Japan and USA Whipple Bowstrings – World's First Scientifically Designed Truss Bridges

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ABSTRACT: In 1841, the American engineer, Squire Whipple, patented a bowstring truss iron bridge for the enlarged Erie Canal (1836-1862) and similar waterways, especially in New York State. His design was the first to use scientific principles, published in his seminal 1847 book: "A Work on Bridge Building." For the first time in the world, this book presented the correct methods of analyzing and designing safe, durable, and economical truss bridges. Of the hundreds of original Whipple Bowstring Truss bridges built, only eight are known to survive (and recently four new bridges, inspired by the Whipple Bowstring design, were built in Buffalo, New York State). Two of the surviving Whipple bowstring truss bridges are special. One is in Japan, originally built in 1878 by Souichiro Matsmoto (who had attended Rensselaer Polytechnic Institute in Troy, New York State, from 1871 to 1876). This bridge was later moved to the Fukagawa Hachiman Shrine, Tokyo and renamed the Hachiman Bridge. As the first iron bridge entirely constructed by Japanese builders it is an important Japanese cultural property. Another special example of a Whipple Bowstring is the Shaw Bridge over the Claverack Creek about two hours north of New York City. Built by John D. Hutchinson in 1870, it is the only double span and the only one not relocated. Neglected for 30 years, the Shaw Bridge is in remarkably good original condition (except for the replaced wooden deck), and will be restored according to original specifications. This paper argues that the restored Shaw Bridge should be eligible for World Heritage Status.

1 INTRODUCTION

Two bridges on opposite sides of the planet – one in Japan and the other in America – have much in common and are of special interest to this conference chaired by Japan and American bridge engineers. Both are examples of iron bowstring truss bridges that were first designed and patented in 1841 by the American pioneering engineer Squire Whipple. The Japan bridge, named the Hachiman Bridge, is in Tokyo near the Fukagawa Hachiman Shrine and the American bridge, named the Shaw Bridge, is in a quiet picturesque area about two hours north of New York City. Hundreds of Whipple bowstring truss bridges were built and this paper provides a summary of all the known surviving Whipple Bowstring Truss bridges (and four new Whipple Bowstring-style bridges), with emphasis on the Hachiman Bridge and the Shaw Bridge. We begin with a brief description of the modest gentleman who designed them and his importance.

2 SQUIRE WHIPPLE (1804-1888) THE GENIUS BEHIND THE DESIGN OF THE WHIPPLE BOWSTRING TRUSS BRIDGE

Squire Whipple was born in Massachusetts in 1804, the ninth son of a farmer and mill owner. The young Whipple was exposed to the latest construction techniques and materials and methods used to power mills of all kinds. When he was 13, his family moved to a farm in New York State.

After receiving the best common school education available, in 1830 he graduated from Union College in Schenectady, New York after one year of study. He spent the decade of the 1830s working on various railroads and the Erie Canal enlargement. When work was slow, he designed, built, and sold mathematical instruments such as transits and engineer's levels and drafting equipment (Griggs 2002, 2015).

Figure 1 Squire Whipple (a) Young (b) Senior

In 1841, Whipple designed and built a weigh lock scale with a capacity of 300 tons to weigh canal boats. This was the largest weighing device in the country at the time.

Whipple became interested in the design and construction of bridges. He knew that wooden bridges on the original Erie Canal had a short life and the new, wider canal would require longer span bridges. So he devised methods to study bridge designs using various materials including iron. These investigations led to his design of the elegant bowstring truss that used cast iron for compression members, wrought iron for tension members, and a wooden deck that could be replaced without affecting the strength of the bridge. He applied for and was issued a patent, April 24, 1841. See Figure 2.

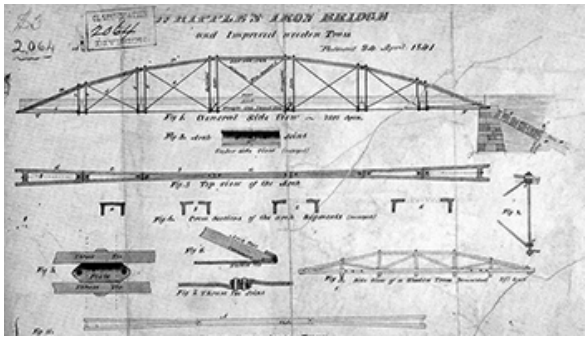

Figure 2. Whipple's Patent Drawings 1841

Whipple tried to convince the Canal Commissioners that a bridge built of iron was a good long-term investment (thus becoming a pioneering advocate of life-cycle costing), but they were reluctant. To illustrate the stability and strength of his bridge, Whipple had one built at his own expense near the offices of the Canal Commissioners. His design was eventually adopted by the Commission as the standard bridge to cross the canals of the state. Between 1842 and 1880, hundreds of Whipple Bridges were built over the Erie and its branch canals, either by Whipple or to his patent. See Figure 3 for an example.

Others (like the Shaw Bridge) were built over waterways in the United States and one was even built in Japan (developed by Souichiro Matsmoto a Japanese 1876 graduate of Rensselaer Polytechnic Institute in Troy, New York). Frequently, contractors would build to his patent without paying patent fees, so he never received large sums of money from builders using his patent (Griggs 2002, 2015).

Whipple wanted to share his discoveries with the world and to bring credibility and respect to bridge building, so in 1846 he wrote *"*An Essay on Bridge Building: containing analyses and comparison of the principal plans in use with investigations as to the best plans and proportions and the relative merits of wood and iron for bridges." It included an analysis of the bowstring truss and other bridges, including the trapezoidal form. Whipple's decision to write this essay was probably based on his intention to show that his bowstring truss was the best form available in terms of efficient use of material but he found instead "each of the three forms – the arch, and the trapezoidal with and without verticals, possessed certain practical advantages entitling each to preference in respective cases". The 47-page essay marked the beginning of analytical truss design, and the following year it was made part of his 1847 seminal book "A Work On Bridge Building: consisting of two essays, the one elementary and general, the other giving original plans and practical details for iron and wooden bridges" (Whipple 1847). For the first time anywhere in the world, this book presented the correct methods of analyzing and designing a truss using the properties of the latest appropriate materials. His technique, now known as the method of joints, is still the way that truss analysis is taught. He used both trigonometry and geometrical construction – the force polygon method – to find his member forces.

Figure 3. Lithograph of Whipple's Bowstring Bridge in Syracuse NY, one of hundreds built over the Enlarged Erie Canal.

In 1852-53 Whipple went on to design and build the first successful long span trapezoidal railroad bridges. This double intersection design was the most common railroad truss bridge until the 1890s, being built over western rivers with spans over 150 m (Griggs 2002, 2015).

About 1860 Whipple turned his business over to his nephew J. M. Whipple but took on a few jobs including designing and building trapezoidal bridges, swing bridges, and lift bridges. In December 1872, he designed and patented the first vertical lift bridge in the United States and built one over the Erie Canal in Utica.

Whipple continued to update and expand his first book with an Appendix in 1869 and wrote a more formal book on bridge building (first

printed in 1872 then reprinted until 1899): "An Elementary and Practical Treatise on Bridge Building, An Enlarged and Improved Edition of the Author's Original Work." (Whipple 1872). He contributed several articles to American Society of Civil Engineers (ASCE) Journals, and was the first person, after the post-Civil War rebirth of ASCE, to be named an Honorary Member of the Society in 1868.

3 EIGHT SURVIVING 19TH CENTURY WHIPPLE BOWSTRING TRUSS BRIDGES AND FOUR NEW BRIDGES INSPIRED BY WHIPPLE'S DESIGN

3.1 *Eight 19th Century Whipple Bowstring Truss Bridges*

Below are photos of the eight known historic Whipple Bowstring Truss Bridges (in decreasing order of age).

Figure 4. 1859 Ehrmentraut Farm Bridge. Photo by Jet Lowe 1994, Historic American Engineering Record (HAER).

Figure 5. 1867 Normanskill Farm Bridge. Photo by Jack Boucher/David Plowden 1969, HAER.

The 1859 Ehrmentraut Farm Bridge carries a farm road over the Black Creek in rural Monroe County, NY. It is a nine-panel Bowstring Pony Truss, with one span. Built by John Hutchinson of Troy, NY, originally a three truss bridge to cross the Erie Canal in Brockport, NY, then relocated, circa 1880, east of Brockport and changed to two truss design, finally moved again to current location, circa 1910, by farmer Ehrmentraut.

The 1867 Normanskill Farm Bridge carries Mill Road over the Normans Kill Ravine in Albany County, NY. It is a nine-panel Whipple Bowstring Through Truss. Built by Simon DeGraff of Syracuse, NY, it has one 34.5 m span. Originally erected at another site, it was moved and re-erected at the Normanskill site circa 1900.

Figure 6. 1869 Johnstown Bridge at Union College after relocation from Johnstown. Photo by Jet Lowe 1994, HAER.

Figure 7. 1869 Vischer Ferry Bridge at Fonda before relocation to Vischer Ferry. Photo by Jet Lowe 1994, HAER.

The 1869 Johnstown Bridge carries a pedestrian walkway over a seasonal stream on the Union College campus, Schenectady County, NY. The seven-panel Bowstring Pony Truss has one span. Built by Shipman & Son of Springfield Center, NY, it was moved from Johnstown in 1979. Squire Whipple was a 1830 graduate of Union College. The bridge is listed as a National Historic Civil Engineering Landmark.

The 1869 Vischer Ferry Bridge is a pedestrian walkway over Enlarged Erie Canal in the Vischer Ferry Nature and Historic Preserve, Saratoga County, NY. The seven-panel Bowstring Pony Truss has one 23 m span. The only surviving

Bowstring Truss Bridge actually built by Squire Whipple, it originally was over the Erie Canal at Fultonville, then relocated in 1919 to cross Cayadutta Creek at Fonda NY, and finally moved to the current site 1996-98. The bridge is listed as a National Historic Civil Engineering Landmark.

Figure 8. 1870 Shaw Bridge. Photo is from a circa 1900 postcard when the bridge was only about thirty years old.

Figure 9. 1870 Talcottville Bridge over Sugar Creek before relocation to Boonville. Photo by Jet Lowe 1994, HAER.

Figure 10. 1872 Rodrick Bridge over Wills Creek before relocation to Ohio State University Newark Campus. Photo by Joseph Elliot 1992, HAER.

The 1870 Shaw Bridge carries Wyck Lane over the Claverack Creek in rural Columbia County, NY. It is a nine-panel Bowstring Pony Truss, with two spans each 24.4 m. Built by J. D. Hutchinson of Troy, NY it is now closed, waiting for restoration as a pedestrian walkway. This bridge is the only surviving multi-span Whipple bowstring and the only one still in its original 19th century location.

The circa 1870 Talcottville Bridge is a pedestrian walkway over the Utica & Black River Canal in Boonville, Oneida County, NY. It is a seven-panel Bowstring Pony Truss, with one 23.5 m span. The builder is unknown. The bridge was moved from Sugar Creek at Cheese Factory Road, Talcottville, Lewis County, NY in 1997.

The 1872 Rodrick Bridge is a pedestrian walkway over a seasonal stream on Ohio State University Newark Campus, Licking County, OH. The nine panel Bowstring Through Truss has a 30.8 m span. The bridge was built by James W. Shipman (nephew of Squire Whipple) who worked with his father building Whipple bridges in New York and decided to move west and open his own business in Coshocton, OH. Unfortunately after the Rodrick Bridge was made, his foundry blew-up sending the company into receivership. The bridge was moved from Wills Creek at Town Route 144, Coshocton County, OH in 1998.

Figure 11. 1878 Hachiman Bridge. Photo from Wikimedia, 2007

The Hachiman Bridge is a pedestrian walkway over the vestiges of an ancient moat. It is a five panel Bowstring Pony Truss with a 15.2 m span. Built in 1878 by Souichiro Matsmoto it was moved from Kaede River to the current site near the Fukagawa Hachiman Shrine in Tokyo, Japan, after the Great Kanto Earthquake in 1923. The bridge is listed as a Japan Historic Civil Engineering Landmark.

Co-author Francis Griggs was involved in the restoration of the Johnstown, Vischer Ferry, and Talcottville Bridges. Both authors, Ian Nitschke and Francis Griggs, are involved in promoting the restoration of the Shaw Bridge. Note that 19th century Whipple Bowstring bridges all have distinct top cords wider at the base than at the top to provide rigidity and stability.

3.2 *Four Recently Built Bridges in Buffalo NY Inspired by Whipple's Bowstring Truss Design.*

Beginning 2008, a multi-million dollar Buffalo waterfront project was initiated to recreate the 19th century area at the terminus of the Erie Canal, as it emptied into Lake Erie. Four new bridges were built emulating Whipple's Bowstring Truss design. But the trusses were factory-made whole, using modern materials and methods, transported to the site and assembled with the help of huge cranes, unlike the originals. Two of the bridges are technically not Whipple Bowstring Truss Bridges. In any case, the bridges are important tourist attractions at the waterfront, Canalside, which uses the stylized Whipple Bowstring Bridge as its logo:

CANALSIDE

Figure 12. 2008 Commercial Slip Bridge. Photo by Royce and Bobette Haley, BridgeHunter.com, 2016.

Figure 13. 2014 Lake Street Bridge. Photo by Royce and Bobette Haley, 2016.

The 2008 Commercial Slip Bridge at Buffalo's Canalside, carries pedestrians over the reconstructed Erie Canal Commercial Slip as it enters Lake Erie. There is a central wide path and two walkways on each side of the central path (as many original Bowstring Truss Bridges had in the 19th century – but none have survived). The bridge is a nine-panel Bowstring Pony Truss with distinctive Whipple wide-base top chords.

The 2014 Lake Street Bridge at Canalside is similar to the Commercial Slip Bridge.

Figure 14. 2014 Commercial Street Bridge. Photo by Royce and Bobette Haley, 2016.

The 2014 Commercial Street Bridge at Canalside also carries pedestrians over the reconstructed Erie Canal. It only has a walkway on one side (common in the 19th century but none have survived). The signature Whipple top chord (wider at the base) has been dropped and the bridge now uses Swartz massive iron end posts and rods for rigidity, perhaps as a nod to the Buffalo inventor Abram Swartz who in 1857 patented a similar truss bridge (see Figure 15).

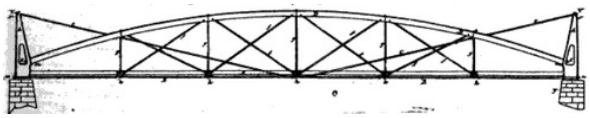

Figure 15. Swartz Bridge Patent Drawing 1857.

Figure 16. 2015 Lloyd Street Bridge. Photo by Royce and Bobette Haley, 2016.

The 2015 Lloyd Street Bridge over the reconstructed Erie Canal is a three-truss bridge that allows for two traffic lanes. (This was also the case when the original Ehrmentraut Bridge was over the Erie Canal in Brockport, NY). The Lloyd Street Bridge has two walkways, one on each side of the two traffic lanes, and all four paths together provide a broad platform for pedestrians to watch summer water activities and winter ice skating events. Again, the characteristic wide base of the Whipple top chord has been dropped, relying instead on Swartz's design for rigidity.

4 TWO SPECIAL WHIPPLE BOWSTRING TRUSS BRIDGES: THE HACHIMAN BRIDGE & THE SHAW BRIDGE

4.1 *The Hachiman Bridge*

What makes the Hachiman Bridge special? Co-author Francis Griggs notes in his draft Whipple Biography: "That hundreds of Whipple Bowstring Truss bridges were built in Squire's lifetime was the ultimate complement. But perhaps the most surprising example of Whipple's influence outside of the United States was the discovery, in Japan, of a classic Whipple Bowstring truss. This bridge was originally built in 1878 in Tokyo to cross the Kaede River and was named the Danjo Bridge. The designer of the Danjo Bridge was Souichiro Matsmoto who had attended Rensselaer Polytechnic Institute between 1871 and 1876… [The Danjo Bridge] was later moved to the Fukagawa Hachiman Shrine, Tokyo, and renamed the Hachiman Bridge. It is now preserved as an important cultural property. It is the oldest iron bridge in Toyko and the second oldest iron bridge in the country, but…it was the first constructed by Japanese builders…In 1989 the bridge was designated a Japan Historic Civil Engineering Landmark…That his [Whipple's] bridge would be the first built of Japanese iron and by Japanese engineers is also testimony to his design. The fact that his patent had been issued, and the first bridge built to it [in 1841], 37 years before the Japanese selected his pattern for their bridge, is another indication of the soundness of his early creation. In summary, Squire's ideas spread worldwide prior to his death… The pin-connected truss was now a distinct American creation, and his single-canceled and double-canceled trusses were the most common truss patterns in use in the United States and had begun to make inroads around the world."

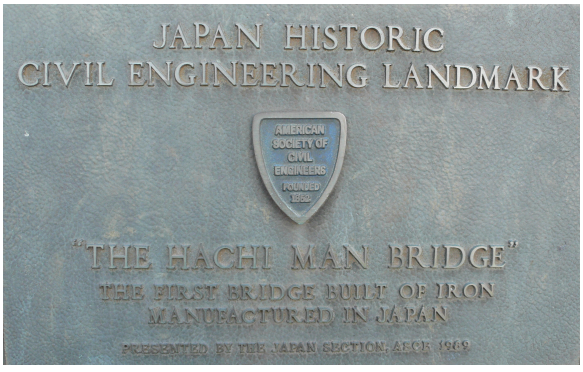

Figure 17. Japan Historic Civil Engineering Landmark Plaque honoring the Hachiman Bridge. Photo from Wikimedia 2007

What also makes this bridge special and distinctively Japanese – perhaps a tribute to the nearby Fukagawa Hachiman Shrine – are the cast iron and wrought iron components assembled with ends shaped like the imperial chrysanthemum.

Figure 18. Chrysanthemum Decoration on the Hachiman Bridge. Photo from Wikimedia 2007.

Further information about the career of Souichiro Matsmoto can be found online from the following Rensselaer Polytechnic Institute sources:

Education for a Technical Society by Samuel Rezneck (published in 1968) states: "Souichiro Matsmoto of Ogaki, graduated in 1876, at twenty-five years of age, the first of his nationality to do so [at Rensselaer]… [He] came to the United States and to Rensselaer as part of Japan's effort at modernization, following the Meiji Revolution of 1867."

Biographical Record of the Officers and Graduates of the Rensselaer Polytechnic Institute 1844-1886 (published 1887): "Souichiro Matsmoto, C.E., was born in Ogaki, Japan, December 13th, 1851. At present a [35 year-old] mining engineer … Sapporo, Japan."

Rensselaer Polytechnic Institute Bulletin – Photographic Reproductions of Work of Graduates (published in 1931) reproduces photos of a masonry bridge and steam train and a metal railway bridge under construction with caption "Imperial Government Railway of Japan – S. Matsmoto, '76, Director General." See Figure 19. By that time (1931) he was almost 80 years old, so obviously he had a very long and distinguished engineering career in Japan.

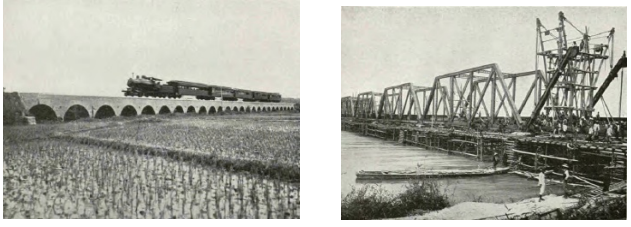

Figure 19. IMPERIAL GOVERNMENT RAILWAY OF JAPAN. – S. Matsmoto, '76, Director General.

4.2 *The Shaw Bridge*

What makes the Shaw Bridge special? Of all the known Whipple Bowstring Truss Bridges, the Shaw Bridge is the only double span and the only one in its original location, so is unique in having its original stonework abutments and pier.

The vital Albany to New York Post Road changed paths over its 300-year history but by 1870 it crossed the Claverack Creek via a double-span bowstring truss bridge later named the Shaw Bridge. The bridge builder (J. D. Hutchinson) and construction date (1870) are clearly established by the inscription embossed along the top of each of the four cast iron trusses. John D. Hutchinson (1842-1897) and his father John S. Hutchinson (1814-1870) built more than 50 bridges using the patented Whipple design but defaulted on paying fees to Whipple (after a small down payment), resulting in lengthy court cases that were settled with a paltry sum paid by New York State.

Traditionally, local bridges were named after the owner of the nearest farm. In 1879, William Shaw, having made a fortune from his import-export business in Brooklyn, New York, purchased the farm next to the bridge, and the bridge became known as the "Shaw Bridge".

Later, the bridge was photographed, featured on a postcard dated circa 1900 with caption: "Bridge at Claverack, near Hudson, NY", and widely distributed (see Figure 8) so the photograph for the postcard was taken when the bridge was essentially in original condition. Note that the wooden deck reaches through the trusses. This is consistent with "New York State Canals – 1871 – Specification of the Manor of Constructing Whipple's Patent Iron Arch Truss Bridge Superstructure". The postcard and official New York State Canals Specification are the fundamental documents that will be used to carefully restore the Shaw Bridge to its original condition.

"When the present State Route 9H was constructed in 1931, this remnant of the Old Post Road…became a little used road belonging to the Town of Claverack…However, when the hurricane of September 21, 1938, struck, the Shaw Bridge was one of the few in all Columbia County that was passable".

In 1956 the bridge was condemned then repaired and reopened. Ten years later (1966), measured drawings of the deck provided an accurate list of materials to replace the wood stringers and deck, the last time they were replaced. On September 6, 1980, a ceremony celebrated the Shaw Bridge's listing on the National Register of Historic Places. This event included speeches emphasizing the historical importance of the bridge and a parade across the bridge led by a horse-drawn buckboard, followed by 1922 Essex Speedster, 1923 Studebaker, 1924 Ford, 1922 White truck, 1929 Ford truck, and 1930 Ford truck. However, despite significant support, by June 1989 the bridge was closed to motorized vehicle traffic because of "structural deficiencies."

During 1990, various newspaper articles reported that the Town of Claverack was seeking funds to repair the Shaw Bridge. Meetings were attended by Van Wyck Lane residents interested in seeing the bridge preserved. One neighbor suggested the span be rehabilitated and reopened only to pedestrian traffic in order to preserve "the tranquil character of our neighborhood". By August 1990 it was announced that the state would grant $146,650 for half the cost of repairs. However, the town and county failed to come to an agreement on matching the state grant and the grant expired. Meanwhile, in the summer of 1994, Jet Lowe, the famous Historic American Engineering Record (HAER) photographer, photographed the Shaw Bridge. However, in November 1995, the county engineer stated there are "no plans to re-open Van Wyck Lane over the Claverack Creek at this time". Thirteen years later, Wikipedia recorded how the famous bridge had become overgrown with vines and weeds. In 2010, several photos by Rick Ehrenberg (see Figure 20) conveyed the deplorable state of this important bridge to the Claverack Town Supervisor.

Figure 20. Shaw Bridge. Photo by Rick Ehrenberg 2010

This led, in 2011, to clearing of the vegetation from the bridge by the Town Highway crew and photo documentation of the bridge by HistoricBridges.org, culminating in a proposal to the Preservation League to fund a Historic Structure Report, which, alas, was rejected. A

second (this time successful) proposal was sent to the Preservation League in 2012, which resulted in the development of reports by engineering consultants Ryan-Biggs Associates and co-author of this paper, Dr. Francis Griggs Jr. These reports were then used to prepare a New York State Consolidated Funding Application (CFA) to restore the bridge in 2014. Unfortunately, the 2014 application was rejected. In 2016 a revised application was submitted and this time it was successful. With CFA money ($170,000) now available, it is expected that matching money, material and in-kind services will finally result in the initiation of the restoration of the Shaw Bridge.

5 CONCLUSION

Whipple had a fondness for the first bridge he designed – the bowstring truss. He wrote: "The arched truss, moreover, may, by some, be thought to have a more graceful and agreeable appearance than the cancelled truss. I will not take upon myself to decide on this point, except by remarking, that, to a person who comprehends the principles and properties of different kinds of structures, in a case where strength is the grand desideratum, that plan of structure which secures this in the greatest degree, with the least amount of material and expense, will generally excite the most pleasing sensations in the mind" (Whipple 1847). The charming Shaw Bridge closely follows the bowstring truss design patented by Squire Whipple. Despite being neglected for so long, the bridge is in remarkably good condition, which speaks well for its original design and materials (19th century cast and wrought iron being more rust resistant than most modern steel).

The restoration project will be guided by recommendations from the Historic Structure Report and overseen by New York Office of Parks, Recreation and Historic Preservation according to the U.S. National Parks, Secretary of the Interior, "Standards for the Treatment of Historic Properties."

Once restored the Shaw Bridge is certainly eligible to be a Historic Civil Engineering Landmark structure and a case can be made that it is a candidate for World Heritage Bridge status.

To be included on the World Heritage List, sites must be of outstanding universal value and meet at least one out of ten selection criteria (see http://whc.unesco.org/en/criteria/). The Shaw Bridge may satisfy four of the ten selection criteria: (i), (ii), (iv), and (vi)

(i) *Represents a masterpiece of human creative genius*

As outlined earlier, the Shaw Bridge represents the best example of a Whipple Bowstring Truss Bridge, which is considered a masterpiece of human creative genius, the first truss bridge in the world designed using scientific principles to provide simple, safe, durable, and economical bridges across canals, creeks, and other similar waterways.

(ii) *Exhibits an important interchange of human values, over a span of time or within a cultural area of the world, on developments in…technology*

Whipple's 1847 book "A Work on Bridge Building" had a profound influence on bridge design, beginning in the United States, spreading to Japan, England, and Europe. It was the first to document scientific design principles for truss bridges and compares his first design (Bowstring Truss Bridge) with other truss bridges including the long span trapezoidal railroad bridges that he also designed.

(iv) *An outstanding example of a type of…technological ensemble…which illustrates a significant stage in human history*

The supremely important Shaw Bridge, the best example of Whipple Bowstring Truss Bridge, may be considered the forerunner of other famous scientifically designed iron arch truss bridges, for example: the Hell Gate Bridge built in 1917 in New York City and the iconic Sydney Harbor Bridge built in 1932.

(vi) *Directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance (preferably used in conjunction with other criteria)*

Whipple's Bowstring Truss Bridges contributed to the success of the enlarged Erie Canal that opened western United States to the world through Buffalo, Albany, the Hudson River, and New York City and so contributed to the worldwide prominence of 19th century New York State and New York City.

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