber connections. ... All improvements such as steel angles or joist hangers must be hidden.[22]

For the Lower Brewer's reconstruction the structural integrity of the historic timber swing bridge was to be respected through accurately reproducing the structural design details, the working principles of the swing bridge structure, and the dimensions and spacings of the structural members, while re-using the historic metal hardware to reconstruct the historic structure as accurately as possible. In effect, the intention was to preserve the Lower Brewer's timber swing bridge through a traditional replacement-in-kind reconstruction. This could be done, and the load carrying capacity upgraded, only through taking advantage of the superior physical properties of ekki. It was to be substituted, however, only where absolutely necessary to replace Douglas fir structural members that would be over-stressed under a 10-ton loading.

A reconstruction of the historic structure exclusively in Douglas fir would yield a swing bridge with a safe 5-ton load capacity and a projected life span of 12 to 15 years, whereas it was calculated that through a selective use of ekki the swing span could be upgraded to a 10-ton loading capacity with a significant margin of safety, and its life span extended to a projected 25 years or longer. Hence, the increased capital costs—an estimated $10,000—would be offset by the longer life span.[23]

As of 1983 the existing timber swing span at Lower Brewer's—last reconstructed in 1967—was the sole surviving timber swing bridge extant on the Rideau Canal with mortise-and-tenon framing connections. However, structurally it was a hybrid structure. In 1981 Parks Canada had bolted heavy steel plates and angles at many of the interior corner connections to reinforce the swing span.[24]

Some consideration was given to framing the heavy timber members of the new Lower Brewer's swing span with mortise-and-tenon joints, thereby preserving the historic system of timber framing. However, it was decided that framing the structural timbers with mortise-and-tenon joints would significantly weaken the structure at its critical stress points and thereby detract from the effort to upgrade the timber truss swing bridge to a 10-ton loading capacity. There was also concern about the potential decay problem that mortised joints posed for the Douglas fir components based on what had been observed on the extant Lower Brewer's structure and subsequent field studies.[25]

In May 1983 core samples taken from some 39 locations in the existing 16-year-old Lower Brewer's swing bridge revealed that there was serious rot in the mortise-and-tenon joints. The surface appeared sound, but the core wood was seriously decayed. Given these structural considerations and the perceived decay problem, it was decided to frame the timbers of the new bridge with butt joints, and join them with the modern steel connectors employed in heavy timber framing. This would eliminate mortise cavities where water could penetrate and collect; water penetration would be further inhibited by treating the Douglas fir timbers with a chemical wood preservative, chromated copper arsenate (CCA).

The wisdom of this decision was further confirmed when the existing Lower Brewer's swing bridge was cut up and examined. It was found that moisture had penetrated into the mortise-and-tenon joints and gathered in the slight gaps around each tenon. From there it had migrated into the structural timbers through the end grain, forming hollow rotten areas just under the surface paint a short distance from the joints.[26] By the 1960s, the traditional method of bedding the tenons in a thick coating of a white lead/linseed oil sealant had been discontinued in favor of using an oil-based primer and oil-based paint to seal the mortise-and-tenon joints.[27] This new sealing method had obviously failed to prevent water migrating into the joints and penetrating into the end grain of the structural members.

During the summer and fall of 1983, the stress analysis calculations and design details for the reconstruction of the Lower Brewer's swing bridge were worked out. The allowable stresses for all structural timber and steel connectors were based on the then-current Canadian building codes. In October 1983, a finite element computer analysis of the stresses in the timber swing bridge was carried out by WMJ Engineering Software of Ottawa, utilizing a structural analysis program to analyze data defined by Eric Sunstrum, Senior Bridge Engineer, Parks Canada. The stresses in the structure were analyzed under dead load and live load, with the bridge closed and swung open, and in all cases with the stay rods removed, and with the stay rods post-tensioned.

With the stay rods removed (theoretically), it was found that the allowable bending stresses for the two 12" x 16" Douglas fir girders were almost the same as the bending stress under a 10-ton live load, with but a small margin for safety. With the stay rods attached the girders were substantially more rigid, and when the stays were heavily post-tensioned, the timber span was capable of carrying three times the live load. Hence, the computer analysis confirmed that the Douglas fir girders, supported by the stay rod trusses, were capable of carrying a 10-ton load, and there was no need to substitute a wood of higher design values.

However, modifications were needed in the sizing of the interior structural members to upgrade the swing span to a 10-ton load capacity; and the computer analysis was used to size all of the timber components to achieve a 10-ton loading capacity throughout. It was determined as well that the existing steel stay rods of 1¼" diameter would be more than adequate for the upgraded swing span. In effect, the existing stay rods, stirrup anchors, and regulators could be salvaged and re-used, or replaced in kind if damaged, in the reconstructed swing bridge in keeping with the traditional approach of preservation through replacement-in-kind.[28]

Although the existing stay rods truss system remained capable of fulfilling its original design functions, the truss system was given an additional function. As originally designed the function of the truss was to keep the long arm from sagging when the swing span was swung off the abutments, and with a flexible regulator at its apex, the truss was able to relieve the stay rods of stress on a moving load deflecting the girders. However, the stay rods of the truss system were now post-tensioned to take some of the dead load, and to provide support to the girders in carrying the heavier 10-ton live load. In effect, the physical components of the historic truss system were to be retained, or reproduced as accurately as possible, but the post-tensioning of the stay rods converted the traditional beam bridge into a composite beam bridge/partially stayed structure.[29]

With the stay rods post-tensioned, it proved necessary to substitute ekki for only seven structural members to upgrade the Lower Brewer's bridge to a 10-ton load capacity—the pivot beam, five floor beams on the long arm, and the cap beam of the gallows frame. Shop drawings were prepared by Parks Canada for the ekki members, which were ordered in January 1984 from Tropical Marine Timber of Richmond, British Columbia. The specifications called for all timbers to be free of defects and rough sawn to the actual sizes required with all notches, holes and radii pre-cut or pre-drilled. The ekki timbers were delivered in late March to the Rideau Canal yards at Smith's Falls, Ontario. This delivery schedule compared favorably with that for the select structural Douglas fir from the west coast. However, the Douglas fir timbers were already in storage in the Smith's Falls yard; they had been ordered earlier and stored for seasoning.

With the exception of the seven ekki structural members, the wood species used in the reconstructed Lower Brewer's swing bridge matched the historic structure. Douglas fir was used for the two girders of the mainframe, all of the corbel frame timbers, and the mainposts, side braces, and cap beam braces of the gallows frame, as well as for the deck planking. White pine continued to be used for the railings.[30]

On March 26, 1984, the Lower Brewer's contract was awarded to W.V. Wallans Contracting Ltd., Carrying Place, Ontario, the low bidder at $49,090 Cdn. for reconstructing the timber swing bridge and removing the old structure. The ekki and Douglas fir timbers were forwarded to the contractor, as well as templates for the bolt-hole patterns of the existing pivot assembly and balance wheel trucks. The Douglas fir timbers were cut, shop-assembled with the ekki timbers for fit, and then disassembled for shipping to Montreal for pressure treating.[31] Only one problem was experienced in working with the ekki hardwood. The ⅝"-diameter lag screws twisted off when torqued in ekki in accordance with CAN3-086-M80 specifications. This was resolved through increasing the diameter of the lead hole from 75% to a maximum of 90% of the shank diameter of the lag screws.[32]

In the reconstruction several design modifications were authorized. All of the heavy Douglas fir timbers of the mainframe and corbel frame were of the same 12" x 16" dimensions as in the former structure but, as specified in the Design Brief, the mortise-and-tenon framing connections were not reproduced. The heavy timbers were framed with butt joints and steel connectors—framing angles, splice plates, and deep-beam hangers (shear-plate hangers)—typical of modern heavy timber construction practice, with steel dowels used for the visible connections of the gallows frame. Similarly, the cap beam corner braces were simply fastened in place with a lag screw at each end, rather than mortised into the gallows frame timbers.

On the long arm of the swing span, the six floor beams of Douglas fir on the historic bridge were replaced by five ekki beams on the reconstructed structure. The floor beams were of the same size, 6" x 12", but the ekki beams were spaced at 7'-5" centres rather than 5'-0" centres. The greater strength of the ekki beams enabled the spacing to be increased, while simultaneously upgrading the load capacity of the structure. Secondly, the floor joists, which continued to be constructed of Douglas fir, were enlarged from 4" x 12" to 6" x 14", and their spacing was decreased from 2'-8" centres to 2' centres. According to the intent of the Design Brief, the floor beams ought to have been spaced and sized to match the structure being replicated. However, the new 10-ton loading requirement had to be met in spacing and sizing the Douglas fir floor joists.

In addition, the transverse centre beam, which was bolted to the top of the pivot beam between the two bridge girders of the historic timber swing bridge, was discarded, and the connection with the floor joists modified. On the historic structure, the ends of the floor joists on the heel and long arm sections of the swing span were notched down into the centre beam, but on the reconstructed swing span they were carried over the pivot beam, with lapped ends. A 2" x 6" wood spacer was placed on the pivot beam to bring the top of the 6" x 14" joists flush with the top of the 12" x 16" bridge girders. Why this departure was made is not clear. It simplified the construction of the floor system, but weakened the lateral support for the gallows frame. It resulted in the steel support bracket on the inside of each mainpost being lagged to floor joists, rather than to a heavy centre beam between the girders as was previously the case.

Additional modifications were introduced at the toe beam of the mainframe. In a departure from the historic swing bridge design, the ends of the floor joists were no longer notched down into the toe beam, although they continued to be notched down into the heel beam in the traditional manner. On the reconstructed span, the floor joists merely abutted against the toe beam with no fixed connection to save the weight of the heavy steel joist hangers. It was calculated that the short cantilever of the floor joists—some two feet past the outer floor beam—was not sufficient to require additional support, but that supposition would ultimately prove erroneous under traffic loads. (Figure 5)

The gallows frame timbers were of the same dimensions, and design, as previously, but the cap beam was now made of ekki to preclude the ends being crushed under a heavy moving load with the stay rods post-tensioned.

The corbel frame was of the same length as the former bridge structure, maintaining the 7 to10 comparative length ratio of corbel frame to the mainframe, as well as the same configuration and timber dimensions as the former span. It was also constructed of the same species of wood, Douglas fir. The corbel beams rested on the notched shoulders of the pivot beam in the traditional manner. The pivot beam, now constructed of ekki, was of the same 26" x 20" cross-section as the historic bridge being replaced, and was stepped at its outer ends with a 10" deep shoulder to carry the corbel frame beams and to fit up inside the full 16" depth of the corbel frame in the same manner as the historic structure.

The traditional cast-iron pintle and socket assembly on which the historic timber swing span rotated had been replaced some years earlier by a steel pivot assembly. It consisted of a pintle shaft of 5.82" (148 mm) diameter that rotated in a steel socket casting machined to close tolerances. On the Lower Brewer's reconstruction project, however, steps were taken to obtain a greater ease of rotation. The pintle was shortened in length to enable a bronze disc bushing of 0.39" (10 mm) thickness to be set into the socket casting, and grease grooves were cut into the upper surface of the disc. Lubrication was provided by means of a hole drilled up through the pintle and a short copper tube connected to a grease galley.

The railings of the swing span were identical to the historic structure, but the railing posts of the reconstructed swing span were no longer mortised and

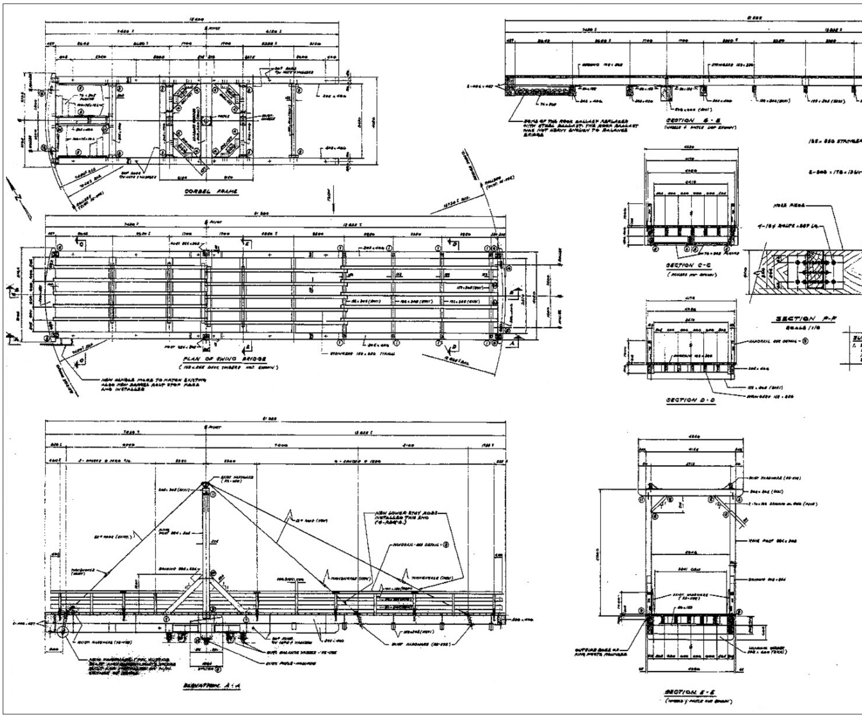

Figure 5. Drawing of the timber swing bridge as reconstructed by Parks Canada at Lower Brewer's in 1984. (Parks Canada, "Lower Brewers, New Bridge", detail of Drawing 10-891, Sheet 104, January 31, 1984)

pinned into the bridge girders as was the case on the historic structure. At Lower Brewer's small steel angles had been lagged to the rail posts and girders of the extant swing span several years earlier to reinforce the railing; these steel angles were salvaged and re-used to support the railing posts of the reconstructed span. They constituted, however, a highly visible departure from the original appearance of the historic swing bridge.[33]

In May 1984 the former swing bridge was demolished to salvage the metal hardware for re-use, and the new swing bridge span was assembled next to the bridge site. Almost all of the metal hardware was re-used: the pivot assembly, end rollers, balance wheels, stay rods, the two regulators, and the stirrup anchors, as well as the cast-iron bracket for each mainpost. The only exceptions were the lower section of four stay rods, below the turnbuckle, which had to be replaced in kind, and a pin on one of the stirrup anchors. All fasteners (bolts, lag screws, and nails) were renewed.[34]

The woodwork of the reconstructed swing bridge was painted primarily white, with some blueish-grey areas on the heel section to match the color scheme on the former span, and the metal hardware was painted white. The wood components were given a single coat of an oil-based primer, and two topcoats of an alkyd house paint gloss. All re-used metal hardware was sandblasted, and given one coat of a marine primer and two topcoats of an enamel alkyd marine paint matching the color and shade of the paint on the extant swing bridge. The fasteners were hot dip galvanized. No specifications were provided concerning a sealing treatment for timber joints. The ends of all members were simply painted with the primer before assembly, and paint was worked into all cracks, crevices, and corners of the assembled timber work. The seams between built-up members, such as between the corbel frame and girders, were caulked with a common silicone sealant, and given a second coat of primer before painting proceeded.[35]

Figure 6. Lower Brewer's swing bridge, showing the swing span reconstructed by Parks Canada in 1984. (Photo by author, October 2006)

In mid-June the completed bridge was hoisted onto the pivot pier, with a Linkbelt 3-axle Zephyr crane of 30 tonnes lifting capacity. Given the increased weight of the ekki members, some steel ballast had to be substituted for rock ballast to properly balance the swing structure, but otherwise no problems were experienced. On June 26, 1984, the bridge was accepted by Parks Canada and placed in service.[36] (Figure 6)

Overall, the upgraded timber swing bridge reconstructed at Lower Brewer's had a high degree of accuracy, and integrity, in preserving the evolved form of the historic timber swing bridge at that bridge site. However, the discarding of the mortise-and-tenon framing system was a major departure, and several other authorized changes further compromised the historic integrity of the reconstructed structure. These included reducing the number of floor beams from six to five on the long arm, and the enlarging of the Douglas fir joists from 4" x 12" to 6" x 14" on closer spacings. This was done, in conjunction with the post-tensioning of the stay rods of the truss system, to upgrade the swing span to a 10-ton load capacity, while retaining the traditional wood—Douglas fir—in use to the maximum extent possible. Otherwise the design integrity of the timber swing bridge was preserved through a selective use of ekki timbers to increase design value, while maintaining the traditional dimensions of the structural members.

Overall, the substitution of ekki for seven heavy structural members of the reconstructed Lower Brewers timber swing bridge did not appreciably affect the cost of the bridge-reconstruction project. The final cost, inclusive of all materials, was $76,000, of which only $3,311 was expended on the ekki members. In effect, the ekki components accounted for less than 5% of the total expenditure on the upgraded bridge.[37]

Through using ekki, the loading capacity of the traditional timber swing span was upgraded from 5 to 10 tons while achieving a reconstruction that was highly accurate in its visible structural design features and that conserved and re-used the historic hardware of the bridge superstructure. The entire project was in keeping with the traditional practice of preservation through replacement-in-kind reconstructions. Moreover, ekki was highly resistant to decay, and did not require pressure treatment with a chemical wood preservative. All of the softwood was pressure treated with CCA—the Douglas fir structural members and deck planks and the Jack pine railings.

The paint scheme on the reconstructed Lower Brewer's swing bridge was rather odd, but matched the former structure, which was painted white overall, with a blueish-grey color on the heel section. Traditionally, the historic timber swing bridges on the Rideau Canal were painted a stone color. However, when Parks Canada acquired the Rideau Canal in 1972, the five surviving timber swing bridges were painted in different schemes: the Upper Nicholson's bridge was all white; the Jones Falls and Brass Point bridges were white with black metalwork; and the Kilmarnock and Lower Brewer's spans were painted a bluish-grey on the heel section, white on the remaining woodwork, and black on the ironwork. Sometime thereafter, however, Parks Canada began painting the stay rods of all the timber swing bridges white, while continuing to paint the rest of the metalwork black. It was found that white rods absorbed far less heat during the summer, requiring fewer adjustments on the turnbuckles to keeping the stay rods properly tensioned.[38]

Upper Nicholson's and Kilmarnock Swing Bridges Reconstructions, 1986

Following the reconstruction of the Lower Brewer's swing bridge, two additional timber swing bridges on the Rideau Canal were reconstructed in a similar manner—through a selective use of ekki hardwood in an effort to reconstruct as accurately as possible the evolved form of the historic swing bridge design, while upgrading the span to a 10-ton loading capacity. Both the Upper Nicholson's and Kilmarnock bridges' reconstructions were undertaken as part of a larger contract involving the partial reconstruction and pressure grouting of an adjacent stone masonry canal lock. In both cases, a firm of engineering consultants was hired to prepare the contract specifications for the canal and bridge work. For the timber swing bridge component of the contracts, the consultants were supplied with copies of the working drawings that Parks Canada had prepared earlier for the Lower Brewer's swing bridge reconstruction.

Work began at Upper Nicholson's in October 1985 with the contractor demolishing the extant swing bridge. The metal hardware was salvaged, sandblasted, and painted for re-use. The stirrup anchors for the stay rods were in

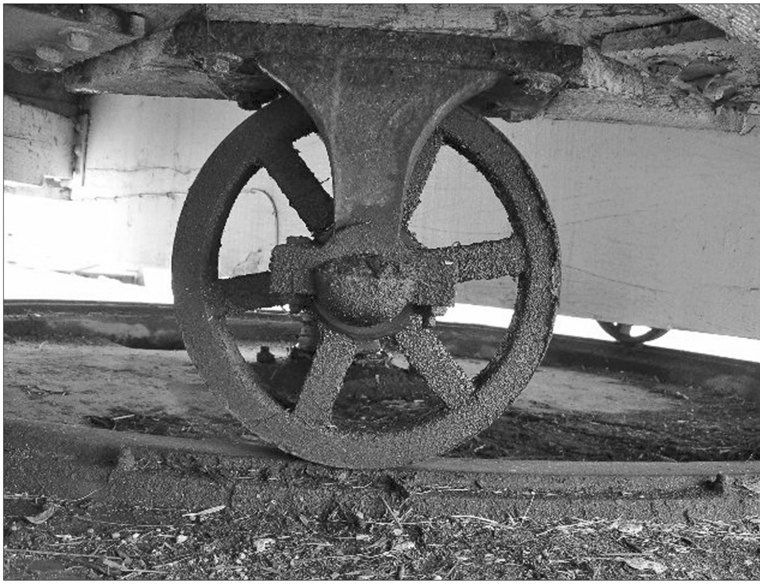

Figure 7. Balance wheel truck, Upper Nicholson's, an example of the traditional ironwork salvaged and re-used during successive swing bridge reconstructions. (Photo by author, October 2006)

poor condition, and had to be replaced in kind. But otherwise all of the metal hardware — the pivot assembly, balance-wheel trucks, end rollers, cast-iron mainpost brackets, the stay rods, and the two regulators — were salvaged and re-used, as well as the existing steel pivot assembly. (Figure 7)

The Upper Nicholson's swing bridge was erected on site in February-March 1986. During the course of construction several changes in the specifications were authorized. Red pine, which was more readily procurable on short notice, was substituted for Jack pine in constructing the railings; a 1000 kg (2,200 lbs) steel plate was used to floor the ballast box, with some stone ballast added, rather than using the traditional stone and scrap-iron ballast; steel shoes were introduced to anchor the railing posts rather than the exterior steel angle support used at Lower Brewer's; and Ammonium Copper Arsenate (ACA) was used in pressure treating the Douglas fir rather than CCA. Once assembled on site the Upper Nicholson's swing bridge was balanced, painted, and placed in service on 25 March 1986. (Figure 8)

Structurally, the new Upper Nicholson's swing bridge closely approximated the design of the evolved form of the former historic swing span at the bridge site, with respect to the mainframe, corbel frame and gallows-frame timbers, and the configuration and balance of the reconstructed swing span, and the retention of the metal hardware and working components. The retention of the historic dimensions of the main structural members was made possible once more by a selective use of ekki.

In at least two respects, the Upper Nicholson's swing bridge reconstruction was more accurate than the earlier Parks Canada reconstructions. Six ekki floor beams were placed on the long arm of the swing span, thereby matching the number and spacing of the Douglas fir floor beams on the former Upper Nichol-

Figure 8. Upper Nicholson's swing bridge, as reconstructed by Parks Canada in 1986. (Photo by author, October 2006)

son's span. This marked a retention of the traditional number of floor beams and their spacing, which had been departed from in the Lower Brewer's reconstruction. However, in the interior of the swing span the enlarged dimensions and closer spacing of the Douglas fir floor joists, introduced at Lower Brewer's in 1984, were retained in the Upper Nicholson's bridge reconstruction.

Ironically in one other respect—its framing connections—the reconstructed Upper Nicholson's swing bridge constituted a more accurate reconstruction than the earlier Lower Brewer's bridge. The former Upper Nicholson's swing bridge had been reconstructed previously by the Department of Transport in 1971 with butt joints and steel framing angle connectors, rather than the traditional mortise-and-tenon joinery. Thus, the modern system of timber framing used by Parks Canada on the Upper Nicholson's bridge reconstruction accurately replicated the framing system of the evolved historic structure being reconstructed, whereas previously at Lower Brewer's that historic swing bridge had had mortise-and-tenon framing connections.

In the framing of the swing span, there was one additional departure. At Upper Nicholson's the pivot beam of ekki was increased 2" in depth, to 28" x 20" in cross-section, so that the floor joists rested directly on the pivot beam, thereby eliminating the 2" x 6" spacer upon which the floor joists rested in the earlier Lower Brewer's reconstruction. This simplified the construction of that component of the timber swing span; however, the Lower Brewer's arrangement was in itself a major departure from the traditional plan of construction. On the evolved historic structures extant in 1972 when Parks Canada acquired the Rideau Canal, the ends of the floor joists were notched down for their full depth into a transverse centre beam bolted along the top of the pivot beam.[39]

In the subsequent reconstruction at Kilmarnock, an even more accurate reconstruction was achieved by Parks Canada. The Kilmarnock project was let on contract during the summer of 1985, and in the fall the Douglas fir timbers were ordered from Burnaby, British Columbia, and the ekki from Tropical Marine Timbers of Richmond, British Columbia. The Parks Canada working plans for the ekki model of timber swing bridge were reviewed by a firm of engineering consultants, and several modifications were introduced before the swing bridge reconstruction commenced in March 1986.

The eight ekki components of the upgraded swing span at Kilmarnock were the same as at Upper Nicholson's. They comprised six transverse floor beams on the long arm, the pivot beam, and the cap beam connecting the mainposts of the gallows frame. Overall the Douglas fir structural members were of the same size as on the historic structure; and the dimensions of the ekki floor beams and cap beam matched the Douglas fir components of the former swing span. As was the case at Upper Nicholson's, the number and spacing of the floor beams on the long arm corresponded exactly to the historic structure being reconstructed. Within the structure, however, the Douglas fir floor joists were increased in size, and decreased in their spacing, to match what had been done earlier on the Lower Brewer's and Upper Nicholson's reconstruction projects.

At Kilmarnock, the pivot beam of ekki was of the same cross-section, 26" x 20", as on the historic swing bridge, but a transverse centre beam, 12" x 16", was bolted along the top of the pivot beam between the bridge girders, in keeping with the traditional design practice. The floor beams were then abutted against the centre beam, and connected to it with steel framing connectors to match the former Kilmarnock swing span as previously reconstructed by the Department of Transport in 1970. This arrangement greatly enhanced the structural integrity of the reconstructed timber swing bridge, and contrasted with the Lower Brewer's and Upper Nicholson's reconstructions wherein the centre beam was discarded by Parks Canada in favor of carrying the floor joists across the pivot beam.

In addition, the traditional method of balancing the swing span was continued at Kilmarnock. A ballast box was constructed in the heel section by planking the bottom of the outer panel of the corbel frame, and it was filled with the traditional stone ballast supplemented with pig-iron weights. The ballast of the former swing span, which consisted of rubble stones and various pieces of scrap iron, was recorded and discarded.

All of the heavy framing timbers of the reconstructed Kilmarnock swing bridge were butt jointed with steel connectors, which replicated the evolved historic structure that had been reconstructed in 1970 by the Department of Transport with butt joints and steel framing connectors. The floor joist also were butt jointed with steel connectors at the heel beam, but at the toe beam a modification was introduced that was unique to the Kilmarnock reconstruction project.

On the five historic timber swing bridges extant when Parks Canada acquired the Rideau Canal in 1972, the floor joists were notched down into the heavy toe and heel beams (Jones Falls, Brass Point, and Lower Brewer's), or were joined to the toe and heel beams by modern steel connectors as on the Kilmarnock and Upper Nicholson's reconstructions carried out by the Department of Transport in 1970 and 1971, respectively. However, on the upgraded timber swing bridges reconstructed by Parks Canada at Lower Brewer's (1984) and Nicholson's (1986), the floor joists were not fixed to the toe beam. The outer end of the floor joists, which cantilevered out two feet beyond the outer floor beam, were left unsupported at their ends to save weight by dispensing with the heavy steel connectors. Subsequently, on the upgraded Lower Brewer's swing span, it was found that some deflection occurred in the cantilevered floor joists on the transfer of a moving load from the toe beam to the floor joists. There were also signs of deterioration in the wood at the connection between the girders and the toe beam, caused by a perceived tendency of the toe beam to rotate outwards slightly under the impact of a moving load.

To address this problem, at Kilmarnock a steel I-beam was introduced along the inner edge of the toe beam, and the floor joists were connected to the toe beam by steel connectors. The flanges of the I-beam, which had a slightly shallower web depth than the girders and the toe beam, were set into the wood members and lagged securely. In this manner, the I-beam was not visible once the planking was laid across the top of the mainframe of the swing span. (Thereafter, this innovation was introduced retroactively on the reconstructed swing bridges at Lower Brewer's and Upper Nicholson's.)

At Kilmarnock, the novel steel shoe introduced at Upper Nicholson's to support the railing posts was rejected. A steel dowel of ½" diameter was used to connect the rail post with the bridge girder, and the posts were reinforced by a steel angle lagged to the side of the rail post and girder. Although this arrangement detracted from the historic appearance of the railings, it was an accurate reproduction of the railing-post support arrangement on the extant swing bridge that was being reconstructed.

With the demolition of the existing Kilmarnock timber swing bridge, the metal hardware was salvaged, cleaned, and re-used on the reconstructed bridge. All of the metal hardware—balance-wheel trucks, pivot assembly, stay rods, regulators, stirrup anchors, and the cast-iron brackets for supporting the mainposts—proved salvageable, with the exception of the end rollers of both the toe and heel beams. New end rollers were fabricated in the Rideau Canal shops at Smith's Falls, as were the framing angles, deep beam hangers, for all of the timber swing bridge reconstructions. All fasteners—nails, lag screws, and bolts—and connectors were renewed with hot-dipped galvanized replacements of the same type. The ekki timbers, of course, were not chemically treated, but the Douglas fir components were pressure treated with a chemical wood preservative. The existing steel pivot assembly was retained in use.

The reconstructed swing bridge was painted in keeping with the same paint specifications as the previous Parks Canada reconstructions. The woodwork and metalwork was painted white throughout to match the demolished structure. The unequal arm swing span was then balanced through adding additional ballast, and the stay rods were post-tensioned. On May 26, 1986, the newly reconstructed and upgraded Kilmarnock timber swing bridge was inspected; accepted by Parks Canada; and opened for traffic.[40] (Figure 9)

In reconstructing the Kilmarnock swing bridge, consideration was given to using ekki for more than simply the structural members which would be overstressed under the upgraded 10-ton loading capacity, but that approach was consciously rejected in favor of using the historic materials whenever feasible and economical.[41] Douglas fir was not the original material of construction of the timber swing bridge design prototype introduced on the Rideau Canal in 1866, but that species of wood had attained an historical importance in the evolution of the timber swing bridges through over 80 years of use on the Rideau Canal to that date.

Figure 9. Kilmarnock swing bridge, as reconstructed by Parks Canada in 1986. (Photo by author, October 2006)

Ecological Concerns

In opting for a limited, highly selective structural use of ekki in reconstructing the Rideau Canal swing bridges, Parks Canada engineers were well aware of conservation issues worldwide. With a rapidly growing demand in Europe for West African hardwoods, there were concerns being expressed about the long-term viability of the timber harvesting. Some feared that African hardwoods might become depleted, resulting ironically in ekki going the way of the North American white oak. Heavy logging in the earliest areas of exploitation (Malaysia and Indonesia) had proceeded much faster than the rate of regeneration, threatening the continuation of supply, and similar fears were expressed with respect to the West African hardwood harvest.

Well over a decade earlier, several tropical rainforest countries had engaged forest-management companies to develop sustainable-yield exploitation and regeneration strategies by way of conserving their hardwoods. To ensure the survival of mature trees capable of sustaining the forests, clear cutting or strip logging was outlawed in favor of selective harvesting, with the cuttings limited to trees of 60 cm. (23.6") diameter or more. Nonetheless, with accelerating rates of exploitation, by the mid-1980s conservationists were calling for a greater selectivity in end-uses to further ensure the conservation of the tropical rainforests as a source of commercial structural timber.

In Europe, conservation efforts focused on substituting pressure-treated softwoods for tropical hardwoods in housing construction applications where only durability was being sought. This approach was intended to reduce the rate of exploitation and conserve valuable tropical hardwoods, such as ekki, for selective applications in hydraulic and structural engineering works wherein the exceptional properties of the hardwoods are utilized to a maximum. In effect, this selective structural use approach was followed by Parks Canada in reconstructing the timber swing bridges on the Rideau Canal.[42]

Assessment of the Reconstructions

On the Rideau Canal a selective structural use of a West African hardwood, ekki, enabled three timber swing bridges to be reconstructed—Lower Brewer's (1984), Upper Nicholson's (1986), and Kilmarnock (1986)—and upgraded from a 5-ton to a 10-ton loading capacity, while continuing the traditional cultural practice of preserving the historic Rideau Canal timber swing bridges through replacement-in-kind reconstructions. In a series of reconstructions Parks Canada managed to achieve an increasingly high degree of accuracy and integrity in preserving the historic appearance, scale of construction, the sizing and spacing of the visible structural members, and the working components of the evolved form of the original design prototype. Moreover, the historic hardware was salvaged and re-used, and the reconstructed timber swing spans were able to continue in service, *in situ* in their historic setting, with the traditional manual system of operation retained. On all three reconstructions, there was only one major departure—the insertion of a steel I-beam on the interior of the toe beam of the mainframe. Otherwise, though a selective use of ekki only a few minor modifications proved necessary in the sizing and spacing of floor joists; and they were hidden within the structure.

At Lower Brewer's the reconstruction occasioned one significant loss of integrity—the mortise-and-tenon timber framing system of the historic structure that was being reconstructed. However, that loss had nothing to do with the introduction of West African hardwood. Ironically, given its durability, an increased use of ekki might well have negated the earlier rationale for abandoning mortise-and-tenon connections in the framing of the reconstructed Rideau Canal timber swing bridges. At both Upper Nicholson's and Kilmarnock the traditional joinery techniques had already been abandoned in a previous reconstruction, respectively, in favor of framing the swing spans with modern steel, heavy timber connectors. Consequently those two reconstructions more closely approximated the structure being reconstructed—the evolved form of the historic Rideau Canal timber swing design prototype as it existed at their respective bridge sites when the reconstruction was undertaken.[43]

The reconstructed timber swing bridge at Lower Brewer's was a transitional structure in an on-going effort by Parks Canada to preserve the historic Rideau Canal timber swing bridges through continuing the traditional cultural tradition of replacement-in-kind reconstructions, and while doing so to enhance the accuracy of the reconstruction through employing a selective use of a West African hardwood to increase design values. In effect, the intention was to use ekki to upgrade the reconstructed structures to a 10-ton load capacity sufficient for service on secondary county and township roads without augmenting the dimensions of the structural members or replacing the traditional hardware.

At Upper Nicholson's a more accurate reconstruction was attained than at Lower Brewer's two years earlier, particularly so in replicating the number of floor beams of the historic structure, and their spacing, on the long arm of the swing span. However, additional modifications were introduced in altering the dimensions of the pivot beam and inserting a new type of ballast. Moreover, several modifications introduced earlier on the Lower Brewer's reconstruction project were integrated into the Upper Nicholson's reconstruction—the discarding of the centre beam over the pivot beam; the change in the sizing and spacing of the floor joists; and the failure to connect the floor joists to the toe beam.

At Kilmarnock an even more accurate reconstruction was attained through a selective use of ekki hardwood, while upgrading the reconstructed structure to a 10-ton loading capacity. The centre beam over the pivot beam was retained, as well as the traditional ballast, and the railing posts were anchored in the same manner as on the extant structure, which made for an exceptionally accurate reconstruction with a high degree of design integrity. However, the insertion of a steel I-beam at the toe beam, although hidden in the interior of the swing span, detracted from the structural integrity of the reconstructed Kilmarnock swing span. As there were no problems recorded previously from impact loads at the toe beam of the historic timber swing bridges prior to the discarding of the fixed connection of the floor joists to the toe beam at Lower Brewer's and Upper Nicholson's, the insertion of the steel I-beam appears to have been a questionable departure. The installation of steel connectors to fix the floor joists directly to the toe beam, as had been done in the previous reconstruction by the Department of Transport at Kilmarnock, would have resulted in a more accurate reconstruction, and presumably would have eliminated the impact problem.

The post-tensioning of the stay rods to carry part of the dead and live loads was a significant design departure, but was deemed necessary to achieve a 10-ton load capacity while retaining Douglas fir girders of the historic dimensions. Although the post-tensioning of the stays of the support truss converted the timber swing bridge from a beam bridge to a composite beam bridge/partially-stayed structure, as was the case at Upper Nicholson's and Lower Brewer's earlier, it did allow the historic metal working components of the truss system to be preserved unchanged. It was a design modification that served to preserve much more than was lost; and it was a departure that was neither visible, nor readily detectable.

Earlier, at Brass Point (1978), a reconstructed timber swing bridge was upgraded from a 5-ton to a 15-ton loading capacity, and widened from the traditional 12' width to a 16' width through utilizing an augmentation approach in which the size of the Douglas fir structural members was increased, and the spacing decreased, until the structure was capable of carrying a much greater load. However, at Brass Pont that approach resulted in a reconstructed bridge that modified the design details, and discarded the hardware and traditional elements of the historic structure.[44]

The augmentation approach resulted in the erection of an exceptionally heavy structure, with a mass totally out of keeping with the evolved historic structure that it replaced. The historic Douglas fir swing bridges extant on the Rideau Canal in 1972, with a 12' width and 5-ton loading capacity, weighed some 22 tonnes (24 tons), whereas the Brass Point swing bridge, of equal span, made 4' wider and upgraded to a 15-ton loading capacity with enlarged Douglas fir structural members, weighed upwards of 55 tonnes (61 tons). In contrast, the historic timber swing spans upgraded to a 10-ton loading capacity with a selective use of ekki hardwood at Lower Brewer's, Upper Nicholson's, and Kilmarnock, weighed but 29 tonnes (32 tons).[45]

Indeed, at Brass Point the heavy dead weight of the massive timbers of the reconstructed span required the scrapping of the original metal hardware traditionally re-used in the bridge reconstructions, and the replacement of the historic pivot assembly—the pintle and socket, and the balance-wheel trucks—with more modern heavy-duty components. Moreover, the historic truss components were discarded, and the flexible stay rods truss system was replaced by a rigid truss with heavily post-tensioned stays. The flexible stirrup anchors for the stay rods—first introduced on the previous Brass Point Bridge reconstruction in 1964—were abandoned in favor of a fixed anchorage that simply mimicked the appearance of the stirrup anchor, but abandoned its function; the flexible regulator at the apex of the truss system was discarded as well. The regulator was replaced by a fixed plate saddle to which the stay rods were rigidly welded. Moreover, almost all of the design features of the historic timber swing bridge were redesigned, and substantially modified in detail. In addition, exceptionally heavy steel connectors and fastenings had to be designed for framing the enlarged heavy timbers; and ultimately an electro-hydraulic operating system had to be installed under the heel of the reconstructed structure to swing the span, thereby displacing the traditional manual mode of operation.

As a result, the reconstructed timber swing bridge at Brass Point preserved little other than the general appearance of the historic structure. Although these changes were necessary, given the very demanding load specifications in force, the augmentation approach resulted in a great loss of integrity with respect to the historic character and structural integrity of the evolved form of the historic Rideau Canal timber swing bridge. Every effort was made to maintain "the line, level and fabric ... as true to the original as possible" in keeping with the contemporary Parks Canada *National Historic Sites Policy* (1968), but the required upgrade—a three-fold increase in loading capacity—resulted in the construction of an inordinately massive structure that necessitated other changes that greatly compromised the integrity of the historic Rideau Canal timber swing bridge.

With the introduction of a new *Parks Canada Policy* (1979), which stated that a reconstruction must be accurate in detail in preserving the design integrity of the historic resource being reconstructed, Canals Engineering began to investigate the properties of an African hardwood, ekki, in seeking ways to increase the design values of the traditional structural material—wood. Hence the introduction of ekki hardwood in three subsequent reconstructions, which marked a decided improvement over the earlier approach undertaken in reconstructing and upgrading the Brass Point swing bridge crossing.

In a situation where structural-quality white oak timber—the original historic structural timber—was no longer commercially available in exceptionally large dimensions, ekki hardwood imported from Africa permitted a return to a high-strength wood for the highly stressed structural members of the historic timber swing bridges on the Rideau Canal. Through a selective structural substitution of ekki, taking advantage of its superior mechanical properties, the loading capacity of the traditional timber swing bridge was successfully upgraded to 10 tons.

Ironically, in their selective substitution of ekki for the more heavily stressed structural members of the timber swing span, the Parks Canada reconstructions closely approximated the original design prototype of 1866. In the original plan and specifications for the unequal arm, centre-bearing timber swing bridge, a species of wood of strong mechanical properties—white oak—was used for the more heavily stressed members to augment the load carrying capacity and durability of the structure, and a softwood—white pine—was used for the less heavily stressed members, whereas in the Parks Canada reconstructions ekki was used for the more heavily stressed members, and Douglas fir for the less heavily stressed members.[46] In effect, a selective use of ekki structural members made possible not only a more accurate reconstruction of the historic timber swing bridges on the Rideau Canal, but also served to restore the design capabilities of the design prototype of 1866, which had had an 8- to 10-ton loading capacity.[47]

Moreover, the use of ekki actually constituted a continuation of a long tradition of substituting different wood species when the original species was no longer procurable in large-dimensioned sticks. In effect, white oak gave way to white pine during the last quarter of the 19th century, and by the 1890s with the great stands of white pine rapidly disappearing, Douglas fir was introduced. With the introduction of ekki in the reconstructed timber swing bridges on the Rideau Canal, Parks Canada brought the cycle full circle with a selective reintroduction of a high-strength, durable hardwood of superior mechanical properties.

Retrospective

The use of ekki timbers in the reconstruction of the Lower Brewer's swing bridge in 1984 marks one of the earliest structural uses of African hardwood in North American bridge building, if not the first use in a historic bridge reconstruction. After over 20 years of service at Lower Brewer's, Upper Nicholson's and Kilmarnock in carrying automobiles, light trucks and school buses, the timber swing bridges reconstructed with ekki components function as intended with no sign of decay in the pivot beam or other ekki members, beyond a few weathering cracks on the surface of several timbers. Moreover, the pressure-treated Douglas fir swing span at Brass Point appears to be equally sound. On the reconstructed bridges only the Douglas fir deck planking has had to be renewed, and the planks are no longer pressure treated with a chemical wood preservative, both on ecological and practical grounds. At an early date problems were experienced with excessive and uneven wear patterns in the incised pressure-treated deck planks. It became clear that there was no need for treating the deck planks with a chemical wood preservative. The deck planking, whether treated or not, required replacement due to surface wear long before wood decay could become a serious problem.[48]

Where durability is concerned, it is evident that the timber swing bridges reconstructed with a selective use of ekki will exceed the more than 20-year life span of the timber swing bridges constructed of white oak on the Rideau Canal at the mid-19th century. This represents a major gain over the 12- to 15-year life span of the untreated Douglas fir swing bridges reconstructed earlier on the Rideau Canal. Although efforts to extend the life span of Douglas fir through pressure treating have proven successful, that preservation approach is no longer acceptable. More recently, concerns about hazardous chemicals leeching out into the water resulted in the use of chemical wood preservatives being banned in 1993 from the Rideau Canal. Thus, the substantial difference in life span in favor of ekki over untreated Douglas fir is once again a major factor in any assessment of durability.[49]

Any decision concerning future reconstructions of the timber swing bridges on the Rideau Canal must be take into account several additional factors. Foremost is the Cultural Resource Management (CRM) Policy, adopted by Parks Canada in March 1990, which governs the management and treatment of cultural resources designated of historic value within National Historic Sites, National Parks, and Historic Canals administered by Parks Canada. According to the CRM policy, reconstruction is an interpretive activity that can be justified only in exceptional circumstances where it constitutes "the best possible means of achieving public understanding of a significant aspect of the past"; and it may be undertaken only where:

i) reconstruction of the vanished resource would make a significant contribution to historical, scientific or technical knowledge; and

ii) the cost of reconstruction, including its maintenance and operation, can be justified in relation to the historic significance and interpretive potential of the work.[50]

Where the second principle is concerned, a partial response can be found in the comparative cost and expected life span of a reconstructed timber swing bridge versus the cost of erecting a modern swing bridge structure to fulfill the same function. On the Rideau Canal, the reconstruction of a single-lane timber swing bridge, upgraded to a restricted 10-ton load capacity through a selective use of ekki, will cost about $80,000 (Canadian dollars); whereas a modern two-lane, steel plate girder swing span of a 20-ton highway load capacity would cost about $1 million (1990 Canadian dollars) to erect. On a township road of low traffic volume, the reconstruction of a restricted-capacity historic timber swing bridge may well be justified strictly in terms of cost-efficiency, even when the comparative life spans of the historic versus the modern bridge are factored in: 25 years or more (expected) for the composite ekki/pressure-treated Douglas fir timber swing span, as opposed to a service life of 50 years for a steel plate girder swing span.[51]

In addition to CRM policy principles, there are ecological concerns of a global nature that need to be taken into account with respect to the use of West African hardwoods, such as ekki. There is currently a well-established illegal trade in tropical hardwoods that is threatening to defeat efforts to introduce sustainable management programs for tropical rainforests in West Africa, South America, Indonesia, and Southeast Asia. Hence, there is a need to exercise due diligence in purchasing tropical hardwood from timber suppliers to ensure that the timber was harvested legally, in keeping with acceptable conservation standards.[52]

Conclusion

On the Rideau Canal, a selective substitution of ekki hardwood for overstressed Douglas fir components has enabled Parks Canada to preserve three timber swing bridges, and upgrade them to a more acceptable modern loading capacity, while continuing the traditional cultural practice of preservation through replacement-in-kind reconstructions. That approach has enabled the historic timber swing bridges to be reconstructed with a high degree of accuracy and integrity and has facilitated their retention in service on county and township road crossings of the Rideau Canal. Hopefully, such a promising heritage preservation approach will continue to be employed within the Rideau Canal National Historic Site of Canada in order to preserve the historic function, as well as the historic integrity of its timber swing bridges.[53]

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earlier study of the Parks Canada timber swing bridge reconstructions, undertake by the author in 1992–1993. The argument and analysis presented in this article are the author's, and do not necessarily represent the views or interpretations of the Parks Canada Agency or PWGSC. The Parks Canada bridge files cited herein are currently on deposit at the Library and Archives Canada in Ottawa.

Notes

1. Robert W. Passfield, "Swing Bridges on the Rideau Canal," *IA: The Journal of the Society for Industrial Archeology*, Volume 1, No. 2, 1976, 60–62. By way of definition, on the Rideau Canal "replacement-in-kind" is a type of reconstruction that encompasses the substitution of a similar or like material, such as another species of wood for the original wood fabric, in situations where the original type of material is no longer procurable, or affordable, in the requisite dimensions. In contrast, "replication" is a type of reconstruction that is accurate in every detail, including the use of exactly the same type of material—e.g. white oak for white oak.
2. Parks Canada, Canal Registry Records, File 4652/R85-261, Vol. 4, Canal Advisor to Acting Director, Agreements for Recreation and Conservation (ARC) Branch, Parks Canada, 12 Feb 1975; and *ibid.*, Staff Engineer, memorandum on "Brass Point Bridge," to Superintendent, Rideau Canal, 2 June 1977. As of the late 1940s, if not earlier, temporary timber trestles were placed under some of the timber swing bridges in winter to carry the heavier loads of county snow ploughing equipment (see Department of Transport, *Annual Reports*, 1947, 25; 1949, 33).
3. Parks Canada, Canal Registry Records, File 4652/R85-261, Vol. 4, Director General, Parks Canada, to Assistant Deputy Minister, Parks Canada, memorandum on Brass Point Bridge, 18 Sept 1975.
4. Parks Canada, *National Historic Sites Policy* (Ottawa, 1968), 8, Article 9, "Standards for Structural Restoration and Reconstruction."
5. Parks Canada, Canal Registry Records, File C-8562-4301-53409, Vol. I, Senior Bridge Engineer, memorandum on "Kilmarnock and Lower Brewer's Swing Bridges," 13 Jan 1983; Personal communication, Eric Sunstrum, Senior Bridge Engineer, to R.W. Passfield, 12 August 1992; and Parks Canada, Canal Registry Records, File 5052-272, "List of Bridges, Rideau Canal," entry #26, Rideau Ferry Bridge, Rideau Canal, n.d.
6. Eric Sunstrum personal files: Building Structures Section, Division of Building Research, National Research Council, Canada, "Report on Swing Bridge," 3 Sept 1976. The static stresses on the stay rods were no greater than 10 Kips per Square Inch (KSI), with dynamic stresses up to 13 KSI. The results of the behavior tests were conveyed in the following tables: 1) Static Load Tests (Stress KSI, Deflection Inches); 2) Maximum Dynamic Stresses; 3) Estimated Compressive Strength of Cables; 4) Estimate of Stress from Frequency; and 5) Estimated Average Stresses KSI. A "kip" (kilopound) is a unit of force equivalent to 1,000 inch-pounds; and a "KSI" (kilopounds per square inch) is a unit of pressure or stress, often used to express the strength of materials.
7. Parks Canada, Canal Registry Records, File 4652/R85-261, Vol. 5, Acting Director, A & E Branch, to Superintendent, Rideau Canal, 27 May 1976.
8. PWGSC, Technical Documents Centre, Rideau Canal Bridges, R2-501.13 and R2-501.14, "Brass Point Bridge, Swing Bridge Detail," 31 May 1978.
9. PWGSC, Technical Documents Centre, Rideau Canal Bridges, R-2-501.A4, Brass Point Bridge, Drawing #113, Detail #2, 31 May 1978.
10. Parks Canada, Canal Registry Records, File 4652/R85-261, Vol. 5, Regional Manager, A& E Branch, memorandum "Brass Point Bridge," 8 Sept 1977; and Chief, Canals Engineering Division, A & E Branch, Parks Canada, to Dineen Roads and Bridges, 13 March 1978. The cost estimate for reconstructing the timber swing

bridge was $50,000 Cdn., which was but a fraction of the cost of the broader construction project.

11. PWGSC, Technical Documents Centre, R-2-501.13, Brass Point Bridge, Drawing #112, Detail #1, 31 May 1978.
12. Personal communication, Sunstrum to Passfield, 20 April 1993.
13. Robert W. Passfield, "Historic Bridges on the Rideau Waterways System: A Preliminary Report" (Parks Canada, Manuscript Report Series, No. 212, 1976), 4–5; and PWGSC, Technical Documents Centre, Rideau Canal, Brass Point Bridge, "General Plan of New Construction – As Built," drawings R2-501A-4, R2-501A-9, and R2-501A-10, 31 May 1978. New timber crib piers were built on concrete pile platforms, and the four steel spans were replaced with high strength steel trusses closely matching the truss pattern, elevation and configuration of the former spans, even to the extent of fabricating the trusses with high-strength carriage bolts that conveyed the appearance of rivets. The 4" x 12" plank flooring, was supported by larger 6" x 14" joists, which were placed in pairs at 18" centers, to attain the 15-ton loading capacity on the truss spans.
14. Parks Canada, Canal Registry Records, File 4652/R85-261, Vol. 5, Bridges & Tunnels, memorandum on file, "Brass Point Bridge," 20 July 1984.
15. Eric Sunstrum personal files: Tropical Marine Timbers, Richmond, B.C., to A & E Branch, Parks Canada, 26 Sept 1983; and personal communication, Sunstrum to Passfield, 16 July 1992.
16. "Azobé," *Revue Bois et ForLts des Tropiques* (Centre Technique Forestier Tropical), No. 170, novembre-décembre 1976, 35–50; and Eloise Gerry, Technologist, Forest Products Laboratory, U.S. Department of Agriculture, "Information Leaflet Foreign Wood" (Report No. R-1913, 1951), 6 p. The comparative strengths and toughness of ekki and Douglas fir are set forth on the website of the timber supplier, Tropical Marine Timbers.
17. "Guide to the Use of West African hardwoods for Structural Purposes, No. 1, The H Super Group," United African Co. (Timber) Ltd., London, n.d., 43 pages; and Sunstrum personal files: Tropical Marine Timbers to Sunstrum, 3 Feb 1992, "General Information Sheet about Ekki timber – Specification, Comparative Strengths of Timber Species, and Mechanical Test Results."
18. Eric Sunstrum personal files: Tropical Marine Timbers to Sunstrum, 3 Feb 1992, enclosure, "General Information Sheet about Ekki timber"; and "Specification for timbers 12" x 12" and larger for lengths of no less than 30 feet."
19. Eric Sunstrum personal files: Tropical Marine Timbers to Sunstrum, 3 Feb 1992, enclosure "The Durability of Some Wood Species," based on studies by the Institute for Wood Research, Delft, Holland. As noted, the timber swing bridges of Douglas fir have required reconstruction every 12 to 15 years whereas a timber swing bridge constructed with white oak structural timbers at Lower Brewer's in 1872 had a 24-year life span.
20. Parks Canada, Canal Registry Records, File 8562- 4301-53409, Vol. I, "Project Brief for Lower Brewer's Swing Bridge," February 2, 1983. The high level bridge just off-site at Upper Brewer's lock station was opened in January 1967. It has a 30' clear roadway width and a 20-ton highway loading capacity, and replaced a timber swing bridge that had been located at the Upper Brewer's lock station.
21. Minister of the Environment, *Parks Canada Policy* (Ottawa, 1982, 1st ed., 1979), "Reconstruction," 29– 30. In the 1979 policy statement, the reconstruction standards are set forth by the National Parks division of Parks Canada, but were applied throughout Parks Canada.
22. "Project Brief for Lower Brewer's Swing Bridge," 2 Feb 1983. On the evolution of Parks Canada's heritage preservation policies during the 1968–1979 period, see Robert W. Passfield, "The Role of the Historian in Reconstructing Historic Engineering Structures: Parks Canada's Experience on the Rideau Canal, 1976–1983,"

IA, The Journal of the Society for Industrial Archeology, Vol. 11, No. 1, 1985, 11–14, "Policy Elaboration," and 14–17, "Policy Implementation."

23. Parks Canada, Ontario Service Centre, "Replacement Policy for Timber Swing Bridges on the Rideau Canal," 1982.

24. Parks Canada, Canal Registry Records, File C-8562-4301-53409, Vol. I, memorandum on file, 4 Feb 1983.

25. Personal communication, Sunstrum to Passfield, 6 Oct 1992.

26. Parks Canada, Canal Registry Records, File C-8562-4301-53409, Vol. I, Joe Brown, Rideau Canal Office, memorandum, "Lower Brewer's Swing Bridge," 4 Nov 1983. Ironically a similar situation occurred at Lower Brewer's 50 years earlier. In 1933 the timber swing bridge was undergoing a reconstruction, and core samples were taken from the discarded timbers of the former swing bridge erected in 1921. Extensive decay was found just beneath the surface wood of the twelve-year-old timbers. At that time the superintending engineer, A.T. Phillips, observed: "Douglas fir rots in the heart leaving the outside of the timber apparently sound" (File 4652/R85-248, Vol. I, A. T. Phillips to Col. A. E. Dubuc, Chief Engineer, Department of Railway and Canals, 15 Nov 1933).

27. Personal Communication, Ashton Dale to Robert Passfield, 29 Oct 1992. Ashton Dale began work on the Rideau Canal in December 1934 as an apprentice timberman, repairing timber crib waste weirs and reconstructing timber swing bridges. He became a carpenter in 1937, was appointed Carpenter Foreman in 1949, and retired in April 1977 as the Maintenance Supervisor, Rideau Canal.

28. Personal Communication, Sunstrum to Passfield, 6 Oct 1992. At the time of the swing bridge reconstructions, there were three codes governing the construction of timber structures in Canada: CAN3-086-M80 (1980), a working stress design code for all types of timber engineering structures; CAN3-S6-M78, a design code for bridges; and the "Ontario Highway Bridge Design Code" (OHBDC, 1979) which included wood bridges (Borg Madsen & Robert Sexsmith, *Recent Developments in Timber Engineering* (Structural Division, Canadian Society for Civil Engineering, 1983).

29. In a modern cable-stayed bridge structure, the deck is fully supported by heavily post-tensioned stays emanating from the pylon(s), whereas on the four timber swing bridges reconstructed by Parks Canada the deck is only partially supported by the stays emanating from the gallows frame. Hence, they are described herein as a "beam bridge/partially stayed structure."

30. Parks Canada, Canal Records, File C-8562-4301-53409, Vol. I, Eric Sunstrum, Acting Head, Design Section, A & E Branch, to Chief Engineer, Rideau Canal, 22 Nov 1983; and *ibid.*, Tropical Marine Timbers, Richmond, B.C., to Parks Canada, 26 March 1984.

31. Parks Canada, Canal Registry Records, File C-8562-4301-53409, Vol. I, Chief, Contract Services, to W.V. Wallans Contracting Ltd., 27 March 1984; and *ibid.*, memorandum on file, "Lower Brewer's Swing Bridge," 30 March 1984.

32. Parks Canada, Canal Registry Records, File C-8562-4301-53409, Vol. I, Chief, Construction Maintenance Service, to W.V. Wallans Contracting Ltd., 16 April 1984. Presumably the lag screws were being used to anchor the cap beam braces to the ekki cap beam of the gallows frame.

33. PWGSC, Technical Documents Centre, "Rideau Canal, Lower Brewer's Swing Bridge, As-Built," Drawing 10-891, Abutments, Sheet #102, and New Bridge Details, Sheets # 104, #105, and #106, 31 January 1984. In the mid-1970s , Canada converted to the metric system of measurement; and the drawings for the Lower Brewer's, Upper Nicholson's, and Kilmarnock reconstructions are dimensioned in metric units. However, in this article all dimensions for the reconstructed bridges are cited in the Imperial system for ease of comparison.

34. Parks Canada, Canal Registry Records, C-8562-4301-53409, Vol. I, Project Meeting

Notes, 16 May 1984.

35. Personal Communication, Joe Brown, Chief Engineer, Rideau Canal, to Robert Passfield, 12 Nov 1992.

36. Parks Canada, Canal Registry Records, C-8562-4301-53409, Vol. I, W.V. Wallans Contracting Ltd., to Parks Canada, 25 June 1984; and *ibid.*, memorandum on file, 26 June 1984.

37. Parks Canada, Canal Registry Records, File C-8562-4301-53409, Vol. I, Lower Brewer's Swing Bridge, Change Order No. 2, Contract CR-84-07, 20 July 1984; and *ibid.*, Tropical Marine Timbers, Richmond, B.C., (invoice), 26 March 1984. The contractor was paid $49,315 for the framing and erection of the swing span, exclusive of materials, but inclusive of removing the old swing span, work on the abutments, landscaping, and an allowance for several extras. Parks Canada paid $3,311 for the ekki components, and approximately $16,600 for the Douglas fir and pine components, plus an additional $4,500 for pressure treating, and approximately $3,000 was expended on new fastenings and replicating the damaged historic metalwork. (All figures in Canadian dollars.)

38. Personal communication, Joe Brown, Chief Engineer, Rideau Canal to Robert Passfield, 12 Nov 1992; and Parks Canada, National Historic Sites Directorate, Rideau Canal Historic Prints & Drawings Collection, R.W. Passfield photos of July 1974: R4-020-G-0062, Jones Falls; R4-026-G-0059, Brass Point; R4-024-G-0018, Lower Brewer's; R4-010-G-0014, Kilmarnock, and R4-007-G-0012, Upper Nicholson's.

39. Parks Canada, Canal Registry Records, File 4060/R85-117, Vol. I, Upper Nicholson's Swing Bridge, correspondence and site meeting notes, 7 August 1992 through 26 March 1986; and Parks Canada, Ontario Service Centre, "Nicholson's Lock 19 Reconstruction, Swing Bridge Superstructure Plans, Elevation, and Details," CORCN 84/R103, Sheets # 6, #7, and #8. The design consultants on the Upper Nicholson's project were J.L. Richards & Associates Limited, Consulting Engineers & Planners (Ottawa, Ontario), and the construction was supervised by Delcan, DeLeuw Cather Canada Ltd., Consulting Engineers & Planners (Ottawa). The contractor was Ron Engineering & Construction Ltd., Engineers & Contractors (Ottawa).

40. Parks Canada, Canal Registry Records, File 4060/R85-118, Vol. I and Vol. II, Kilmarnock Swing Bridge, correspondence and site meeting notes, 20 April 1985 through 30 April 1986; and Parks Canada, Ontario Service Centre, "Rideau Canal, Kilmarnock Lock Reconstruction, Swing Bridge Superstructure," CORCK 83/R13, General Arrangement, Sheet #13, and Construction Details, Sheets #14 and #15. The consultants were Totten Sims Hubicki Associates, Consultants (Cobourg, Ontario), and the contractor was JRB Construction Ltd. (Gloucester, Ontario).

41. Parks Canada, Canal Registry Records, File 4060/R85-118, Vol. I, Kilmarnock Swing Bridge, marginalia on memorandum to file, "Ekki timber: Kilmarnock Swing Bridge," 29 April 1985.

42. Cor F.W.M. Meijenfeldt, "The Use of and alternatives for tropical hardwood in the Netherlands," *Netherlands Journal of Agricultural Science*, Vol. 33, 1985, 115–123; J.E.D. Fox, "Exploitation of the Gola Forest," *Journal of the West African Science Association*, Vol. 13, No. 2, 1968, 185–210; and personal communication, Tropical Marine Timbers to Robert Passfield, 14 Dec 1992. The ecological implications of using ekki is a rather complex subject. As a representative of Tropical Marine Timbers pointed out, "alternative materials such as metals, plastics/polymers and concrete consume a great deal more energy to produce than wood," and treated softwoods pose a particular problem in use and disposal (*ibid.*). See also, Canadian Wood Council, *Wood Reference Handbook, A guide to the architectural use of wood in building construction* (Ottawa, 1991), 70, "The Energy Impact of Wood Products."

43. Herein the accuracy of the four Parks Canada reconstructions is assessed solely in terms of the evolved historic structure being reconstructed at each particular site. An evaluation of the authenticity of a Parks Canada reconstruction would require

an assessment of the extent to which the heritage values of the original design prototype of 1866, and any acquired heritage values pertaining to the evolved historic timber swing bridge being reconstructed, were preserved in the reconstructed structure. An evaluation of the authenticity of five reconstructed timber swing bridges extant when Parks Canada acquired the Rideau Canal in 1972—Robert W. Passfield, "Evaluating Authenticity: Reconstructed Timber Swing Bridges,"—will appear in a future publication.

44. Of the five timber swing bridges extant when Parks Canada acquired the Rideau Canal in 1972, only the Jones Falls timber swing bridge has been lost, rather than preserved through a replacement-in-kind reconstruction. A modern, high-level by-pass bridge was already under construction upstream of Jones Falls when Parks Canada acquired the Rideau Canal; and efforts to preserve the existing timber swing bridge *in situ*, in an open position at the closed crossing, were unsuccessful. The spread of decay in the heavy timbers eventually necessitated the swing span being disassembled and cut up. The metal hardware, however, was salvaged for use in swing bridge reconstructions at other Rideau Canal bridge sites.

45. Personal communication, Sunstrum to Passfield, 29 April 1993.

46. For example, on the swing bridge erected at Oliver's (Rideau) Ferry in 1874, white oak was used for the cap beam, the toe and heel beams, and for the heavy transverse timbers over the balance wheel trucks in the mainframe, as well as for the corbel frame timbers and the pivot beam, whereas white pine was used for the two girders, the floor beams on the long arm, and the gallows frame except for the cap beam. The reinforcing knees in the mainframe and corbel frame were of tamarack. (Department of Public Works plan, elevation, and cross-section drawing, "Oliver's Ferry Bridge, Rideau Canal," [1873], Library & Archives Canada, NMC 130281).

47. During the 1860s timber swing bridges of white oak, erected by the Department of Public Works on Canadian canals, had a loading capacity anywhere from 8 to 10 tons depending on their particular design (LAC, RG 12, Volume 3596, James Slater, Chief Engineer, Rideau Canal, to Frederick Braun, Secretary, DPW, 28 April 1865, marginalia).

48. Personal communication, Sunstrum to Passfield, 13 July 2006. The deck planking wear problem was conveyed earlier: personal communication, Joe Brown to Robert Passfield, 18 Jan 1993. Lock gates on the Rideau Canal were pressure treated with a chemical wood preservative from 1974 to 1993.

49. The treatment of the Douglas fir members of a reconstructed swing bridge with a chemical wood preservative and the abandonment of mortise-and-tenon framing connections have contributed also to a greatly increased longevity for a reconstructed swing bridge. At Brass Point, after almost 30 years of service, the bridge reconstructed with pressure-treated Douglas fir shows no visible signs of decay, whereas previously the untreated Douglas fir spans with mortise-and-tenon framing connections had to be reconstructed on a 12- to 15-year cycle because of decay in the end grains of the tenons in the mortise pockets. However, given the tendency of Douglas fir to rot in the interior, the soundness of the timbers of the Brass Point structure needs to be affirmed by taking core samples.

50. Parks Canada, *Guiding Principles and Operational Policies*, "Cultural Resource Management Policy," 114. If a reconstruction can be justified, then it can only proceed if:

    i) there are no significant preservable remains that would be threatened by reconstruction; and

    ii) the action will not compromise the commemorative integrity of the site; and

    iii) there is sufficient research information to support an accurate reconstruction.

51. Personal communication, Sunstrum to Passfield, 13 July 2006. For example, in 1989–1990, it cost $1.23 million (Canadian dollars) to erect a steel plate girder swing span with an upgraded load capacity (20 tons), and enlarged width (29'-6" roadway and 6' sidewalk), at a Rideau Canal lock station. The cost included, in addition to the plate girder span, the removal of the superstructure and substructure of the previous swing span, the construction of a larger reinforced-concrete sub-

structure, the new electrical and hydraulic installations, the erection of a control building, and the cost of erecting and maintaining a temporary detour structure during an extended construction period. The life span of a steel plate girder swing span is considered to be 50 years, but depends in large measure on the salt damage inflicted through salting the roads in winter. Life span comparisons are rendered even more complicated by the banning of the use of pressure-treated wood on the Rideau Canal.

52. Today, timber suppliers world-wide are under increasing pressure from governments in Europe and North America to ensure that their tropical hardwood timbers were harvested legally. As of 2006, conservationists have estimated that only five percent of the world's tropical forests are under sustainable management and that some 80 percent of the $1.5 billion tropical hardwood timber trade is supplied by illegal sources in South America, West Africa, Indonesia and South-East Asia.

53. Yet another heritage preservation approach is to increase design values by replacing over-stressed timbers with glue-laminated members. This approach was adopted in the United States in 1989 in repairing and restoring the historic Cornish-Windsor Covered Bridge, a 458' span structure erected in 1866 over the Connecticut River between New Hampshire and Vermont. (Teresa Austin, "Caring for a Covered Bridge," *Civil Engineering* (New York), July 1991, 44–45).