Deck Plate Girder Highway Bridges

Engineering Significance Study of Three New Hampshire Types

Littleton Bridge 109/134 carrying NH 18 over the Connecticut River, built 1934

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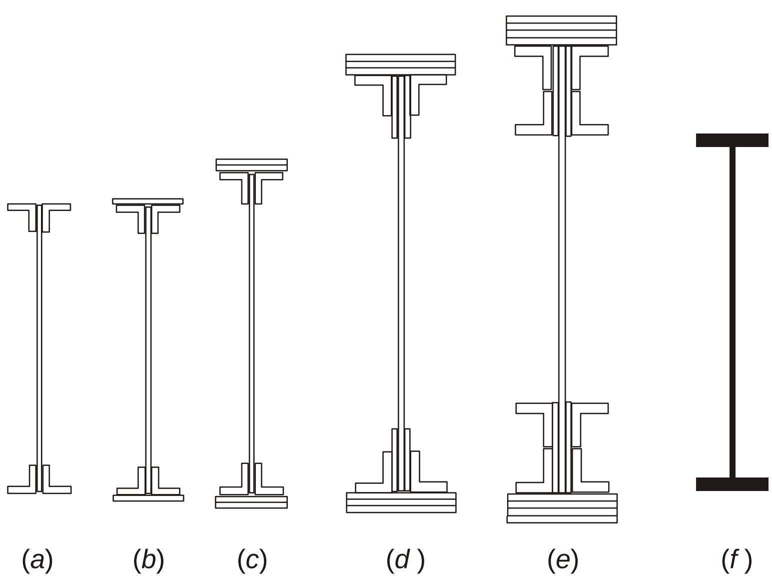
Introduction

The following discussion examines the origins of the deck plate girder highway bridge and the subtypes represented by the Lebanon Bridge 188/126, built 1930 and two other deck plate girder bridges: Littleton Bridge 109/134 carrying NH 18 over the Connecticut River, built in 1934, and Gorham Bridge 092/058 carrying NH 16 over the Peabody River, built 1950. The three bridges represent three different structural bridge types. The Lebanon Bridge, the subject of a separate documentation report, is a simple span riveted deck girder with floorbeams. The Littleton Bridge is a continuous span riveted girder with floorbeams. The continuous girders of the Littleton Bridge are of variable depth with slightly arched bottom flanges, a feature with often both structural and aesthetic purpose. The Gorham Bridge is a simple span multiple girder without floorbeams. For a comparison of the physical characteristics of the three bridges, refer to the accompanying drawings at the end of this section.

Plate Girders

A plate girder is I-shaped in section, "built up" or assembled with steel plates and shapes that are riveted, bolted, or welded together to form a deeper beam than can be produced by a rolling mill. In its simplest form, a plate girder consists of a rectangular steel plate (the web) in the vertical position, to which flanges are riveted or welded along the top and bottom edges. The flanges may consist of an assemblage of angles and plates in a riveted girder, or a single plate in a welded girder. Typically, top and bottom flange cover plates and vertical web-stiffener angles at the ends and intermediate points are added for greater strength.



Typical Bridge Plate Girder Construction
(*a*) simplest type of riveted plate girder with web plate and four angles forming flanges
(*b*) short span type with one full length flange cover plate
(*c*) medium span type with multiple cover plates of varying lengths
(*d*) long and heavy spans, esp. railroads, with extra vertical side plates and multiple cover plates
(*e*) extra heavy railroad spans with added flange angles, side plates and multiple cover plates
(*f*) simplest type, modern welded girder of three plates

Each additional cover plate is usually made progressively shorter and centered on the girder to increase the cross-sectional area of the girder near the middle where the bending moments are the greatest.

In 1847 the first simple span, wrought iron plate girder bridge was erected in America for the Baltimore and Susquehanna Railroad by James Mulholland. Plate girders were widely adopted by the railroads for simple spans up to 100' throughout the nineteenth century, and by 1906 all but an insignificant percentage of short span railroad bridges were of plate girder construction.[1]

In explaining the popularity of simple-span plate girders, bridge engineer Frank Skinner states that

> the stresses in plate girders are somewhat indeterminate and the weight of materials is generally in excess of the theoretical amount required except in very short spans, but they are largely used instead of trusses because of their simplicity, ease of construction, shipment and erection, durability and less liable to injury by accident, more effective mass and rigidity, and best suited for use into positions of small clearance. Almost exclusively used for spans of 30-60 feet, generally used for spans 20-100 feet and occasionally for spans up to 130 feet, and almost exclusively for spans 30 to 60 feet.[2]

Trusses were still preferred for long spans for several reasons. Efficient use of material, and therefore lower cost, is the mark of a good design, and on longer spans the waste represented by the excess material in the solid web of the plate girder became significant. Truss bridges could be assembled at the plant and disassembled for shipment, unlike girders, and girders could not be transported or handled in one piece much beyond 100' in length; also, the extensive field riveting necessary to splice a girder was impractical prior to the invention of the air-powered rivet gun in the late nineteenth century.[3]

In 1900, 24" deep I-beams were the largest the rolling mills were capable of producing. Mills gradually increased in capacity and by the mid-1930s standard-production rolled beams were available up to 36 inches deep, 60 feet long and weighing 300 pounds per foot.[4] These deep rolled beams, with wide flanges for increased strength, were less costly than labor-intensive riveted plate girders and replaced them in many circumstances. The refinement of automated welding machines after World War II and the application of x-ray technology to inspect welds, led to the widespread adoption of welded plate girders over riveted girders during the second half of the twentieth century.

Plate Girder Highway Bridges

During the 19th century and early years of the 20th century, plate girders bridges were used primarily by the railroads who could economically transport and handle their massive size and weight.[5] When used for highway bridges, the most common application was for railroad overpasses where they were easily delivered by rail and lifted into place by a derrick car. Even for fairly short-span highway bridges, trusses remained more popular due to their lighter weight, which equated to lower material cost, lower transportation cost, and usually lower erection cost.

In the early part of the 20th century, plate girders were considered "not well adapted to country highway bridges" due to their excessive strength even in their lightest form and because of the "difficulty in hauling plate girders of any considerable length over country roads." [6] But plate girders had advantages in terms of simplicity and standardization of design, ease and speed of erection, and greater durability, which equated to lower maintenance and life-cycle cost. They were the practical and often economical choice for highway bridges in certain situations including railroad overpasses to eliminate crossings at grade and urban bridges with heavy dead or live loads due to a great width, masonry-paved roadways or the addition of street railway tracks.

By 1908, designs for plate girder highway bridges up to 109' span were appearing in engineering textbooks and steel fabricators including the American Bridge Company were offering pre-engineered standard production plate girder highway bridges in various lengths.[7] During the second decade of the 20th century, state highway departments were formed and staffed with bridge engineers who developed standard short span bridge designs in steel and concrete. The designs were often made available to county and towns governments free of charge to promote economical and safe bridge construction.[8] By 1920, the Wisconsin Highway Commission for example, had prepared standard plans for plate girder highway bridges in five-foot increments from 35 feet to 80 feet.[9]

Having standard plate girder highway bridge designs on hand saved engineering time and allowed for fast replacement of old lightweight steel truss bridges or wood beam bridges that were failing or bridges destroyed by floods. Plate girder bridges could be ordered and delivered within weeks and dropped into place on the existing abutments with often only minor alterations to the substructure.

Early Examples

The earliest example of a plate girder highway bridge found in the engineering literature is the Dean Road Bridge over the Boston & Albany Railroad tracks in Brookline, Massachusetts, built in 1891 by the Town of Brookline. It was a through bridge, with girders "about 63' long, 4 ft. 9 ins. deep at the ends and about 6 ft. at the middle with the top chord curved to a radius of 318 feet." [10] Each girder weighed 10 tons and was hoisted into place by a rail steam derrick. When a highway was elevated to pass over the railroad, overpass bridges were usually of the through bridge design (roadway carried on the lower flanges and passing through the girders) to limit the height of the abutments and amount of filling required in the approaches. Through bridges are also commonly used when passing over streams with low banks to provide the maximum under clearance to accommodate floods.

The State Street Bridge, built in 1892 over the Rock River in Rockford, Illinois is the earliest example found in the literature of a plate girder highway bridge not built by or associated with a railroad. It was designed, however, by a well-known railroad engineer, De Clermont Dunlap, during his brief stint of civic employment as City Engineer for Rockford. Dunlap designed a long and heavy through bridge, 60' wide, consisting of five 90' spans. The girders were 8' deep with 3/8" thick webs that in turn carried 4' deep plate girder floor beams. The floor system consisted of timber stringers, wood plank decking and 5" thick vertical grain cedar block paving. The total thickness of the beams and floor system left about 3' of girder above the roadway to serve as railings, a typical design feature of through plate girder bridges.[11]

The Spring Avenue Bridge over the Poestenkill River in Troy New York, built in 1894, is the earliest example found in the literature of a deck plate girder highway bridge. It had a "solid floor system" of the steel buckle-plate and concrete type, predecessor of the modern orthotropic bridge decks. Buckle plate and steel trough type decks were in use at the time by the railroads, but this was one of the earliest highway applications. The City Council had specified a deck bridge with a granite-paved roadway and bluestone curbs and sidewalks. This heavy dead load, coupled with a deck width of 60 feet and clear span of 96 feet, necessitated deep girders of heavy construction. Three girders were used, each 105' long, 9'-6" deep and weighing 36 tons. Today the structure would be classified as a multiple girder and floorbeam bridge. The girders were shipped by rail in one piece and delivered to the site with heavy carts built for the job.[12]

Deck Girder Bridges

Deck bridges, where the roadway is carried on the top flanges, are usually more economical than a through bridge and possess several inherent advantages particularly for highway applications. According to renown bridge engineer J.A.L. Waddell, "whenever there is a real choice between a deck structure and a through structure for any crossing, or any portion of a crossing, the deck structure will nearly always be found the more economical for two reasons: first, the piers for the deck bridge will be lower, shorter and smaller than for the through bridge; and second, there is often, but not always, a saving in the cost of the superstructure." [13]

Probably the greatest advantage of the deck design for highway bridges is their ability to be easily widened in many cases, as was done in 1957 with the Lebanon Bridge. Deck girders also allow for closer spacing of the girders, which in turn allows the floorbeams to be cantilevered beyond the girders to carry part of the roadway or sidewalks with a resultant cost savings. [This was also done of the Lebanon Bridge]. Other advantages of deck bridges: easier snow removal, the girders not subject to damage from collisions and the flanges and web are better protected from weather and corrosive agents.

By the 1930s the deck bridge had become the preferred type for highway bridges. With the dramatic increase in the number and speed of automobiles another important advantage of the deck type became more apparent to highway engineers. Unlike a through bridge, a deck bridge provides an unobstructed view, creates less anxiety in the motorist in terms of feeling hemmed in, and allows greater speed and safety because the optical illusion of a narrowing roadway is almost entirely eliminated.[14]

Other Types

The Kearney Avenue Bridge over the Erie Railroad tracks in Newark, New Jersey, built in 1900 is an early example of a combined street railway and highway deck plate girder bridge. The bridge was designed to carry two electric railways tracks, two carriageways and two wide sidewalks. The street railway company, the railroad and the city all shared in the cost. The deck design allowed for multiple girders to support wide deck. The bridge was 65' long and 60' wide and consisted of three plate girders with 15" transverse floor beams carrying a jack arch concrete deck.[15] The Kearney Avenue Bridge is also an early example of a multiple girder deck bridge, like Gorham Bridge 092/058, but with floor beams.

The Wabash River Bridge at Terre Haute Indiana, built 1905, was a long (812') and wide (74') deck highway bridge was an unusual combination of half-through trusses on the outside with three lines of deck plate girders between them. The girders were 121'-6" long and 10' deep, and "believed by the designers to be the longest highway plate girder spans yet built." [16] The bridge deck was concrete on buckle-plate construction. It was designed by Malverd A. Howe, Professor of Civil Engineering at Rose Polytechnic Institute in Terre Haute.[17]

Variable Depth Girders

The Dean Road Bridge (discussed above) is also the earliest example found of a simple plate girder span[18] with variable depth girders, described at the time as "girders with non-parallel flanges." [19] The terminology for naming or describing variable depth girders is inconsistent in the literature. In 1906 Skinner describes a bridge with variable depth girders as having "horizontal top flanges and curved bottom flanges." [20] Waddell (1913) also resists assigning a name to the sub-type and simply differentiates between "girders with parallel flanges" and "girders with flanges not parallel." [21] Other writers have referred to girders with "curved" or "inclined" flanges, or simply "variable depth"[22] girders, the term preferred by this author. Continuous girders are often designed with abruptly increased depth for a short section of their length over the supporting piers. The deeper section has become commonly refered to as the haunch of the girder. [Note: The term "variable section girder" was apparently coined by one of the authors of the New Hampshire historic bridge survey in the 1980s to describe girders that vary in depth along their length. It was not found anywhere else in the technical engineering literature and is a misnomer since "section" as used by engineers typically refers to cross sectional area and parallel flange girders with multiple, progressively shorter cover plates are also girders with "variable sections" along their length.]

From the engineering standpoint, varying the depth of a girder makes more economical use of material by increasing or decreasing the depth of section of the girder to coincide with the stresses at various points along its length. However, curved flanges and web plates required additional and careful fabrication steps, the cost of which usually exceeded any savings in material cost. The higher fabrication costs might be justified for aesthetic reasons or other special conditions.

A plate girder footbridge with "inclined upper flanges and lower flanges curved to resemble an arch" was built in 1900 to span 50' over railroad tracks passing through a city park in Madison, New Jersey.[23] It was designed by H.G. Tyrell of Boston Bridge Works and is the eariest example of an aesthetically designed plate girder found in the literature. The arched section was parged with mortar to match the abutments and give the appearance of a slender concrete arch supporting a solid plate railing.

Another example of plate girder highway bridge used for a grade crossing elimination also with "non-parallel flanges" is the Madison Street Bridge over Erie Railroad in Wellsville, New York, a 47' through span built in 1900.[24] The unusual feature of the bridge was the variable depth girders with lower flange inclined to match the rising grade of the approach spans (like a shallow pointed arch) to allow clearance over the center track – an unattractive but apparently functional solution.

The former Water Street Bridge over the Boston and Maine Railroad in Concord, New Hampshire, built 1936, demolished ca. 1996, was similar to the Dean Street Bridge in design but with a span of 121' it was roughly twice as long. It was a through plate girder highway bridge with girders varying in depth from 3'-6" at the ends to 6'-0" at the center, giving the top flange a low arched profile.[25]

Continuous Girder Spans

Littleton Bridge 109/134 is an early example of a continuous plate girder deck highway bridge dating from the developmental years of the type, which began about 1930 and culminated in the early 1940s with the construction of several Class A monumental bridges. A continuous girder (or bridge) can be visualized as a single beam, supported at three or more points along its length. The structural advantage of the continuous girder over a simple span, which is supported only at its ends, results from the bending forces created in the beam over the piers, which counteract and reduce the bending forces in the center of the span. The practical advantages are economy of material, convenience of erection in that no falsework is required, and increased rigidity under traffic.[26]

During the 1930s there was an increasing tendency toward the general use of continuous structures and other statically indeterminate forms. Engineers were gradually overcoming their fear of reversal stresses in continuous girders, principally because of the recent development of mechanical and photoelastic methods of checking stresses in celluloid, metal, or glass models of complex statically indeterminate structures. Models enabled the designers to visualize the behavior of every part of the structure under various conditions of loading, which gave confidence to analytical results and encouraged the use of indeterminate structures.[27]

As engineers gained a better understanding of the elastic properties of steel, it became apparent that adjustment of reactions for small settlements of the piers was unnecessary for continuous beam spans. The beams were found to be more limber than originally thought, and by locating the splices at or near points of zero dead load moments, the possibility of unknown moments or shears being locked up in them was eliminated.[28]

Bridge engineers within state highway departments were chiefly responsible for the adoption of the continuous plate girder bridge form. The form was the most economical solution for most elevated and medium span highway bridge applications, and the economic depression demanded that new technologies that afforded economy along with safety be embraced.

Perhaps the boldest and most aggressive highway department to adopt the new bridge form was in Kansas, where between 1933 and 1935 the department designed and supervised the construction of over 50 continuous bridges, a large number of which were plate girders. Savings over simple span structures were estimated at between 10 to 30 percent, covering the increased engineering cost many times over. In addition to the savings in structural steel afforded by the design, a saving was realized by the elimination of expansion joints and a reduction in the number of rockers and bolsters. The greater rigidity reduced deflections by about 50 percent, which allowed shallower concrete deck construction. Additional savings were obtained by reducing the size of the pier caps, elimination of some end floor-beams, and the opportunity to increase the economical span length of the plate girder.[29]

In 1937 the Capital Memorial Bridge in Frankfort, Kentucky was built with a 200' main span making it the longest continuous plate girder in the United States. With its gracefully arched web and bottom flange it also won the “most beautiful bridge of the year award” in its class from the American Institute of Steel Construction. Although more expensive to fabricate, the introduction of the curved bottom flanges on deck plate girders decreased deflections on longer spans with the added benefit of providing a more pleasing appearance.[30]

By 1940 the continuous plate girder deck highway bridge was widely used across the United States by state highway departments because of its many attractive cost and engineering features. Over the second half of the 20th century the continuous deck girder bridge became one of most widely used steel bridge types in the world.

New Hampshire Plate Girder Bridges

The first plate girder highway bridge in New Hampshire was the Tappan Street Bridge over the Mad River, in Farmington, a through span believed to have been built about 1900.[31] The Walpole-Westminster Bridge over the Connecticut River, built 1911, was a three span through plate girder bridge with two cantilever spans and a suspended pin-connected center span. The cantiver spans were variable-depth girders with the bottom flange curved to form a low arch. It was an innovative design by renowned engineer Joseph R. Worcester of Boston. His most famous bridge was the monumental Bellows Falls Steel Arch Bridge built over the Connecticut River in 1905.[32]

Probably the first deck plate girder highway bridge in New Hampshire was a two-span structure built in 1915 to carry Broad Street over the Sugar River in Claremont. It was designed by Storrs and Storrs of Concord and erected by United Construction Company of Albany, New York.[33]

During the 1920s the majority of bridges constructed by the State Highway Department were of reinforced concrete. Prior to the great flood of November 1927, only two plate girder bridges were constructed, both built in 1926: the Newfields-Stratham Swing Bridge over the Squamscott River, a through plate-girder center-bearing manually operated swing span with one through plate girder approach span; and a 91' span plate girder on Crawford Notch Road in Hart's Location.[34]

Among the many replacement bridges built with Flood Emergency funding in the wake of the 1927 flood were nine plate girder bridges. All the superstructures were built by American Bridge Company except for the Hart's Location Bridge that was built by the Standard Engineering and Construction Company.[35]

NH Flood Emergency Plate Girder Highway Bridges Built 1928		
Town	**Location**	**Spans – Lengths**
Bethlehem	Gale River	1 - 65'-10"
Carroll	Little River	1 - 65'-10"
Campton	W. Campton	2 - 105'-4"
Campton	Branch Brook	1 - 85'-4"
Carroll	Fabyans	1 - 97'-4"
Gorham	Moose Brook	1 - 53'-4"
Hart's Location	Saco River	1 - 94'-0"
Rumney	Baker River	1 – 97'-4"
Warren	Lane Brook	1 – 97'-4"

In 1930 another large plate girder bridge, almost as large as the Lebanon Bridge, was built in Franklin over the Pemigewasset River. Franklin Bridge 152/110, replaced in 1994, was 394' overall. Three of the five spans were deck plate girders. Simple-span riveted deck plate girders bridges continued to be built by New Hampshire when conditions favored them up through the 1960s when they were mostly phased out by welded girder bridges.

The use of continuous plate girder bridges in New Hampshire began in 1930 with Bartlett Bridge 203/172, a 193' continuous plate girder bridge consisting of two 95'-0" deck spans. State Architectural Historian James L. Garvin compiled the following information on the application of the more advanced continuous girder bridge type:

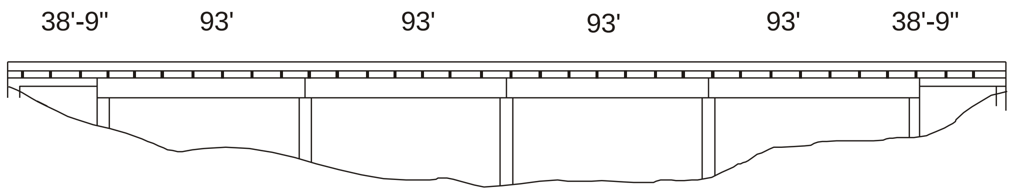
> In 1931, the State Highway Department designed a continuous through plate girder bridge over the Connecticut River between Clarksville and Pittsburg, and another over the Saco River at Bartlett. In 1934 and 1935, the department designed dramatic deck plate girder bridges over the Connecticut River, the first between Littleton and Waterford, Vermont [Littleton Bridge 109/134], and the second – the Ledyard bridge – between Hanover and Norwich, Vermont. Both bridges were continuous structures with graceful girders of variable [depth] section, their curved bottom profiles giving them maximum strength at points of greatest stress. These Connecticut River bridges of the 1930s illustrate the evolution that has taken place in structural analysis and bridge design in the two decades since Worcester built the Walpole-Westminster bridge as a statically determinate structure. The Littleton and Hanover bridges became prototypes for other continuous deck plate girder spans: the Sagamore Creek Bridge in Portsmouth (1941), a bridge over the Boston and Maine Railroad at Lebanon (1945), and a bridge over the Saco River at Conway (1945).[36]

Summary and Significance

Lebanon Bridge 188/126 is an excellent example of a riveted deck plate girder highway bridge dating from the beginning of the peak period of their use that ended during the 1950s and 60s when welded plate girders superseded them. It is a typical example of its type and period without radical features and representative of many thousands of similar bridges built across the US that are becoming increasingly rare due to replacement.

Gorham Bridge 092/058 is significant as an example of how certain features of the deck plate girder bridge technology advanced while other remained the same. The riveted girders themselves remained unchanged in their basic design and remained in popular use due to their exceptional record of safety and service. Advances in the strength of reinforced concrete allowed for stronger and thinner decks which in turn allowed the use of a third center girder and elimination of the floorbeams. These features developed out of the great shortage of structural steel that persisted for nearly a decade after WWII and represent the beginning of the trend in highly engineered and lighter bridge deck design that continues today.

Lebanon Bridge is significant as a very early example of a continuous plate girder deck highway bridge. It dates from the very beginning of the developmental years of the type, which began about 1930, the same year the bridge was built. It differs in technology from the simple-span Lebanon and Gorham bridges and represents the innovativeness and skill of the bridge engineers of New Hampshire's State Highway Department.

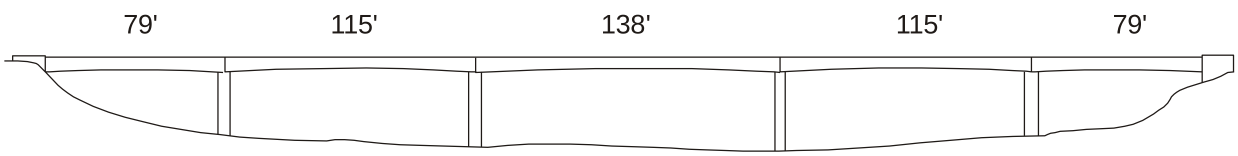


6 SIMPLE SPANS 463' L.O.A.

LEBANON BRIDGE 188/126

US 4 OVER MASCOMA RIVER

BUILT 1930

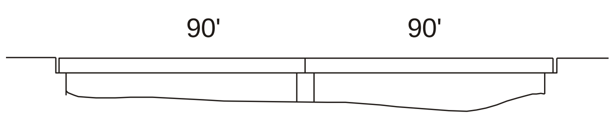


3 CONTINUOUS, 2 SIMPLE SPANS 526' L.O.A.

LITTLETON BRIDGE 109/134

NH 18 OVER CONNECTICUT RIVER

BUILT 1934

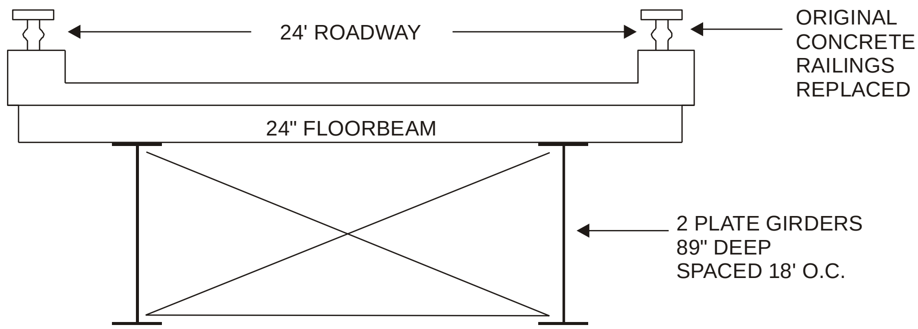


2 SIMPLE SPANS 189' L.O.A.

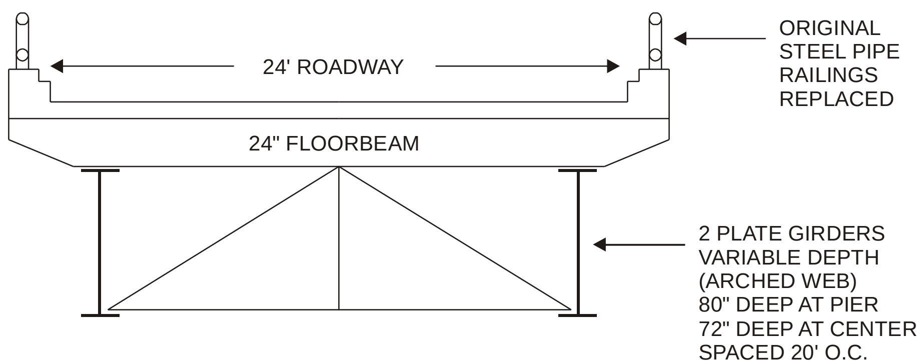
GORHAM BRIDGE 092/058

NH 16 OVER PEABODY RIVER

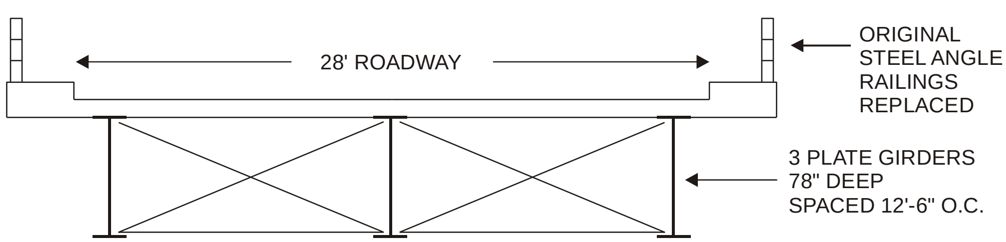
BUILT 1950



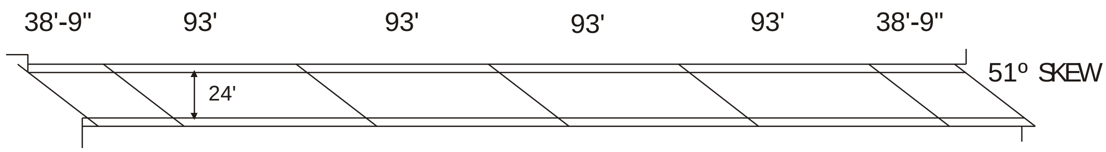
LEBANON BRIDGE 188/126
DECK GIRDER WITH FLOORBEAMS
BUILT 1930



LITTLETON BRIDGE 109/134
CONTINUOUS DECK GIRDER WITH FLOORBEAMS
BUILT 1934

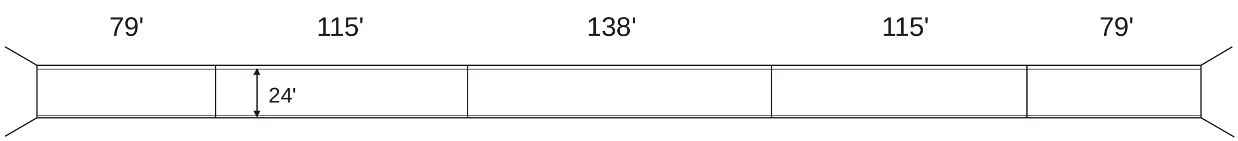


GORHAM BRIDGE 092/058
MULTIPLE BEAM DECK GIRDER
BUILT 1950



6 SIMPLE SPANS 463' L.O.A.

LEBANON BRIDGE 188/126
BUILT 1930



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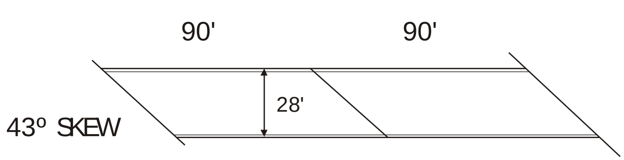
LITTLETON BRIDGE 109/134
BUILT 1934



2 SIMPLE SPANS 189' L.O.A.

GORHAM BRIDGE 092/058
BUILT 1950

Lebanon Bridge 188/126

Lebanon Bridge 188/126

Lebanon Bridge 188/126

Lebanon Bridge 188/126

Littleton Bridge 109/134

Littleton Bridge 109/134

Littleton Bridge 109/134

Littleton Bridge 109/134

Gorham Bridge 092/058

Gorham Bridge 092/058

Gorham Bridge 092/058

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[1] Albert F. Hill, "Riveted Girders," *Engineering News* (April 8,1882):109; Frank W. Skinner, *Types and Details of Bridge Construction, Part II: Plate Girders* (New York: McGraw Publishing Company, 1906), p. 4.
[2] Skinner, *Types and Details of Bridge Construction,* pp. 3-4.
[3] F.C. Kunz, *Design of Steel Bridges* (New York: McGraw-Hill Book Company, 1915), p. 15.
[4] Almon H. Fuller and Frank Kerekes, *Analysis and Design of Steel Structures.* (New York: D. Van Nostrand Company, Inc., 1936), p.107.
[5] Discussion of plate girder highway bridges in the engineering literature prior to 1900 is rare. Structural engineering and bridge design texts typically provide examples and design specifications for plate girder railroad bridges only and in brief passing mention the application of the plate girder for highway bridge. William H. Warren in *Engineering Construction in Iron, Steel and Timber* (New York: Longman Greens & Co., 1894) does not mention highway plate girder bridges. Johnson, Bryan & Turneaure in *Theory and Practice of Modern Framed Structures* (New York: John Wiley and Sons, 1894) in their discussion of web-plate thickness state "in light work, as for highways, a minimum thickness of one forth inch may be used up to a depth of 5 or 6 feet." (p. 325). Nearly the same statement is made by Merriman and Jacoby in *A Text-Book on Roofs and Bridges, Part 3* (New York: John Wiley and Sons, 1894, p.107), except that 5/16 of an inch is specified as the minimum for highway bridge plate girder web plates. Neither discuss of give examples of plate girder highway bridges.
[6] Melville B. Wells, *Steel Bridge Designing.* (Chicago: Myron C. Clark Publishing Company, 1913), pp. 72-73.
[7] See Milo S. Ketchum, *The Design of Highway Bridges of Steel, Timber and Concrete* (New York: McGraw-Hill Book Co. 1908), pp. 222-224. A plan for a standard 80' span through plate girder highway bridge with a solid reinforced concrete floor available from American Bridge Company is reproduced therein.

[8] Parsons Brinkerhoff Quade & Douglas, Inc., *Small Structures on Maryland's Roadways.* Prepared for Maryland State Highway Administration by Parsons Brinkerhoff Quade & Douglas, Inc., Baltimore, Maryland, 1997, pp. 3-11; "County Highway Bridges," *Engineering Record* 61 (January 22, 1910):89-90; "Highway Bridges in Illinois," *Engineering Record* 61 (March 19, 1910):318.

[9] Milo S. Ketchum, *The Design of Highway Bridges of Steel, Timber and Concrete* (New York: McGraw-Hill Book Co. 1920), p. 167.

[10] "Plate Girder Highway Bridge: Brookline, Mass." *Engineering News* (September 19, 1891):257.

[11] "The State Street Plate Girder Bridge." *Engineering News* 27 (February 27, 1892):205

[12] "The Spring Avenue Bridge, Troy, N.Y." *The Engineering Record* 32 (November 30, 1895): 471-472.

[13] J.A.L. Waddell, "Suitability of the Various Types of Bridges for the Different Conditions Encountered at Crossings." *Journal of the Western Society of Engineers* 32 (October 1927):2.

[14] C.W. Ogden, "The Modern Trend in Bridge Design," *Civil Engineering* (June 1937):402-405.

[15] "A Plate Girder Bridge with Concrete Floor." *The Engineering Record* 42 (October 6, 1900):323.

[16] "The Highway Bridge over the Wabash River at Terre Haute," *Engineering Record* 51 (June 17, 1905):672-675; Malverd A. Howe, "The Wabash River Bridge at Terre Haute, Indiana," *Engineering News* 55 (March 8, 1906):273-275.

[17] Malverd A. Howe is known for two early engineering texts, *The Theory of the Continuous Girder* (1889) and *A Treatise on Arches* (1906).

[18] Simple girder spans are beams supported only at each end, as opposed to continuous girder spans which are beams having one or more intermediate supports.

[19] "Plate Girder Highway Bridge: Brookline, Mass." *Engineering News* (September 19, 1891):257.

[20] Skinner, 1906, p. 323.

[21] J. A. L. Waddell, *Bridge Engineering,* vol.1. (New York: John Wiley and Sons, 1916), p. 433.

[22] Emory Bond and Gene E. Ellis, "Vertical Clearance Without Center Pier," in *Welded Interstate Highway Bridges*, James D. Clark, editor. (Cleveland, Ohio: James F. Lincoln Arc Welding Foundation, 1960): 55.

[23] "Plate Girder Park Foot Bridge at Madison, N.J.," *Engineering News* 44 (August 23, 1900):134.

[24] "The Wellsville Over-Grade Bridge," *Engineering Record* 42 (August 4, 1900):101.

[25] "Water Street Bridge." Historic American Engineering Record No. NH-29. Prepared by the Preservation Company, Kensington, New Hampshire, 1996.

[26] Gustav Lindenthal, "Bridges With Continuous Girders," *Civil Engineering* (July 1932):421; Frank W. Skinner, *Types and Details of Bridge Construction* (New York: McGraw-Hill Publishing Company, 1906), p. 3.

[27] Harold Hughes Bird, *The Practical Design of Plate Girder Bridges* (Philadelphia: J.B. Lippincott, 1920); H.H. Houk, "Developments in Highway Bridge Design," *Civil Engineering* (December 1935):763-767; Clarence W. Hudson, *Notes on Plate Girder Design* (New York: John Wiley & Sons, 1911).

[28] C.W. Ogden, "The Modern Trend in Bridge Design," *Civil Engineering* (June 1937):402-405.

[29] George W. Lamb, "Continuous Spans Favored for Kansas Highways," *Engineering News-Record* (November 21, 1935):702-705.

[30] E.D. Smith, "Building a Beautiful Bridge," *Engineering News-Record* (December 21,1939):59-61.

[31] "Bridge Building in New Hampshire, An Historic Overview." Anonymous typewritten manuscript located in "Historic Bridge Survey" binders shelved in the Bridge Section, NHDOT. Presumed written about 1988 by John W. Moore, a NHDOT bridge engineer.

[32] "Walpole-Westminster Bridge." Historic American Engineering Record No. NH-13. Prepared by Christopher W. Closs Planners, Inc., Concord, New Hampshire, 1988.

[33] "John William Storrs/Storrs and Storrs, Concord, New Hampshire." Anonymous typewritten manuscript located in "Historic Bridge Survey" binders shelved in the Bridge Section, NHDOT. Presumed written about 1988 by John W. Moore, a NHDOT bridge engineer.

[34] "Newfields-Stratham Swing Bridge." Historic American Engineering Record. Prepared by 2000 by Louis Berger Group, Needham, Mass.; Fourth Annual Report of the State Highway Department of New Hampshire (Concord) 1927, p. 76.

[35] "Flood Emergency Bridges," *New Hampshire Highways,* June 1928.

[36] James L. Garvin, "Bridge Book, volume 2, January 2000 Draft." Unpublished draft manuscript available from the author, New Hampshire Division of Historic Resources, Concord.

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