Cornish-Windsor Covered Bridge
Cornish
Sullivan County
New Hampshire

HAER No. NH-8

HAER
NH,
10-CORN,
2-

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Department of the Interior
Washington, D. C. 20240

HISTORIC AMERICAN ENGINEERING RECORD

Cornish-Windsor Covered Bridge

HAER No. NH-8

Location:	Across Connecticut River between Cornish, New Hampshire and Windsor, Vermont Sullivan County, New Hampshire
Date of Construction:	1866
Engineers/Builders:	James F. Tasker and Bela J. Fletcher
Owner:	New Hampshire Department of Highways and Public Works
Significance:	Comprised of two spans measuring 203 feet and 204 feet in length, this bridge is an excellent example of the Town Lattice Truss. It is also among the longest covered wooden bridge still surviving in the United States.
Transmitted by:	Donald C. Jackson and Jean P. Yearby, HAER, 1985

ADDENDUM TO
CORNISH-WINDSOR COVERED BRIDGE
Across Connecticut River between
Cornish, New Hampshire and Windsor, Vermont
Cornish
Sullivan County
New Hampshire

HAER No. NH-8

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ADDENDUM TO:
CORNISH-WINDSOR COVERED BRIDGE
(Cornish Bridge)
Spanning Connecticut River between Cornish, NH, & Windsor, VT
Cornish City
Sullivan County
New Hampshire

HAER NH-8
NH,10-CORN,2-

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

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HISTORIC AMERICAN ENGINEERING RECORD

ADDENDUM TO
CORNISH-WINDSOR COVERED BRIDGE
(Cornish Bridge)
HAER No. NH-8

This report is an addendum to a one-page report previously transmitted to the Library of Congress.

LOCATION: Spanning Connecticut River between Cornish, New Hampshire and Windsor, Vermont, Cornish City, Sullivan County, New Hampshire
UTM: 18.711572E.4781676N, Mt. Ascutney, VT, Quadrangle

STRUCTURAL TYPE: Wood covered bridge, Town lattice truss

DATE OF CONSTRUCTION: 1866; rehabilitated 1988

DESIGNER/ BUILDER: James F. Tasker and Bela J. Fletcher

PRESENT OWNER: State of New Hampshire

PREVIOUS USE: Vehicular bridge

PRESENT USE: Vehicular bridge

SIGNIFICANCE: The Cornish-Windsor Bridge is the longest covered bridge in the U.S. and the second-longest two-span covered bridge in the world. It is an excellent example of the work of James Tasker and Bela Fletcher, two prolific New England bridge builders.

AUTHORS: Lola Bennett, Historian, August 2003
Dorottya Makay, Engineering Technician, with Justin M. Spivey, August 2003

PROJECT INFORMATION: The National Covered Bridges Recording Project is part of the Historic American Engineering Record (HAER), a long-range program to document historically significant engineering and industrial works in the United States. HAER is administered by the Historic American Buildings Survey/Historic American Engineering Record, a division of the National

Park Service, U.S. Department of the Interior. The Federal Highway Administration funded the project.

Chronology

1784 Jonathan Chase establishes a ferry at this site.

1796 First toll bridge built at this site reportedly by Timothy Palmer and Moody Spofford.

1824 First bridge destroyed by a flood.

1824 Second bridge built at this site.

1849 Second bridge destroyed by a flood.

1850 Third bridge built at this site by Col. Edward Brown.

1866 Third bridge carried away in an ice floe.

1866 Fourth (present) bridge built at this site by James Tasker and Bela Fletcher.

1884 Roof re-shingled.

1887 James Tasker makes extensive repairs on the bridge.

1892 New flooring laid.

1908 Engineer John Storrs inspects the bridge and finds it overstressed. He stated in his report that the bridge sagged, the trusses were out of alignment and the bottom chords could not support more than their own weight. Storrs recommended adding arches, reinforcing the bottom chord, or adding two more piers.

1921 East abutment faced with concrete after settlement is discovered.

1924 Original wood shingle roof replaced with corrugated steel.

1936 Toll company bought out by the State of New Hampshire ($20,000) and the State of Vermont ($2,000).

1943 Cornish Bridge made free.

1954 Cornish Bridge closed for six months for major repairs, including replacing the floor beams and patching the chords with steel plates.

1970 Cornish Bridge designated a National Historic Civil Engineering Landmark (ASCE).

1976 Cornish Bridge listed on the National Register of Historic Places.

1977 Ice breaks timbers in bottom chord, floorboards and siding on east side.

1984 New Hampshire Department of Transportation (NHDOT) announces it will repair the bridge with steel; David W. Wright, President of the National Society for the Preservation of Covered Bridges (NSPCB), lobbies for authentic restoration of the historic structure.

1986 2,500 cars use Cornish Bridge daily. Andrews & Clark Consulting Engineers inspect the bridge and recommend reducing the load limit and strengthening the bridge by adding arches or trusses.

1987 David C. Fischetti completes five reports of lattice truss analysis and structural evaluation for the National Society for the Preservation of Covered Bridges. This is a response by the NSPCB to the 1986 Andrews & Clark report.

1987 State of New Hampshire appropriates $1.5 million for bridge repairs. Department of Transportation lowers load limit to 3 tons. Bridge closed to traffic following a second inspection.

1988 David C. Fischetti presents a report entitled "Glulam Chord Replacement Alternative," which was immediately endorsed by NHDOT as a workable (acceptable) solution.

1988 Rehabilitation by Chesterfield Associates of Westhampton, New York, with David C. Fischetti, consulting engineer and Jan Lewandoski, timber framer.

1989 Cornish Bridge reopens to traffic.

1990 Cornish Bridge designated a New Hampshire Historic Civil Engineering Landmark (NH DOT).

Description
The Cornish-Windsor Bridge is a two-span Town lattice truss covered bridge on a mortared stone pier and abutments.[1] The total length of the bridge at the floor is 450', with clear span lengths of 204'-0" and 203'-0". The truss is 17'-0" high from the top of the upper chord to the bottom of the lower chord, 21'-0" wide overall, with a roadway width of 19'-4".

The trusses are framed in the manner patented by Ithiel Town in 1820 and 1835. Although most Town lattice bridges were built with planks (typically 3" thick and 10" to 12" wide) fastened together with treenails, in this case the lattice members are squared timbers and the connections are notched and bolted. This is unusual among the surviving population of Town lattice trusses in the United States.[2] The upper chord is paired timbers, each composed of one 3"x10" plank and one 5"x10" timber with shear blocks between them. Paired 8"x10" glue-laminated timbers replaced portions of the lower chord (originally the same as the upper chord) in 1988. There are secondary chords above the lower chord and below the upper chord, as patented by Town in 1835. The chords sandwich a lattice web that is three diamonds high and fastened at each intersection with a 7/8" diameter bolt. The lattice is composed of 6"x8" timbers, notched together (1¼" notches) and bolted with 5/8" diameter bolts, rather than the conventional treenail connection used for plank lattice trusses. There is 6"x8" timber blocking over the pier to carry the vertical loads from the chords to the pier.

The upper lateral system consists of 8"x10" tie beams on top of the upper chord, spaced 2½ diamonds apart. The 1988 rehabilitation doubled the number of tie beams. There are 4"x5" diagonal lateral braces between every other tie and 4"x6" sway braces between the lattice web and tie beams. Rafters measuring approximately 2"x8" frame onto the upper chord and support a series of 1"x4" nailers, spaced 1' apart, to which the metal roof is fastened.

The lower chords of the bridge rest on large bed timbers on top of the abutment facewalls. Glue-laminated timber bolster beams 11"x35" have been cantilevered 13' from the abutments and pier to reduce the clear spans of the trusses. Transverse 6 ¾"x17 7/8" glue-laminated floor beams rest on top of lower chord; these replaced previous 4"x16" timber floor beams in 1988. There are no stringers. The timber deck is nailed on top of the floor beams.

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[1] The structure's official and common name is Cornish Bridge, but today it is more commonly known as the Cornish-Windsor Bridge (for those living in New Hampshire) or Windsor-Cornish Bridge (for those living in Vermont). Newspaper accounts from 1866 variously refer to it as Windsor toll bridge, Cornish toll bridge, the bridge at Windsor or Cornish Bride. The hyphenated names came into usage more recently.

[2] In his 1938 travelogue, Crossing and Re-crossing the Connecticut River, p.89, Charles Whittlesey noted: "This may be a modification of the Towne [sic] lattice truss, for I noticed that the members of the truss at intersections were let into each other about one third and pinned by an iron bolt with washers. I have supposed that in the Ithiel Towne truss the members simply crossed each other, and were held by two or more wooden pins at each intersection." According to covered bridge historian Joseph Conwill, notched timber lattice bridges were never widespread. Plank lattice bridges were commonly built in the north and south, but timber lattice bridges were a regional style centered mainly in the upper Connecticut Valley. This is the only surviving example.

Shiplap pine siding to the eaves covers the exterior of the bridge; in 1988 this replaced flush-board siding that had previously covered the bridge.[3] The sheathing is fastened to nailers on the outer faces of the lattice webs. There are eighteen 2'x3' hooded windows on each side of the bridge. The portals have elliptical arched openings and white clapboard pediments corbelled over the approaches.

Connecticut River Covered Bridges

At 410 miles long, the Connecticut River is the longest river in New England. Its west bank forms the boundary between New Hampshire and Vermont. Although the river was used for navigation at an early date, and many ferries crossed it in the eighteenth century, it was not bridged until 1785 when Col. Enoch Hale erected the first framed timber bridge in America across the river at Bellows Falls. By the mid-nineteenth century, there were at least two dozen spans. Most of these were originally toll bridges and most were covered. According to covered bridge authority Richard Sanders Allen, at one time there were thirty-five covered highway and railroad bridges across the Connecticut River between Vermont and New Hampshire, but as of 1957, only four of these covered bridges remained.[4] Today, there are three: located at Lemington (1912), Lunenburg (1911) and Cornish (1866).[5] The Cornish Bridge is the longest covered bridge in the United States and the second longest two-span covered bridge in the world.[6]

Cornish Bridge History[7]

In 1784 the New Hampshire General Court authorized Jonathan Chase of Cornish to establish a ferry across the Connecticut River between Cornish and Windsor. Chase operated the ferry for eight years, and in 1792, petitioned the Court "for liberty to build a toll bridge over a certain part of Connecticut River at his ferry place at said Cornish." The New Hampshire House of Representatives passed an act allowing Chase to build such a bridge on January 14, 1795. A toll bridge was constructed at, or near, this site in 1796 at a cost of $20,000. The builders of that bridge were reportedly Spofford and Boynton.[8] According to written accounts, the first Cornish Bridge was a 521', uncovered timber structure with massive arches, similar in appearance to the Haverhill Bridge over the Merrimack River.[9] In 1797, John Andrew Graham, published the following description of the Cornish Bridge:

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[3] Historic photos show that the bridge siding did not always extend to the eaves and that there have been various numbers of window openings throughout its history.

[4] Richard Sanders Allen, Covered Bridges of the Northeast (Brattleboro, VT: Stephen Greene Press, 1957), p.43.

[5] Joseph Nelson, Spanning Time: Vermont's Covered Bridges (Shelburne, Vermont: The New England Press, 1997), p.93.

[6] According to the National Society for the Preservation of Covered Bridge's World Guide to Covered Bridges, the Hartland Bridge (1899) spanning the St. John River in New Brunswick Province, Canada, (1,282', seven spans) is the longest covered bridge in the world. A 600', 4-span covered bridge is presently being constructed in Ashtabula County Ohio.

[7] For a more extensive history of the Cornish Bridge see New Hampshire Department of Public Works and Highways, A History of the Proprietors of Cornish Bridge and the Cornish, NH-Windsor, VT Covered Toll Bridge (1796-1943).

[8] The Rising Sun (Keene, New Hampshire), November 8, 1796. Moody Spofford was a well-known architect who was associated with Timothy Palmer (1751-1821), a housewright from Newburyport, Massachusetts. In 1792 Palmer—reportedly with the help of Spofford—built America's first long-span arched truss bridge across the Merrimack River. Palmer subsequently took out a patent for an arched truss bridge and built several other long span bridges, including bridges at Andover (1793), Haverhill (1794), Portsmouth (1794), and Philadelphia (1805).

[9] In 1821, Yale University president described the Haverhill Bridge as follows: "Haverhill bridge is a noble structure of wood consisting of three triple framed arches. There are two passages over the bridge; each 15 ½ feet in the clear…No bridge, which I

> In the last week of October 1796, was completed a bridge between Cornish, (New Hampshire), and this town, which is five hundred and twenty one feet, from one abutment to the other, and thirty four feet wide. With a sublime boldness its arms embrace the subjugated flood that rolls beneath; there are two arches, each one hundred and thirty four feet and four inches in length, with a pier in the center forty six feet one way, by forty one the other. …This bridge is universally allowed to be the best and most perfect in America: and it is the first of the kind thrown across Connecticut River.[10]

There was a toll gate on the Windsor side of the bridge and a toll house at 45 Bridge Street. Rates of toll were initially established as follows:

Foot Passengers	2 cents
Horse & rider	6¼ cents
Each horse & chaise, chair or sulky	12½ cents
Each Coach, Phaeton Chariot or other four wheel carriage for passengers	30 cents
Each cart or other wheel carriage of burden drawn by one beast	8 cents
Each cart or other wheel carriage of burden drawn by two beasts	15 cents
Each cart or other wheel carriage of burden drawn by three beasts	20 cents
Each cart or other wheel carriage of burden drawn by four beasts	25 cents
For every additional beasts above four	4 cents
Sleigh drawn by one beast	8 cents
Sleigh drawn by more than one beast	12½ cents
Each horse, jack or mule, exclusive of those rode on	3 cents
Each neat creature not belonging to a team	2 cents
Each sheep or swine	1/2 cent

The high cost of construction caused the proprietors to post higher toll rates almost immediately. The venture paid off and during the first five years tolls brought in $7,171. After maintenance costs were subtracted, the proprietors realized a gross profit of $5,879. Records of the toll keepers are in the collection of the New Hampshire Historical Society at Concord. In the decade following the Revolutionary War private companies build most of the bridges and turnpikes. According to Richard Dana's 1926 study, The Bridge at Windsor, Vermont and Its Economic Implications,

> This enterprise, which involved an investment at that time of nearly twenty thousand dollars, comparable with about a quarter of a million dollars today, was undertaken with the immediate purpose of expediting traffic between both sides

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have seen, except that over the Picataqua, can be compared with this as a fine object to the eye. The length is 864'. The arches above and below have a degree of boldness of grandeur, unrivaled in this country." [Timothy Dwight, Travels in New England and New York (New Haven, Connecticut: author, 1821), p.69.]

[10] John Andrew Graham, A Descriptive Sketch of the Present State of Vermont, One of the United States of America (London: Henry Fry, 1797), p.x. The first bridge across the Connecticut River was Enoch Hale's timber frame bridge at Bellows Falls; the Cornish Bridge, however, was of a much more permanent character, with arched trusses and stone piers. In this regard, Cornish Bridge is one of the earliest long-span bridges in America.

> of the river and was financed largely by the men of affairs of the flourishing town to whose business this traffic necessarily contributed a considerable share. It was essentially a hazardous undertaking because of the lack of data by which the earnings could safely be computed and because, as the event showed, the rises from heavy rains and freshets to which the Connecticut river was susceptible made very precarious the tenure in situ of any such structure. This was not the first of the old toll bridges, but it was one of the earliest.[11]

On February 16, 1824, a spring freshet destroyed the first Cornish Bridge. Ferry service was reinstated while a new one was built. The second bridge was a four-span covered timber pony truss that lasted until 1849, when "high water and the breaking up of an unusual quantity of ice in the Connecticut river" destroyed it.[12] The third bridge at this site was a two-span covered wooden Town lattice truss built in 1850. Edward Brown reportedly built that structure.[13] In February 1866, an ice floe lifted the bridge off its abutments and carried it downstream. The local newspaper reported:

> The River below Windsor was so dammed by ice as to raise the stream opposite that place some 30 feet. About 4 o'clock Sunday morning the ice formed an embankment against the north side of the Windsor toll bridge by which it was moved bodily from its supports—and, wheeling around, it passed endwise about one third of a mile downstream, till it came in contact with the Sullivan Rail Road Bridge, which maintained but a feeble resistance to its course—about three quarters of it parting from its moorings, and proceeding down stream with its companion. It appears they soon parted company, however—most of the toll bridge lodging, in separate parcels, on the Islands and shores along the river.[14]

Cornish Bridge Construction

The proprietors of the Cornish Bridge pressed the ferry back into service and began to make plans to rebuild the toll bridge; however, some local residents saw this as an opportunity to promote the idea of a free bridge, and some went so far as to threaten to burn down the new toll bridge if it was built.[15] The Vermont Journal published a lengthy editorial on the subject, stating that the proprietors felt it "their duty to the public…to rebuild without unnecessary delay":

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[11] Richard T. Dana, The Bridge at Windsor, Vermont and Its Economic Implications (New York: Codex Book Company, Inc., 1926), p.10.

[12] Edward Seager's 1848 pencil sketch of that bridge appears in New Hampshire Department of Public Works and Highways, "A History of the Proprietors of Cornish Bridge and the Cornish, NH-Windsor VT Covered Toll Bridge (1796-1943)" (Concord, New Hampshire, 1983), p.28. A painting of the Cornish Bridge appears on the cover of Jerold Wilkoff's book The Upper Valley: An Illustrated Tour Along the Connecticut River (1985). See also The Vermont Journal, March 23, 1849, p.3.

[13] Ed Barna says Tasker and Fletcher; however, a letter in the Cornish Bridge Papers at the New Hampshire Historical Society, dated March 6, 1866 to George E. Brown (Edward Brown's son) from Henry Warden (one of the proprietors) states that the proprietors wanted the same type of bridge as the previous one, and suggests that they were soliciting bids from the former builder's son, among others. The name Brown is confirmed in the provisions of the 1866 contract, as cited in Richard Dana, The Bridge at Windsor, p.25.

[14] The National Eagle [Claremont, NH], March 3, 1866. See also The Vermont Journal, March 3, 1866.

[15] A cryptic note contained in the Proprietors papers at the New Hampshire Historical Society said simply, "To the Bridge Company, Windsor. If you put a tole bridge on those old butments it shall be burnt as soon as convenient. We want a free bridge and will have it."

> We hear many expressions of regret on the part of our New Hampshire friends, whose business connections with Windsor are seriously interrupted in consequence of the loss of the Cornish Bridge. We hear many sober complainings from our neighbors in Windsor, on account of the loss of business from the same cause. We also hear frequent suggestions from citizens from both sides of the river in relation to the possibility of having a free bridge, all of which are quite natural, and to be expected. But there is another class of persons, who, thoughtless of the rights of others, ignorant of the relations which exist between the public and the bridge proprietors, and utterly regardless of anything and all things, except what may seem to be their own immediate convenience, are loud with their clamors; first, because the proprietors do not work miracles in navigation; and secondly because they do contemplate taking steps toward the restoration of a toll bridge.[16]

The proprietors solicited and received bids from a number of contractors, including Bela Fletcher, of Claremont, New Hampshire, who bid $23 per foot and won the contract. The bridge was reportedly framed in a meadow north of Bridge Street. The contract specified a bridge "to be constructed after the plan of and in all respects equal to the late one," but placed higher over the water, using spruce for timbers, rather than hemlock, with the lower chords 11 inches rather than 10 inches wide. The builders were allowed to use "such portion of the old bridge as they may find on Horace Weston's land," but only with the bridge corporation's approval.[17] No further details have been found concerning the construction of the bridge. The proprietor's ledger for 1866 contains this single entry: "Tasker & Fletcher, building bridge as per contract $9,000." The Vermont Journal contains no news of construction until September 22, 1866, when it reported: "The new toll bridge across the Connecticut from Windsor village to Cornish is now ready for travel."[18]

James Tasker and Bela Fletcher

James F. Tasker was born at Cornish in 1826 and died at Claremont July 18 1903. Vital records of the town of Claremont list Tasker's occupation as "contractor and builder."[19] Bela J. Fletcher, was born in Newport, New Hampshire, January 16, 1811 and died at Claremont July 26, 1877. Vital records list Fletcher's occupation as "bridge builder."[20] The two men worked together on a number of bridges in the Vermont-New Hampshire area, including presumably the Pompanoosuc Bridge, the Hanover Bridge, and the Fairlee-Orford Bridge, which were all of the same type of notched and bolted timber lattice construction as the Cornish Bridge. The Cornish Bridge is one of seven surviving covered bridges attributed to James Tasker.[21]

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[16] The Vermont Journal, March 24, 1866, p.8.
[17] Papers of the Proprietors of the Cornish Bridge, collection of the New Hampshire Historical Society.
[18] The Vermont Journal, September 22, 1866.
[19] Vital Records of the Town of Claremont, vol. 1902, p.56. Claremont Town Hall, Claremont, NH.
[20] Vital Records of the Town of Claremont, vol. 1877-1880, p.12. Claremont Town Hall, Claremont, NH.
[21] Notes in the Richard Sanders Allen Collection at the library in Westminster, Vermont, list eleven bridges known to have been built by Tasker, plus several more attributed to him.

Town Lattice Truss

Ithiel Town was born in Thompson, Connecticut in 1784 and died in New Haven in 1844. As a young man he learned carpentry and later studied architecture at Asher Benjamin's school in Boston. From 1829 to 1835, Town was a partner in the New York City firm of Town & Davis. For most of his life, Town practiced architecture and designed a number of noteworthy buildings, including Christ Church in Hartford (1825), the New York City Custom House (1837), the North Carolina State Capitol in Raleigh (1841), the Yale College Library (1842), and the Virginia State Capitol at Richmond (1842). Although he is primarily recognized as an architect, Town also made a significant contribution to the field of engineering when, in 1820, he was granted a patent for a truss bridge. In 1820, Eli Whitney wrote Town a letter regarding his bridge design, in which he stated:

> It appears to me to be much lighter, in proportion to its strength, than any other wooden bridge which I have seen; a consideration of much importance, both as respects expense, and the greater ease with which it supports its own weight. …On the whole, its simplicity, lightness, strength, cheapness and durability, are, in my opinion, such as to render it highly worthy of attention.

Town's design consisted of two layers of overlapping planks, with each layer arranged at an angle to the chords, forming a lattice fastened together with wooden pins or treenails at each intersection. The most significant feature of this design was that it could be quickly erected and utilized sawn planks instead of heavy hewn timbers. As Town explained in his 1821 pamphlet, "A Description of Ithiel Town's Improvement in the Construction of Wood and Iron Bridges," this new method of bridge construction was designed to be "the most simple, permanent, and economical, both in erecting and repairing."[22]

The lattice design actually functioned as a series of overlapping triangles so that the load in any one triangle affected distribution of stress in all other triangles. Because the webs were fastened at every intersection, no triangle could function independently, and, as bridge historian Richard Sanders Allen points out, "Therein lay the great strength of the Town truss. It was a real invention, not resembling any design advanced for wooden spans in the thousands of years before its time that bridges had been built."[23] Because it did not rely on European precedents, the Town Lattice is considered "the first truly American design" for a bridge truss.[24]

Town received a second patent in 1835, adding a second lattice web, which was used primarily for railroad bridges. Town built only a few bridges himself, but aggressively promoted his truss design through agents who sold the rights to use his patent at $1 per foot of bridge. It is said that Town actually derived more income from his engineering work than from his architectural

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[22] Ithiel Town, "A Description of Ithiel Town's Improvement in the Construction of Wood and Iron Bridges: Intended as a General System of Bridge-Building" (New Haven: S. Converse, 1821), p.4.
[23] Richard Sanders Allen, <u>Covered Bridges of the Northeast</u> (Brattleboro: Stephen Greene Press, 1957), p.15.
[24] Raymond E. Wilson, "Twenty Different Ways to Build a Covered Bridge," <u>Technology Review</u>, Massachusetts Institute of Technology, May 1971.

practice.[25] Even after Town's death in 1844, the Town lattice system continued to be used for bridges well into the twentieth century. Its popularity was based on the a number of factors: it used small, reasonably sized lumber; it required a minimal amount of intricate framing, allowing it to be easily erected by local unskilled labor; it could span up to 200'; and it showed stress long before collapse would occur.[26]

Thousands of Town lattice trusses were built in the United States in the nineteenth century, but there are only about 150 surviving examples in the United States today, and these are located primarily in the northeastern states.[27] The Cornish-Windsor Bridge is a notched and bolted Town lattice truss bridge, the only one of its kind remaining in the United States.[28]

Subsequent History of the Bridge
According to timber framer Jan Lewandoski, "the bridge is a great bridge, but … its truss was only marginally adequate to its exceptional span and traffic even when built." As early as 1887, James Tasker was called back to make repairs to the structure. The newspaper noted, "The toll bridge is undergoing extensive repairs under the direction of James Tasker, the well known bridge builder."[29] In 1884 the roof was reshingled, and in 1892 the newspaper reported: "The toll bridge has been undergoing repairs, and now has a new and substantial plank flooring, well laid and secure."[30]

By the turn of the twentieth century, the bridge was showing signs of structural damage in the lower chords, and the bridge had a negative camber of almost 10". Traditionally, it was thought that the bolted lattice joints of this bridge were too flexible, causing tension stresses in the lower chords; however, more recent analysis has shown that excessive deflection was due to the ratio of the depth of the truss to the bridge span (i.e. the truss was too shallow in depth for the extremely long span and this caused the bridge to sag).[31] In 1908 civil engineer J.P. Snow recommended adding arches to the structure to take some of the strain off the lower chords, but nothing was done to fix the problem.[32] Snow later stated, "The Town lattice is the best of the various types of wooden trusses to serve as an arch stiffener because its web members serve either as counters or main braces. The value of arches framed with trusses, if heeled against the masonry, has been amply demonstrated by other types of trusses, some of which have stood for a century."[33]

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[25] Henry F. Withey and Elsie Rathburn Withey, "Ithiel Town," biographical sketch in Biographical Dictionary of American Architects (Deceased) (Detroit: Omnigraphics, 1970), p.604.
[26] Brenda Krekeler, Covered Bridges Today (Canton, Ohio: Daring Books, 1988), p.19.
[27] National Society for the Preservation of Covered Bridges, World Guide to Covered Bridges, computer database printout, April 2002.
[28] David C. Fischetti, "Conservation Case Study of the Cornish-Windsor Covered Bridge," APT Bulletin 23, no. 2 (1991): p.22-28.
[29] The Vermont Journal, August 27, 1887, p.8.
[30] The Vermont Journal, July 16, 1892, p.8.
[31] David C. Fischetti, Editorial comments on Cornish-Windsor Bridge draft HAER Report, February 9, 2004.
[32] Lewandoski, Jan. "The Restoration of the Cornish-Windsor Bridge," Society for Industrial Archeology, New England Chapters, Newsletter 10, no. 1 (1990): p.11-16.
[33] Robert Fletcher and J.P. Snow, "A History of the Development of Wooden Bridges," Proceedings of the American Society of Civil Engineers vol. 58 (November 1932), republished in American Wooden Bridges (New York: American Society of Civil Engineers, 1976), p.52.

In 1919 a break was noted in the lower chord at the northeast end of the bridge. A new, larger piece of spruce replaced the broken member. The bridge was inspected again in 1924 and "showed no evidence of further deterioration or adjustment to the stresses except a slight sag on the North side in the east span."[34] Nothing further was done to the structure until 1936 when the east span was jacked up on piles and many of the damaged lattice members on the north side were replaced.

In 1935, the State of New Hampshire purchased the bridge for $20,000.[35] It continued to be a toll bridge until 1943 when an act of the New Hampshire State Legislature made the bridge free. This was the last wooden toll bridge to operate on the Connecticut River. Subsequently, the tollgate was removed. The tollhouse is still extant at 45 Bridge Street, Windsor.

In 1954 the bridge was closed for six months for major repairs, which included replacing the floor beams, patching the chords with steel plates, and covering the structure with new siding and roofing.

By 1980, the sag noted in 1909 had increased considerably, and there was intermittent discussion and controversy over repairing and strengthening the bridge. By the mid 1980s, the bridge was said to be "functioning with marginal, decayed components," and the decision was made to rehabilitate the structure.[36] The debate then turned to the best way to accomplish this, and boiled down to preservationists vs. engineers over three rehabilitation alternatives: replacing deteriorated chord members in-kind, adding timber arches to the existing structure, or replacing chords with glue-laminated members. The first alternative was shown not to be feasible because "solid timbers of sufficient strength are not available."[37] The Committee for the Authentic Restoration of the Cornish-Windsor Bridge proposed the second alternative, because adding arches to timber trusses is a traditional method of reinforcing covered bridges. There were many proponents of this plan, including one of the nation's foremost authorities on the repair and restoration of covered bridges, Milton Graton, who said, "This bridge should be treated the way Mr. Tasker treated it, using the same materials."[38] The Vermont Agency of Transportation, the Vermont Division for Historic Preservation and the Town of Windsor objected to this proposal, because the arches would be installed on the outside of the bridge to maintain the roadway width, raising aesthetic concerns, and the arches would require raising the bridge and houses along the approaches. The third alternative, which involved incorporating modern materials into an historic structure, had some strong objectors, including the National Society for the Preservation of Covered Bridges. Ultimately, the state highway departments agreed that, although it was a compromise in terms of historic integrity, the third alternative was the most acceptable solution, in that it preserved the appearance of the bridge, did not require modifications to the pier and

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[34] Dana, p.60.
[35] "Cornish Bridge to Be Freed," The Union, April 13, 1943.
[36] "In New Hampshire: A Rare Span," Time 128, no. 21 (November 24, 1986): p.13.
[37] Fischetti, "Conservation Case Study," p.24.
[38] As quoted by Sallie Graziano, "Preservationists Plead: Fix Bridge With Wood," The Valley News, March 23, 1984.

abutments, and allowed the structure to meet modern highway load ratings and thus remain in service.

The contract for the rehabilitation of the Cornish Bridge was awarded to Chesterfield Associates of Long Island. New York. The State of New Hampshire paid about $4,450,000, while Vermont paid $200,000 of the total cost. During the course of the work, about 30 percent of the original timbers were replaced.[39] According to David C. Fischetti, structural engineer for the project, the design concept included the addition of glue-laminated timber chords in long lengths in order to remove strength reducing splices from critical areas of the chords of the bridge trusses while substituting timber materials of substantially greater strength. Adding glue-laminated timber bolster beams also reduced the effective truss span. The floor was strengthened as well as the lateral bracing. The Cornish-Windsor Bridge reopened to traffic in December 1989.

[39] The floor was also replaced, but it was not original.

APPENDIX A: ENGINEERING REPORT

Introduction

The Cornish-Windsor Bridge, the longest surviving covered bridge in the United States and the longest two-span covered bridge in the world, is a rare example of the notched squared timber Town lattice truss design.[40] Built in 1866, it is listed on the National Register of Historic Places, and the American Society of Civil Engineers designated it as a National Historic Civil Engineering Landmark in 1970.

One of the objectives of this study was to review and summarize the technical bibliography published about Cornish-Windsor Bridge. Since the bridge has an extraordinary span, its history includes a series of reinforcement, rehabilitation, and preservation issues that are worthy of study.

The notched squared timber Town lattice truss is important as it represents a specific solution and modification to a known design to achieve a high load-bearing capacity and a high degree of stiffness, or rigidity, in a long structure. Notched squared timber Town lattice trusses, patented by Ithiel Town in 1839, represent a compromise-based solution by including fitted joints in the lattice. The most frequently cited advantage of the Town lattice trusses was that they did not need specialized carpentry work. Replacing overlapped planks and treenail joints with large-section lumber and notched joints meant that this criterion was not totally respected, though scarf (notched) joints–even if the members met at angles other than 90 degrees–were one of the simplest carpentry joints to make.

The early development of wooden truss bridges and a general description of the major types, including the Town lattice truss, has been presented in detail in the history report for this bridge, and in materials listed in the bibliography, so they will not be repeated herein.[41]

The principal objectives of this study were:

- to summarize technical information on notched squared timber Town lattice trusses generally and on Cornish-Windsor Bridge in particular.
- to summarize the 1989 restoration intervention designed by David C. Fischetti.
- to analyze deflection, stiffness, and general behavior of notched squared timber Town lattice trusses, including creep effect, long span, reduced stiffness, and joint looseness.
- to review the former finite element analyses that have been carried out for the bridge.
- to compare stiffness and efficiency of timber lattice versus plank lattice members, webs, and joints.
- to analyze the possibility of increasing stiffness and efficiency.

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[40] Philip C. Pierce, Covered Bridge Manual, draft ms, n.p., n.d.

[41] For a general history of early development of wooden truss bridges see J. G. James, "The Evolution of Wooden Bridge Trusses to 1850," Journal of the Institute of Wood Sciences 9 (June 1982): p.116-35 and (December 1982): p.168-93; see also HAER No. OH-122, "Eldean Bridge," and HAER No. VT-28, "Brown Bridge"; Pierce, Covered Bridge Manual.

Historical Context
Spanning wide rivers such as the Connecticut River had always presented extraordinary challenges for bridge constructors. New England was a region with large, primarily spruce, forests and numerous saw mills that could provide milled lumber, so wood was the primary building material throughout the nineteenth century. Spruce in particular was well-suited for timber structures like bridges.

Timber was, and still is, considered a safe building material for such structures because it gave evidence of distress long before failure. Repairs were relatively easy to make as well. Many roadway bridges, though repaired several times during their life span, are still in use, even though live load conditions have significantly risen from the middle of the nineteenth century to the present. Additionally, there were a number of ways to increase the load bearing capacity and stiffness of Town lattice bridges to permit longer spans, including:

- constructing continuous trusses over a central pier.
- constructing trusses with an initial camber to counter the expected sag.[42]
- increasing the intersection angle of the lattice members.
- increasing the displacement (spacing) of the lattice members.
- increasing the number of lattice intersections.
- constructing a double Town lattice truss.
- using square timber and notched joints instead of the usual planks and overlapped joints pinned with treenails.

Town lattice trusses were frequently criticized for not being well-engineered in terms of sizing and efficiency of material usage. Their simplicity and ease of construction, coupled with an excellent safety record, made the form very popular, as noted by bridge builders Robert Fletcher and J. P. Snow:

> The Town lattice principle is similar to that of the English iron riveted lattice. Both will stand more abuse from service than any other type of truss. Both will give indications of distress long before collapse, and those that were properly built are found doing duty far longer than many other types. [43]

Town lattice structures have to be considered–as they were conceived–holistically. The elements' geometries are interlinked. With their many redundant paths for stress, they are statically indeterminant structures, meaning that a thorough, detailed stress analysis is possible

[42] J. P. Snow, "Wooden Bridge Construction on the Boston and Maine Railroad," Journal of Association of Engineering Society XV (July 1895): p.31-43; J. P. Snow, "A Recent All-wood Truss Railroad Bridge," The Engineering Record. 60, no. 17 (October 23, 1909): p.456-457.
[43] Robert Fletcher and J. P. Snow, "A History of the Development of Wooden Bridges," American Society of Civil Engineering. Paper no. 1864, Proceedings ASCE. 1932, vol. LVIII, p.1455-1498, republished No.4, New York. 1976.

only by considering the effects of deflection on each member. Lattice displacement is dependent on floor beam capacity, as the usual design placed only one beam in one lattice panel.

Town lattice structures are commonly analyzed using the concept of an "equivalent girder." Detailed computer-based linear finite element analyses have shown that the overall behavior is close to that of an arch, as the assembly of compression diagonals and upper chords resembles an arch, while the lower chords mimic the role have the role of a tie-rod, and the mid-span lattice webs work as suspension ties.

Notched Squared Timber Town Lattice Bridges

Ithiel Town first patented the simplest form of his lattice truss, the plank lattice truss, in 1820. The need to carry heavier loads, such as railway trains, prompted Town to develop and patent lattice trusses with multiple lattice webs in 1935.[44] Four years later, he received yet another patent, this one for a stronger lattice truss that used squared timber with interlocking notches at the lattice joints. This notched squared timber Town lattice truss also was significantly stiffer than plank trusses and suitable for longer spans. Being more complex and expensive to build than their plank lattice cousins, far fewer were built, and only a handful survive. Figures 1 and 2 illustrate the single and multiple web forms of the Town lattice truss. The notched squared timber variant could be built in both forms.

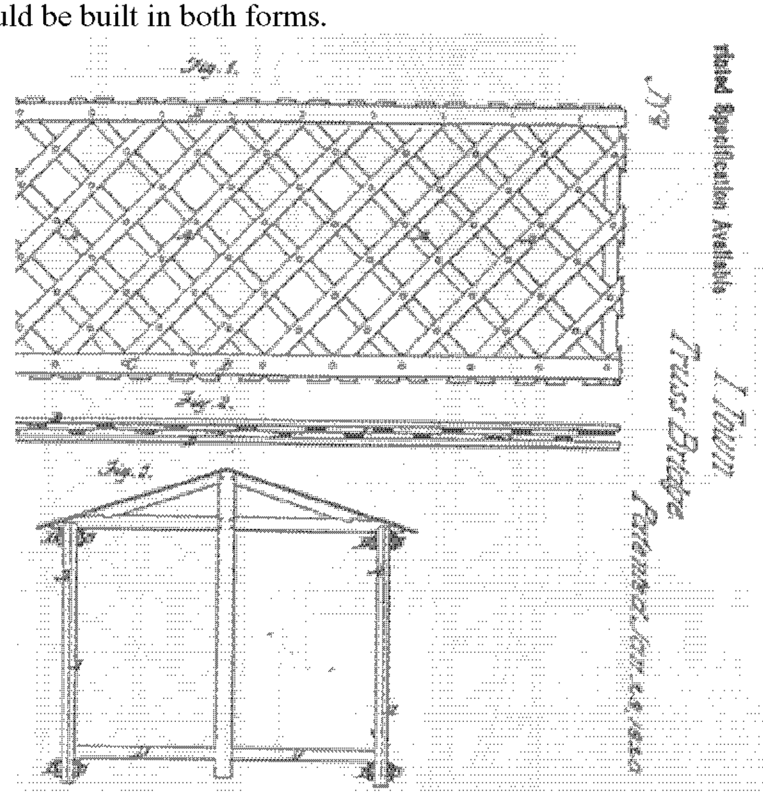


Figure 1. Town's 1820 plank lattice truss patent.

[44] In his patent, Town included double, triple, and quadruple lattice webs, but no examples of the latter two are known. See J. G. James, The Evolution of Wooden Bridge Trusses to 1850, p.175.

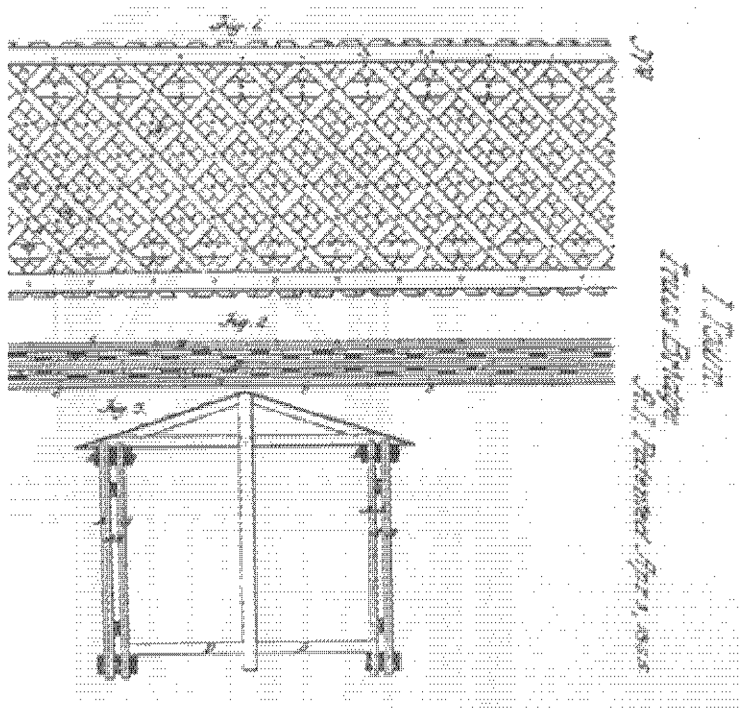


Figure 2. Town's 1835 multiple plank lattice truss patent

Historic Simplified Calculation of Town Lattice Structures

The simplest analytical method for a Town lattice truss is the equivalent plate girder analysis. It is useful for height/span ratios similar to those found in large wide-flange beams, whose behavior is similar. A more sophisticated calculation involves deconstructing the Town lattice truss into an intersecting series of Warren trusses.[45] Since treenailed joints are more similar to riveted than to pinned joints, this deconstruction actually forms multiple indeterminate structures, so in practice, the same equivalent girder method was often used as a simplified way to analyze Warren trusses, too.[46]

Existing iron lattice structural reports have included comparisons between the results of simplified multiple Warren "quintangular" truss analysis and computer-aided calculations. These have shown good agreement between the two methods.[47] Most lattice trusses consist of four Warren trusses and are referred to as "quadrangular." Using this terminology, the Cornish-Windsor Bridge would be a "sextangular" structure.

[45] The Warren truss was patented by the British bridge builder James Warren with Theobald Monzani in 1848, and it was being used in the United States by the 1860s. See Historic American Engineering Record (HAER), National Park Service, U.S. Department of the Interior, "Upper Bridge at Slate Run," HAER No. PA-460, p6-7.

[46] Morgan W. Davies, The Theory and Practice of Bridge Construction in Timber, Iron and Steel (London: Macmillan and Co. Limited, 1908), p.73-85.

[47] Historic American Engineering Record, (HAER), National Park Service, U.S. Department of the Interior, "Structural Study of Pennsylvania Historic Bridges," HAER No. PA-478.

THE CORNISH-WINDSOR BRIDGE

Present Configuration

The Cornish-Windsor Bridge is 450’-5” long at floor level (407’ total clear-span length), consisting of two spans of 204’ and 203’. It has an overall width of 24’ and a roadway width of 19’-6”. Its vertical clearance above the roadway is 12’-9”.

The lattice trusses are built of 6 x 8” Eastern Spruce timbers placed at the general diagonal offsetting distance of 4”, with the classical double lower and double upper chord pattern. Chord members originally were composed of two 3 x 10” and 5 x 10” members that were partially replaced by laminated wooden members in 1989. The overall appearance of the truss is shown in Figure 3, and the properties of Eastern Spruce used in the analysis are listed in Table 1.

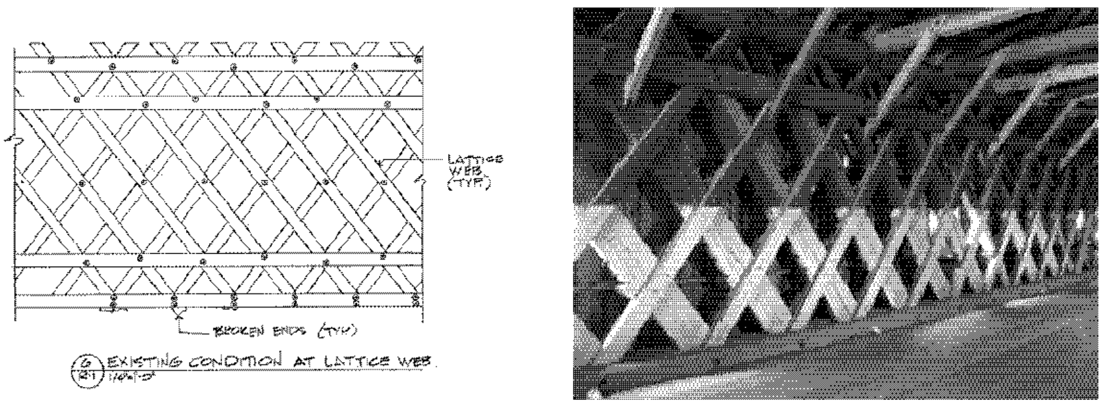


Figure 3. General arrangement of the Cornish-Windsor Town lattice truss structure[48]

Table 1. Properties of Eastern Spruce

mass per unit volume	4.40E-08 kip / in^3	0.9133 lb / ft^3
weight per unit volume	1.70E-05 kip / in^3	29.3976 lb / ft^3
modulus of elasticity	1340.277 kip / in^2	1.93E+08 lb / ft^2
Poisson ratio	0.372	0.372

As originally built, the lattice-chord and lattice-lattice joints were notched ¼”. Details of these joints are shown in Figure 3. The lattice-lattice joints interlocked the members, but lattice members typically butted against chord members.

[48] Unless noted, structural drawings from David C. Fischetti’s 1989 rehabilitation.

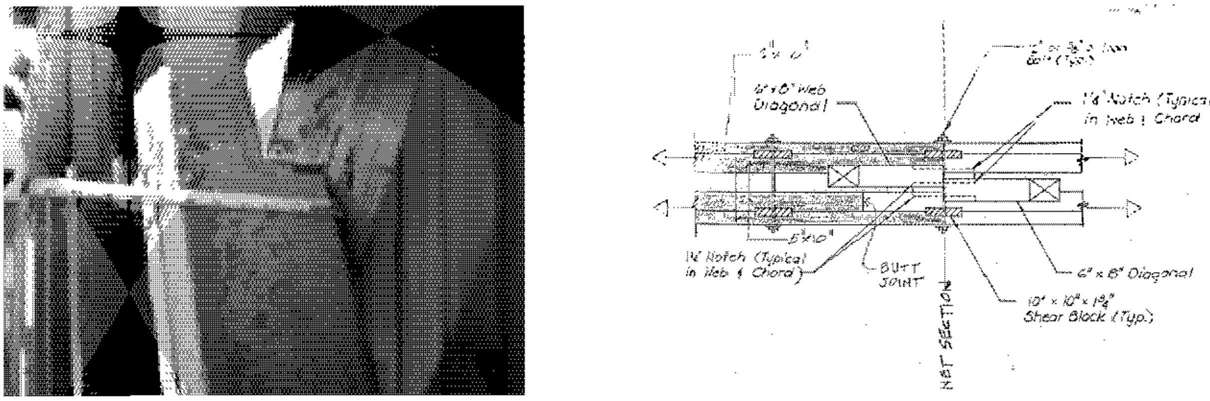


Figure 4. Notched squared lattice joint details

Sub-structures
In addition to the two main trusses, each span consisted of several sub-structures and the joinery needed to connect them to the trusses. The upper and lower horizontal bracing consisted of ties (the upper ones also serving as tie beams for the roof structure) and "X" cross members. The floor consisted of 4 x 16" transverse beams resting on the primary lower chord on 2' centers. The 1989 rehabilitation design proposed the total replacement of the floor beams with 6¾ x 17 7/8" prefabricated glue-laminated, or "glulam," timbers in their original positions. Partial replacement was actually done.[49] Representative details are shown in Figure 5.

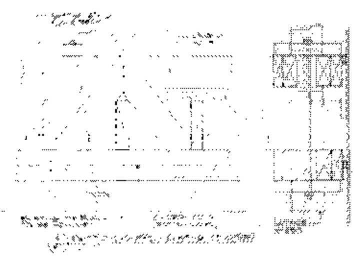


Figure 5a. Floor beam detail, before 1989 rehabilitation

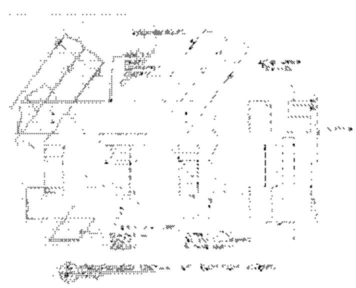


Figure 5b. Replaced floor beam detail, as designed for 1989 rehabilitation

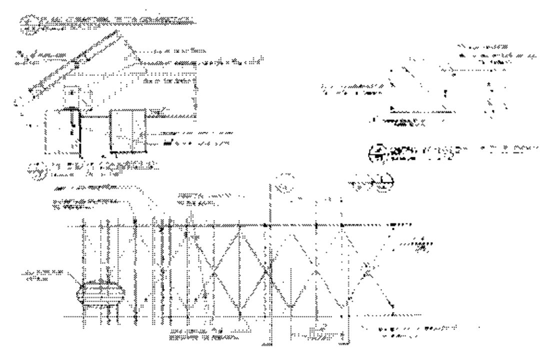


Figure 5c. Lower horizontal bracing and connection details, as designed for 1989 rehabilitation

[49] Jan Lewandoski, "The Restoration of the Cornish-Windsor Bridge," Society of Industrial Archeology, New England Chapters 10, no. 1 (1990): p.11-16.

A medium-pitch (8:12) gable roof covers the entire bridge, but it does not overhang beyond the gable ends. Light rafters that extend from the top chords to abut at the ridge frame the roof. Knee braces continue to the collar beam. Corrugated metal sheeting now covers the roof, though it was originally shingled.

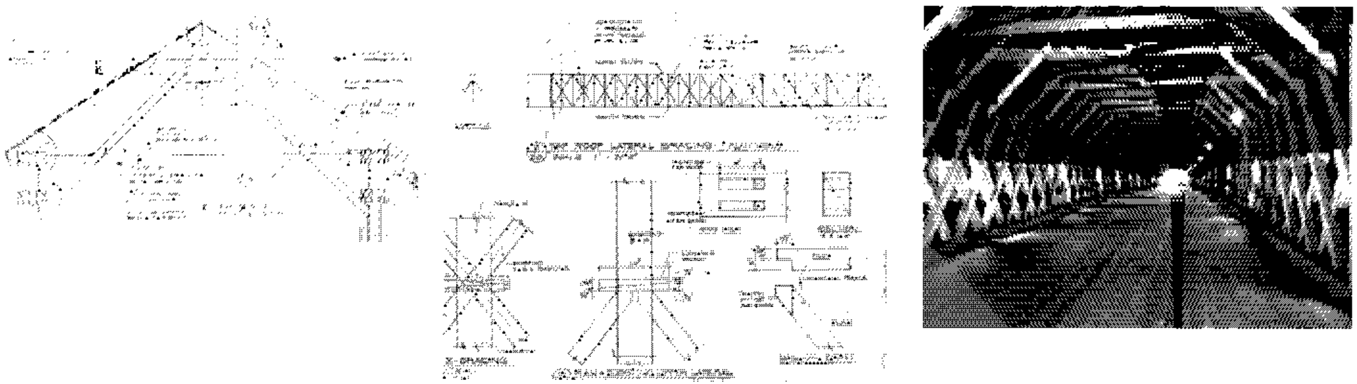


Figure 6. Upper horizontal bracing system and roof detail, as designed for 1989 rehabilitation

Characteristic Features of the Cornish-Windsor Bridge
Being a notched squared timber Town lattice truss bridge, the Cornish-Windsor Bridge is characterized by a set of specific joints that are not found in a simple plank lattice structure. Additionally, the 1989 rehabilitation introduced a set of new members, joints, and details, including:

- new joints to improve structural continuity in the chords.
- new glulam replacement elements and connections to original chord timbers.
- new sister lattice members in selected locations.

The lattice web, a "sixtangular" system (seven horizontal lines of joints), was already quite stiff for a wooden truss. The truss's 15' height, which is significantly greater than the 12 – 13' height of most plank lattice bridges, also contributes to this stiffness. The diagonal end design of the truss, shown in Figure 7, is also unusual, though not entirely unique. This figure also includes end joint details, some of which may well be unique to this bridge.

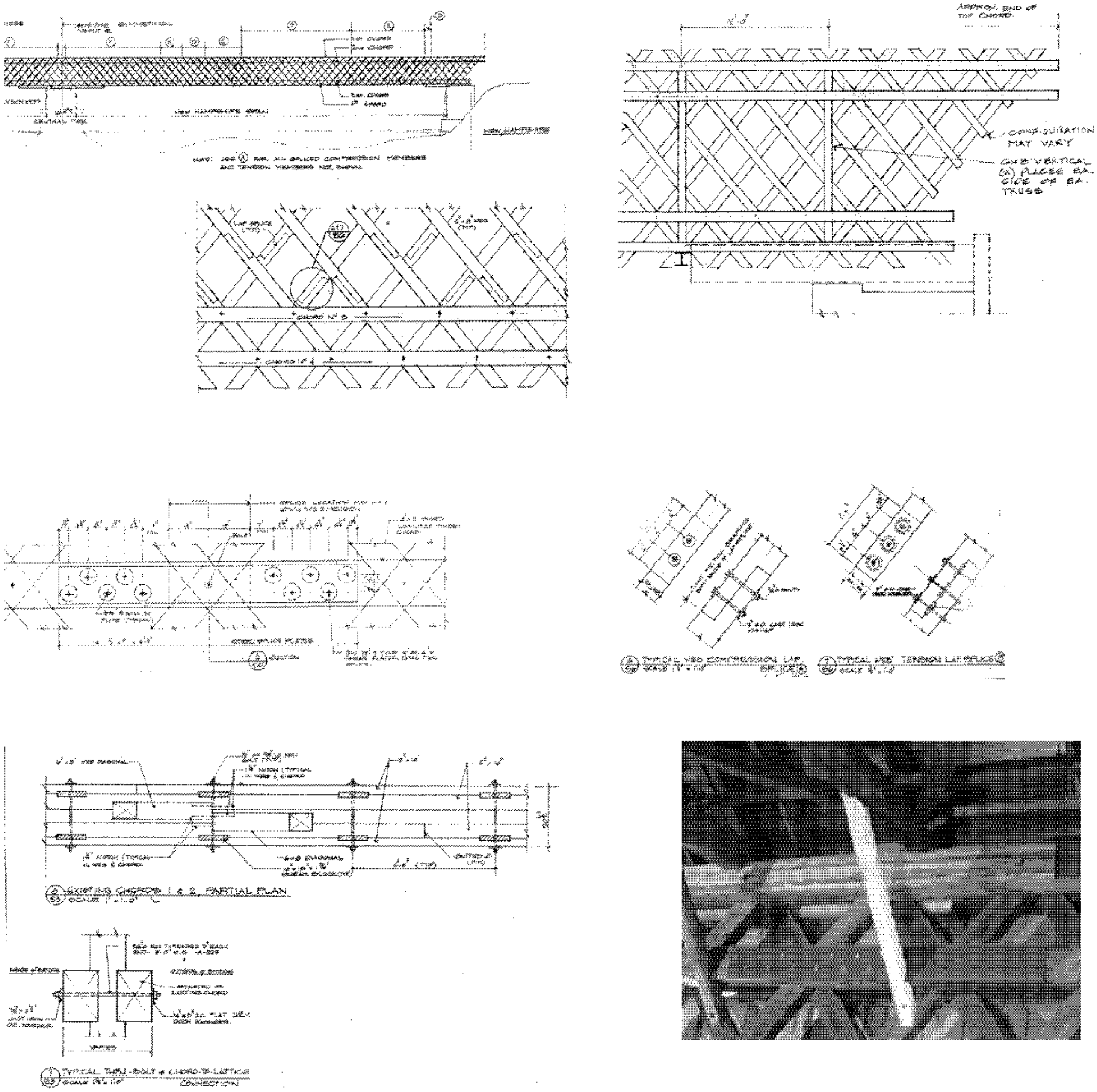


Figure 7. End lattice and joint details

Simple butting of chord members was always one of the weaker points of Town lattice trusses, even if combined with shear blocks. Therefore their 1989 elimination from the structure in areas with the highest stresses improved the structure's overall behavior, transforming it into a safe bridge for HS15-44 loading condition.

Interestingly, the chord-lattice and lattice-lattice joints were originally assembled with threaded fasteners, two for lower chord and new lattice sister joints and one elsewhere. Not known is whether this use of nuts and bolts in place of treenails was standard practice for notched square timber Town trusses, or unique to the Cornish-Windsor Bridge.

Summary of the 1989 Rehabilitation

The rehabilitation, designed by structural engineer David C. Fischetti, assured the bridge an HS15-44 load capacity through insertion of industrial grade, prefabricated, structural glued laminated (glulam) timber chords and floor beams in areas of high tensile stress. [50] Although desirable from the historic perspective, the "replacement-in-kind" solution could not be adopted because of the unavailability of solid timbers in the size and quality required. "Replacement-in-kind" would also have retained the butt and shear-block joints, which would have unacceptably reduced the net chord areas and increased stresses.

The lengths of glulam elements were selected to place splices at locations of minimum stress. Notches for shear blocks and butt splices were removed from the chord members in maximum stress areas to maximize the net chord section. Figure 8 shows how the new elements were integrated into the existing structure.

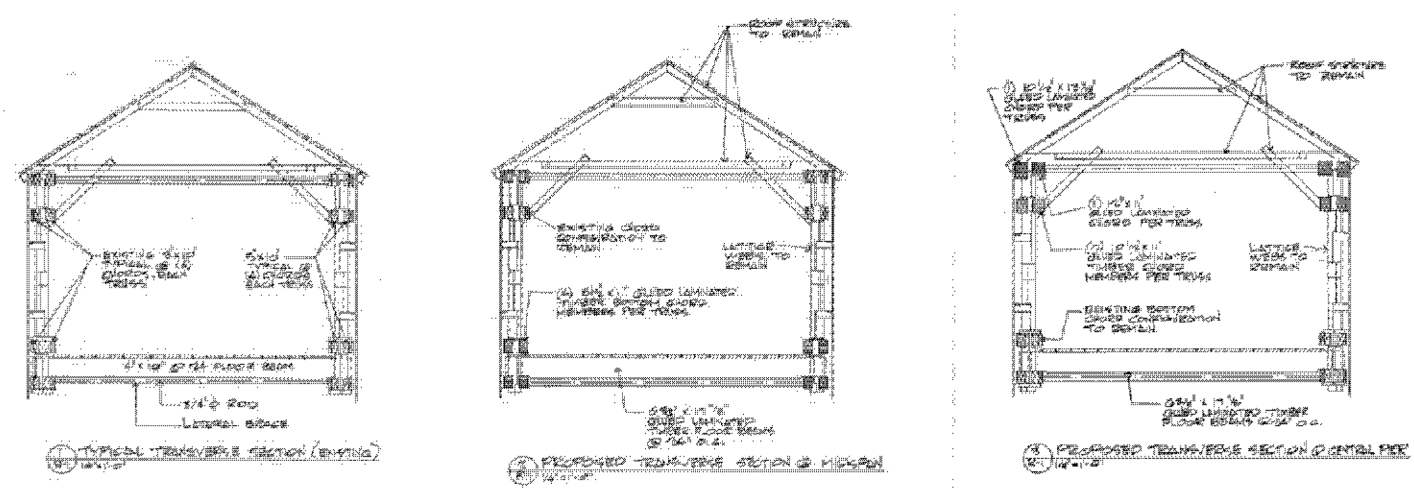


Figure 8. Before and after rehabilitation transverse sections, showing existing and new chord elements.

[50] David C. Fischetti, Glulam Chord Replacement Alternative Cornish-Windsor Bridge, Cornish, NH – Windsor, VT, S-4134. Prepared for: State of New Hampshire. Commissioner of the Department of Transportation Concord, New Hampshire: January 19, 1988.

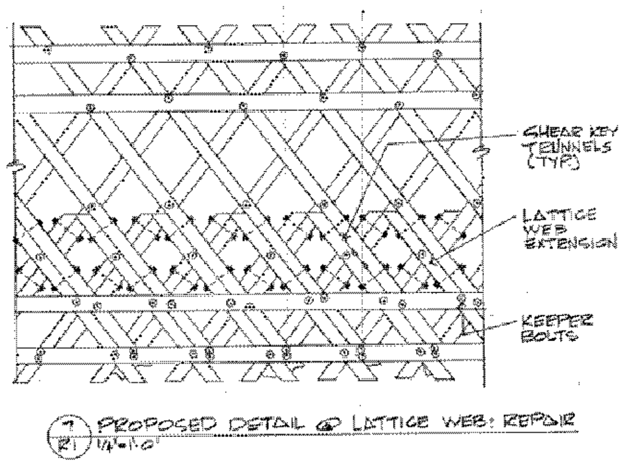


Figure 9. New sister lattice webs.

Larger glulam floor beams replaced the original ones. A number of deteriorated lattice members needed reinforcement, especially at certain joints, so the historically common approach of adding sister members insertion was taken, as shown in Figure 9. Abutments and bolster beams were also reinforced.

ANALYSIS OF THE CORNISH-WINDSOR BRIDGE

Notched Squared Timber Versus Plank Lattice Members

Three-dimensional structural models are complex to design and configure properly. The three-dimensional mathematical model of the Cornish-Windsor Bridge developed for use with the STRAAD structural analysis software consisted of 1,132 joints and 2,143 members. To get an initial sense of how the basic behavior of a notched squared timber (hereafter termed "timber") Town truss compared to a plank truss, the first set of analyses used a proven, three-dimensional model the author developed for another, similar HAER project involving the Contoocook railroad bridge. Analyses were performed for the following cases:

- continuous truss with two, 71' spans, plank members (Contoocook design).
- continuous truss with two, 71' spans, timber members.
- single truss, 142' span, plank members.
- single truss, 142' span, timber members.

Figures 10 and 11 are plots showing the general nature of deformation for the continuous and single-span trusses, respectively.

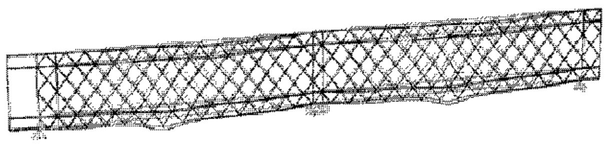


Figure 10. Continuous, two-span truss deformation

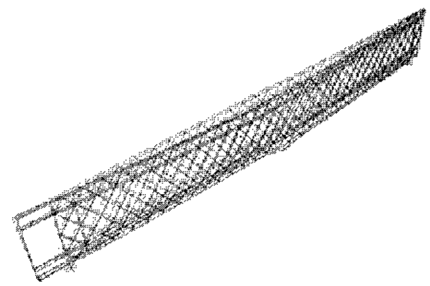


Figure 11. Single-span truss deformation

One key question involved the effects of joint stiffness and how best to model it.[51] The importance of the interlocking notches, compared to the overall truss geometry, in stiffening a timber truss was unknown. Consequently, the stiffness was initially assumed to be the same as for a plank truss, with the expectation that this could be improved upon in the final model.

Overall Stiffness
An overall stiffness comparison of timber and plank Town lattice trusses is shown in Table 2.

Table 2. Overall stiffness comparison of timber and plank Town lattice trusses.

Bridge	Type	Angle of lattice (deg)	Span length (ft)	Overall depth (ft)	Deflection at mid-span, dead load (in)	Deflection at mid-span, 20 kip live load (in)
Contoocook 1 truss double span	plank	53	71	20	-0.105305	-0.185078
1 truss double span	timber	53	71	20	-0.118635	-0.207551
1 truss double span - treenail stiffness	timber	53	71	20	-0.092114	-0.15555
1 truss single span	plank	53	142	20	-0.570769	-0.420194
Contoocook 1 truss single span	timber	53	142	20	-0.618696	-0.417857
1 truss single span - treenail stiffness	timber	53	142	20	-0.532148	-0.35253
1 truss single span - 1 in 2 stiffness	timber	53	142	20	-0.93111	-0.676053

[51] For the mathematical model of plank lattice joints' rotational and shear performance, see HAER No. NH-38, "Contoocook Railroad Bridge," 2003.

The data in Table 2 indicate the following conclusions:

- Timber Town lattice members are more efficient for longer spans. For the 71' plank lattice, deflections are smaller than the timber lattice deflections when joint stiffness is according to the mathematical model of lapped bolted joint, though difference is less than 10 percent.
- If the stiffness of a 1¼" joint was equal to that of a treenail joint, the timber lattice webs modeled would be 15 percent stiffer for the 71' span.
- For the 142' span, the timber lattice was essentially as stiff as the plank lattice, even with the less stiff lapped and bolted joints.

Lateral Stability

Lateral stability becomes an important issue for a plank lattice web as its span increases. In this regard, the calculations indicate that a timber Town lattice structure will be approximately 25 times stiffer than a plank lattice web for spans in this range. This is due to the much larger lateral dimension of a square timber, when compared to a plank, and the consequently greater moment of inertia.

Effect of Chord Splices

While the stiffness of lattice web joints is slightly less important for timber versus plank lattice webs, timber structures are considerably more vulnerable to weaknesses caused by butt splices in the chords. In the three-dimensional model, the reduction of chord continuity (sectional area) for splices in plank lattice webs was 25 percent, whereas it was 53 percent, over twice as much, for timber lattice trusses. This would have a directly proportional effect on the tension and compression forces a chord could carry, and it would have to be carefully considered by the bridge designer or rehabilitation designer.

Effect of Lattice Angles and Placement on Overall Truss Stiffness

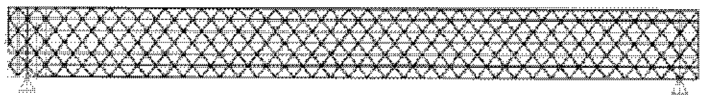
Lattice member placement was often determined by the floor system in both single and double Town lattice trusses. The basic concept was to place a single floor beam in each lattice panel. This effectively limited lattice member spacing to something between 4 and 5'. Additionally, since the proper erection of a lattice depended on the accurate, consistent location of the many joints, builders tended to work with dimensions that could be easily measured in both vertical and horizontal directions. This led to a few convenient dimensions and proportions that were used in many Town trusses. Each of these dimension combinations yielded a specific inclination angle for the web members. Some of the common combinations were:

Horiz. x vert.	Angle from horiz.
2' x 2'	45 degrees
2' x 2½'	51 degrees
2' x 3'	60 degrees
3' x 4'	53 degrees

Some observations are qualitatively apparent.

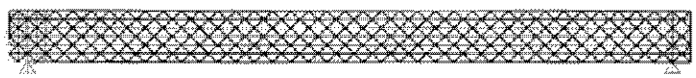
- For the same number of member interfaces, greater angles will result in a greater overall height and, thus, greater stiffness.
- Angles less than 30 degrees or greater than 60 degrees would change the forces on the web members from predominantly axial forces to predominantly shear, which would not be desirable.

The structures shown in Figure 12 (a) through 12 (e) were quantitatively analyzed, using a two-dimensional model, to determine their deflections and characteristic forces. In all cases, both plank and timber versions were been analyzed. Table 3 contains the data.

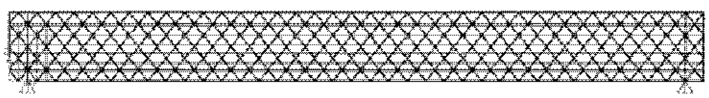


(a) 53° – 4'10 ¾" interax lattice distance – 7 joint lines

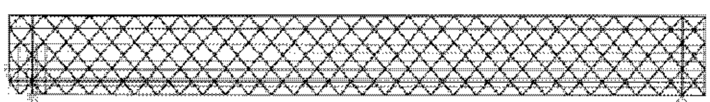
(b) 53° – 4'10 ¾" interax lattice distance – 5 joint lines



(c) 45° – 4' interax lattice distance – 7 joint lines



(d) 60° – 4' interax lattice distance – 7 joint lines



(e) 60° – 5' interax lattice distance – 7 joint lines

Figure 12. Town lattice trusses for quantitative comparison.

Table 3. Deflections and characteristic forces for selected Town plank and timber trusses.

Bridge	Truss Type	Angle of lattice (deg)	Interax lattice	Span (ft)	Overall depth (ft)	Deflection at mid-span, 20 kip live load (in)
Contoocook 1 truss single span three chords	plank	53	4' 10 3/4"	142	20	-0.3484
Contoocook 1 truss single span	plank	53	4' 10 3/4"	142	20	-0.35734
Contoocook 1 truss single span	timber	53	4' 10 3/4"	142	20	-0.32176
5 intersection Contoocook 1 truss single span	plank	53	4' 10 3/4"	142	16.58	-0.48792
5 intersection Contoocook 1 truss single span	timber	53	4' 10 3/4"	142	16.58	-0.4503
7 intersection 45 angle, 4' inteax	plank	45	4'	142	12	-0.81512
7 intersection 45 angle, 4' interax	timber	45	4'	142	12	-0.77642
7 intersection 60 angle, 4' interax	plank	60	4'	142	15	-0.57499
7 intersection 60 angle, 4' interax	timber	60	4'	142	15	-0.53175
7 intersection 60 angle, 5' interax	plank	60	5'	142.5	18.75	-0.4416
7intersection 60 angle, 5' interax	timber	60	5'	142.5	18.75	-0.41333

These data yield the following conclusions:

- Changing the overall height by 23.76 percent (by reducing the number of joint lines) resulted in a stiffness reductions of 36.5 percent for plank trusses and 40 percent for timber trusses.

- The overall stiffness of a timber truss depends less on the rotational stiffness of the joints than on its overall height.
- The overall stiffness of a timber truss depends less on the web member angle than on its overall height.
- A given change in height that causes the web member angle to be above 45 degrees is not as effective in increasing stiffness as when the angle can be maintained below 45 degrees.
- Maintaining the web member angle while changing the interax (lattice center offset distance) is the least efficient way to obtain greater stiffness by increasing the overall height.

Creep Effect

Wood has time-dependent stress-strain behavior. For example, creep is the increase of strain over time in wood at a constant stress. Creep occurs in three stages. The first stage of creep deformation occurs when the structure is initially loaded, the second stage is reached when the rate of creep begins to approach zero, and the third stage, which occurs under large live loads over long periods of time, is when the rate of creep increases quickly to failure. The second stage is typically reached within a short period of time, and it can last for many years.[52]

An accurate analysis of creep would require a viscous stress-strain model that was not available, so no attempt was made to model the effect of creep in the wood of the truss.

Historic data concerning the Cornish-Windsor Bridge indicate that it has been characterized by increasing sag (9 $^{7}/_{8}$" in 1912 to 17" in 1986). This is a strong indicator of creep in the joints. During rehabilitation work in 1989, a 24" positive camber was introduced to each span. As expected, first-stage creep reduced the camber by a little more than 2" during the first few months of service after the temporary supports had been removed.[53]

Although the Cornish-Windsor spans are quite long, these data suggest that the notched joints of a timber truss are more susceptible to rotation because of creep deformation than the treenail joints of a plank truss. Part of this results from the nature of wood itself, but a portion is likely due to notched joints being less-precisely made than treenail joints, which could easily increase localized contact forces where joint notch faces bear against one another at a slight angle that prevents initial full-face contact.

SPECIAL CONSIDERATIONS ON TIMBER LATTICE WEBS AND JOINTS

Joint Details

As has been demonstrated above, timber lattice trusses achieve their overall stiffness more through member stiffness than joint stiffness. Even so, the truss could have benefited from more careful design and execution of the notches.

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[52] Forest Products Laboratory, Wood Handbook, Wood as an Engineering Material, 1999
[53] Lewandoski, "The Restoration of the Cornish-Windsor Bridge," p.11-16.

The notches are too shallow. This resulted in small contact areas, and since the joints tend to twist, they work under a triangular compression stress distribution. The stress is limited by perpendicular on-grain compression, which is highest in the darkened corners of Figure 13. The resulting capacity for shear is only 1.425 kip.

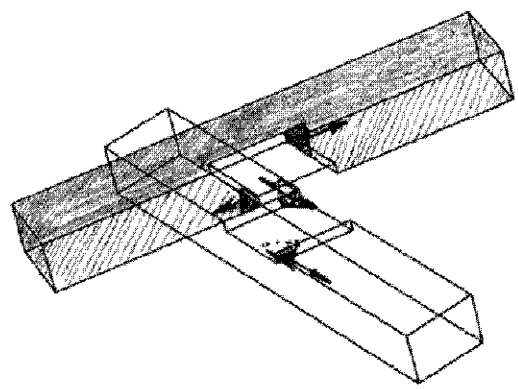

Figure 13. Notched joint detail. Note darkened areas of high contact stress at the joint corners.

In many forms of wood construction, it is common to notch each intersecting member one-half its thickness, termed a halved scarf joint. This optimizes the joint's rotational strength, providing about three times the rotational and crushing/shear capacity, and it puts both members in the same plane. It does, however, reduce the local sectional area of each member by one-half as well, which similarly reduces the member's axial strength in tension, an important consideration in timber lattice truss design.

Some comparisons were made to plank trusses, particularly those joined with dual treenails. Since the joints of the Cornish-Windsor Bridge were working only under triangular compression and were relatively shallow, their rotational stiffness was only about one-seventh of the rotational stiffness of a dual treenail joint.

Treenail connections, particularly accurately made ones using two treenails, would have been more efficient than the seemingly more-modern bolted connections actually used in the Cornish-Windsor Bridge, but they would have been difficult to execute consistently well on such a large scale.

Lateral Stiffness and Stability

The lateral stability of timber lattice trusses is higher than that of plank lattice trusses. This is due to the greater stiffness of square members compared to planks, and it depends very little on the rotational stiffness of the web joints. Since the need for lateral stiffness increases dramatically as span length increases, this was probably the primary reason the notched squared timber design was selected for the Cornish-Windsor Bridge.

Splices in Lower Chords and the Addition of Glulam Timber

This analysis indicated that continuity in the lower (tension) chords was more important for timber lattice trusses than for their plank lattice cousins. Whether because of engineering analysis or an understanding based on experience, the builder of the Cornish-Windsor Bridge included shear blocks—pieces not normally used in plank lattice trusses—to improve the strength continuity of the chords. Through engineering thoughts or just based on carpentry knowledge the original designers included shear blocks (generally not used in plank lattice trusses). Clearly, the builders understood the importance of chord continuity, even though, at only 1" thick, the original shear blocks were undersized.

The installation of glulam continuous chords in the primary strain areas during the 1989 rehabilitation corrected these deficiencies and assured the necessary safety factor for modern live loads. The introducing of glulam elements necessarily included new mechanical joints and fasteners. Compared to the original joint work, these modern joints were well engineered and executed. The only remaining question, one that only time can answer, is the long-term compatibility of these modern components and connections with the original materials and joints.

Sources

Allen, Richard Sanders. Covered Bridges of the Northeast. Brattleboro, Vermont: Stephen Greene Press, 1957.

Allen, Richard Sanders. Rare Old Covered Bridges of Windsor County. Brattleboro, Vermont: The Book Cellar, 1962.

American Society of Civil Engineers, Committee on History and Heritage. A Biographical Dictionary of American Civil Engineers, vol. 1. ASCE Historical Publication No. 2 (1972).

American Society of Civil Engineers, Committee on History and Heritage. American Wooden Bridges. ASCE Historical Publication No. 4. New York: American Society of Civil Engineers (1976).

Bacon, Edwin M. The Connecticut River and the Valley of the Connecticut. New York and London: G.P. Putnam's Sons, 1907.

Barna, Ed. Covered Bridges of Vermont. Woodstock, Vermont: The Countryman Press, 1996.

Brock, F.B. "Truss Bridges, An Illustrated Historical Description of All Expired Patents on Truss Bridges." Engineering News and American Contract Journal, October 23, 1882-September 8, 1883.

Burleigh, L.R. "[View of] Windsor Vermont, 1886." Troy, New York: Burleigh Lithographers, 1886.

Child, William H. History of the Town of Cornish, New Hampshire, 1763-1910. Concord, New Hampshire: Rumford Press, 1910.

Colby, Virginia Reed and James B. Atkinson. Footprints of the Past: Images of Cornish, New Hampshire and the Cornish Colony. Concord: New Hampshire Historical Society, 1996.

Condit, Carl W. American Building. Chicago: University of Chicago Press, 1968.

__________. American Building Art: the Nineteenth Century. New York: Oxford University Press, 1960.

Congdon, Herbert Wheaton and Edmund Homer Royce. The Covered Bridge: An Old American Landmark Whose Romance Stability and Craftsmanship are Typified by the Structures Remaining in Vermont. Middlebury, Vermont: Vermont Books, 1959.

Conlin, Katherine E. Chronicles of Windsor, 1761-1975. Taftsville, Vermont: Countryman Press, 1977.

Dana, Richard T. The Bridge at Windsor, Vermont and its Economic Implications. New York, 1926.

Davies, Morgan W. The Theory and Practice of Bridge Construction in Timber, Iron and Steel. London: Macmillan and Co. Limited, 1908.

Delany, Edmund. The Connecticut River: New England's Historic Waterway. Chester, Connecticut: The Globe Pequot Press, 1983.

Dreicer, Gregory K. "The Long Span: Intercultural Exchange in Building Technology: Development and Industrialization of the Framed Beam in Western Europe and the United States, 1820-1870." PhD Dissertation, Cornell University, 1993.

Dwight, Timothy. Travels in New England and New York. New Haven, Connecticut: author, 1821.

Fischetti, David C. Design reports and drawings prepared for the State of New Hampshire, Commissioner of the Department of Transportation, Concord, New Hampshire.

_________. "Conservation Case Study of the Cornish-Windsor Covered Bridge." APT Bulletin 23, no. 2 (1991): p.22-28.

Foster, Margaret. "Freeing the Windsor, VT-Cornish, NH Covered Bridge of Toll Charges." Society for the Preservation of Covered Bridges Bulletin, n.d.

Foster, Margaret. "The Cornish-Windsor Bridge." Connecticut River Valley Covered Bridge Society Bulletin 13, no. 2 (Fall 1966).

Garvin, Donna-Belle and James Garvin. On the Road North of Boston: New Hampshire Taverns and Turnpikes, 1700-1900. Concord: New Hampshire Historical Society, 1988.

Graham, J.A. A Descriptive Sketch of the Present State of Vermont, One of the United States of America. London: Henry Fry, 1797.

Hayes, Lyman S. The Connecticut River Valley in Southern Vermont and New Hampshire. Rutland, Vermont: The Tuttle Company, 1929.

Henry, Hugh H. National Register of Historic Places Inventory-Nomination form: Cornish-Windsor Covered Bridge, 1976.

"In New Hampshire: A Rare Span." Time 128, no. 1 (November 24, 1986): p.13.

Jackson, Donald. Great American Bridges and Dams. New York: John Wiley & Sons, Inc., 1988.

Jacobs, David and Anthony E. Neville. Bridges, Canals and Tunnels. New York: American heritage Publishing, 1968.

James, J.G. "The Evolution of Wooden Bridge Trusses to 1850." Institute of Wood Science Journal 9, nos. 3 and 4, June and December 1982, issues 51 and 52.

Jones, Harvie P. "The Town Lattice Truss in Building Construction." APT Bulletin 15 (1983): p.38-41.

Kelly, Leslie A. "A Link to Our Heritage." Window of Vermont 3, no. 2 (October 1986): p.43, 46-47.

Kenyon, Thedia Cox and Stan Snow. New Hampshire Covered Bridges. Sanbornville: Wake-Brook House, 1957.

Lewandoski, Jan. "The Restoration of the Cornish-Windsor Bridge." Society for Industrial Archeology, New England Chapters, Newsletter 10, no. 1 (1990): p.11-16.

McKee, Brian J. Historic American Covered Bridges. New York: ASCE Press, American Society of Civil Engineers, 1997.

Nelson, Joseph C. Spanning Time: Vermont's Covered Bridges. Shelburne, Vermont: The New England Press, 1997.

New Hampshire Department of Public Works and Highways. "A History of the Proprietors of Cornish Bridge and the Cornish, NH-Windsor VT Covered Toll Bridge (1796-1943)." Concord, New Hampshire, 1983.

New Hampshire Department of Transportation. "The Cornish-Windsor Covered Bridge: Celebrating the Reopening of the Nation's Longest Covered Bridge," Souvenir Booklet, 1989.

Newton, Roger Hale. Town and Davis, Architects. New York: Columbia University Press, 1942.

Pease, G.B. "Timothy Palmer, Bridge-Builder of the Eighteenth Century." Essex Institute Historical Collections 83, no. 2 (April 1947).

Pierce, Philip C. Covered Bridge Manual. Draft ms., n.p., n.d.

Plowden, David. Bridges: the Spans of North America. New York and London: W.W. Norton Co., 1974.

Rawson, Barbara Eastman. History of the Town of Cornish, New Hampshire, 1910-1960. Littleton, New Hampshire: Courier Printing Co., 1960.

Roy, Richard. "Country's Longest Bridge Reopens." Covered Bridge Topics, Spring 1990, p.4-6.

Snow, J.P. "Wooden Bridge Construction on the Boston and Maine Railroad." Journal of Association of Engineering Society XV (July 1895).

_______. "A Recent All-Wood Truss Railroad Bridge." The Engineering Record 60, no. 17 (October 23, 1909).

Stekland, William F. and Evan Hill. The Connecticut River. Middletown, Connecticut: Wesleyan University Press, 1972.

Sweeney, Thomas W. "Arch Rivals Win N.H. Bridge Fray." Preservation News, June 1988.

Town, Ithiel. "A Description of Ithiel Town's Improvement in the Construction of Wood and Iron Bridges: Intended as a General System of Bridge-Building." New Haven, Connecticut: S. Converse, 1821.

Town and City Atlas of New Hampshire. Boston: D.H. Hurd & Co., 1892.

Town, Ithiel. "Letters Patent, Jan. 28, 1820," in Covered Bridges of Georgia by Thomas L. French Jr. and Edward L. French (Columbus, Georgia: French company 1984), appendix.

Vermont Department of Highways. "Covered Wooden Bridges on Public Highways in Vermont, 1939."

Waddell, J.A.L. Bridge Engineering. New York: John Wiley, 1916.

Wade, Hugh Mason. A Brief History of Cornish, 1763-1974. Hanover, New Hampshire: University Press of New England, 1976.

Wagemann, Clara. Covered Bridges of New England. Rutland, Vermont: Tuttle Company, 1931.

Walling, H.F. Atlas of the State of New Hampshire. Comstock & Co., 1877.

White, W. Edward. Covered Bridges of New Hampshire. Littleton, New Hampshire: Courier Printing Company, 1942.

Whitelaw, James. "A Correct Map of the State of Vermont, 1796."

Whittlesey, Charles W. Crossing and Re-Crossing the Connecticut River: A Description of the River from its Mouth to its Source, with a History of its Ferries and Bridges. New Haven: Tuttle, Morehouse & Taylor Co., 1938.

Wilkoff, Jerold. The Upper Valley: An Illustrated Tour Along the Connecticut River. 1985

Wilson, Harold Fisher. "The Roads of Windsor." The Geographical Review XXI, no. 3 (July 1931): p.379-97.

Withey, Henry F. and Elsie Rathburn Withey. Biographical Dictionary of American Architects (Deceased). 1970.

Wright, David W. "Plans for the Authentic Restoration of the Cornish-Windsor Covered Bridge." Westminster, Vermont, 1984.

Ziegler, Phil. Sentinels of Time, Vermont's Covered Bridges. Camden, Maine: Down East Books, 1983.