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Covered Bridges: Modern-day Engineers Cross into Historic Bridge Design

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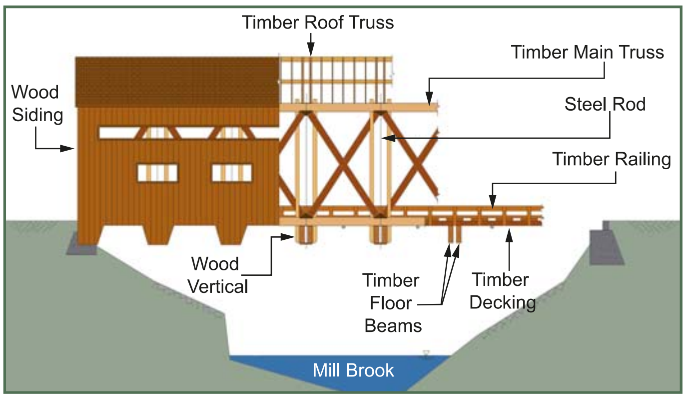
Covered timber bridges have been a part of the Massachusetts landscape since the early 1800s, but with just nine remaining in the state today, the Massachusetts Highway Department (MHD) initiated an effort to preserve some of New England's historic structures. Working with MHD, HDR is responsible for designing the reconstruction or rehabilitation plans for three of these important landmarks.



The graphic shows the main elements of Bissell Bridge near Charlemton, Mass., a modern 19th century covered bridge.

One of the biggest challenges that engineers faced on this project was gaining an understanding of the principles, behavior and unique connection details of the timber-framed Howe truss. Patented in 1840 by William Howe of Massachusetts, the Howe truss became known for its ability to carry heavy loads by using timber diagonals in compression. Before designing the first bridge in this three-part project, the Bissell Bridge near Charlemont, Mass., the team researched historical texts and visited some of the few remaining Howe trusses in New England. The research provided sample details and design assumptions, and the site visits gave insight into the long-term performance of various details.

Case Study – Bissell Bridge

The Town of Charlemont and MHD collaborated on a decision to model a replacement for the Bissell Bridge after a 19th century Howe truss. The existing Bissell Bridge, built in 1951, is a two-lane, 92' single-span covered bridge with a height of 27' and an original design live load rating of HS-15. The new covered bridge will maintain the span length and horizontal alignment while re-using the existing abutments, but will feature two modern 12' lanes, a vertical clearance of 16'6" (current clearance is 14') and HS-20 design live load.

In designing the new bridge with authentic 19th century timber Howe truss framing, the behavior and detailing of this classic structural system had to be researched and understood. Following are some of the basic elements of the Howe truss as applied to the Bissell Bridge:

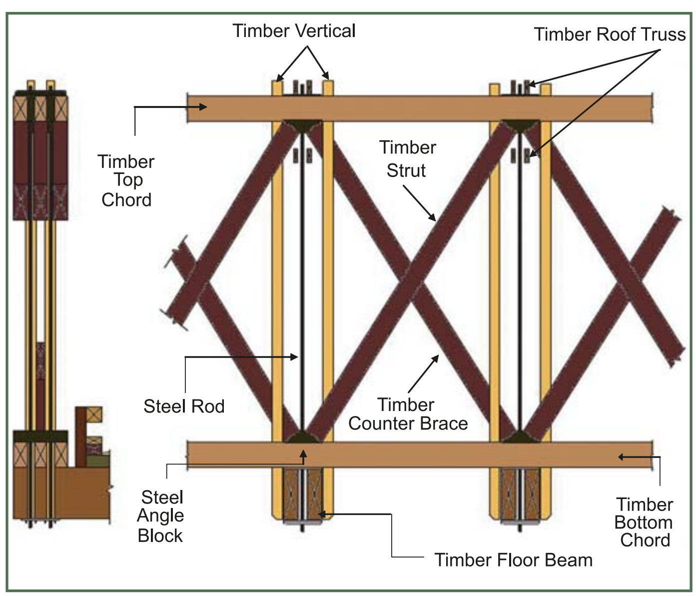
- Top and bottom chords were made of continuous-length timber pieces to avoid the need for splicing. Fabricated glue-laminated timbers were used for the Bissell Bridge to achieve the approximate 92' length.

- Main timber diagonal members, called struts, were oriented to carry primary panel shear in compression and were made of sawn timber.

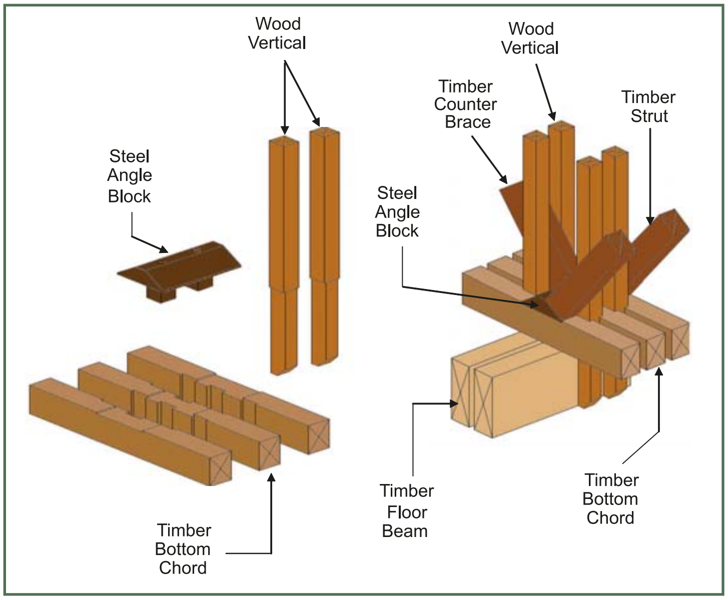
- Counter compression diagonals, called counter-braces, were used in center panels to carry the reverse panel shear due to moving live load. Counter-braces were typically not needed in end panels where there is no shear reversal. However, they often were still provided in all panels to stiffen the structure, thereby mitigating the vibrations caused by moving live load. Counter-braces were used in all panels of the Bissell Bridge.

- Timber verticals, struts and counter-braces transfer load to the chords at panel points through end bearing only. There was no use of bolts to positively connect these members to the chords as in traditional bolted type truss connections. The connections function in bearing only and have zero tensile capacity.

- Timber struts and counter-braces were square-ended to bear against the inclined faces of an angle block, which typically was made of oak or cast iron in original designs but was made up of welded plates for the Bissell Bridge.



The Howe truss became known for its ability to carry heavy loads by using timber diagonals in compression.



Timber struts and counter braces transfer loads to chords at panel points through end bearing on steel angle blocks.

These angle blocks were designed to transfer load – both vertical and horizontal components – from the diagonals to the chords. Vertical loads are transferred in bearing on the chords through a base plate. In addition, each angle block has two pintels, or tubes, which fit into recesses in the side faces of the chords. These pintels transfer the horizontal thrust from the diagonal web members.

- Because of the end-bearing type connections of verticals, struts and counter-braces at panel points, iron rods originally were used to pre-compress the joints and to keep the counter-braces in bearing when not carrying any panel shear. These vertical rods ran from the top of the top chord to the underside of the bottom chord and had threaded ends with bearing plates and nuts.

- Truss verticals and chord members were cut and notched so that the verticals could socket into the chords.

Design of the counter-braces and the vertical pre-stressing rods became an interesting part of the project. During the course of conducting field research for the Bissell Bridge design, the project team consistently observed covered bridges in which counter-braces were no longer bearing against the top angle blocks. The counter-braces also had shifted up the inclined faces of the lower angle blocks, seemingly indicating a cyclic loading and unloading.

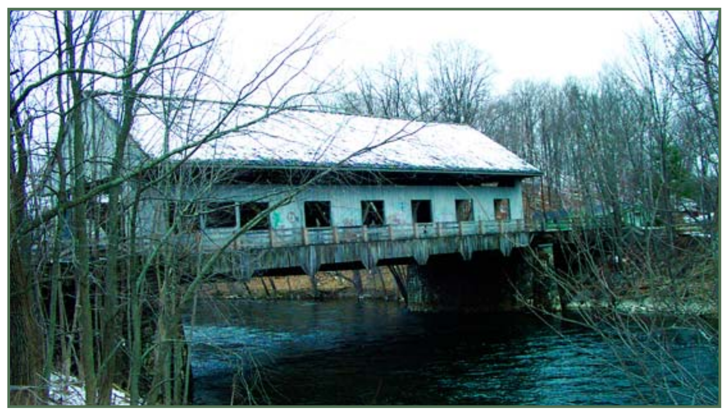
Having observed failed counter-braces in other Howe trusses, the team developed a procedure to minimize the likelihood of this occurrence. The struts are placed in a diagonal configuration that results in primary compression, but the counter-braces are positioned to have primary tension. Because there is no positive connection between the counter-braces and the angle block, the counter-braces would tend to separate from the angle block under primary load. This tendency to separate from the angle block can be overcome by providing sufficient pre-compression to cause the counter-brace to remain in compression under maximum unloading. Once the load is removed, the counter-brace returns to the pre-compressive stress level. This pre-compression is accomplished by post-tensioning the vertical rods at each panel point.

Design plans for the Bissell replacement timber bridge have been completed, and construction currently awaits final agreement between MHD and the Town of Charlemont.

Waterous & Pumping Station Bridges

The Chester H. Waterous Covered Bridge in Pepperell is the only covered bridge in Massachusetts still open to vehicular traffic. It is a three-span structure with two short approach spans and a 105’ Pratt timber truss main span. It features two-directional travel inside and two sidewalks on the outside. The Waterous Bridge dates back to 1848, but the current configuration was constructed in 1963 after the original had deteriorated to the point it could only support its own weight. Currently posted for 6 tons, the bridge is heavily used due to its central location. The timber trusses have some cracks, checks and chips of varying degrees in most of the members, and, in some cases, there are cracks extending through bolted connections. A type study report (25 percent plans) has since been submitted, in which the existing Pratt truss main span configuration will be replaced with a Howe truss, similar to the Bissell Bridge, per MHD’s request.

The Pumping Station Covered Bridge in Greenfield, Mass., is a timber Howe truss structure with a single span of 91’3”. It was built in 1972 to replace an 1870 structure that was destroyed by fire in 1969. Though not a designated historic structure, project stakeholders wanted to retain the site’s tradition of a covered bridge. This bridge is currently closed to vehicular traffic due to failure of a controlling element of the truss structure – a steel plate-and-angle assembly that anchors the vertical steel rods to the top and bottom timber truss chords. Rehabilitation likely will include replacing the steel plate-and-angle assemblies; the vertical, top and bottom truss steel rods; the abutments, which are in poor condition; and the footings, which show significant signs of scour (erosion of the footing area caused by water flow).



The Chester H. Waterous covered bridge in Pepperell is the only covered bridge in Massachusetts still open to vehicular traffic.

Summary

Covered timber bridge design presents unique design challenges compared with today’s modern bridge design. Codes and loading scenarios that would factor into the design of a typical bridge have to be adjusted for a timber covered bridge. Because revitalization of timber covered bridges appears to be a growing trend, the engineers of today will continue to be challenged to apply their knowledge of complex contemporary design principles to the functionality of these historic structures.

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