A British perspective on American civil engineering achievement before 1840

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Abstract

Consideration of selected remarks of leading British engineers D. Stevenson and T. Telford on this theme has enabled the essential contribution of timber construction to America's early public works infrastructure to be better understood. As an example, L. Wernwag's 1810 Neshaminy River timber and iron truss bridge, of which I.K. Brunel possessed a lithograph, is discussed as an innovative achievement in bridge development.

Introduction

From a search for a perspective from contemporary British engineers, including B.H. Latrobe, W.Weston, Sir M.I. Brunel, and C.B.Vignoles, all of whom worked in the USA, and J. Rennie, T. Telford and D. Stevenson who did not, although they advised on some North American projects, only contributions by Stevenson and, to a lesser extent, Telford came to light. Both are considered authoritative and reliable commentators.

Thomas Telford (1757-1834) was at the head of the British civil engineering profession with an international reputation for innovation and excellence in road, bridge and canal engineering. His contribution is taken from the influential *Edinburgh Encyclopaedia(1)* to which he was a major contributor and a leading proprietor, and a parliamentary report*(2)*. David Stevenson (1815-1886), uncle of the writer Robert Louis Stevenson, was an up-and-coming young engineer who had had an exemplary training as a civil engineer under his father Robert Stevenson and national railway contractor William Mackenzie in the Midlands and at Edge Hill tunnel on the Liverpool and Manchester railway. He was destined within a decade to become head of the Stevenson engineering consultancy and one of Britain's leading river navigation, harbour and lighthouse engineers. From 1853-85, he was Engineer to the Northern Lighthouse Board and an international authority on river and lighthouse engineering.

Stevenson was a skilful writer producing more than 60 authoritative publications*(3)*. Those relating to this subject are, *Sketch of the Civil Engineering of North America(4)*,

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and papers to the Royal Scottish Society of Arts (of which he became twice President) on "Long's frame bridge"(1839), and "Building materials of the United States of America" (1841), which were also published in the *Edinburgh New Philosophical Journal* (1841). Reference has also been made to Stevenson's pocket book, diary and autobiography.

American support for the selection of Stevenson as an appropriate source for this paper comes from Brooke Hindle who calls Stevenson's *Sketch* the best of the early European works on American engineering, adding that the earliest American surveys of native civil engineering feats were not as elaborate or well executed as British works on American technology*(5)*. Also, from Kip Finch's scholarly critique on the *Sketch.* He wrote "one cannot fail to be impressed with the outspoken yet, fair, impartial and keen observation of this young engineer of 23 years"*(6)*.

Stevenson's 3-month North American tour in 1837 (5 April- 8 July)

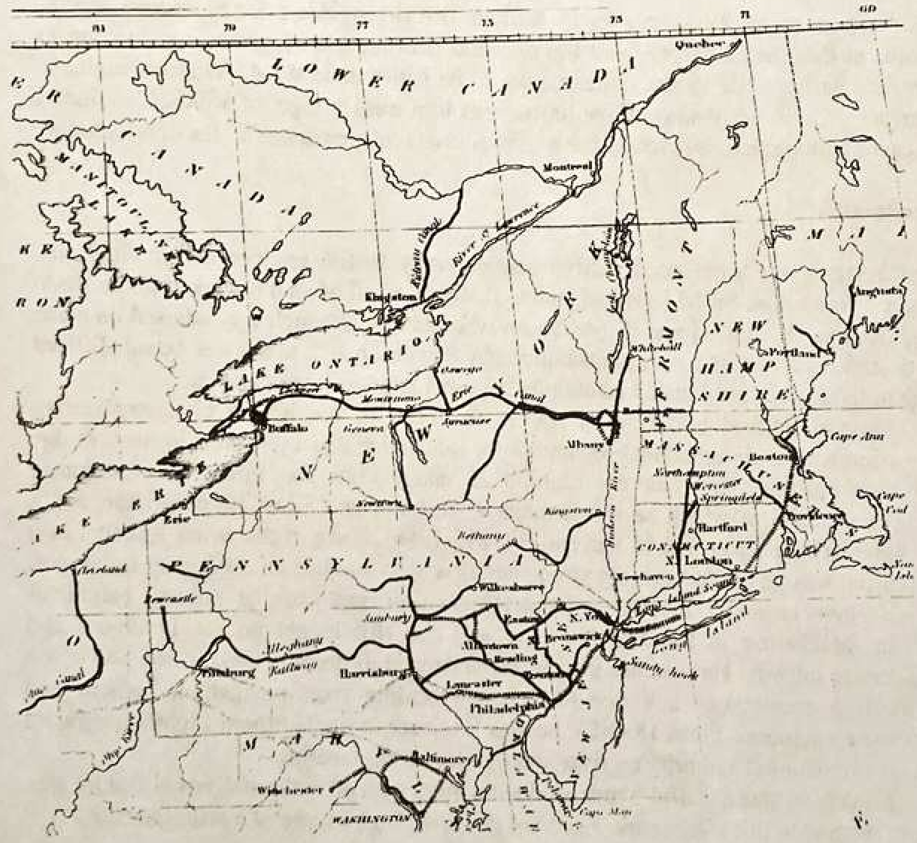


Figure 1. Map covering Stevenson's tour, 1837*(3)*. [basically, New York – Philadelphia - Baltimore – Washington – Philadelphia – Harrisburg - Alleghany Railway – Pittsburg – Erie – Buffalo – Niagara – Toronto – Montreal – Quebec – Montreal – Whitehall -Albany – NewYork - Boston – Lowell – Boston – Newhaven - New York, with local excursions. He traveled, 2000 miles by steamer, 450 miles by road and 590 miles by railway*(7)*.]

Before Stevenson visited America reports were prevalent in Britain "of great American feats in Engineering and Mechanics which no one was disposed to put much faith in, the Americans having got the unenviable credit of being better at drawing 'long bows' than doing real work"*(8)*. His *Sketch* under the following heads helped to dispel this myth.

Harbors. Stevenson noted that in many ports the accommodation for large ships had been obtained at a much smaller expense than European docks and harbors of similar capacity. Economy in design and construction had been achieved by means of a quay arrangement of primitive and temporary structures, using wood from land clearance, which were fit for purpose because of their sheltered natural locations near deep water. Harbors lacked quay cranes. Ship repair facilities were primitive. The only two dry docks, the finest specimens of masonry Stevenson saw in America, were at Boston and Norfolk for naval use.

Stevenson instanced New York harbor with its tidal range of about 5 ft. as a typical example of a good American harbor. Protected from the Atlantic waves and without the aid of docks or dredges, vessels of the largest class lay afloat during low water of Spring tides, moored to the quays, and by the erection of wooden jetties the port was enlarged at low cost. For ship repair, he noted the "screw" dry dock arrangement for suspending vessels from a submersible wooden platform and thought the hydraulic version "a beautiful application of the principle of Bramah's press"*(9)*. As regards shipping, the American packet ships trading between New York and Europe were "generally allowed to be the finest class of merchant vessels at present navigating the ocean"*(10)*. Their voyages, by sail, averaged 22 days from New York to Liverpool and 32 days in return*(7)*.

Stevenson considered the harbors along the 4,000 miles of coast from the Gulf of St. Lawrence to the Mississippi, in conjunction with river, lake and canal navigation, to have had a "mighty" effect in advancing the prosperity of America*(10)*.

Lake and river navigation. In contrast to the East Coast seaports, most of the lake harbors were formed in exposed locations and were of a more permanent construction. The 1,452 ft. long Buffalo pier was formed of pitched rubble masonry without mortar. Presque-Isle had breakwaters of 3,000 ft. and 4,000 ft. in length. Dunkirk harbor breakwater had been formed during winter by erecting strong wooden cribs filling them with stones on the ice in the correct position and then breaking the ice to sink them into place. Most lake harbors had encountered wave damage and required annual repair.

Stevenson comments that steam navigation was first fully and successfully introduced into real use in America on the River Hudson in 1807 and that it was still capable of further improvement, particularly in the taking of measures to reduce the incidence of boiler explosions. He found the Western Water (Ohio–Mississippi) steamboats with their small high-pressure engines built for economy and finery of their cabins often decidedly unsafe. In contrast, the Great Lakes steamers were strongly built and similar to sea-going boats.

The Eastern Water steamboats were characterized by their small draught, light and slender construction, great speed, and use of large condensing engines. From timings made on a trip from Albany to New York in the "Rochester", Stevenson calculated its average speed at 14.97 mph with a maximum of about 16.5 mph*(11)*. Its "combination of fine lines and great engine power" produced nearly double the speed of the fastest British steamer. "The secret was that the bow of the Yankee boat was like a knife and the speed of her piston 500 ft. per minute as against the English tub's 210 ft.". Stevenson had 8 ft. long models made of the "Rochester" and the sea-going "Naragansett" and published drawings of their lines and "very soon thereafter vessels with fine lines and long stroke pillar engines were plying on the Clyde at higher speeds than in America!"*(7)*.

Canals. Stevenson considered the North American canals "stupendous" in that they enabled vessels suited to inland navigation to pass from the Gulf of St. Lawrence to the Gulf of Mexico, and from New York to Quebec or New Orleans, the latter involving a journey of 2,702 miles*(12)*. He emphasized that the most remarkable feature of these canals was their length, in which they far surpassed those of Europe, rather than their cross-sectional area which was not as large as that of many European canals, and the zeal and rapidity applied in their provision. The chief objective of their designers was to achieve works quickly with economy, safety and stability, but "although on an extensive scale...not in the same spacious style as that of older and more opulent countries"*(13)*.

Stevenson commented, "At the first view, one is struck with the temporary and apparently unfinished state of many of the American works, and is very apt before inquiring into the subject, to impute to want of ability what turns out, on investigation, to be a judicious and ingenious arrangement to suit the circumstances of a new country, of which the climate is severe...where stone is scarce and wood is plentiful, and where manual labour is very expensive"*(13)*. Although "wanting in finish and even in solidity", such works served their purpose efficiently for many years. The undressed slopes of cuttings and embankments, roughly built rubble arches, stone parapet walls coped with timber and timber canal locks did not arise from any lack of engineering skill. The use of wood in canal locks enabled their quick completion at low initial cost and provided for possible improvement later by enabling the easy, cheap and speedy transport of more durable and expensive materials and, where this occurred, the necessity of destroying substantial and costly masonry was obviated.

Stevenson also noted the important contribution of slackwater navigation to inland transport, that is, damming rivers by mounds or sluices, bypassed by locks, to increase water depth along a reach. The 363-mile Erie Canal (543 miles with branches) connecting New York via the Hudson to the Great Lakes made from 1817 to 1825 was "perhaps the most important" American public work, being the first in America to convey passengers and the longest in the world for which accurate information was available*(14)*. By 1837 its success was such that it was being widened to 70 ft. and deepened to 7 ft., by bank raising, largely by "an iron scoop drawn by two horses, which acted like a plough"*(7)*. The River Mohawk was crossed by aqueducts of 748 ft. and 1,188 ft. in length (with timber troughs on masonry supports). The 16 ft. deep Louisville and Portland Canal bypass of rapids on the Ohio had been excavated in rock for nearly all of its length. The Morris Canal built by J.D. Douglass (1790-1849) was remarkable for its use of 23 inclined planes, instead of locks, with an average lift of 58 ft. for 30-ton boats. In his table of details of 79 canals Stevenson noted that on the Chesapeake & Ohio Canal a 4 miles and 80 yd. long tunnel was required through the Alleghany Mountains*(15)*.

Roads. Stevenson found road making "very little cultivated" and most roads in a "neglected and wretched condition". He experienced the discomfort of "corduroy" or log roads over which the coach advanced by a series of jumps "calculated to shake the teeth out of the heads of the unfortunate passengers"*(7)*. Labor for road making was inadequate and expensive. The best roads were those of New England which were made of gravel, but no attention had been given to forming or draining them. More attention had been given to one or two lines of road, the most "remarkable" being the partly built "National Road" stretching 700 miles from Baltimore to Illinois. Experiments to obtain a durable city road had been made on Broadway, New York, including a pine pavement over which carriages passed easily and noiselessly, a practice later tried in Europe*(16)*.

Bridges. Stevenson found that American bridges were generally constructed of wood and on a scale far surpassing those of Britain, instancing nine examples varying in length from 1500 ft. to over a mile. Although good building materials were generally plentiful, to have built stone bridges would in most cases have been too costly. Many bridges consisted of a wooden superstructure resting on stone piers. Generally they exhibited "good engineering" and he instanced the 5-arch timber bridge over the River Delaware at Trenton (1804-1806) with its 160-200 ft. bowstring spans of laminated planking and iron hangers built by Theodore Burr. Stevenson considered the bridge over the Susquehanna at Columbia with its 29 arches of 200 ft. span built on a similar principle in 1832-1834 in 6 ft. of water by Moore and Evans*(7)*, "perhaps the most extensive arched bridge in the world, a magnificent work and its architectural effect is particularly striking"*(17)*.

Stevenson was impressed by two timber bridges over the River Schuylkill in Philadelphia, Market Street (1801-1804) built by Timothy Palmer and the large span "Colossus" (1812-1813) by Lewis Wernwag, which he sketched on the spot (see Figure 2). Also, more generally, by Ithiel Town's Lattice and Stephen Long's frame timber bridges, both of which Stevenson promoted in British publications, by preparing designs for their use in Scotland at Norham and in India, and making a scale model of the latter.

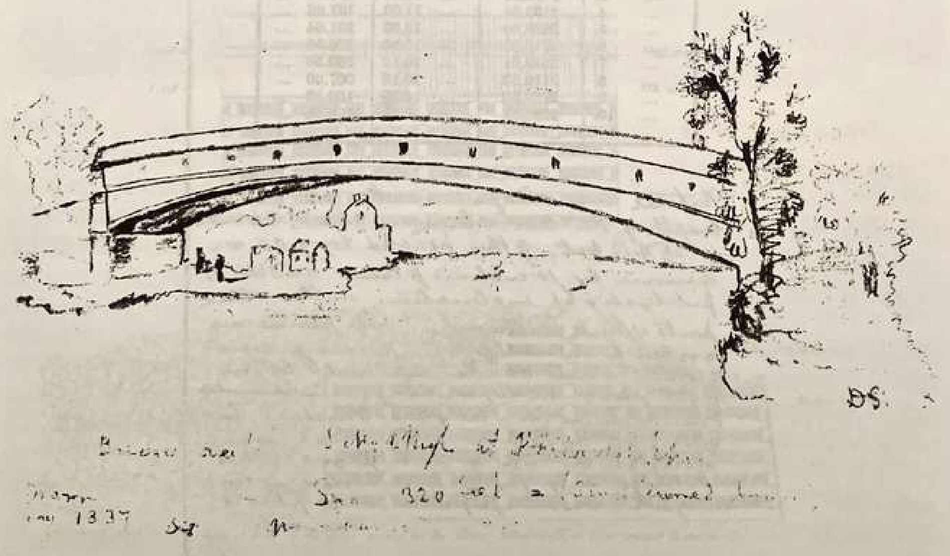
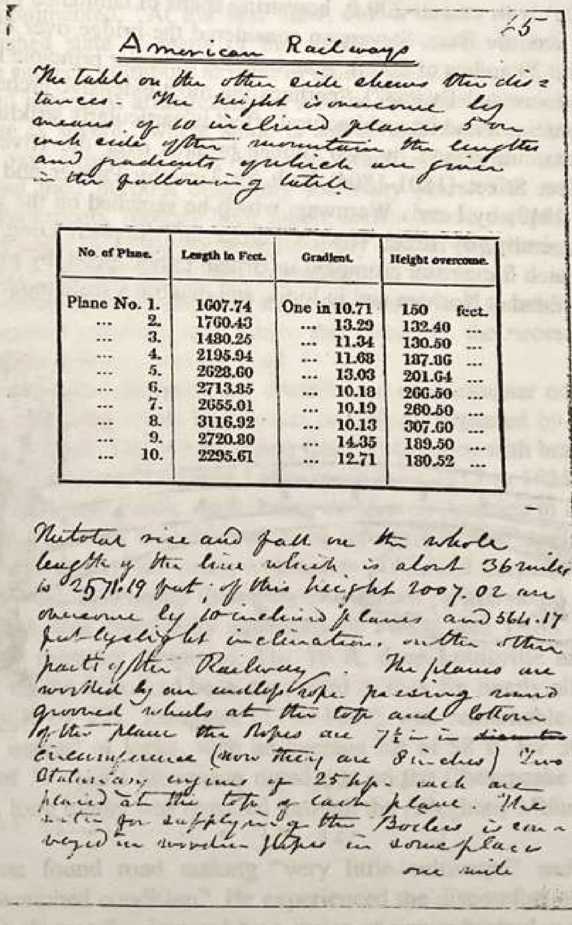


Figure 2. Stevenson's sketch of the "Colossus" Bridge, Philadelphia in May 1837*(18)*.

Railways. Stevenson commented on their rapid development, noting that between the opening of America's first railway in 1827 and 1837, more than 1,600 miles of railway had been built with a further 2,800 miles ongoing. He took a particular interest in the track and found that there was little uniformity of construction on the different lines. The stone blocks often used to support the rails were frequently damaged by the severe frosts. The use of wooden supports for rails was in most situations more economical than stone. They were also less liable to frost damage, made track repair easier and, being more elastic, were less damaging to locomotives and wagons. Most of the early rails and chairs were of British manufacture. American railroads were generally constructed at a much lower cost than their British counterparts because of their exemption from high land costs and compensation for damages, their execution in a less substantial and costly manner and because wood, the principal material used, was obtained at a very small cost.



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American Railways

The table on the other side shews the distances. The height is overcome by means of 10 inclined planes 5 on each side of the mountain the lengths and gradients of which are given in the following table

No. of Plane.	Length in Feet.	Gradient.	Height overcome.
Plane No. 1.	1607.74	One in 10.71	150 feet.
... 2.	1760.43	... 13.29	132.40 ...
... 3.	1480.25	... 11.34	130.50 ...
... 4.	2195.94	... 11.68	187.06 ...
... 5.	2628.60	... 13.03	201.64 ...
... 6.	2713.85	... 10.18	266.50 ...
... 7.	2655.01	... 10.19	260.50 ...
... 8.	3116.92	... 10.13	307.60 ...
... 9.	2720.80	... 14.35	189.50 ...
... 10.	2295.61	... 12.71	180.52 ...

The total rise and fall on the whole length of the line which is about 36 miles is 2571.19 feet; of this height 2007.02 are overcome by 10 inclined planes and 564.17 feet by slight inclinations on the other parts of the Railway. The planes are worked by an endless rope passing round grooved wheels at the top and bottom of the plane the Ropes are 7½ in in ~~diameter~~ circumference (now they are 8 inches) Two Stationary engines of 25 h.p. each are placed at the top of each plane. The water for supplying the Boilers is conveyed in wooden pipes in some places one mile

Figure 3. Alleghany Railway details from Stevenson's pocket notebook*(19)*.

Stevenson also took a particular interest in the stationary steam engine operated inclined planes used for transit where the summit level of a railway could not be attained by an gradient sufficiently gentle for the use of locomotive engines or where the formation of such inclinations would have been too costly. He gave as an example the Portage or Alleghany Railway over the Alleghany Mountains which had inclined planes "on a more extensive scale than in any other part of the world"*(20)*. This link was part of a route extending 395 miles from Philadelphia to Pittsburg via the Columbia Railroad, the eastern division of the Pennsylvania Canal, the Alleghany Railroad and the western division of the Pennsylvania Canal. Stevenson traveled this line in 91 hours averaging 4.34 mph. The 36-mile Alleghany Railway had 10 inclined planes overcoming 2,007 ft. the longest of which carried 72 tons/hr.(see Figure 3).

The first steam locomotives in America were made in Britain, but by 1837 they were being made in great numbers in America the largest works being at Philadelphia and Lowell. "Those parts indispensable to the efficient action of the machine were very highly finished but the external parts were left in a much coarser state than in engines of British manufacture"*(21)*.

Waterworks. Although commenting on numerous waterworks, Stevenson found those at Fairmount, Philadelphia (1819-22-36), using River Schuylkill water and operated by waterwheels, "remarkable for their efficiency and simplicity as well as their great extent, being the largest waterworks in North America"*(22)*. New York's "gigantic" Croton scheme devised by J.D. Douglass, although underway was not completed until 1842. Stevenson was impressed with the 1,204 ft. long overfall dam executed on Ariel Cooley's plan using timber cribs filled with stone, sunk into place and then rubble-backed *(23)*.

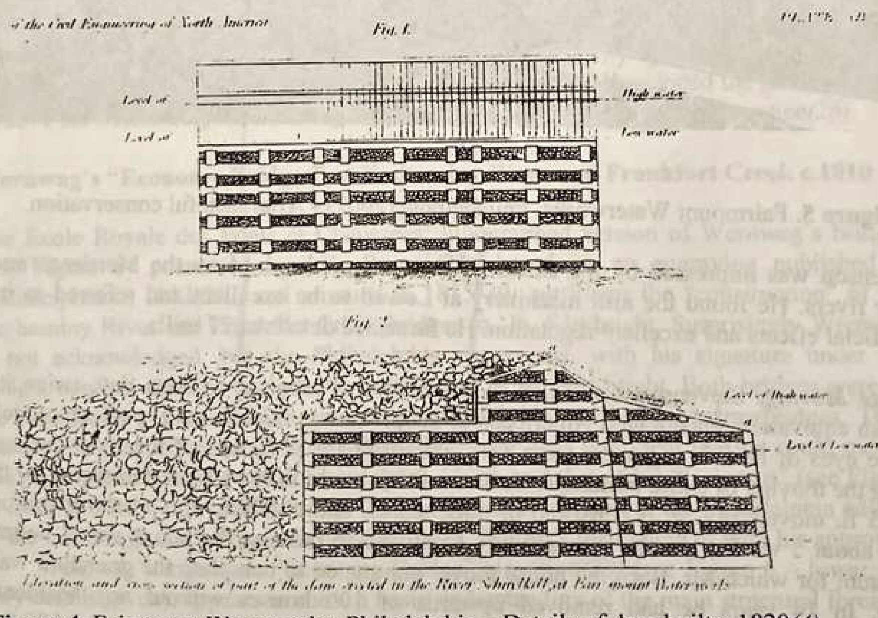

Figure 4. Fairmount Waterworks, Philadelphia – Details of dam built c.1820*(4)*.

This construction method, very generally practiced in America for creating slackwater navigations, in this instance the Schuylkill Navigation with 33 other dams and 29 locks, and for some bridge foundations in moving water, had proved successful. For the 98¾-mile city distribution system, pipes made of cast iron were used rather than wood, about one half of which were cast in America and the remainder were imported from Britain.

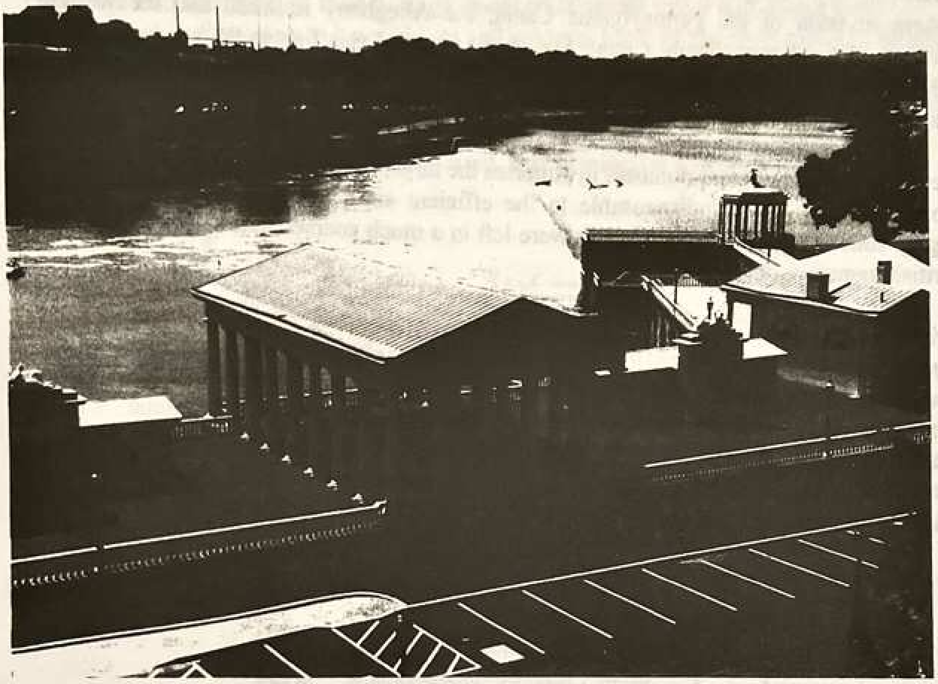

Figure 5. Fairmount Waterworks, Philadelphia (2002) - After tasteful conservation.

Stevenson was impressed by the extent of the waterpower used on the Merrimac and other rivers. He found the mill machinery at Lowell to be excellent and referred to its beneficial effects and excellent regulation. He furnished details of 27 mills.

House Moving. Stevenson noted that the high cost of labor, a dollar a day, twice its British equivalent, encouraged Americans to adopt "many mechanical expedients which in the eyes of British engineers seem very extraordinary"*(24),* one of the most curious being the moving of entire buildings. He saw a brick house in New York measuring 50 ft. by 25 ft. moved 14½ ft. It consisted of three stories and a garret. The whole operation took about 5 weeks, but the time actually employed in moving the house was 7 hours. The sum for which Mr. Burn the house mover contracted to complete the operation was £200. In 14 years he had removed upwards of 100 houses without any accident. Stevenson also saw a wooden church with galleries and spire which was moved 1,100 ft.

Telford

Telford's authoritative treatise on world inland navigation published in the *Edinburgh Encyclopaedia(1)* includes 6 pages relating to North America giving an overview and brief descriptions of particular projects taken mainly from Gallatin's report*(25)*.

Telford considered North America "singularly favoured by nature in the immense extent and ramification of its navigable waters…forming a triangle…of which the line from New Orleans to above Pittsburg on the Ohio, 1,000 miles, may be reckoned the base, and the other sides 1,600 miles each so that the basin of navigation is nearly one half greater than that of the Volga…From the gentle inclination and the very winding course of the rivers, the branches of the Mississippi are for the most part navigable for some kind of craft almost to their heads. But by far the most important branch is the Ohio as affording a direct communication with the eastern states and, being already the channel of a great inland trade, forming a great river which flows 1,188 miles to join the Mississippi. The great extent of ship navigation in the St. Lawrence and its lakes, making altogether a distance of not less than 2,000 miles, and its lying in the direct line towards Europe, will always render this the cheapest channel of communication…By running canals over the spaces where portages and obstructions by rapids…now occur, the most distant sections of the union may be connected". He noted the American "eagerness" to develop their inland navigation and their "already numerous and extensive projects"*(1)*.

Individual elements noted by Telford included the two lower locks 18 ft. deep excavated out of solid rock on the Potomac at Great Falls (Weston 1795-1796) and an aqueduct 280 ft. long and 22 ft. above the river on the Middlesex to Boston Harbor canal (1808), "the greatest work of the kind in the United States" at that time.

Telford was generally influenced by the success of James Finley's Merrimac Bridge, Newburyport, suspension bridge from the account in T. Pope's *A Treatise on Bridge Architecture* (1811), but thought that "British dexterity upon superior materials" would improve on American practice*(2)*. From 1814 Telford developed the technology to achieve the Menai suspension bridge by 1826 independently of Finley's practice*(26)*.

Wernwag's "Economy Bridges" at Neshaminy River and Frankfort Creek c.1810

The École Royale des Ponts et Chaussées' lithographed version of Wernwag's bridges (see Figure 6) possessed by I.K. Brunel*(27)*, based on an engraving published at Philadelphia in 1813*(28)*, and reissued in 1815*(29)*, attributes the "construction" of the Neshaminy River and Frankfort Creek bridges to 'Jh. Kirkbright. Surprisingly Wernwag is not acknowledged, but the Philadelphia engravings, with his signature under the design, confirm that the bridges were "built for" Josh. Kirkbright. Both bridges were on the Post Road to New York northeast of Philadelphia and included drawbridges. Their spans were from 52 ft.(draw span)-60 ft. Wernwag was confident that he could extend this principle to spans of 120 ft.(draw span)-150 ft. and that of his "Colossus" (see Figure 6) from 340 ft. 3¾ in. to 500 ft.*(30)*. This bridge also featured in the Philadelphia edition of the *Edinburgh Encyclopaedia* presumably at Telford's instigation or with his approval.

Wernwag's ingenious "Economy Bridge" elevation*(28)* (see Figure 6 – lower, the only details given), appears to show a basic understanding of the main structural forces at work, almost certainly derived from practical expertise and experience rather than theory

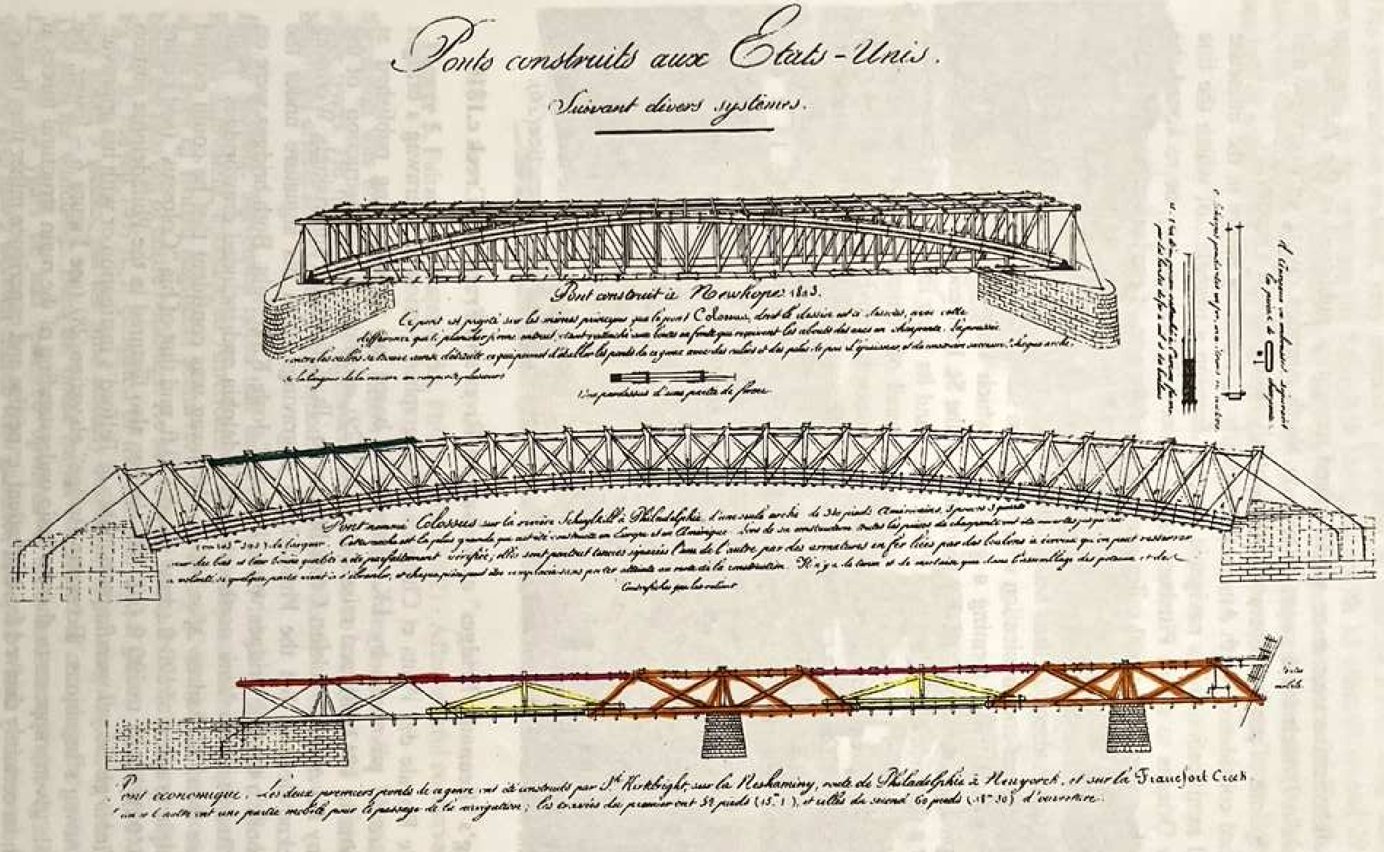

Figure 6. École Royale des Ponts et Chaussées lithograph of Wernwag bridges c.1810-1813 (1826)*(27)*.

and, in general, represents a good and economical solution to a difficult problem*(31)*. In erecting these bridges it seems probable that the timber and iron cantilever elements were pre-assembled and bolted into position. The portion over the abutment allowed a standard pier unit cut short to be used, providing fixity at the end. The pre-assembled suspended span portions, although somewhat clumsy in appearance, allowed the center of the span to be placed by boat or crane, followed by completion of the remainder of the top chords. In its finished state the structure formed a continuous open-webbed truss, the earliest known to the author in which iron was allowed a principal structural role. Without the interconnecting top chord its design principle is reminiscent of Scotland's Forth Bridge.

Conclusions

Chrimes rightly comments that standard histories of civil engineering make little mention of developments in the USA prior to 1850, apart from some notable bridge works, and that they are "glossing over a remarkable achievement as regards development of the transportation infrastructure"*(32)*. As has been shown, knowledge of this achievement in advancing the prosperity of the nation had already been promoted by Telford and particularly by Stevenson who, in his historically valuable *Sketch,* emphasized the essential role played by low cost, high quality, timberwork. Both commended the "zeal" and "eagerness" which drove this transportation revolution. A British perspective of this achievement is, therefore, its indispensable contribution in diverse ways to the creation of the nation's vast water-borne transportation infrastructure, to the building of railways and bridges and to the provision of water for public health and powering machinery.

The means of creating this achievement differed from British practice. Although American engineers were guided by the same basic design principles as British engineers, dissimilarities in their practice arose from the different circumstances applicable, such as the nature and cost of the materials and labor employed, climate, topography and ground conditions. A need for economy, rapid execution and future design flexibility dictated timber construction, different from the situation in Britain with its developed ironworks and technologically skilled and relatively low-paid workforce. The lack of "solidity" and "finish" in American works, therefore, stemmed not from any want of knowledge or skill, but from a judicious weighing of the circumstances. In general, any work done was the minimum necessary that was fit for purpose over its design life. Passenger comfort and aesthetics had low priority, a notable exception being the neo-classical adornments at Fairmount Waterworks. On lighthouses, overall coverage of the 5,450 miles of coast was good, but the apparatus and its regulation were below European standards. Overall, by c.1840 an indigenous, largely self-contained, American practice had developed.

Particular elements of this achievement which can be considered of international significance included, the Alleghany mountain railway despite its operational drawbacks, Finley's development of the suspension bridge exemplified in Merrimac bridge which acted as a catalyst for Telford's epoch-making improvements and the development of fast, elegant, steamboats in Britain encouraged by Stevenson. Arguably, the most outstanding, were the magnificent timber bridges of Burr, Palmer and Wernwag and, more generally, the development by c.1810 of the medium span open-webbed truss, which led progressively to Town's trusses from 1820, Long's from 1830, Howe's from 1840 and later the Warren trusses familiar to modern engineers.

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