

Building Bridges and Boundaries

The Lattice and the Tube, 1820–1860

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Questions about technology and nationality smoldered in the nineteenth century, as they do in the twenty-first, when labels of origin—“Made in America,” “Made in China”—still hide as much as they reveal. Globalization, presented today as new, flourished in the 1800s, thanks to growing networks of transportation and communication.¹ Within these networks, technologists and their chroniclers participated in the construction of the conceptual and physical infrastructure of the modern nation-states.² They built national identity along with bridges and railroads; with identity came reputation and opportunity. Claims regarding national character and technological significance supported each other. Nationalist perspectives intensified as infrastructure enabled quicker and easier connections across the globe.

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1. Regarding twenty-first-century national labels, see, for example, David Barboza, “Some Assembly Needed: China as Asia’s Factory,” *New York Times*, 9 February 2006, C1, C7: “‘Made in China’ is mostly made elsewhere—by multinational companies in Japan, South Korea, Taiwan and the United States that are using China as the final assembly station.” On the recent (1983) origin of the term *globalization* see “Theodore Levitt, 81; Coined the Term ‘Globalization,’” *New York Times*, 6 July 2006, B7.

2. Geoffrey C. Bowker and Susan Leigh Star consider classification systems as “information infrastructure” that becomes part of the physical environment; see Bowker and Star, *Sorting Things Out: Classification and Its Consequences* (Cambridge, 1999), 5, 33–39.

The classification of technologies as local or foreign reinforces beliefs about national character and the workings of the inventive process. Technology transfer narratives, for example, balance on the idea that invention originates within individuals bounded by “national culture” and spreads like the rays of the sun to individuals in other nations.³ Within the transfer framework, categories such as *British* and *American*, *inventor* and *borrower*, and *wood* and *iron* become substitutes for critical analysis. Taken without examination, a web of such categories enables technology’s storytellers to portray creation myths, nationalist ideologies, and borders as unchanging and inevitable. These identities strengthen professional and political power structures.

Viewing invention as an identity-building activity, however, demonstrates the ambiguity of categories and highlights their cultural roles. Exploring the construction of identity means investigating the people with the authority to engineer the world and make money and history along with it. Treating a label as fluid rather than fixed re-orientates nationalistic and progress-oriented accounts of technological change.

This article examines debates between the technologists who reinvented building with the erection of thousands of lattice bridges (in the United States, Europe, and elsewhere), and the developers of the tubular bridge, who built four (in Wales, England, and Canada). As they considered which type of bridge to build, engineers developed an essential component of the world, the I-beam. Based on primary and historical accounts, this article places a “British” icon, the tube, within the context of its creation: a multinational landscape shaped by an “American” invention, the lattice. It looks at mid-nineteenth century engineers defining technological—that is, cultural—boundaries while developing the fundamentals of industrial production.

The Lattice Phenomenon

An “improvement in the construction of wood and iron bridges” was registered with the U.S. Patent Office on 28 January 1820 by Ithiel Town

3. For opposing interpretations of national engineering differences, see for example Robert A. Jewett, “Structural Antecedents of the I-Beam, 1800–1850,” *Technology and Culture* 8 (1967): 362, and Eda Kranakis, *Constructing a Bridge: An Exploration of Engineering Culture, Design, and Research in Nineteenth-Century France and America* (Cambridge, 1997), 211. Foundational texts on national style are Richard H. Shryock, “American Indifference to Basic Research during the Nineteenth Century,” *Archives internationales d’histoire des sciences* 28 (1948): 50–65, and Nathan Reingold, “American Indifference to Basic Research: A Reappraisal,” in *Nineteenth-Century Science: A Reappraisal*, ed. George H. Daniels (Evanston, Ill., 1972). Critiques of “technology transfer” include J. M. Blaut, “Diffusionism: A Uniformitarian Critique,” *Annals of Association of American Geographers* 77 (1987): 30–47, and Jennifer Tann, “Space, Time and Innovation Characteristics: The Contribution of Diffusion Process Theory to the History of Technology,” *History of Technology* 17 (1995): 143–63.

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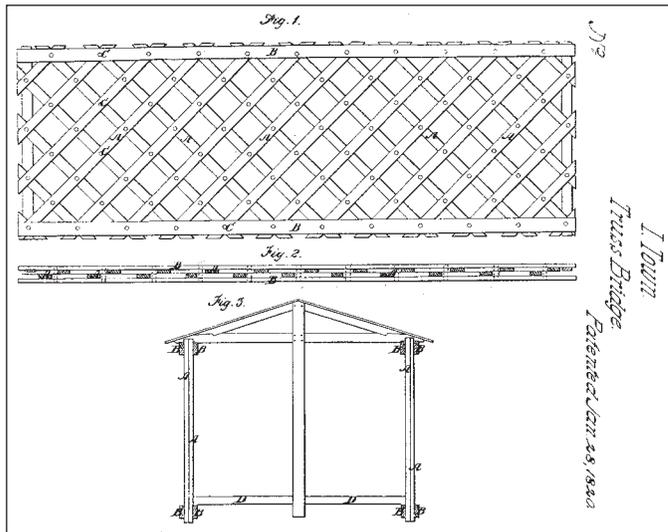


FIG. 1 Ithiel Town, lattice bridge patent, 28 January 1820. (Courtesy of the National Archives and Records Administration.)

(1784–1844) of New Haven and New York, who subsequently became one of the most well-known engineer-architects in the United States.⁴ Town's 1820 and 1835 patents (figs. 1 and 2) for a lattice bridge described a structure that was neither arched nor suspended (as most long spans were) and was designed for manufacture on a mass scale. This framework, with parallel top and bottom chords, contained a lattice of multiple diagonally intersecting planks pegged at the intersections.⁵ It was relatively simple to fabricate and construct, and it allowed long distances to be spanned with relatively short members. The lattice bridge was an industrial milestone that altered the thinking of technologists and helped transform the global landscape.

In the decades following the granting of the 1820 lattice patent, inventors, engineers, and theorists responded—by building it, altering it, condemning it, and using it as an inspiration to create new structures and to devise methods of structural analysis. The dissemination of the lattice concept was enhanced by the growth in technical publishing that took place

4. See Roger Hale Newton, *Town and Davis, Architects* (New York, 1942). There is no adequate biographical work on Town. Town issued advertising brochures in 1821, 1825, 1831, and 1839.

5. Original patent: 28 January 1820. The framework exerted primarily a compressive stress on piers, which meant they could be lighter and thinner than arch-bridge piers, a significant cost saving. Fewer piers were needed because long spans were possible, and the area beneath the bridge was left open for navigation and the passage of ice. The bridge was lighter than others with similar capacity.

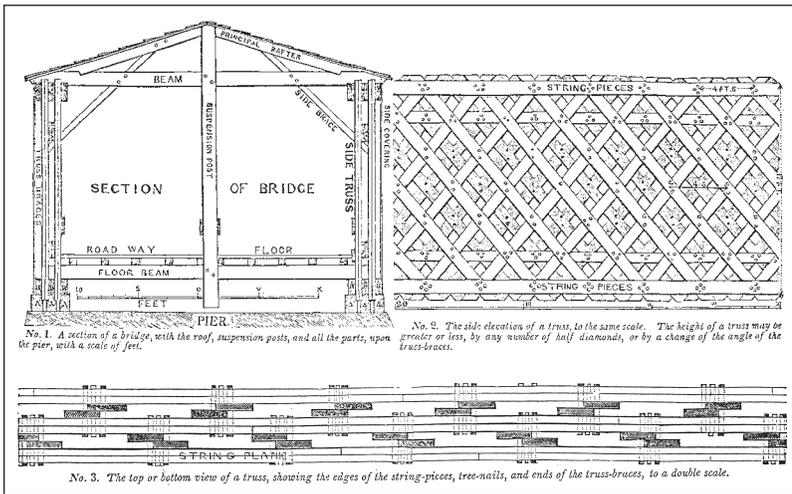


FIG. 2 Illustrations depicting Ithiel Town's lattice bridge patent of 3 April 1835, from *A Description of Ithiel Town's Improvement in the Principle, Construction, and Practical Execution of Bridges, for Roads, Railroads, and Aqueducts* (New York, 1839), 13. (Courtesy of the Library of Congress.)

during the nineteenth century and that facilitated the border-crossing exchange of ideas. The international shipment of U.S. publications was not unusual during an era of popular and professional curiosity about all aspects of American life. Moreover, the lattice bridge design was well suited for graphic reproduction. In comparison to the existing frame systems, it possessed a clarity and uniformity that helped make it an engineering pin-up of the railway age.⁶

News of the lattice idea was spread by engineers including French topographical engineer Guillaume-Tell Poussin (1794–1876), Scottish marine engineer David Stevenson (1815–1886), French engineer and economist Michel Chevalier (1806–1879), Austrian mathematics professor and engineer Franz Anton Ritter von Gerstner (1793–1840), and Bavaria-based engineer and theorist Karl Culmann (1821–1881).⁷ By the late 1830s, engi-

6. Ithiel Town, "A Description of Ithiel Town's Improvement in the Construction of Wood and Iron Bridges," *American Journal of Science* 3 (1821): 158–66, 3 figs.; Ithiel Town, "Some Account of Ithiel Town's Improvement in the Construction and Practical Execution of Bridges for Roads, Railroads, and Aqueducts," *American Journal of Science* 38 (1840): 276–97.

7. Essential texts reporting on the lattice include: Major-General Howard Douglas, *Essay on the Principles and Construction of Military Bridges*, 2nd ed. (London, 1832); Guillaume-Tell Poussin, *Travaux d'améliorations intérieures projetés ou exécutés par le gouvernement général des États Unis d'Amérique de 1824 à 1831* (Paris, 1834–1836); Guillaume-Tell Poussin, *Öffentliche Bauwerke in den vereinigten Staaten von Amerika*, trans. H. F. Lehrtritter (Regensburg, 1836/7); David Stevenson, *Sketch of the Civil Engineering of*

neers had begun to build lattice bridges in France, England, Russia, Austria-Hungary, Prussia, Holland, Ireland, and England. Between 1837 and 1840, for example, William Scarth Moorsom (1804–1863), at the time one of Britain's foremost railway engineers, directed the construction of "at least a dozen" lattice bridges on the Birmingham & Gloucester Railway.⁸

By the 1840s, the lattice had become part of the structural vocabulary; in subsequent years, builders in Europe knew Town's bridge (fig. 3) and the structures of lattice-inspired inventors as "American bridges."⁹ Ten years later, the largest-scale engineering achievements in Europe included long-span lattice bridges. The creations of Town, along with Theodore Burr (1771–1822), Stephen H. Long (1784–1864), and William Howe (1803–1852), became "American" design archetypes, found in engineering texts and general encyclopedias. (I am not using the term *truss* in this essay because of its broad and changing meanings and because lattices were often excluded from the *truss* classification.)¹⁰

North America (London, 1838); Michel Chevalier, *Histoire et description des voies de communication aux États-Unis* (Paris, 1840–1841); Franz Anton Ritter von Gerstner, *Die innern Communicationen der vereinigten Staaten von Nordamerika* (Vienna, 1842); Karl Culmann, "Der Bau der hölzernen Brücken in den Vereinigten Staaten von Nordamerika . . . in den Jahren 1849 und 1850," *Allgemeine Bauzeitung* 16 (1851): 69–129, figs. 387–97, and "Der Bau der eisernen Brücken in England und Amerika," *Allgemeine Bauzeitung* 17 (1852): 163–222, figs. 478–87.

8. See J. H. Garella, "Note sur deux ponts provisoires en charpente construits dans le système américain de M. Town," *Annales des ponts et chaussées* 2, no. 2 (1842): 371–83, pl. 34; De Saint-Claire, "Sur une travée en charpente construite au Vaudreuil, route royale de Mantes à Rouen, dans le système des ponts américains de M. Town," *Annales des ponts et chaussées* 2, no. 1 (1841): 303–9, pl. 9; S. C. Brees, *Railway Practice*, 3rd ed. (London, 1840), pl. 9; Moorsom, in J. R. Mosse, "American Timber Bridges," *Transactions of the Institution of Civil Engineers* 22 (1862–1863): 324–25; J. G. James, "The Evolution of Wooden Bridge Trusses to 1850," *Journal of Institute of Wood Science* 9 (1982): 181; Carl Ghega, *Über nordamerikanischen Brückenbau und Berechnung des Tragungsvermögens der howeschen Brücken* (Vienna, 1845), 62–63; Chas. F. Zimpel, *Das Eisenbahnwesen von Nordamerika, England und anderen Ländern, praktisch und populär dargestellt* (Vienna, 1840), 102; "Geschiedkundige Herinnerlingen betrekkelijk den Ijzeren Spoorweg van Amsterdam naar Haarlem, Leiden . . . en Rotterdam: . . . Kunstwerken," *De Nederlandsche Stoom Post* 31 (1 August 1847): 131–32; and *Tijdschrift van het Koninklijk Instituut van Ingenieurs, Notulen* (1869–1870): 167.

9. By the 1850s, the lattice was known beyond engineering circles in western Europe because of highly visible, well-publicized bridges.

10. Long and Howe were familiar with Town's lattice bridge; they and others referred to it when explaining the Long and Howe bridge patents. The "Howe Truss" began as a modified lattice bridge. See, for example, Stephen H. Long, *Description of Col. Long's Bridges, Together with a Series of Directions to Bridge Builders* (Concord, N.H., 1836), 40, and Lewis M. Prevost Jr., "Description of Howe's Patent Truss Bridge, Carrying the Western Railroad over the Connecticut River at Springfield, Massachusetts," *Journal of the Franklin Institute*, 3rd ser., 3 (1842): 292. In Long's definition, the lattice was not a truss (in order to distinguish it from his patent). A truss is a rigid framework usually consisting of triangulated forms; its joints may be rigid. Regarding truss history, see David T. Yoemans, *The Trussed Roof: Its History and Development* (Hants, UK, 1992). The lattice

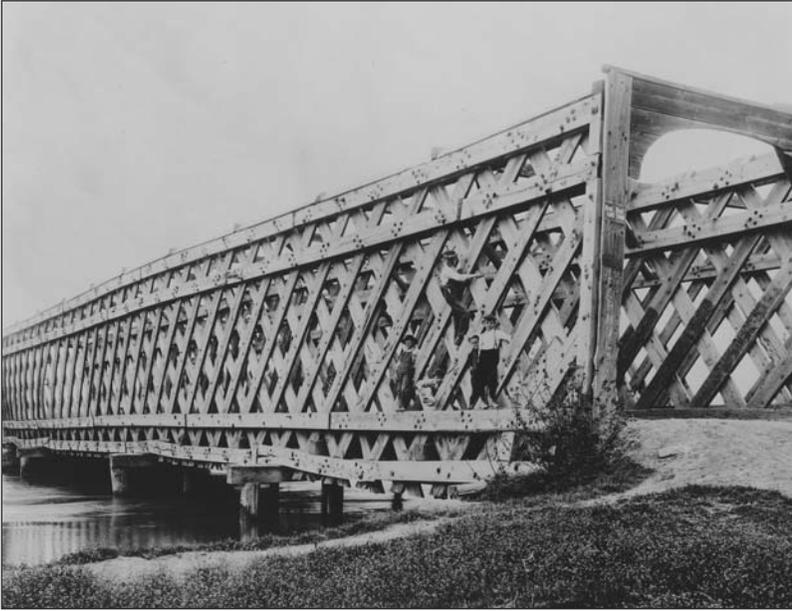


FIG. 3 Lattice bridge, Jordan River, Salt Lake City. (Courtesy of the Smithsonian Institution, National Museum of American History.)

Inventing the Tube

Today, most chroniclers present the lattice as a quaint covered bridge type—a step in an evolutionary scheme of technological development. The Britannia and Conway tubular bridges, on the other hand, constitute a significant historical engineering achievement, described in numerous books and articles. These rectangular, hollow wrought-iron plate tubes were large enough for trains to pass through. Robert Stephenson (1803–1859), one of Britain’s most prominent nineteenth-century railway engineers, developed the tubular bridge with William Fairbairn (1789–1874), an engineer with extensive experience in shipbuilding and the use of wrought iron. The two bridges lay about fifteen miles apart on a line that ran between Dublin and London. Each consisted of a pair of parallel, unattached tubes—one per track. The construction of the bridge over the Conway River lasted from May 1846 to December 1848; it was a “test case” for the Britannia, which was completed in October 1850. There was no precedent in a bridge-building project for the use of wrought iron on such a scale (figs. 4 and 5).¹¹

is sometimes excluded from the truss category because some lattices lacked vertical members.

11. Regarding the Britannia, begin with Nathan Rosenberg and Walter Vincenti, *The Britannia Bridge: The Generation and Diffusion of Technological Knowledge* (Cambridge,

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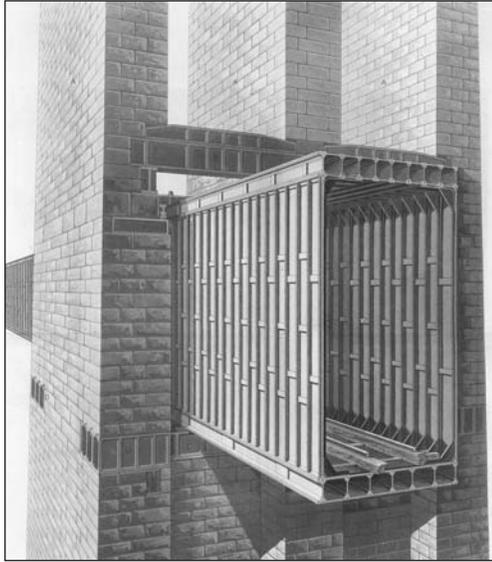


FIG. 4 Britannia Bridge, from William Fairbairn, *An Account of the Construction of the Britannia and Conway Tubular Bridges* (London, 1849). (Courtesy of the University of Chicago Library.)

How did Stephenson come up with his design? He had to span the treacherous currents of the Menai Strait without obstructing shipping with construction scaffolding or elements of the completed bridge. After the Admiralty rejected his plan for a cast-iron arch bridge, Stephenson, according to his own account, considered how a suspension bridge roadway might be made rigid enough for railway traffic. He considered several bridges in which lattices were used as lightweight railings. Stephenson studied, too, a canal aqueduct built by engineer John A. Roebling; he objected to its lattice framework (in combination with a suspension system) because he believed that “a much stronger and more ponderous system” was required, and because “the direction and amount of the complicated strains throughout the trussing become incalculable.” (The “strains”—that is, stresses—would be just as incalculable in a tube.) Finally, he found wood “inadmissible” because of durability and fire risk concerns.¹²

Mass., 1978), and Stanley Smith, “Development and Use of the Tubular Beam, 1830–1860,” *History of Technology* 14 (1992): 108. Smith states that structural designs for which Stephenson is given credit were executed by employees and contractors. The Conway had two 400-foot spans, each box 18 feet 6 inches high and 14 feet 8 inches wide, with nine plate girders on top and seven underneath forming cells. Britannia’s center spans were 460 feet, and the two side spans were 230 feet (over 1,500 tons each).

12. Robert Stephenson, “Introductory Observations on the History of the Design,” in Edwin Clark, *The Britannia and Conway Tubular Bridges* (London, 1850), 1:22–24. An

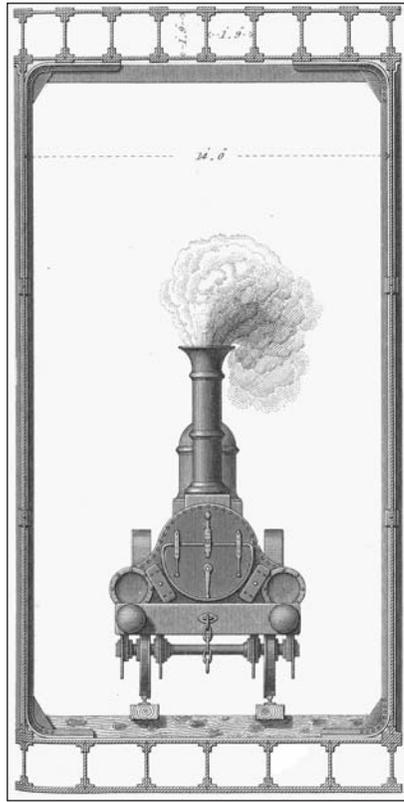


FIG. 5 Britannia Bridge, section, from William Fairbairn, *An Account of the Construction of the Britannia and Conway Tubular Bridges* (London, 1849). (Courtesy of the University of Chicago Library.)

During the period that Stephenson settled on the tube, the “American bridges” were the most widely built bridge types that were tubular in form.¹³

ICE discussion of the Montrose Bridge included mention of the Hammersmith Bridge, stiffened by truss-railings as well as king-post trusses in the center of the deck, and of Telford’s Menai suspension bridge, whose section (as drawn) resembled the section of the tube that Stephenson would build. The Menai bridge had a seven-foot-high, light-weight lattice-rail that was not effective against high winds; see C. W. Pasley, “Description of the State of the Suspension Bridge at Montrose,” *Transactions of the Institution of Civil Engineers* 3 (1842): 19–27, fig. 3. The suspension idea was abandoned late in the tube’s construction; the towers were constructed to accept chains. Regarding Roebling, see Robert M. Vogel, “Roebling’s Delaware & Hudson Canal Aqueducts,” *Smithsonian Studies in History and Technology* 10 (1971): 5–11. When, around 1845–1846, Stephenson argued against the wooden lattice, he neglected to note that between 1843 and 1845, John MacNeill (1793–1880), formerly one of Thomas Telford’s assistants, was responsible for three iron lattice bridges.

13. Before Stephenson’s tubes were complete, a writer in the British journal *Builder*

Study of the lattice frame was instrumental to Stephenson's inventive process, just as it was for many bridge-system designers. But he did not devise a frame structure. According to his own account, Stephenson thought of a proposed wrought-iron plate bridge at Ware over the Lea and then mentally went back to a suspended lattice roadway and Roebling's lattice aqueduct, "substituting for the vertical wooden trellis trussing, and the top and bottom cross braces, wrought-iron plates riveted together with angle-iron. . . . The first arrangement . . . of the tubular structure was exactly similar in form to the trellis trussed wooden design . . . but it was evident that the action of the top and bottom of the tube, composed of thick wrought-iron plates, would be infinitely more efficient than the top and bottom braces, whose duty was chiefly to keep the side trusses in their vertical position"¹⁴ In his mind, Stephenson changed each lattice framework to solid plate and the parallel pair of frameworks to a tube.

Tube versus Lattice: Development and Discourse

Members of the design and construction team, including Stephenson, Fairbairn, engineer Edwin Clark (1814–1894), and Eaton Hodgkinson (1789–1861), an expert in the mechanics of materials, told the tale of the design and construction of the Britannia Bridge in sumptuous publications and through lectures.¹⁵ Questions of technological authorship—which great man deserved the credit?—led to detailed public descriptions. The glow of self-congratulation, however, contrasts with the critical response from the professional engineering community. An examination of the tensions behind the development and reception of the tube reveals the levels of discourse that shaped it: technological and national, professional and personal.

Chief Inspecting Officer of Railways General Charles William Pasley

said of a Howe bridge in Canada: "It will thus be seen that the bridge is a piece of construction in timber, which might call to mind Mr. Stephenson's project for the Britannia Bridge, at least in its appearance, when passing over it"; "Construction and Principles of Timber Bridges," *Builder* 5 (1847): 435. Before the lattice patent, the most widely diffused image of a structural lattice was the floor framework of Hans Ulrich Grubenmann's Schaffhausen Bridge over the Rhine in Switzerland (1757). The choice of the rectangular form for the Britannia probably had much to do with the fact that it could be more readily analyzed and built than a circular form; see Rosenberg and Vincenti, 19.

14. Stephenson, in Clark, 25–26. The suspension structure foremost in his mind was the Montrose Bridge.

15. In addition to Clark, see William Fairbairn, *An Account of the Construction of the Britannia and Conway Tubular Bridges* (London, 1849); G. Dreydale Dempsey, *Tubular and Other Iron Girder Bridges* (London, 1850); and Rosenberg and Vincenti, 57–59. Rapley labels Clark's book a "work of propaganda" written under Stephenson; John Rapley, *The Britannia & Other Tubular Bridges and the Men Who Built Them* (Charleston, S.C., 2003), 8.

(1780–1861), who approved the tubular project when Stephenson was examined before the House of Commons in May of 1845, found Stephenson’s initial scheme for a cast-iron arch bridge to be “crude and ill-digested . . . and either impracticable, or nearly so”; he proposed instead that Stephenson build a suspension bridge “trussed to advantage by wrought-iron lattice work, such as Sir John MacNeil had adopted for passing the Dublin and Drogheda Railway over the Royal Canal near Dublin.” He approved of Stephenson’s tubular plan with a comment—“whether it would be better than a latticed or a trussed bridge, I cannot pretend to say.”¹⁶ Stephenson and his allies subsequently ignored or discredited the lattice and “trussed” structures, such as a bridge invented by William Howe that contained a series of St. Andrew’s crosses with vertical iron tension rods. Richard Boyse Osborne (1815–1899), an English engineer who worked from 1838 until 1845 on U.S. railroads, including the Philadelphia & Reading, recounted a June 1845 meeting with Stephenson during which Osborne showed him a ten-foot model of an iron Howe bridge. Osborne was astonished that “he pronounced my model a Lattice!!” “Mr. Stephenson had evidently ‘*Tube on the brain*,’ he would investigate *nothing else*.”¹⁷

The tubular engineers attempted to eliminate the lattice as a category of long-span bridge construction. When in 1847 five people were killed in the collapse of the River Dee girder bridge at Chester—consisting of cast-iron beams reinforced by wrought-iron bars, and designed under Robert Stephenson—the resulting inquest quickly led to a broader investigation, published as *Report of the Commissioners Appointed to Inquire into the Application of Iron to Railway Structures* (1849).¹⁸ Stephenson, his career in jeopardy, answered about 140 questions on 16 March 1848. At the very end of the interrogation, the subject turned to the lattice:

Have you had any experience as to the stability of lattice bridges?

—No, I have never used them, because my experience in railway bridges has always led me to something more substantial than wood.
[He then goes on to quote a Mr. Stevens of New York re the prob-

16. [Pasley and Stephenson], “The Britannia Tunnel Bridge Over the Menai Straits: General Pasley’s Letter, and Mr. Stephenson’s Reply,” *Journal of the Franklin Institute* 3, no. 14 (1847): 301 (from *Mechanics’ Magazine*); Clark, 65–66. See below regarding the Drogheda bridges.

17. Richard Boyse Osborne, “Diary,” autographed manuscript, 4:21 and 4:28–29 (cited with permission of the Council of Trustees of the National Library of Ireland). Osborne built a Howe bridge of iron in 1846 at Ballysimmon on the Waterford and Limerick Railroad. Osborne, a friend of Howe, built what is called the first all-iron Howe bridge.

18. Peter R. Lewis and Colin Gagg, “Aesthetics versus Function: The Fall of the Dee Bridge,” *Interdisciplinary Science Reviews* 29 (2004): 177–91; R. A. Buchanan, *The Engineers: A History of the Engineering Profession in Britain, 1750–1914* (London, 1989), 184–85. Lewis and Gagg, 178, note that Pasley was dismissed after the collapse of the Dee bridge, which he had approved.

lems of wooden lattice bridges, and states that he prefers to use wood in “whole logs” rather than “slices.”]

Does that objection equally apply if you make lattice work of wrought iron, on something like the principle of Sir John MacNeil’s?

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—No, it does not apply certainly; but a new difficulty there starts up, that it is utterly impossible to convey compression through that bridge when made of thin bars of iron; the base upon which the strains have to pass is so narrow, that it becomes, to use a north country expression, ‘wabby’; the lattice bridge is the same as the sides of the tubes in the Conway. Suppose you went on with a lattice work, until you closed it all up; it then becomes the sides of a tube.

There is no provision for the compression of the top of the lattice girder?

—Yes, that is just the objection. At Dublin, Sir John MacNeil has remedied that by putting a cast-iron top to it.

[The Witness withdrew.]¹⁹

Stephenson’s strategy was to construct a tubular category distinct from the lattice, which he portrayed as irreparably defective. He classified the lattice as wooden, which branded it flammable and obsolete. When confronted with the existence of an iron lattice, he prescribed the use of cast iron. The failure of a cast-iron beam, however, was the cause of the Dee bridge collapse, which led to the royal investigation; a jury had subsequently declared cast-iron bridges “unsafe.” In other words, Stephenson presented the lattice as a type that could not be salvaged.²⁰

A remarkable denial of the lattice occurred within the extensive and expensive design-phase testing program, conducted 1845–1847 by Fairbairn with the collaboration of Hodgkinson. The tests became an essential part of tubular legend and a noted event in the history of strength of materials. In their classic history of the Britannia Bridge, Nathan Rosenberg and Walter Vincenti claimed that the dissemination of test results was the structure’s prime legacy.²¹ The testing focus was on the form and proportions of

19. UK Parliamentary Papers, *Report of the Commissioners Appointed to Inquire into the Application of Iron to Railway Structures* (London, 1849), 340. Regarding issues such as “wabby-ness,” see Gregory K. Dreicer, “The Long Span. Intercultural Exchange in Building Technology: Development and Industrialization of the Framed Beam in Western Europe and the United States, 1820–1870” (Ph.D. diss., Cornell University, 1993), 231, 250–57.

20. Lewis and Gagg, 182–84; UK Parliamentary Papers, *Report of the Commissioners*, 359. Stephenson’s observation that the tube was a “closed-up” lattice showed he had considered both and indicated what he was to discover (if he didn’t know already): that the tube, like the lattice, was “wabby”—and that this could be treated with vertical members. Per Michael Bailey, ed., *Robert Stephenson: The Eminent Engineer* (Burlington, Vt., 2003), 91 and 158, Stephenson was skilled at giving evidence and negotiating; historians such as Bailey, and Lewis and Gagg, have begun to analyze the dark side of this skill.

21. Rosenberg and Vincenti (n. 11 above), 29. For example, they state that the results

the tubes and the cells that would best provide for rigidity, lightness, and strength; the need for suspension chains; and the strength of iron. For about a year following May 1845, the designers tested cylindrical, elliptical, and rectangular tubes, as well as built-up I-beams.²² But an astonishing fact remains. The engineers of the tube did not test their system against its inspiration and rival, the lattice. They did not wonder, as General Pasley had, how the tube compared to the lattice. Subsequently, by adopting the tubular engineers' perspective, historians neglected the basis and context of the tube's development. Historians made the builders' construction of history everyone's history.

The tubular builders' view of their own achievements did not correspond with contemporary technologists' perspectives. In a recent look at reactions to the tube in Britain and the United States, historian Stanley Smith wrote that "within 15 years the tubular solution had started to fall into disfavor, and after 1860 very little more is heard about large span structures of this type." This, Smith continued, was because "change . . . had taken place with regard to economics" during the years after the construction of the Britannia.²³ Money was certainly an issue, but engineers were dubious from the beginning of the costly and controversial project. Although they regarded the Conway and Britannia as unprecedented, the bridges seemed to upend the tenets of industrial engineering. Efficient use of money and materials seemed not to apply. Technologists and their chroniclers define terms such as *economic* and *American* according to the case; in this one, Stephenson constructed meanings for engineering efficiency that contrasted with the views of many of his contemporaries.

Stephenson did not convince engineers that the tube was viable as a bridge type. Eugène Flachat, whose importance to railway construction in

of Hodgkinson's test of thin wall structures were used for forty years. It was important, the authors concluded, for information it provided about the use and performance of wrought iron in structures. Otherwise, the "tubular bridge . . . merits not much more than a footnote as far as the history of bridge building is concerned" (pp. 67–68).

22. By February 1846, tests confirmed the rectangular iron-plate tubular design. From July 1846 to April 1847, tests were conducted on a one-sixth scale model. William Pole, in J. C. Jeaffreson, *Life of Robert Stephenson* (London, 1864), II:86, 91. The tests were criticized; see, for example, Smith (n. 11 above), 123; "Railway Bridges," *Engineer* 9 (1860): 157; D. J. Jourawski, "Remarques sur les poutres en treillis et les poutres pleines en tôle," *Annales des ponts et chaussées* 3, no. 2 (1860): 128; [Auguste] Dallot, in "Procès-verbaux" (19 January 1866), *Memoires et comptes rendus des travaux de la Société des Ingénieurs Civils* (1866): 50.

23. Smith, 101 and 123–24. Smith claims that criticism came mainly from younger engineers at the ICE, Irish engineers, and Zerah Colburn; in fact, criticism came from many sources. According to historian J. G. James, the "economic unsoundness" of the Britannia Bridge "was repeatedly shown by almost every continental writer on design over the next 20 years." J. G. James, "Some Steps in the Evolution of Early Iron Arched Bridge Design," *Newcomen Transactions* 59 (1987–1988): 153. Engineer-historian Henry Petroski claims that to the railway company, "Stephenson's scheme appeared to be the most economical means of achieving the desired results within the constraints of the time"; Petroski, "The Britannia Tubular Bridge," *American Scientist* 80 (1992): 221.

France rivaled Stephenson's in Britain, wrote admiringly in 1851 of the tubular project and the information its engineers provided for the use of iron plate. He did not, however, defend the tube as a type. Karl Culmann compared it unfavorably to other bridges. In 1855, D. J. Jouravsky in St. Petersburg, who only skimmed "the well-known flaws of the system," felt that the tubular builders had made a "grave error in the arrangement of the iron plates in the parts of the tube subject to tension," which would lead to rupture. Émile With, in his railroad handbook of 1857, explained the gravity of the potential problems: rust would be difficult to detect, since the cells couldn't be examined; tubes presented more of a surface to the wind than lattice bridges, a condition that would loosen the rivets; and the rivets added a great deal of weight—30 percent of the total. Alfred Bommart, a French member of the jury at the international exhibition in London, stated that the iron walls "by themselves offer no resistance to buckling," "they imprison the view while crossing the bridge," and their "heavy and unsightly appearance [is] completely in conflict with the impression that should result from the nature of the material used." He went on to state that for the last ten years, most metal bridges were constructed of lattice "suivant le mode américain."²⁴

According to Smith, debates among engineers working in Britain illuminated the engineering conflicts that often divided a younger, formally trained generation of engineers from their elders, who had learned on the job—although some lattice builders, such as Moorsom, were no longer young. Debates also seemed to pit Irishmen against Englishmen.²⁵ Tension surfaced in a meeting of the Institution of Civil Engineers [ICE] on 23 April 1850 in London, when William Thomas Doyne (1823–1877), who earlier in his career had worked under MacNeill, presented his recently built wrought-iron lattice bridge on the Rugby and Leamington railway. Referring to Stephenson and Brunel, Doyne noted that the "prejudice amongst engineers against this mode of construction" was based on poorly designed examples. He explained, in detail, the lattice's advantages of

24. See Eugène Flachet, "Introduction," in L. Yvert, *Notice sur les ponts avec poutres tubulaires en tôle* (Paris, 1851), xix–xxiv (Flachet was involved in the design and construction of early box-girder bridges in France at Clichy [1851] and Asnières [1852]); Culmann, "Der Bau der eisernen Brücken" (n. 7 above), 179–80 (Culmann felt [185] that the strengthening of the tube over the piers was similar to strengthening of the struts and tension rods of the Howe bridge); D. J. Jouravsky, *Remarques sur la résistance d'un corps prismatique et d'une pièce composé en bois ou en tôle de fer à une force perpendiculaire à leur longueur* [extract and translation from a Russian-language publication] (St. Petersburg, 1855), ii and 38–48; Émile With, *Nouveau manuel complet de la construction de chemins de fer* (Paris, 1857), 115–16 (With did state that the "American bridges" [i.e., lattice bridges] had similar rivet issues and that further study was required); and Bommart, "Travaux publics," in *Exposition universelle de Londres de 1862: Rapports des membres de la section français du jury international sur l'ensemble de l'exposition*, ed. Michel Chevalier (Paris, 1862) 3:406–7.

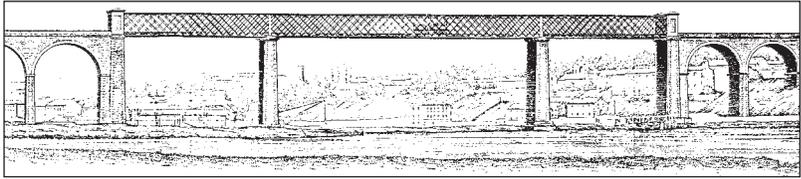
25. Smith, 122 and 125–26.

“economy and facility of construction,” particularly in relation to iron plate (the tubular material). Reacting to the obfusatory arguments of Stephenson, Doyne clarified: “all the parts [of the lattice] perform the same duties as in boiler-plate girders, and are subject to the same rules for calculating their strength.” In response, George Parker Bidder (1806–1878), an eminent railway engineer who enjoyed close personal and professional relationships with Stephenson, stated, in short, that the tube was better. He gave his opinion, he said, “with a desire to guard the younger members of the profession from adopting [the lattice] form and disposition of material”; Bidder apparently feared that the lattice would subvert—perhaps Americanize—engineering training in Britain.²⁶ The professionalization of engineering and the industrialization of construction created a divide that engineers could view in technological and national terms.

James Barton, the engineer in charge of the design and construction of the 264-foot-span Dublin and Belfast Junction Railway bridge over the Boyne River near the town of Drogheda, the most prominent lattice in Britain at the time, presented a paper that ICE engineers discussed during portions of four evenings in April 1855, just after the opening of the bridge (built 1851–1855). Early in his presentation Barton paid homage “to the genius which designed and executed the Britannia and Conway Bridges.” His “anxiety for the advancement of practical science” drove him, however, to claim that the lattice structure was more in line with the action of tensile and compressive forces in a beam, that it required substantially less material than tubular beams, and that it was cheaper than the tubular and even the Warren—a parallel-chord frame bridge consisting of isosceles triangles. In the Boyne Viaduct (figs. 6, 7, and 8), the engineers proportioned the lattice members according to the amount of stress each was to bear, and they designed tension and compression members differently. Barton concluded that “the lattice-beam . . . is, for carrying heavy loads over wide spans . . . theoretically and practically superior both to the plate-beam and the Warren-beam.”²⁷

26. William Thomas Doyne, “Description of a Wrought-Iron Lattice Bridge, Constructed Over the Line of the Rugby and Leamington Railway,” *Transactions of the Institution of Civil Engineers* 9 (1849–1850): 353–59, fig. 15. In 1851 at the ICE, Doyne stated that the lattice, in comparison to tubular and Warren bridges, allowed easier manufacture and assembly, with concomitant savings; Doyne and William Bindon Blood, “An Investigation of the Strains Upon the Diagonals of Lattice Beams, with the Resulting Formulae,” *Transactions of Institution of Civil Engineers* 11 (1851): 110–12.

27. James Barton, “On the Economic Distribution of Material in the Sides, or Vertical Portion, of the Wrought-Iron Beams,” *Transactions of the Institution of Civil Engineers* 14 (1854–1855): 443–52, quote on 451. Barton worked under John MacNeill, engineer in chief of the railroad. The main span of the Boyne Viaduct was 264 ft., with two side spans of 138 ft. The lattice required less material than the tube, and bars were cheaper than plates. The Warren required expensive connections and heavy bars to prevent buckling; in the lattice the interconnections prevented buckling (Barton, “On the Economic Distribution of Material,” 450–51).



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FIG. 6 Boyne Viaduct, from James Barton, "On the Economic Distribution of Material in the Sides, or Vertical Portion, of the Wrought-Iron Beams," *Minutes of the Proceedings of the Institution of Civil Engineers* 14 (1855): plate 6. (Courtesy of the Library of Congress.)

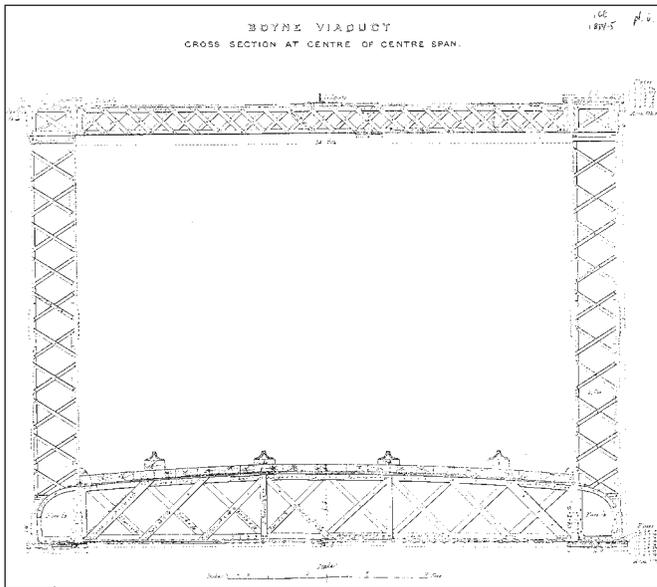


FIG. 7 Boyne Viaduct, cross section, from James Barton, "On the Economic Distribution of Material in the Sides, or Vertical Portion, of the Wrought-Iron Beams," *Minutes of the Proceedings of the Institution of Civil Engineers* 14 (1855): plate 6. (Courtesy of the Library of Congress.)

Stephenson took part in the debate that followed, during which rancor occasionally broke through the polite locutions, and the discussion revealed a variety of beliefs about the behavior of forces in a beam.²⁸ This was a debate about bridges and about who would be the engineering authority. Startling is Stephenson's rejection or misunderstanding of the neutral axis.

28. Several of Stephenson's and Bidder's arguments seem deliberately misleading today; they seemed misleading to their contemporaries as well.

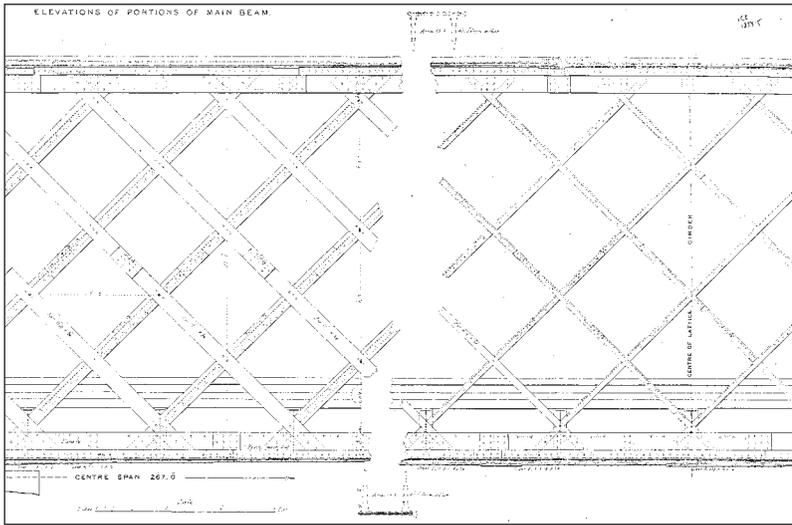


FIG. 8 Boyne Viaduct, lattice beam, from James Barton, “On the Economic Distribution of Material in the Sides, or Vertical Portion, of the Wrought-Iron Beams,” *Minutes of the Proceedings of the Institution of Civil Engineers* 14 (1855): plate 6. (Courtesy of the Library of Congress.)

When a beam is loaded, the top half is in a state of compression (shortening or pushing together), and the lower portion is in tension (pulling or elongation); these forces increase from the unstressed middle, the “neutral axis.” Stephenson, however, claimed that every “particle” of the bridge was subject simultaneously to tension and compression. Hodgkinson had published papers on the neutral axis in 1824 and 1830 (it was not then a new concept), and this had reportedly led to its correct use among engineers in England. Stephenson seemed to disavow a theoretical fundamental—one used in the design of his tubular bridges.²⁹

In March 1856, Stephenson defended his final tubular project, the Victoria Bridge (see below), against the lattice, the Warren, and Roebling’s Niagara suspension railway bridge. He asserted that the lattices would collapse when disconnected from the upper and lower chords, and thus were

29. Stephen Timoshenko, *History of Strength of Materials* (New York, 1953), 127. Hodgkinson’s paper appeared in *Mem. Proc. Manchester Literary and Philosophical Society* 4 (1824). See Isaac Todhunter and Karl Pearson, *History of the Theory of Elasticity* 2, pt. 1 (1893; reprint, New York, 1960), 679–80. In addition to Hodgkinson, Pole and Tate apparently also used the neutral axis concept in the design phase; see S. Tyson, “Notes on the History, Development and Use of Tubes in the Construction of Bridges,” *Industrial Archaeology Review* 2 (1978): 152–53. In another context, Lewis and Gagg (n. 18 above), 183–85, note that Stephenson made “remarkable,” “strange,” and “curious” statements that indicate gaps in his knowledge or honesty.

adding stress to the top and bottom members.³⁰ Barton, who had recently completed the most prominent lattice bridge in Britain, responded to this and several of Stephenson's claims with restrained incredulity.³¹ Historians Rosenberg and Vincenti have acknowledged Stephenson's challenges by emphasizing the unknowns, the time pressure, and the novelty of the tubular project; one should cautiously assess the tubular team's decisions.³² On the other hand, omission of the lattice in testing and arguments that defied the engineering logic of the day, along with the designers' self-promotion, raise questions about the tubular bridge's impact on engineering design. The tube might have been just an unusual and highly publicized case of bridge building, rather than a turning point. Stephenson and Fairbairn were not the only technologists taking inspiration from frame bridges and boilers and producing new forms and knowledge. Baltimore and Susquehanna Railroad engineer and inventor James Millholland, for example, built a 50-foot iron-plate box-girder bridge in the winter of 1846–1847 and installed it in Baltimore in April 1847.³³ That is, a metal box girder, considered a consequence of Stephenson's tubes, was completed while the construction of Stephenson's first tube was only beginning. If the tubular bridge was a turning point, then its significance was more about the end of an engineering era than the start of a new one. The choices engineers made, described in the next section of this article, support this conclusion.

30. Robert Stephenson and Alexander Ross, "Victoria Bridge at Montreal," *Artizan* 14 (1856): 59–61; Stephenson repeated this argument from the previous year; see Barton, "On the Economic Distribution of Material," 472–73. "I must ask you to bear in mind that I am not addressing you as an advocate for a tubular-bridge," Stephenson wrote.

31. James Barton, "On the Comparative Strength of Lattice and Tube Bridges," *Engineering* 9 (1860): 189 [reprint of an 1856 article].

32. Rosenberg and Vincenti (n. 11 above), 30–43.

33. Millholland claimed that at the time of construction, Stephenson was experimenting with cylindrical tubes: "The cylindrical tubes failing, they adopted this plan of bridge." Letter from James Millholland, 1 May 1849, in Herman Haupt, *General Theory of Bridge Construction, Containing Demonstrations of the Principles of the Art and Their Application to Practice* (New York, 1851), 255–56; see also John White, "James Millholland and Early American Railroad Engineering," *U.S. National Museum Bulletin* 252, Paper 69 (1967): 8–9 and 32–33. Zerah Colburn claims that Haupt also built plate bridges on the Pennsylvania Central Railroad; see Colburn, "American Iron Bridges," *Transactions of the Institution of Civil Engineers* 22 (1862–1863): 542–43. From August 1845, Fairbairn had apparently experimented with a rectangular beam, a form he had used in ships; see Jewett (n. 3 above). The form of Stephenson's tubes was decided in December 1846, per Eaton Hodgkinson, "Experimental Inquiries to Determine Strength of Wrought-Iron Tubes," in U.K. Parliamentary Papers, *Report of the Commissioners Appointed to Inquire into the Application of Iron to Railway Structures* (London, 1849), 118. Regarding box structures by Fairbairn and others during the 1830s and 1840s, see Smith (n. 11 above).

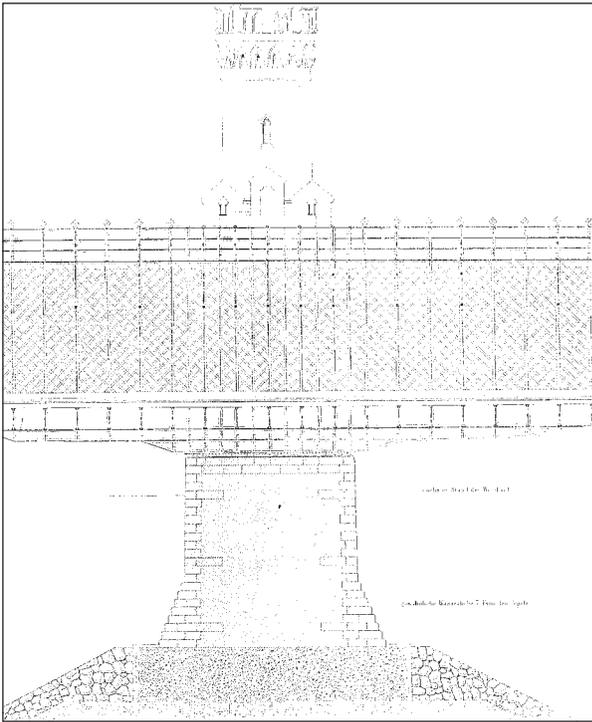


FIG. 9 Bridge over the Vistula at Dirschau (Tczew), elevation, from Karl Lentze, “Die im Bau begriffenen Brücken über die Weichsel bei Dirschau und über die Nogat bei Marienburg,” *Zeitschrift für Bauwesen* 5 (1955): plate 63. (Courtesy of the Library of the Deutsches Museum.)

Lattice versus Tube: Competition

The story of the lattice and the tube illuminates a key moment in the development of industrialized engineering and materials. Is this a clear-cut case of the success and failure of distinct technological types and national engineering cultures? Or does this tale of two bridges depict a multinational collaborative process of invention? To help answer these questions, let us first examine how decision-makers judged the bridges.

The monumental double-lattice bridge project of 1850–1857, carried out in Prussia over the Vistula at Dirschau (figs. 9 and 10) and over the Nogat at Marienburg,³⁴ was comparable to Stephenson’s tubes in scale. Karl Lentze (1801–1883), the engineer in charge for the Prussian *Ostbahn*, traveled and examined bridges in England and France before concluding that a lattice bridge would be lighter, cheaper, and easier to build.³⁵

34. Today, Dirschau (Tczew) and Marienburg (Malbork) are in Poland.

35. Project planning began in the 1840s. Each of the six Dirschau spans was 397 feet

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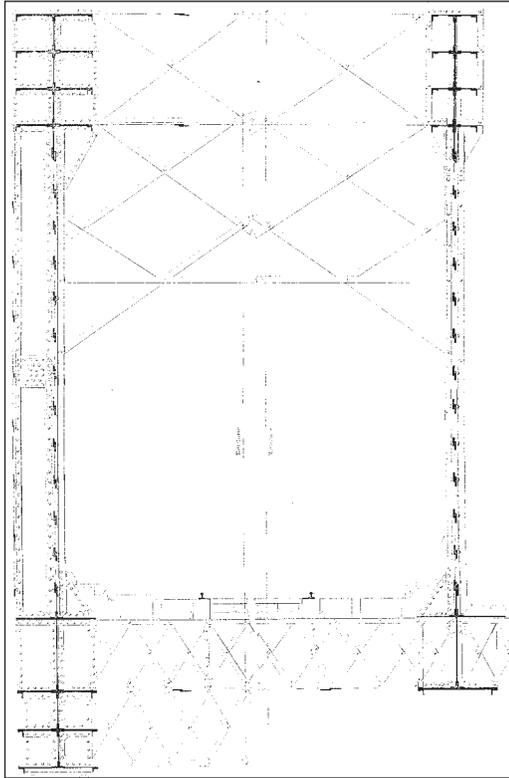


FIG. 10 Bridge over the Vistula at Dirschau (Tczew), cross section, from Karl Lentze, "Die im Bau begriffenen Brücken über die Weichsel bei Dirschau und über die Nogat bei Marienburg," *Zeitschrift für Bauwesen* 5 (1955): plates 64–65. (Courtesy of the Library of the Deutsches Museum.)

Karl Ruppert (1813–1881), a prominent railway engineer who worked in Baden and Austria-Hungary, had a similar opinion. His bridge over the Kinzig at Offenburg (1852–1853) was one of the earliest iron long-span lattices (fig. 11). Ruppert believed that the tubular bridge was ugly; that the lattice bridge was lighter and without question cheaper; that maintaining a

long. A portion of the bridge still exists. See Karl Lentze, "Bemerkungen über die grosseren Brückenbauwerke in Frankreich, England, und Irland auf ein Reise in Winter 1844/45 gesammelt," *Verhandlungen des Vereins zur Beförderung des Gewerbeleißes* (1846): 88–114, figs. 12–17; Lentze, "Die im Bau begriffenen Brücken über die Weichsel bei Dirschau und über die Nogat bei Marienburg," *Zeitschrift für Bauwesen* 5 (1855): 445–58, figs. 42–45, 49, 50a, 58–65, O, P, Q, and R; and Königliches Ministerium für Handel, Gewerbe und öffentliche Bauten, *Die im Bau befindlichen Brücken über die Weichsel bei Dirschau und die Nogat bei Marienburg* (Berlin, 1855). See also the summary in Martin Trautz, *Eiserne Brücken im 19. Jahrhundert in Deutschland* (Düsseldorf, 1991), 63–67.

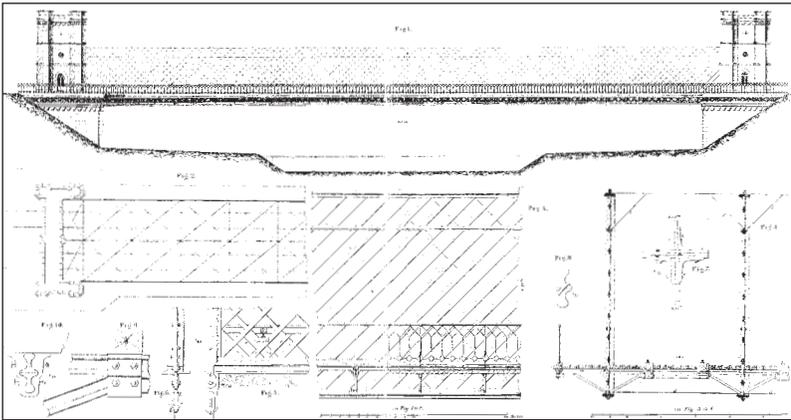


FIG. 11 Kinzig Bridge at Offenburg, from Edmund Heusinger von Waldegg, “Notizen auf einer Reise durch Süddeutschland und die Schweiz über die Tannus und Hessische-Ludwigs-Eisenbahn, die Badische-Bayerische, und Württembergische Staats-Eisenbahnen,” *Organ für die Fortschritte des Eisenbahnwesens* 9 (1854): plates 13–14. (Courtesy of the Library of the Deutsches Museum.)

lattice bridge would be easier, because all of its parts are accessible for inspection and painting; and that the lattice offered less resistance to the wind.³⁶

Tubular engineers had difficulty convincing decision-makers. After the completion of the Conway bridge in 1848, officials in Cologne planning a bridge that would join the banks of the Rhine and serve as a symbol of growing Prussian power invited Fairbairn to Berlin. Despite the intervention of Alexander von Humboldt, who got Fairbairn an audience with King

36. M. Becker [includes portions of the report by Karl Ruppert], “Die Eiserne Brücke über die Kinzig bei Offenburg,” *Allgemeine Bauzeitung* 18 (1853): 179–80. These same advantages, in addition to “the certainty of the [stresses] proceeding in the various channels allotted to them,” were still cited two decades later; see William G. Strype, “Description of the Iron Lattice Girder Road Bridge, Recently Erected Over the River Boyne, at the Obelisk,” *Transactions of Institution of Civil Engineers of Ireland* 9 (1871): 67–78, fig. 10. For a response to Ruppert, see [August?] Prüsmann, “Zur Frage, ob die eisernen Gitterbrücken oder die Blechbrücken den vorzug verdienen,” *Notizblatt, Zeitschrift des Architekten- und Ingenieur-Vereins für das Königreich Hannover* 3 (1854): 207–10; see also G. Boulangé, “Notes recueillies pendant une visite rapide de quelques chemins de fer d’Allemagne,” *Annales des ponts et chaussées* 3, no. 1 (1854): 65. Wind resistance was a concern: after engineer Julius Naehrer traveled from Baden to the Britannia, climbed to the top with Edwin Clark, and stood in the middle, he reported that the tube did not shake or sag when a train passed through, but a “very frightening rocking” resulted from the wind; see Julius Naehrer, “Ueber die Verbindung der Einzelnen Röhrentheile der Britanniabrücke und die Tragfähigkeit derselben,” *Allgemeine Bauzeitung* 17 (1852): 76. Ruppert later designed several lattice bridges without vertical members.

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FIG. 12 Cologne Bridge, with cathedral visible in background. (Courtesy of the Smithsonian Institution, National Museum of American History.)

Friedrich Wilhelm IV, Fairbairn's plan was rejected. "The people of Cologne had declared they would *never* consent to a 15-foot-high bridge that would obstruct the view of Cologne from Deutz!"³⁷ Construction of a lattice bridge at Cologne began in 1855 and ended in 1859 (figs. 12 and 13).³⁸

37. Trautz, 69. Details of Fairbairn's involvement are available in the second edition of his book, *On the Application of Cast and Wrought Iron to Building Purposes* (London, 1854; 2nd ed., 1857–1858); his biographer, Pole, told the story. See *On the Application*, 4th ed. (1870), 319–30, 344–47, figs. 4–6, and William Pole, *Life of Sir William Fairbairn, Bart* (London, 1877): 217–37. See also "The Bridge Over the Rhine at Cologne," *Artizan* 8 (1850): 104, and [Christian Charles Josias] Bunsen to Fairbairn, 20 March 1850, in Pole, *Fairbairn*, 230 (quote). Regarding Friedrich Wilhelm IV, see Erik Grawert-May, "Der Garten des Deus ex machina," *Tagesspiegel* (15 October 1995).

38. An international competition held in 1850–1851 drew 61 entries. First prize went to William Schwedler's suspension bridge design, and Captain W. S. Moorsom received second prize for "a lattice bridge on the American plan"; see Pole, *Fairbairn*, 233, and Moorsom in Barton, "On the Economic Distribution of Material" (n. 27 above), 487. The designs were considered inappropriate ("unbedingt"), and the government again examined bridges in England. Fairbairn submitted tubular and box girder designs with spans greater than the Britannia's (570 ft.). The preliminary lattice design prepared by Regierungs- und Baurath Wallbaum was approved in December 1854 and was reworked by Hermann Lohse, who took over the project; see Hermann Lohse, "Notizen über einige neuere Brücken Englands," *Zeitschrift für Bauwesen* 7 (1857): 216. Regarding the testing



FIG. 13 Cologne Bridge. (Courtesy of the Smithsonian Institution, National Museum of American History.)

The Franco-Baden Commission made the decision concerning the railway bridge over the Rhine at Kehl (built 1858–1861), a politically sensitive link between France and Germany (fig. 14). It selected from three options: a seventeen-span wooden (arch?) bridge, a thirteen-span plate-beam bridge, and an iron “American” bridge of three long spans. They selected the last. By this time, the choice was unexceptional; in Switzerland during the latter 1850s, for example, railways built a number of long-span lattice viaducts. The Kehl bridge’s foundation work attracted at least as much attention as its superstructure.³⁹

of lattice girders, see Hermann Lohse, “Versuche über das Zerknicken der Eisenstäbe in Gitterträgern,” *Zeitschrift für Bauwesen* 7 (1857): 573–82, pl. T.

39. Société Nationale des Chemins de fer Français, “Le pont de chemin de fer sur le Rhin, additif au catalogue de l’exposition ‘Les debuts du chemin de fer à Strasbourg’ à l’occasion du 125e anniversaire du pont de Kehl,” typed manuscript (Strasbourg, 1986). The bridge superstructure was built by the firm Benckiser, in Pforzheim. Engineering theorist Benoît Paul Émile Clapeyron said, regarding the Kehl bridge: “Le pont de Kehl, si remarquable par les procédés adoptés pour les fondations, ne m’a paru offrir rien de particulier en ce qui concerne la superstructure”; see Clapeyron, “Superstructure des ponts en fer,” in *Exposition universelle de Londres de 1862: Rapports des membres de la section français du jury international sur l’ensemble de l’exposition* (Paris, 1862), 3:417. Lattice viaducts constructed in Switzerland included those at St. Gallen, Berne, and Fribourg (completed 1856, 1858, 1862, respectively).

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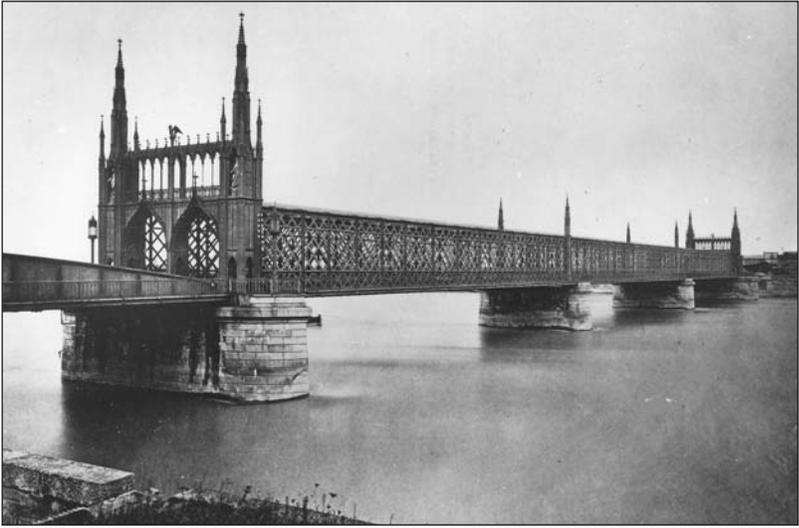


FIG. 14 Kehl Bridge. (Courtesy of the Smithsonian Institution, National Museum of American History.)

And the tube? Two were subsequently built, both under Stephenson. One was in England: the Brotherton Bridge across the Aire (1851), where he finally built a bridge with an elliptical top (always his first choice) and without stiffening webs—the government, however, forced him to cut the top open and make it square.⁴⁰ His final tube project was the Victoria Bridge (fig. 15), built over the St. Lawrence at Montreal. Stephenson reportedly was put in charge in order to attract investors. It gave him the opportunity to realize his invention on a grand scale, and to do it in North America.⁴¹

Six years passed between the completion of the Britannia and the start of the Victoria. Again there were disputes about engineering authorship. A lavish Victoria Bridge book appeared soon after the bridge's opening in

40. Smith (n. 11 above), 115. Stephenson was responsible for two bridges (contracted 1850–1851, built 1853–1855) in Egypt, near Benha over the Damietta branch of the Nile and across the Karrineen Canal at Birket-el-Saba for the Alexandria and Cairo Railway. Trains rode atop 6.5-foot-deep box girders manufactured in England and assembled on-site. See Bau-Inspektor Wild, “Bridge at Benha, on the Alexandria and Cairo Railway,” *Civil Engineer and Architects Journal* 16 (1853): 425, fig. 36, and Pole, in Jeaffreson (n. 22 above), II:68–69, 173–79. Regarding the alteration of the Brotherton Bridge, see J. M. Sutherland, “The Introduction of Structural Wrought Iron,” *Newcomen Society Transactions* 36 (1963–1964): 82–83.

41. Its 1.75-mile overall length contained over a mile of side-by-side tube. The Britannia design was altered, for example through the substitution of built-up I-beams for the stiffening cells in the top of the bridge. Manufactured in England, the tube was shipped in pieces to Montreal and assembled on scaffolding. See Smith, 101–8, and Stanley Triggs et al., *Victoria Bridge: The Vital Link* (Montreal, 1992), 55–68.



FIG. 15 Victoria Bridge, c. 1865. (Courtesy of the Smithsonian Institution, National Museum of American History.)

1860. Another book published that year referred to the structure as the “eighth wonder [in] the world’s museum” and “another trophy to the power of mind over matter.” The encomia were less convincing this time around; a lengthy appendix in the book defended the tube against the lattice and Warren bridges. Headquartered and financed in Britain, the costly Grand Trunk Railway, along with its Victoria Bridge, was “an embarrassment almost from its inception.”⁴²

Decision-makers considered the tube massive and expensive, although it was acknowledged as a great British achievement. The lattice represented an alternative: economical, good-looking, American.

Lattice Is Tube Is Lattice

A historically based perspective of tube-lattice opposition has dominated the story thus far. These categories help us understand how historical figures—engineers and their chroniclers—thought, or at least, how they presented their thoughts. The lattice-tube dichotomy revealed divergent

42. Laudatory quotes from Charles Legge, *A Glance at the Victoria Bridge and the Men Who Built It* (Montreal, 1860), 21, 30. “Embarrassment” per G. P. de T. Glazebrook (1938), cited in James A. Vance, *North American Railroad: Its Origin, Evolution, and Geography* (Baltimore, 1995), 247. See also the amazing “Victoria Bridge,” *American Railroad Journal* 33 (1860): 197–99, 213, 221–23, 241–44, 261–63, 281–83, 301–3, 321–23, 345–47, 369–71, 389–90, 413–14, 443, 789–90.

understandings of structural behavior, theory, and materials. But debates surrounding these issues often obscured the physical and theoretical similarity of the two bridge types. This means that boundaries dividing *lattice* and *tube*, *wood* and *iron*, and *British* and *American* must be explained; they do not explain.

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Why design a bridge in tubular form? With material concentrated at its top and bottom, where compression and tension forces are greatest, a tube provides increased stiffness for less weight than a conventional beam.⁴³ Lightness has significant consequences for the cost of the superstructure, as well as foundations and piers—often the most difficult part of bridge building. Well before Stephenson hit upon the idea of a wrought-iron tube, an understanding of tubular structure resulted in a published design of a wooden tube. In 1840, Herman Haupt, a West Point graduate, structural theorist, and railroad engineer and manager who admired Town's bridge, analyzed its defects and patented an "improved" version, which included the addition of vertical members in the lattice framework. "This arrangement increases the stiffness on the same principle that a hollow cylinder is more stiff than a solid one," Haupt wrote.⁴⁴

Within the discourse about girders, beams, and tubes and the behavior of forces within them—Stephenson's belief in the "efficiency" of the tube's top and bottom notwithstanding—the tubular engineers did not emphasize the advantage of their design as a *tube*—indeed, it appears they never seriously raised the issue. Britannia construction engineer Edwin Clark stated that "tubular" signified only "hollow." Historian Tom F. Peters has pointed out that "they built the bridges as rigid box beams and called them 'tubes,' but everyone still thought of them as plate girders and neglected their three-dimensional behavior."⁴⁵ In terms of design, the tubular bridge was a hollow concept, more visual than structural.

STRUCTURE

Ambiguity characterized the boundary between the bridge types. Lattice bridges sometimes functioned as tubes and sometimes didn't. The designers of the lattice bridges at Dirschau and Marienburg recognized the

43. The box configuration also stiffens against buckling, which is a risk to the compression chord of a conventional beam; per John Ochsendorf, MIT Building Technology Program (personal email).

44. Herman Haupt, "Lattice Bridges," *American Railroad Journal* 11 (1840): 196–200; see also Haupt, *General Theory of Bridge Construction* (n. 33 above), 151, 153. Regarding early tubular invention, see Tyson (n. 29 above), 143.

45. Regarding "efficiency," see Stephenson, in Clark (n. 12 above), I:25–26; regarding "hollow," see Clark, I:42. See also Tom F. Peters, *Building the Nineteenth Century* (Cambridge, Mass., 1996), 168.

tubularity of their spans; Lentze was able to cancel a full-scale test after receiving information provided by Edwin Clark in a talk given in London in 1850. An engineer involved with the Boyne Viaduct noted that “the cross section of the Boyne viaduct . . . is the same as that of the tubular girder, if we substitute intersecting bars for the continuous plate.”⁴⁶ The vertical members of the Cologne bridge stiffened the structure and were directly connected to cross-beams at the top and bottom of the structure; they were intended to spread the load to the entire upper and lower chords and the rest of the lattice; and they resisted horizontal forces.⁴⁷ As engineer-historian Martin Trautz recently observed, the Cologne bridge “merged tubular and beam behavior.” At Kehl, however, each of the bridge’s lattice frameworks functioned more as beams than as the sides of a tube.⁴⁸

Lattice/tube kinship is evident in the inclusion of vertical members as a design solution. In tubular bridges, the sides experienced shearing load and would have buckled if they were too thin or if they were not held in place; this was resolved by riveting vertical bars every two feet.⁴⁹ Earlier, in the “Peacock Bridge” (1839–1840) over the Schuylkill near Reading, Pennsylvania, Moncure Robinson had included intermittent verticals as “reinforcement.”⁵⁰ Ultimately, it was this “great waste of material . . . [that] arises from the great multitude of rivets and laps” required to make the structures rigid that made John Roebling conclude in 1869 that “lattice bridges, like Tubular Girders, have seen their best days.”⁵¹

Beyond the similarity of function and design, lattice/tube opposition is difficult to maintain because there was never one type of lattice bridge (fig.

46. The information Lentze received is not known. Regarding the Boyne Viaduct, see Bindon B. Stoney, “Description of Some Experiments Made at the Boyne Viaduct in 1854,” *Transactions of the Institution of Civil Engineers of Ireland* 5 (1860): 136.

47. Hermann Lohse, “Die Rhein-Brücke bei Cöln,” *Zeitschrift für Bauwesen* (1863): 339. Pole stated that “the girders are formed of open lattice-work, instead of plates, as Mr. Fairbairn had proposed; but in other respects there has not been much material departure from Mr. Fairbairn’s designs”; in other words, this was a tubular bridge with lattice sides. Pole, *Fairbairn* (n. 37 above), 237.

48. Trautz (n. 35 above), 71; analysis of Kehl bridge’s function is from Trautz, 74.

49. Rosenberg and Vincenti (n. 11 above), 28; Smith (n. 11 above), 114. Friends and enemies of both lattice and tube knew that such measures would be necessary. Fairbairn had said that others claimed that plates “would crumple like a piece of leather”; see William Fairbairn, *On the Application of Cast and Wrought Iron*, 2nd ed. (London, 1857–1858), cited in Rosenberg and Vincenti, 98n169. Karl Culmann, who hated the lattice bridge, complained that “the thin flat iron bars are even less suitable than the somewhat stiff wooden lattices to carry compressive forces from the top to the bottom chords” (Culmann, “Der Bau der eisernen Brücken” [n. 7 above], 193–94). He claimed that “using these iron strips against compressive forces is like wanting to make a table leg out of cable.”

50. Chevalier, *Histoire et description* (n. 7 above), 2:497–98, 576–79, fig. 19. See also Ithamar A. Beard, “Description of an Improvement on the Bridge Patented by Ithiel Towne [sic], Esq., the term of which patent has expired,” *Journal of the Franklin Institute*, n.s., 25 (1840): 175–77, and Garella (n. 8 above).

51. John Roebling, *Long and Short Span Railway Bridges* (New York, 1869), 39, 50.

16). Town himself acknowledged lattice “trusses twisting, leaning side ways, or curving in the direction of their length”; in order to correct these deficiencies he devised his second patent of 1835.⁵² Others substituted bolts for pegs or combined lattice with arch. The translation into iron allowed more rigid connections, enabling builders, intentionally or inadvertently, to make lattices more tubelike in performance. The profile of the iron lattice bars might be flat, square, round, L-, U-, or T-shaped, and these might be used in any combination, the spacing between them designed to reflect anticipated loading.⁵³ Like all structures, the lattice was a “bundle” of innovations, and engineers might direct their attention to any of its parts.⁵⁴

ANALYSIS

Methods of structural analysis played a role in lattice/tube confusion.⁵⁵ Both structures were indeterminate. That is, they could not be analyzed in a way that allowed the engineer to estimate the forces in each member; as a result, some engineers considered them to be large beams—determinate structures. (According to engineer-historian William Addis, beam theory “was already well-developed by the end of the 18th century.”⁵⁶) Structural analysts, including Claude-Louis-Marie-Henri Navier, used this type of analogy. J. H. Garella, for example, an engineer who built two provisional “ponts américains” in 1838 near Lyon, France, with the addition of bolts and vertical members, presented calculations in which he considered the lattice as a “hollow solid” consisting of upper and lower chords.⁵⁷ Karl

52. Town’s 1839 brochure (n. 4 above), 4. Tension connections in wood were a challenge, and when joints became loose, excessive movement resulted. The bridges were in damp environments, which caused shrinking and swelling that resulted in loosening of joints and cracking of wood. Sagging and deflection under heavy loads caused vertical cracking at the peg holes. These conditions could not easily be corrected.

53. William Schwedler, “Resultate über die Construction der eisernen Brücken,” *Zeitschrift für Bauwesen* 15 (1865): 331–40, fig. O1. Depictions of various structural configurations can be found in Ph. Croizette Desnoyers, *Cours de construction des ponts* (Paris, 1885), figs. 33–36.

54. See Tann (n. 3 above), 152.

55. At mid-century, there were several methods of analysis for a lattice bridge, including design rules, theoretical abstractions, and mathematical theories. In 1852, an engineer-intern described three ways to analyze a lattice bridge: (1) dimension it proportionally (span to height, as Town recommended); (2) consider the lattice portion as a solid wall; or (3) design according to intuition and then do simple calculations for dimensioning the parts. See A. Straus, “Ueber die Berechnung der schmiedeisernen Gitterbrücken,” *Eisenbahnzeitung* 10 (1852): 193.

56. William Addis, *Structural Engineering: The Nature of Theory and Design* (London, 1990), 70. Per Addis, Carl Ghega’s theoretical work (n. 8 above) was based on the beam analogy. Ghega was mostly concerned with the Howe lattice bridge at Springfield.

57. Garella (n. 8 above), 375–76. Julius Pollack reported Garella’s use of bolts in “Metallbrücke zur Uebersetzung des Royalkanals bei Dublin für die Dublin-Drogheda-Eisenbahn nach Town’s nordamerikanischem Konstruktionsystem gebaut im Jahre 1845,” *Allgemeine Bauzeitung* 13 (1848): 19, 21.

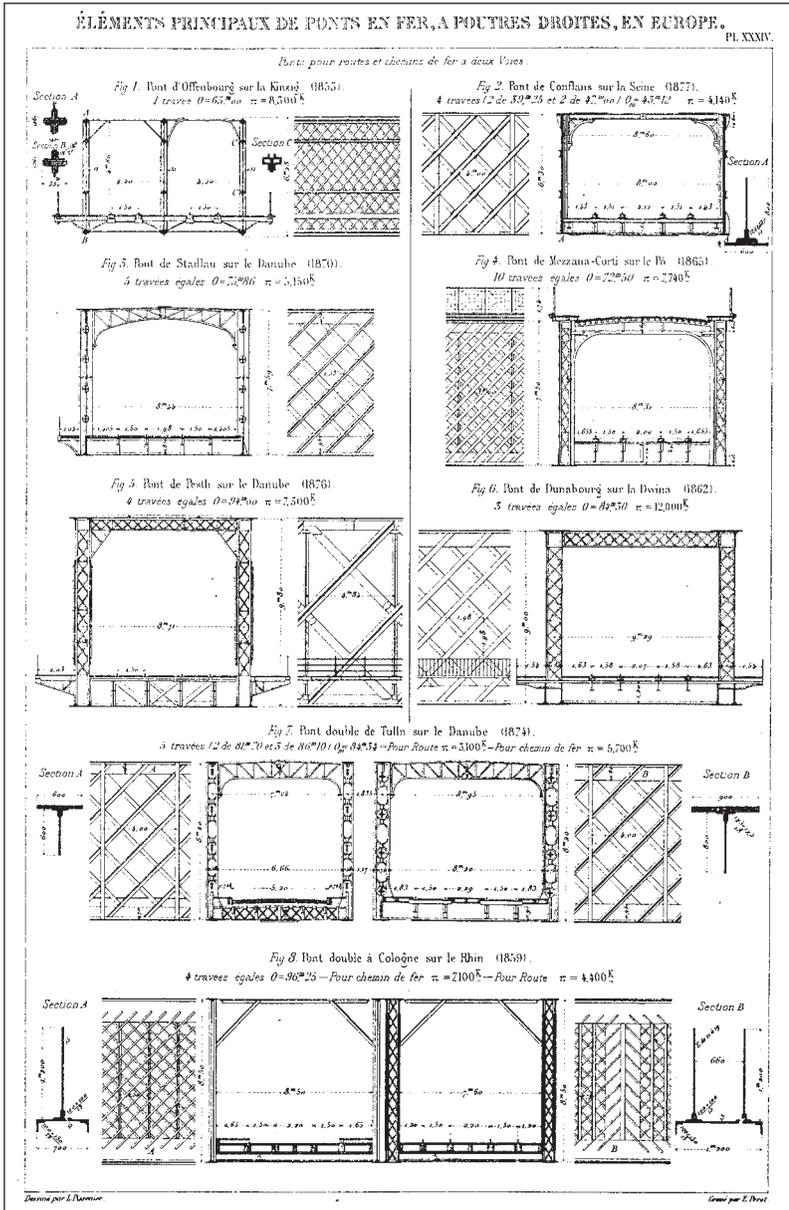


FIG. 16 Various lattice bridges, from Romain Morandière, *Traité de la construction des ponts et viaducs en pierre, en charpente et en métal pour routes, canaux et chemins de fer* (Paris, 1880–1888), plate 34. (Courtesy of the Smithsonian Institution Libraries.)

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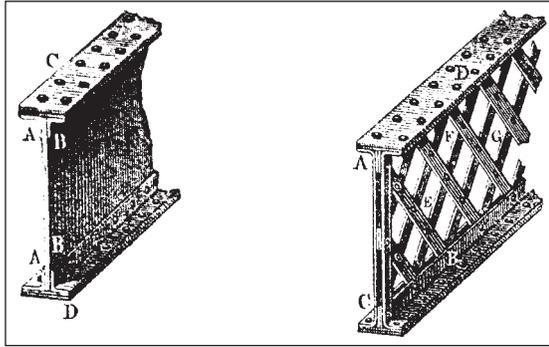


FIG. 17 Beams with solid web and lattice web, from Julius Weisbach, *Lehrbuch der Ingenieur- und Maschinen-Mechanik*, 3rd ed. (Braunschweig, 1857), 2:193. (Courtesy of the Smithsonian Institution Libraries.)

Ruppert employed the beam in his thinking about the bridge at Offenburg. In a theoretical analysis of the iron lattice bridge over the Royal Canal, near Dublin, Ireland (built 1844–1845), engineer Julius Pollack in 1848 referred to its frameworks as “walls, or rather, beams.” He noted how similar Stephenson’s bridge was to the “American bridge systems,” when one imagined a solid where the lattice was.⁵⁸ Some engineers used the lattice to understand the tube, while others used the tube to understand the lattice. Stephenson himself considered each side of the tubular bridges as the theoretical equivalent of a member “in which the trellis bars may be considered infinite in number.”⁵⁹

As engineers treated the Britannia, theoretically, as a beam rather than a tube, the debate about tubular bridges merged with debates about beams. A central question for I-section beams came to be whether the web (i.e., the central portion) should be solid or lattice (fig. 17).⁶⁰ Charles Couche (1815–1879), for thirty years professor of railway construction at the *École nationale des mines*, diplomatically solved the lattice/plate dilemma. “It seems certain, when all is said and done,” he wrote, “that the two systems are about equal”—the conditions in each case would determine the decision. Couche furthermore noted that “it is true that most of the renowned engineers of Great Britain are against the lattice, but with them, the result of a discussion is determined at the start. Consequently, the Prussian engineers, who attribute the double advantage of economy and a more elegant appearance to the

58. Pollack, 1, 22.

59. [Robert Stephenson], “Iron Bridges,” in *Encyclopaedia Britannica*, 8th ed. (Boston, 1856), 12:597.

60. This was discussed along with other big questions of the period: Should bridges be composed of continuous beams or separate spans? Should two tracks be placed on a wider single span, or should each track have its own span, as in the Britannia Bridge?

lattice, ascribe the marked condemnation of the lattice in England to the unfriendly prejudice that welcomes in that country all ideas of American origin.”⁶¹

MATERIAL

Historians have shared the construction task of the tubular engineers by making the transition from wood to iron—and later, from iron to steel—the backbone of the evolutionary tale of technological progress and the superiority of the West. Designers adopted metal for bridges, as they did in ship, clock, doorknob, and airplane construction. But wood played a fundamental role in the development of structural design and industrial methods of construction, and wood continued to be used after metal became the standard.⁶²

There is a gap between the portrayal of wood and its actual role, however. Wooden-beam bridges contained tons of iron—critical components such as bolts, straps, and suspension rods that held them together—but Stephenson and Brunel called the lattice “wooden” in order to emphasize its backwardness. When Clark stated that the “novelty in the tube consists of its being a constructed beam,” he dismissed the earlier novelty of innumerable constructed wooden-beam bridges.⁶³ Like classifications purporting to represent racial purity, the “wooden bridge” designation referred to an ideal homogenous type, not the reality of a mixed composition. Wood, moreover, had a national connotation: technology’s chroniclers have presented wood as plentiful in the U.S. and wooden construction as particularly American.⁶⁴

61. C. Couche, “Travaux d’art des chemins de fer d’Allemagne,” *Annales des Mines* 5, no. 5 (1854): 349; regarding the fundamental bridge design questions of the time, see 359–83.

62. See Gregory K. Dreicer, “Building Myths: The ‘Evolution’ from Wood to Iron in the Construction of Bridges and Nations,” *Perspecta* 31 (2000): 130–41. Regarding material choices and their meanings, see for example Robert Fletcher and J. P. Snow, “A History of the Development of Wooden Bridges,” *Transactions of the American Society of Civil Engineers* 99 (1934): 314–408; Eric Schatzberg, “The Decline of the Wooden Airplane in the United States,” *Technology and Culture* 35 (1994): 34–69; and Steven Lubar, “New, Useful, and Nonobvious,” *American Heritage of Invention and Technology* 6, no. 1 (spring/summer 1990): 14.

63. Clark (n. 12 above), I:42. Not everyone dismissed wood. In 1848, L. Gordon, who taught at Glasgow College, paid fealty to Stephenson while noting that the wooden lattice bridge formed a “box-like girder”; L. Gordon, in Julius Weisbach, *Principles of the Mechanics of Machinery and Engineering* (*Lehrbuch der Ingenieur- und Maschinen-Mechanik*), trans. L. Gordon (London, 1847–1848), 2:404. Gordon noted (p. 2:398) that the Grubenmann bridges at Wettingen included “the introduction of a roof as an integral part of the constructive strength of the bridge” (emphasis in original).

64. Regarding the supposed “wooden age,” see Brooke Hindle, ed., *Material Culture of the Wooden Age* (Tarrytown, N.Y., 1981). Hindle emphasizes wood as a resource, not as an industrialized product. By the seventeenth century, there were wood shortages

Engineers and industrialists had good reason to use and promote metal. Fairbairn's business, for example, was based on the sale of iron-plate construction. And the world-altering high-tech network of the day—*railroad*, *chemin de fer*, *Eisenbahn*—had metal in its name, even if wood was fundamental to its construction. Historians (in many cases, engineer-historians) who composed the story of bridge progress, however, wrote as if it were natural to employ these historical figures' perspectives. Perhaps it was, since historians inhabited or inherited a worldview established by the founding fathers of civil engineering. For as Eric Schatzberg has observed, "the standard histories do little more than codify the [professional] community's own mythology and thus cannot reflect critically on the basic assumptions of that community."⁶⁵ Indeed, a century after the *Britannia*, an account of the girder bridge in Britain virtually excluded wood and lattice beams.⁶⁶

Historians who invoke the "intractable nature of materials" and "the immutable laws of nature" seem to codify the professional mythology.⁶⁷ If instead they were to regard materials as mutable in the hands of technologists, they might shift their investigations to how and why designers choose materials in specific, changing contexts. During the 1830s, builders and manufacturers, including Fairbairn, developed I-section members in various materials and configurations, although it was not until mid-century that manufacturers produced in iron and on a large scale what today are recognized as I-beams.⁶⁸ And the lattice was a model in the design, manufacture, and analysis of beams before Stephenson proposed the tube and before builders commonly used wrought iron. This means that if we discard the evolutionary metaphor and cease to consider material categories as intractable, the (wooden) lattice frame appears as a proto-I-beam, and Town's 1835 patent, in which he doubled each frame, assumes the role of archetypal box beam.⁶⁹ Suddenly, wood reframes (I-beam) history. The

in North America; see Dreicer, "The Long Span" (n. 19 above), 136–41. The *Britannia* burned in part because of a wooden structure placed upon it to protect it from sea air and water; see Paul N. Wilson, "The *Britannia* Tubular Bridge," *Industrial Archaeology* 9 (1972): 238–40.

65. Schatzberg, 35.

66. P. S. A. Berridge, in *The Girder Bridge after Brunel and Others* (London, 1968), 157, mentions lattice and timber near the end of the book, in reference to the Crumlin Viaduct, whose design the author feels was inadequate. He notes a high rate of bridge failure in the U.S.

67. Edwin T. Layton Jr., "Mirror-Image Twins: The Communities of Science and Technology in 19th-Century America," *Technology and Culture* 12 (October 1971): 568. Layton wrote that "the intractable nature of materials constituted one of the most important barriers to the development of technology," and that this "barrier" was removed thanks to "science." Henry Petroski wrote that "though engineering is the art of rearranging the materials and forces of nature, the immutable laws of nature are forever constraining the engineer"; *Invention by Design: How Engineers Get From Thought to Thing* (Cambridge, Mass., 1996), 1.

68. Jewett (n. 3 above), *passim*; regarding Fairbairn, 352–53.

69. This was recognized by Herman Haupt, who wrote that it "act[ed] on the prin-

metal of civilized industrializing nations no longer triumphs over the wood of backward borrower nations. Instead, technologists collaborating and competing in a variety of locations and cultures, using a variety of materials, together invent, design, engineer, build.

Building Categories and Engineering Nations

An engineer named Alexandre Berthault-Ducreux wrote in 1845 that “one of the greats of France said: *the style is the man*. Isn’t it just as appropriate to say: *the works are the nation?*”⁷⁰ Technological objects serve as ideal containers for nationalistic views. They allow feelings about native-ness and foreignness to assume a tangible form. Moreover, infrastructure does seem to reflect the state of the nation by demonstrating a government’s ability to maintain the networks that enable the nation to function. Keeping the “American” lattice and the “British” tube in mind, let’s consider the political and industrial significance of identifying technologies with nations.

In the international engineering arena, iron became common in beam design as the tubular bridge became an engineering curiosity. Unlike most failed inventors, however, Stephenson had the political power to “write the book.” His 1856 *Encyclopaedia Britannica* article on iron bridges therefore claimed that

it is difficult to conceive even now, with all our subsequent experience, any other means than those adopted of solving the great problem which thus inaugurated a new epoch in the history of bridge construction, and led directly to our present theoretical knowledge of the principles of beams, [as well as] all those numberless elegant and ingenious practical combinations of wrought-iron in bridge construction.⁷¹

Stephenson’s hyperbolic account presented the tube as a turning point in

ciple of a hollow cylinder.” Haupt disapproved of it, however, because the doubling of the lattice frameworks only increased the section of the top and bottom chords by half. Haupt, *General Theory of Bridge Construction* (n. 33 above), 151.

70. “Une des gloires de la France a dit: le style, c’est l’homme; ne peut-on dire avec autant de justesse: les oeuvres, c’est la nation?”; see Berthault-Ducreux, “Exposé des faits et des principes sur lesquels repose la solution des principales questions que soulèvent les chemins de fer et les autres voies de communication,” *Annales des ponts et chaussées* 2, no. 1 (1845): 49. The “great” was George Louis Leclerc de Buffon (1707–1788) in his *Discours* (1753).

71. [Stephenson], “Iron Bridges” (n. 59 above), 12:607 (per Rapley [n. 15 above], 116; this was probably ghostwritten by Stephenson associate G. D. Phipps). Engineer Thomas Telford succeeded similarly; in Thomas Telford’s *Temptation* (Shropshire, UK, 1993), 11, historian Charles Hadfield notes that “thinking about Telford’s canal achievements has been dominated by Telford. Most historians and biographers followed his lead, and to some extent they still do.”

theory, practice, and industry. The lattice fit this tale either as an unfit technological form or as an adaptation of the tube.⁷²

When engineer George Buchanan read a paper concerning bridges and the strength of materials at the Royal Scottish Society of Arts in 1848, a Professor Forbes asked about the resemblance of “these American bridges” to iron tubular bridges. Buchanan replied that “the resemblance in principle to the tubular bridges had struck himself forcibly.” He concluded, nevertheless, that despite the strong similarities, “the tubular bridge was, in many respects, a very different structure; and the design of a bridge, of one vast malleable iron tube, was an idea at once happy and original, and was, he considered, due entirely to Mr. Stephenson.”⁷³ Which is to say, the tubular identity was a function of the power, reputation, and business interests of its creators.

Stephenson’s status was a national matter. He, along with his father, railroad pioneer George Stephenson, were (and are) figureheads of British engineering and industry. As a national hero, “a member of English parliament and powerfully rich,” in the respectful words of engineer August Perdonnet, Stephenson (fig. 18) had to stand against the technological giants of other nations.⁷⁴ His tube was a national symbol. The lattice served, inside and outside of Britain, as a defense and sometimes a weapon against the power of an engineering elite personified by Stephenson and his colleagues.⁷⁵ Considering the Britishness of Stephenson, however, compels one to remember that figureheads seem to represent uncomplicated cultural and technological positions. But heroes stand for a particular point

72. A tale repeated, for example, by an engineer-historian who suggested that after tubular bridges, “the subsequent development of bridge building, both in England and on the European continent, was scarcely more than a modification of the solid plate constructions into multiple lattice trusses;” see C. E. Fowler, “Bridge Evolution as Relating to Southern California,” *Bridges* (May 1899): 117. “Today the design of the bridge looks utterly anomalous, without obvious structural antecedents or descendants,” wrote Henry Petroski in “The Britannia Tubular Bridge” (n. 23 above), 220.

73. George Buchanan, “Strength of Materials for Railway Bridges,” *Journal of the Franklin Institute* (1849): 229–30 (reprinted from *Proceedings of Royal Scottish Society of Arts* [1848], via *The Civil Engineer and Architects Journal* [January 1849]).

74. Perdonnet, cited in With, *Nouveau manuel complet de la construction de chemins de fer* (n. 24 above), 231. Regarding hero worship in British engineering biographies, see Buchanan, *The Engineers* (n. 18 above), 19. The tradition continues; for example, “The tubular form . . . was a brilliant concept to meet a seemingly impossible challenge, but today it is hard not to wonder whether this level of innovation was essential,” according to James Sutherland (“Iron Railway Bridges,” in Bailey [n. 20 above], 334). See also Christine MacLeod, *Heroes of Invention: Technology, Liberalism, and British Identity, 1750–1914* (Cambridge, 2007), 318–19.

75. For example, at a meeting of the ICE of Ireland, the lattice Boyne Viaduct was called “that magnificent monument to Irish engineering skill, enterprise, and industry”; *Transactions of the Institution of Civil Engineers of Ireland* 5 (1860): 134. Per Bailey, “Wider Horizons,” in Bailey, 144–49, Stephenson was sometimes “arrogant” in presenting himself as a British engineer in opposition to “Continental Engineers.”



FIG. 18 *Robert Stephenson*, by Henry Adlard, 1858, engraving after a photograph by Mayer and Pierson. (Copyright owned by the Musée McCord, Montreal, acquisition number M3936. Reproduced with permission.)

of view and project an image of unity that does not exist.⁷⁶ Indeed, Stephenson's beliefs did not represent the beliefs of all engineers working in Britain.

Maintaining national boundaries around engineering design is as complex a task as justifying boundaries around lattice and tube. Great Britain, historian Linda Colley explains, “did not come into being . . . because of an integration and homogenisation of disparate cultures. Instead, Britishness was superimposed . . . in response to contact with the Other.” The “Other” included people who were French, Catholic, and North American. The invention of British identity after the Revolutionary War was in no small part a response to an equally new American identity. Engineers constructing a tube in opposition to a lattice were creating national building mythologies that were weapons of competition. Per Colley, “being a patriot was a way of claiming the right to participate in British political life”; similarly, technologists’ claims concerning lattices and tubes, or practice and theory, or wood and iron, were claims about what it meant to be inter alia British and

76. See, for example, June Hargrove, “Shaping the National Image: The Cult of Statues to Great Men in the Third Republic” in *Nationalism in the Visual Arts*, ed. Richard A. Etlin (Hanover, 1991), 49–63.

American.⁷⁷ These were claims for access into cultural and professional engineering communities that existed within and across nations.

It may seem anomalous that a source of a vaunted “British” invention was “American.” This is not a story that technologists working within a competitive, nationalistic environment would want to highlight.⁷⁸ As historian Ludmilla Jordanova notes, “the idioms of competition, national heroism, and universal knowledge were never easily integrated.”⁷⁹ In other words, why acknowledge that one’s worst enemy (economically) was also one’s best friend (creatively)? Moreover, as historian David Thelen points out, during the last two centuries a prime goal of professional historians has been the creation of national rather than transnational stories.⁸⁰ In these histories, national borders obliterated the networks that are the basis of the inventive process.

During the mid-nineteenth century, the tubular engineers faced the transnational specter not of American industry but of American technology.⁸¹ And they must have been perplexed: their industrial enterprises were unsuccessfully competing against technology identified with “a new and comparatively poor country,” according to a British engineer reporting on “American timber bridges” in 1862.⁸² The British engineers and industrialists who failed to obtain contracts for the major long-span bridges described above, at Dirschau, Offenburg, Cologne, and Kehl, however, were not bested by Yankee firms. Europe-based firms wielding “American” and “Continental” technology defeated them.⁸³ Engineer Émile With put this nightmare—

77. Linda Colley, *Britons: Forging the Nation 1707–1837* (New Haven, Conn., 1992), 1, 5–7, and chaps. 4–6. On p. 373, Colley cites Peter Scott, *Knowledge and Nation* (Edinburgh, 1990), 168: “Britain is an invented nation not so much older than the United States.” I am proposing the central mythopoeic role of technology; Colley notes how little research has been done on technology during the period of the creation of the British identity, despite an “unceasing torrent of books and articles on the impact of industrialisation on Britain” (Colley, 3, 385n4).

78. Fairbairn did recognize intercultural exchange, even as he expressed frustration at his unsuccessful attempts to sell bridges abroad; see letter from Fairbairn to Alexander von Humboldt, 15 April 1850, in Fairbairn, *On the Application*, 4th ed. (n. 37 above), 345.

79. Ludmilla Jordanova, “Science and National Identity,” in *Sciences et langues en Europe*, ed. Roger Chartier and Pietro Corsi (Paris, 1996), 230.

80. David Thelen, “Making History and Making the United States,” *Journal of American Studies* 32 (1998): 373–97.

81. Historians and politicians sometimes blur the distinction between technology and industry. Because of Britain’s industrial base, technologies associated with its industries are sometimes labeled “British.” See, for example, D. L. Burn, “The Genesis of American Engineering Competition, 1850–1870,” *Economic History* 2 (1931): 292–311.

82. Mosse (n. 8 above), 305, 317.

83. Stephenson’s railway consulting work in European countries including Austria, Denmark, and Sweden foundered in the 1850s, for reasons perhaps related to the reception accorded the tube—lack of ability to remain on the cutting edge technologically, along with insensitivity to local conditions. See Bailey, “Wider Horizons,” in Bailey (n. 20 above), 144–49, 161. It is possible also that governments wanted to support firms based in their own territories.

for some engineering entrepreneurs based in Britain—into words when he predicted in 1854 that just as wrought-iron plate replaced cast-iron, “my innermost conviction is that the tubular system will soon be replaced by lattices of rolled iron, in the manner of the American system.”⁸⁴

All the lumber milled from slaughtered American forests, assembled in thousands of “wooden” (that is, wood-and-iron) railroad bridges, along with all the mythic national characteristics of the “practical,” “technology-borrowing” Yankees, couldn’t erase what a reconnaissance team from Britain confirmed during the 1850s: “we shall have to contend with no mean competitors in the Americans.”⁸⁵ The 1820 lattice bridge, an invention that strove for the uniformity of parts and mass manufacturability that were also goals of U.S.-government-funded armories, made the so-called American bridges—and later, the American system of manufacturing—technological, industrial, and military threats. But no matter how invigorating the nationalist rhetoric and how intense the industrial competition, invention remains a process of intercultural exchange.⁸⁶

The tubular bridge was a landmark—a symbol of national pride whose creators tried to use it to shape their profession. They could not foresee the consequences, though. Bridge chronicler J. G. James believed that the Britannia steered engineers and manufacturers in Britain to the “mass production of box-girder bridges in the 100–200 foot range just at the time when, like other countries, she should have been perfecting cheaper truss forms”—and that this, along with a tradition of cast-iron arch building, led to the “sad decline of British bridge design in the late 19th century.”⁸⁷ In other words, builders in Britain may have followed the “success” of their elite engineers too well. The choice of a lattice or framework over the tube in long-span construction conveyed a message about Great Britain’s technological power. Industrial might did not make technological right. An upstart, the United States, could become a leader.

During the period in which the construction of networks of roads and

84. Émile With, *Les accidents sur les chemins de fer, leurs causes, les règles à suivre pour les éviter* (Paris, 1854), 23, 139. In With’s translation of Stephenson’s and Brunel’s *Report of Commissioners* testimony, “lattice bridge” is repeatedly translated as “pont américain.”

85. John Anderson, in his 1857 report on machinery in the U.S., cited in David A. Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Baltimore, 1984), 64. Regarding the industrialization of building and the lattice bridge, see Gregory K. Dreicer, “Nouvelles inventions: L’interchangeabilité et le génie national,” *Culture Technique* 26 (1992): 213–20.

86. As Stephenson acknowledged; see Robert Stephenson, cited in Derrick Beckett, *Stephenson’s Britain* (Newton Abbot, UK, 1984), 175.

87. James, “Some Steps in the Evolution of Early Iron Arched Bridge Design” (n. 23 above), 153. Of course, it was not “Britain,” but individuals who designed and built bridges—and some of these individuals manufactured lattices, for example, for export to India; per J. G. James, “The Origins and Worldwide Spread of Warren-Truss Bridges in the Mid-Nineteenth Century. Part 1: Origins and Early Examples in the UK,” *History of Technology* 11 (1986): 65–123; part 2 was published by the author.

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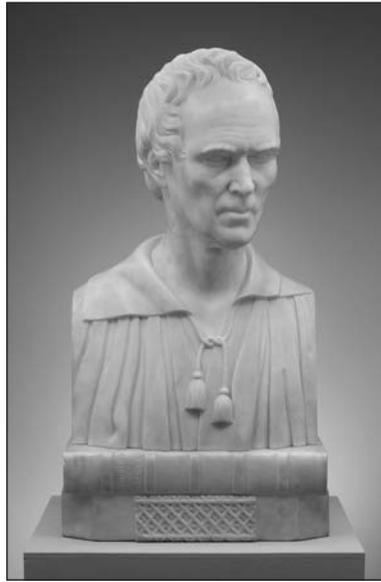


FIG. 19 1842 bust of Ithiel Town, 1784–1844, M.A. (hon.), 1825; gift of Dr. William Thompson Peters, B.A., 1825, M.D., 1830. Sculpture by Chauncey Bradley Ives. (Courtesy of the Yale University Art Gallery.)

rails was crucial for communication, transportation, and defense, bridges were as crucial to the existence of nations as to the lives of individual passengers and pedestrians. A bridge was a symbolic as well as physical bond—a structure of political power. For the diverse, unruly places known as England, France, and the United States, bridges were essential for bounding the category *nation*. To local and multinational communities of builders, the success of a bridge type signaled who held the engineering power.

A Borrower and a Lender Be

Nathan Rosenberg asserted, “it cannot be overstressed that America in the first half of the nineteenth century was still primarily a borrower of European technology.”⁸⁸ During that period, however, builders who lived in the expanding United States were at the forefront of the high-tech field of bridge building. Ithiel Town (fig. 19) was one of a number of inventors whose work transformed the design and construction of frame and suspension systems, and with it building and manufacturing processes around the world. Britain’s *industrial* might was for many years greater than that of

88. Nathan Rosenberg, “Why in America?” in *Exploring the Black Box: Technology, Economics, History* (Cambridge, 1994), 109.

the continental European and North American states. This supported a myth of British *technological* priority that denies the intercultural exchange that is the sine qua non of invention and that, moreover, was the basis of Britain's "Industrial Revolution."⁸⁹ It cannot be overstressed that adopting national borders is only one strategy for cultural study—one that requires careful scrutiny of the mythologies constructed along with those borders.

Borrowing and lending are quintessential inventive acts. Deeming one nation inventor and another borrower, however, builds a nationalist story of superiority and subservience—a story that inflates claims of technological success and failure. At specific times and places, individual people, materials, and methods predominate, or seem to. Engineers and their chroniclers develop and debate ideas such as structure, economy, and beauty. They work via experimentation and calculation and acts of denial, celebration, deception, and admiration. Exploring these fundamental technological activities will enable technology's storytellers to overturn, rather than reinforce, cultural constructs that are never inevitable and always dependent on context.

89. See, for example, Kranakis's account (n. 3 above) of James Finley; D. L. Burn (n. 81 above); Margaret T. Hogden, *Change and History: A Study of the Dated Distributions of Technological Innovations in England*, Viking Fund Publications in Anthropology 18 (New York, 1952), passim, esp. 189–90, 200. Regarding moat theories that encourage historians to separate Europe and North America, see I. K. Steele, *The English Atlantic 1675–1740: An Exploration of Communication and Community* (New York, 1986). Moat theories reinforce beliefs about transfer and diffusion; J. M. Blaut (n. 3 above) dismantles these ideas.