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Title:	Evaluation and Rehabilitation of Historic Covered Bridges		

Abstract

The evaluation and rehabilitation of historic covered bridges (covered bridges) requires appreciation of, and experience with, the nuances of complex timber structures subject to moving loads. This bulletin provides guidance on the myriad of issues involved with this work.

Introduction

There are 800+ extant "historic" covered bridges in the United States. Historic in this context is intended to differentiate those self-supporting bridge superstructures built primarily of wood from more conventional (i.e. steel or concrete) superstructures upon which a wooden cover has been erected (aka "bridges which are covered"). Further, this bulletin is aimed at structures that were built at least 50 years ago, generally satisfying the basic identification of historic per preservation guidelines.

This bulletin is focused on the timber superstructure of extant bridges with minor discussion at the end of the bulletin about design of "replica" covered bridges using traditional materials and joinery. More specifically, this bulletin is focused on the trusses or truss/arch combinations that support the superstructure. Additionally, the discussion herein is intended to include bridges that support vehicular or pedestrian loads as well as those currently closed to all use. While there are a few extant covered bridges that support railway tracks rather than highways, for purposes of this bulletin, vehicles are intended to imply automobiles and trucks.

Much of this material is available in more detail, along with other related information, in the Covered Bridge Manual published by the Federal Highway Administration as FHWA-HRT-04-098, dated April 2005. [2] It is available as a free download at the FHWA website.

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[2] FHWA, 2005, Covered Bridge Manual – HRT-04-098, Federal Highway Administration, Washington, DC

This author served as Principal Investigator for the preparation of that manual. This bulletin is intended to provide an abbreviated focus on the evaluation and rehabilitation of covered bridges.

Additionally, more detail about the evolution of the development of timber specifications was recently published in an article entitled "Reflections on Load Capacity of Historic Covered Bridges", in the September 2013 edition number 109 of Timber Framing, also authored by this writer [3]. Some of the more esoteric content is summarized in the following discussion.

Evaluation of Covered Bridges

Field Evaluation

The field evaluation includes a thorough inspection of the structure. Access to the underside will probably require ladders or scaffolding from the stream bottom or barge, rigging or other equipment to allow "hands-on" examination. A ladder or step ladder will probably be required inside of the structure. And when possible, some means of access is appropriate to examine the exterior of exposed vertical portions of superstructure elements. Exterior or interior siding may have to be temporarily removed to allow examination.

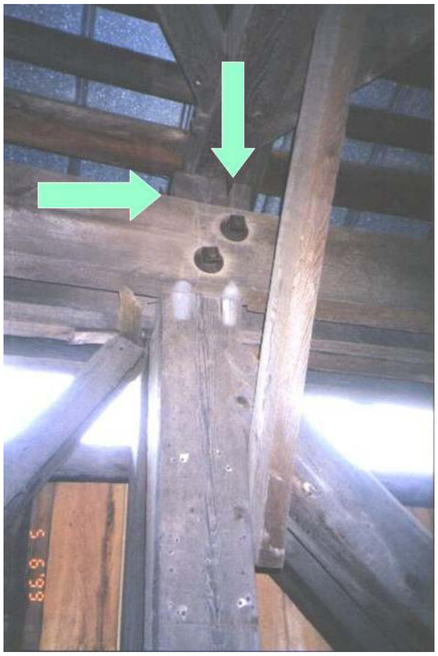
At a minimum, the inspection is based on a visual evaluation. A moisture meter should be available to record other than dry conditions. While not commonly used for "routine" inspections of covered bridges, Non-Destructive Testing (NDT) equipment may be appropriate to evaluate unusual or limited deterioration. In general, NDT is expensive and often not considered financially justifiable, although resistance drilling techniques and equipment are more affordable than most other forms of NDT for identifying limits of contained deterioration.

Some key features that should warrant extra attention include:

- Steel plates that have been added – they are notorious for hiding deterioration of timber behind the steel plates. You will probably be unable to remove them for inspection, but if you are involved with a rehabilitation project of a bridge having such plates – beware! =>

[3] Pierce, P. C. 2013, Reflections on Load Capacity of Historic Covered Bridges, *Timber Framing*, Journal of the Timber Framers Guild, v 109, pp.20-24, Sept

- Splits of the top of heavily loaded posts – potential indication of shear failure. Posts without “check braces” opposite the main diagonals are especially susceptible to such failure. =>



- The extensive area of mating surfaces of Town lattice trusses in particular, are also notorious for hiding deterioration from view – in this case, the mating surfaces were found to be nearly completely removed by a nesting rodent after removal of an outside element. The remaining thin shell of material of the two chord elements might escape notice during a visual examination. =>

If there are no plans, obtain pertinent dimensions and prepare sketches. Focus on details and splices of chord elements to enable proper analytical assessment. If there are plans for the structure, compare them to actual field conditions and record discrepancies.

The follow-up analytical evaluation will require identification of wood species and grade of pertinent elements. It is impractical to pursue this information for all elements of the bridge, but is important to capacity determination as well as weight. At a minimum, this information must be identified for those elements subject to maximum axial forces in truss chords and webs. Additionally, elements subject to high shear stresses such as floorbeams must be explored.

While some bridge inspectors are able to identify typical wood species, the most reliable means of verifying the species is to remove small samples from "out-of-view" and non-critical locations of elements for identification by a trained wood scientist. The cost is nominal and results can be obtained quickly.

Identification of the grade of the critical elements is equally important, but much more difficult to determine because elements are not fully visible – at least some of the sides are obscured by other elements or siding. A structural grade might be based on what is visible. Some investigators assume that those faces not visible would probably contain no more defects than those faces which are exposed. The artisans who built these structures which have successfully withstood the ravages of time were very diligent in selecting the best material for those elements within the bridge subject to the highest stresses. Other investigators might be more conservative and assume that the obscured portion may be worse by assigning a grade equal to one grade value lower than that associated with the visible portion. Some select an even more conservative value. This is a critical issue and has to be selected by the engineer.

Analytical Evaluation

"Analytical evaluation" (aka "load rating") in this context is intended to indicate the procedure and process by which the capacity of the bridge is calculated to determine its level of safety for support of the various loads imposed on it.

The analytical evaluation of highway bridges in the United States is governed by design specifications published by the American Association of State Highway and Transportation Officials (AASHTO). Initial timber design specifications were based on Allowable Stress Design (ASD) [aka Working Stress Design] methodology wherein "predicted" or calculated stresses from loads divided by section properties are compared with allowable stresses based on species and grade.[4] New bridges are now designed in accordance with the Load and Resistance Factor Design (LRFD) methodology that is theoretically refined to provide more uniform factors of safety among the elements of the structure.[5]

[4] AASHTO, 2002, Standard Specification for Highway Bridges, 17th Edition, American Association of State Highway and Transportation Officials, Washington, DC

[5] AASHTO, 2012 LRFD Bridge Design Specifications, 6th Edition, with 2013 Interim Revisions, Washington, DC

Much could be written about the development of the LRFD specifications, but only a few remarks are judged to be pertinent to this article.

While the LRFD specifications contain provisions for timber bridges, they were developed primarily for steel or concrete bridges. The LRFD methodology was inspired to address larger modern bridges in part as a means of maximizing material and structure efficiency. Its probabilistic approach recognizes that some loads are more predictable than others. This is especially important for modern bridges having a higher proportion of live to dead load. LRFD also more accurately represents modern traffic loading and its distribution to the various elements of modern bridges.

Some timber engineers, and more notable for this article, especially those of us involved with engineering associated with covered bridges, believe that the LRFD specifications and methodology are not appropriate for analytical evaluation of covered bridges. The most basic reasons for this position include:

- The number of vehicles passing through covered bridges is very low compared to those assumed in the calibration models of timber bridges in LRFD
- Load combinations of LRFD do not address the low proportion of live to dead forces for the primary elements of covered bridges,
- LRFD does not address those bridges which may have appreciable snow loading atop their roofs

In short, LRFD is more of a “black box” approach and does not provide the timber engineer the flexibility necessary to deal with the complexities of an historic covered bridge. Therefore, continued use of the ASD methodology is considered appropriate for analytical evaluation of covered bridges. It is also noted that several states which have significant numbers of covered bridges still follow ASD methodology.

Accordingly, the remainder of this bulletin is based on ASD. However, it is recognized that other engineers may choose to consider LRFD – the process and procedures described hereafter are similar.

Loads

Within traditional analytical evaluation of covered bridges, it is assumed that all vertical loads (dead, live and snow) are supported by the trusses or truss/arches, while all horizontal loads (wind) are supported by bracing elements. Unlike evaluations of “modern” truss or truss/arch bridges, horizontal loads combined with vertical loads in the evaluation of truss chords of covered bridges will not govern.

Addressing **vertical loads** first, AASHTO specifications identify the unit weight of wood for timber bridge design to be 50 pcf. However, that is rarely appropriate for evaluations of covered bridges. The AASHTO Bridge Subcommittee has subsequently endorsed the use of "site-specific" unit weights, based on the species and moisture content of the elements of the bridge. Many trusses were made from spruce or pine or fir that weighs a lot less – 28-35 pcf is common. Floor elements may weigh more based on higher moisture content and if replaced with pressure treated material. Hence, the ***dead load*** forces should be based on the wood used in the specific bridge being evaluated.

Covered bridges can be subject to transient vertical loads (i.e. ***live loads***) – most commonly vehicles or pedestrian loading. As to **vehicles** - most historic covered bridges were not "designed" for vehicles resembling modern design vehicles. The geometry of the bridge and size of elements were often selected by judgment and experience of the builder based on the success of other bridges supporting loads of the day – freight wagons and the like.

Development of national bridge design specifications in the early 20th century, led to adoption of standardized design vehicles – the "H-15" two-axle truck being the most basic. It weighs a total of 15 tons with the rear axle weighing four times the front axle. Many covered bridges built in the western U.S. during this period were designed for these H-15 vehicles.

Certainly there are some bridges wherein a string of closely spaced vehicles may be possible, simulating AASHTO's "lane loading". Some bridges with taller openings might be crossed by even heavier vehicles similar in configuration to AASHTO's "HS" vehicles that simulate modern semi-tractor trailer trucks.

It must be recognized that current heavier vehicular traffic on covered bridges is often represented by "community" vehicles – oil trucks, emergency vehicles, and school buses. There is no readily available consensus "standard" vehicle representation of axle weight and spacing for these vehicles.

However, as a starting point for purposes of performing the analytical evaluation, and following the load rating procedures of AASHTO for the analytical evaluation of historic covered bridges, most evaluations are based on passage of a single H configuration vehicle. And as described above, the numerical approach leads to the reserve capacity of the bridge as a proportion of the H vehicle – e.g. an 8-ton vehicle, or 4-ton, or often 0-tons (yes, an alarming result to be discussed in more depth in later sections of this article).

It is most important that the analytical evaluation be based on practical vehicle configurations to lessen potential for abuse of the structure by modern design loadings. Yet, for ease, the remaining discussion of this topic will be based on single H vehicles.

As to covered bridges restricted to **pedestrian** loading, AASHTO published the Specifications for Design of Pedestrian Bridges [6, 7]. The most important issue related to it is the selection of uniform loading. The standard design loading (80 psf) represents a very unusual situation wherein people are crammed into the bridge and the total weight would be substantially heavier than a vehicle. Certainly there are examples of bridges subject to large gatherings of people. Such loading would often exceed the capacity of a covered bridge. So the evaluation of a covered bridge for pedestrian loading needs to start with the determination of what average uniform loading can be tolerated based on structural capacity of the bridge and then determine if the equivalent number of people is rational. There are examples of bridges that are posted for a maximum number of people – the engineer (and owner) must decide if establishing such a limit is tolerable from a liability standpoint.

Conventional (non-covered) bridges are not designed for ***snow loading*** since snow is plowed off preventing combinations of full snow load and full design live loading. Therefore, AASHTO bridge specifications do not address snow loading. However, covered bridges located in colder climates are subject to snow loading atop their roofs that must be considered in combination with vehicular loading. The most commonly used and widely adopted reference for snow loading is ASCE/SEI 7 Minimum Design Loads for Buildings and Other Structures (ASCE 7).[8] It is an appropriate reference to use for the prediction of snow loading on a covered bridge.

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[6] AASHTO, 2004, Guide for the Planning, Design and Operation of Pedestrian Facilities, 1st Edition, American Association of State Highway and Transportation Officials, Washington, DC

[7] AASHTO 2009, LRFD Guide Specifications for the Design of Pedestrian Bridges, 2nd Edition, American Association of State Highway and Transportation Officials, Washington, DC

[8] ASCE/SEI 7, 2010, Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineer, Reston, VA

Power House Bridge in Johnson, VT – oops (due to snow)

But, now to the difficult part – combinations of loading and the corresponding load duration factor.

Structural engineers are familiar with assessing the probability of load combinations of dead and live. In the case of these relatively heavy structures, dead load on its own, may be a controlling load. But adding allowance of snow loading confronts the lack of national bridge specification (i.e. AASHTO) guidance on combinations of dead, live and snow [live in this instance might include snow plows which are often quite heavy vehicles]. ASCE 7 does have provision for that combination in buildings – some choose to extend it to bridges.

Timber components have a unique characteristic compared to steel or concrete in that they can absorb loads applied over a short period of time with limited damage. This material behavior specific to timber is addressed through a load duration factor, which may range up to 2, indicating much more capacity than one might expect. This behavior can be confusing to those not accustomed to it, especially as it relates to combinations of loading. Each combination of loads has a corresponding duration of load factor. It is the load combination, factored by its probability of occurrence, and then divided by its duration of load factor that enables ultimate determination of the controlling combination. Refer to other texts for a more thorough discussion of this complex topic.

Now addressing **horizontal loads**, while modern specifications have addressed earthquake loading for many years, it is sufficiently uncommon in the arena of covered bridge work as to be omitted from this discussion. Therefore, horizontal loads will be restricted to consideration of wind only for this bulletin.

AASHTO specifications provide basic wind load provisions, but they are excessively conservative with respect to covered bridges. Guidance provided in ASCE 7 is much more refined and widely used for wind loading. As noted earlier, the evaluation of wind loading is based on the bracing system of the bridge transmitting the force of the wind to the substructure units (abutments for single-span bridges). Unlike more modern steel through-truss bridges that typically contain a top lateral system and heavy end portal system that conveys the wind loads of the top of the bridge to the abutments, covered bridges often do not have the same strong end portal system and rely more on intermediate knee bracing to convey some of the top wind loads down into the plane of the floor or lower lateral system. The floor systems of many covered bridges act as large, strong horizontal diaphragms to transmit forces the ends of the bridges. While the analytical evaluation process for wind loading is based on that load alone (i.e. no group load combination factor), it progresses with consideration of the duration of load factor as mentioned above.

Unknown bridge to farmer's field

Farmer tired of his wagons hitting the tie beams

Oops – farmer doesn't live here anymore, following that little wind storm!

Force Analysis

Given the loading described above, the analysis of the structure proceeds with determination of forces for the various elements. This step is rather elementary for the floor components and will be omitted from this discussion.

The force determination for truss elements often confront the fact that most timber trusses do not have conventional "concentric work points" as do modern steel trusses. Hence, truss elements experience axial force as well as shear and bending forces. Many engineers therefore resort to force determination via a computerized approach. Some limit their work to two-dimensional behavior of a single truss while others develop elaborate three-dimensional models of the entire structure. This approach is fine, provided the engineer does not lose sight of the forest for the trees. Many, if not most, covered bridge trusses can be adequately analyzed by hand quite readily. One must always keep in mind that the strength of timber structures is almost invariably controlled by the joints and method of splicing elements. A good understanding of basic statics goes a long way in analyzing timber trusses.

For those covered bridges supported by combination truss/arches (think Burr Arch – multiple kingpost truss with superimposed arch), the most difficult part of the analysis is convincing oneself which part (truss vs arch) supports what portion of the various loads. This conundrum has confounded every engineer tasked with evaluation of these combination structures. The most important part is to properly recognize the strength or weakness of the connections between the two vertical structures as well as the relative stiffness of them. This is one type of timber structure that truly warrants careful modeling in modern computer software, yet the results can at best only bracket the results. There are few articles about the analysis of specific truss/arch covered bridges. This writer is unaware of consensus among engineers involved in this work about general conclusions.

Taftsville Covered Bridge – rehab underway post Irene damage. A pair of the largest supplemental timber arches known to this author!

The force determination for the bracing elements deals with similar issues of eccentric joints and importance of connections. No further elaboration of bracing system forces will be provided herein.

Calculated Stresses

Given forces, the next step is determination of stresses. Axial stresses along the length of primary members are easily calculated based on gross or net sections, as appropriate for compressive or tensile forces. Flexural and shear stresses can also be calculated from relevant section properties.

Allowable Stresses

Early timber design specifications contained tables of stresses for various species and grade of wood, reduced by a factor of safety. The most widely adopted and cited tabulations of allowable stresses (commonly referred to as "Reference Design Values") are now provided in the National Design Specification for Wood Construction (NDS),[9] promulgated and issued by the American Wood Council, most recently in the 2012 edition. AASHTO's Standard Specifications for Highway Bridges, 17th Edition, provides an abbreviated tabulation of stresses for the most commonly used timber species and grade, based on the NDS values which were current at that time. AASHTO also provided a few guidance values for those features unique to bridges, since NDS is primarily aimed at timber buildings. Inasmuch as NDS specifications continue to be updated periodically, many engineers base their analysis on NDS tables rather than holding to the AASHTO tabulations which are no longer being updated, following AASHTO's adoption of LRFD specifications. (Incidentally, the LRFD specifications remain based on the reference design values of NDS.)

Analytical Results

The final step in the analytical evaluation is comparing calculated stresses to allowable stresses for the various group loading combinations with appropriate adjustments for load duration factor, moisture content, etc. In short, this procedure includes determination of the capacity of elements of the bridge (e.g. the compression capacity of the top chord) from which the force caused by the self-weight (dead load) of the bridge is subtracted leaving the remaining capacity available for live load. Comparing the remaining capacity to that of the design live load force allows determination of an allowable live load for passage across the bridge. More often than not, the allowable live determined by this analysis indicates that live load restrictions are necessary.

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[9] AWC, ASD/LRFD 2012 National Design Specification for Wood Construction with Commentary, American Wood Council, Leesburg, VA

The Timber Framing article cited earlier ("Reflections on Load Capacity of Historic Covered Bridges", September 2013) (see Footnote 3) provides this author's ideas on next steps. Specifically, a more refined determination of load duration factor may be appropriate. And reconsideration of the 5% exclusion value may be appropriate.

It cannot be overstated that strengthening or member replacement should be the last resort.

Load Testing

The potential use of load testing of a covered bridge as an analytical tool is controversial. The following text is lifted from the Sept 2013 TFG article (see Footnote 3):

> "Strain gages are commonly used to measure deflection or other movement of metal elements and sometimes concrete. Can we use strain gages on timber? Hidden defects of larger bridge elements probably obviate strain measurements as indicative of actual stress. How do I know that I am measuring a legitimate "average" stress in an element, or even a realistic maximum stress? And what about the connections?
>
> If we measure strains in an element and predict a capacity, can we say with any certainty that the joints have a similar or higher factor of safety? I think not. What we can do with strain measurements is to compare relative load sharing. For instance, the distribution of forces around a termination of a chord element of a Town Lattice truss can be evaluated by strains with some degree of confidence.
>
> What about deflection measurements? Flexural elements can be tested with some degree of confidence based on deflection, but what about trusses, almost invariably the structural heart of a historic covered bridge? Deflections of timber trusses are extremely small and the required accuracy of measurement makes reliance on the method very suspect also."

Accordingly, if load testing is proposed or used as part of, or in place of, an analytical evaluation, review the results very carefully.

Rehabilitation of Historic Covered Bridges

Historic Issues

As noted at the beginning of this bulletin regarding "historic" covered bridges, these bridges are subject to rules and regulations due to their age and unique characteristics. Virtually all covered bridges in the United States are listed on, or eligible for listing on, the National Register of Historic Places maintained by the National Park Service. Such designation raises restrictions on what can be done with the bridge if federal or state funds are used for its rehabilitation. The federal funds trigger involvement with the historic preservation office of the state within which the bridge is located.

The National Historic Preservation Act of 1966 authorized the Secretary of the Interior to prepare and adopt "Standards for the Treatment of Historic Properties", often cited as the *"Secretary's Standards"*. The standards identify four types of treatment actions – preservation, rehabilitation, restoration, and reconstruction. The nuances may seem slight to some, but it is important to understand that almost all work performed on covered bridges falls under the category of "rehabilitation." In most cases, expenditure of funds on covered bridges is intended to preserve its ability to support vehicles or pedestrians. Rehabilitation emphasizes the retention and repair of historic materials, but more latitude is provided for replacement of elements because it is assumed the structure is more deteriorated prior to work. Rehabilitation standards focus attention on the preservation of those materials, features, geometry, and structural behavior or system that, together, give the structure its historic character.

Each state has its own experience with covered bridges (there is at least one historic covered bridge in 30+ states) and that leads to somewhat different restrictions and interpretations of rules and regulations. Just because one type of rehabilitation action is condoned or approved in one state does not mean that it will necessarily be approved in another state.

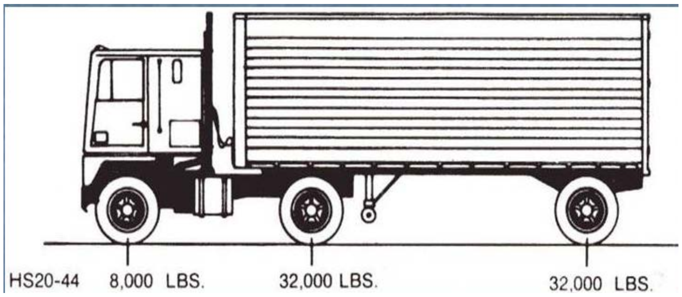
Public Involvement

In general, it is fair to state that there would be no remaining covered bridges if it was not for the support of them by the public. Any proposed work on a particular bridge will likely spark instant interest and potential concern by the public. Therefore, a public involvement program should start early – do not attempt to exclude or ignore public input.

Technical Issues

There are a host of technical issues that must be addressed during a proposed rehabilitation project. In no particular order, they include:

1. *Selection of "design" vehicle.* It is important that the design vehicle be appropriate for an extant covered bridge. The design vehicle should be as light weight as possible to minimize the potential need for replacement or strengthening of existing elements. Many rehabilitation projects have been based on two-axle vehicles having weights of three to eight tons.



Now is this what really ought to be allowed to cross an historic covered bridge???

2. *Floor element replacement*. The floors of most historic covered bridges have been replaced at least once during the life of the bridge. Therefore, there is more tolerance to condone replacement floors having larger dimension elements, or elements of stronger species. Glue-laminated timber elements are often tolerated as replacement components. It is noted that some prefer to retain or provide a floor system which is weaker than the supporting trusses so that failure of the floor would occur before failure of the trusses. This author is not a supporter of such thinking, because the position presupposes that the capacity of the supporting trusses can be calculated with the same degree of confidence as the capacity of the floor. Calculation of floor capacity is substantially more easily assessed than that of the truss.

3. *Truss or arch element rehabilitation*. The preferred approach is to replace damaged, deteriorated, or otherwise weak elements in-kind using connections that match the original construction. Non-wood elements are not preferred, but are occasionally required. The connections of non-wood elements into the fabric of the original wooden bridge should be carefully planned to avoid unnecessary damage to original material. Additionally, dissimilar materials can lead to internal moisture condensation that can lead to premature deterioration of wood, hidden from view.

In-kind replacement posts – Hamden Covered Bridge, Delaware County, NY =>

4. *Bracing improvements.* Few covered bridges were built with robust bracing systems and racking of the superstructure is a common deficiency. Often bracing elements must be replaced due to damaged or broken end connections. The development of historically tolerable details for repairing or improving bracing systems is challenging.

5. *Railing improvements*. Modern bridges are built with protective railing systems along the bridge to prevent errant vehicle impact to above deck components (think through steel trusses). However, most covered bridges did not have a robust bridge railing system. It was often limited to light timbers connected directly to the sides of the trusses. Some believe it is necessary to install an independent bridge rail system during a rehabilitation project, in keeping with this practice on rehabilitation of modern structures. However, most covered bridge rehabilitation projects are completed without much improvement of the bridge railing. A common compromise is to install a relatively shallow curb timber that is attached to the floor system and intended to guide tires, rather than to guide the frame of the vehicle. Such a timber also has the structural advantage in that it forces the vehicles to travel along the center of the bridge thereby equalizing the load to the supporting trusses.

   Similarly, modern bridges are built with approach railing that connects directly to the bridge railing and extends along the approach to the bridge to prevent errant vehicles from leaving the travel way prior to entering the bridge. Covered bridges have a mish-mash of approach railing types from none to quite robust. Few are connected directly to the bridge. Rehabilitation projects usually include improvements to the approach railing system inasmuch as it is considered an important improvement to public safety without unduly affecting the historic characteristics of the bridge proper. Many are constructed of timber (solid sawn or glulam) or steel railing. A few use more expensive composite timber/steel systems.

6. *Siding and Roofing.* When a covered bridge requires rehabilitation, the siding and roofing usually have to be removed to allow work on the trusses or truss/arches. The existing siding might be original to the bridge, but more commonly it has been replaced at least once during the life of the bridge. Historic considerations normally drive the need to replace siding in-kind, when necessary, including paint to match appearance at the time of the rehabilitation. Sometimes, the contractor is required to carefully remove existing siding and reinstall it on at least one of the sides of the rehabilitated structure. When the siding is completely replaced, it is often possible to improve the connection of it to the trusses by inclusion of spacer pieces to improve ventilation and separate siding

from main elements. Wood in contact can retain moisture and cause premature deterioration. Portal geometry is usually retained. Windows or openings along the sides are usually retained to match existing appearances. And those bridges with inside siding at their ends are also typically redone with similar coverings.

While the existing siding might be original to the bridge, the roofing has almost always been replaced previously. Inasmuch as the recent material is probably not the original, there is less historical pressure to duplicate it, hence use of the material with the longest expected service life may also offer the best benefit to cost ratio. Further, as an engineer, the author recommends that roofing material in geographic areas prone to snow be metal which tends to shed snow faster than other types of roofing material, thereby reducing loads on the bridge.

7. *Miscellaneous improvements*. The two most important miscellaneous improvements involve drainage and ventilation. The area most prone to premature deterioration is at the abutment supports where dirt and debris may be in direct contact with critical structural elements of the trusses or arches. Installation of trench drains at the entrance of the bridge can route storm drainage away from the bridge and minimize the flow of approach drainage into the bridge. If the project allows adjustment of the bearing areas, raising the bearing areas with respect to the seat can provide less risk of moisture laden debris from direct contact with primary structural elements. The bearing area improvements also facilitate better ventilation around this critical area of the bridge. As mentioned above, replacement of the siding may afford an opportunity to improve the connection of the siding to the truss. Also, in some instances the top of the siding may be stopped a bit shorter than previously to allow more air flow under the eaves of the bridge. And extending the siding at least to the bottom of the truss or arch elements is recommended if it had not been previously. Details around windows can often be improved to better protect primary members from direct contact by wind-blown rain.

8. *Materials*. Repair or replacement of deteriorated primary elements is commonly performed with solid-sawn Southern Pine or Douglas Fir. Glulam elements are often substituted for replacement floorbeams to gain additional capacity while maintaining similar size. In more rare instances, glulam elements are used for replacement primary members.

9. *Protection.* There are several forms of protection systems that may be incorporated into a rehabilitation project. New timber material may be preservative treated, especially floor members. New metal material should be galvanized (especially important for connectors

in contact with preservative treated timber elements). Field applied fire retardant, insecticide and fungicide coatings are common. Action to improve protection against flood damage may include installation of hold-down devices. Perhaps one of the most insidious risks to covered bridges is vandalism – arson being the most prominent. Fire protection systems may include various forms of fire detection and arresting systems.

Construction Issues

Just as all design work on covered bridges should be performed only by engineers having experience with them, only contractors with a proven track record with the type of work included in the project should be selected for the rehabilitation construction. This is especially true of the type of timber connections and joinery that is involved. There are too many examples of contractors selected only on the basis of low cost that have caused unintended damage to the structure. Accordingly, it is common that bidding contractors must be pre-qualified or provide experience for evaluation with the bid.

Further, the unusual nature of this type of work warrants field observation by qualified personnel – preferably the design engineer. Work on covered bridges invariably encounters unexpected conditions and rehabilitation or repair details must be modified as necessary.

While contractors have responsibility for means and methods of conducting their work, the most important issue involves relocation or support of the bridge during its rehabilitation. In this instance, the design engineer should be directly involved in reviewing the proposed details to prevent unanticipated damage.

Replica Covered Bridges

There are different types of replica covered bridges. Those deemed most authentic and true to the designation of a covered bridge are built of timber with connections that utilize joinery typical of the type of truss or truss/arch being built. Many such structures have been built during the past several decades.

Some covered bridges have incorporated more use of glu-laminated timber elements in trusses or arches. There are also bridges that have incorporated metal plate components into the connections – some would argue that these last do not represent “authentic” covered bridges. One of the advantages of these last two types of bridges is that they can have substantially more capacity for longer spans or wider roadways.

References

[1] FHWA, 2005, Covered Bridge Manual - HRT-04-098, Federal Highway Administration, Washington, DC

[2] Pierce, P. C. 2013, Reflections on Load Capacity of Historic Covered Bridges, *Timber Framing*, Journal of the Timber Framers Guild, v 109, pp.20-24, Sept

[3] AASHTO, 2002, Standard Specifications for Highway Bridges, 17th Edition, American Association of State Highway and Transportation Officials, Washington, DC

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[6] AASHTO, 2009, LRFD Guide Specifications for the Design of Pedestrian Bridges, 2nd Edition, American Association of State Highway and Transportation Officials, Washington, DC

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