Professor Roland Paxton MBE FICE FRSE

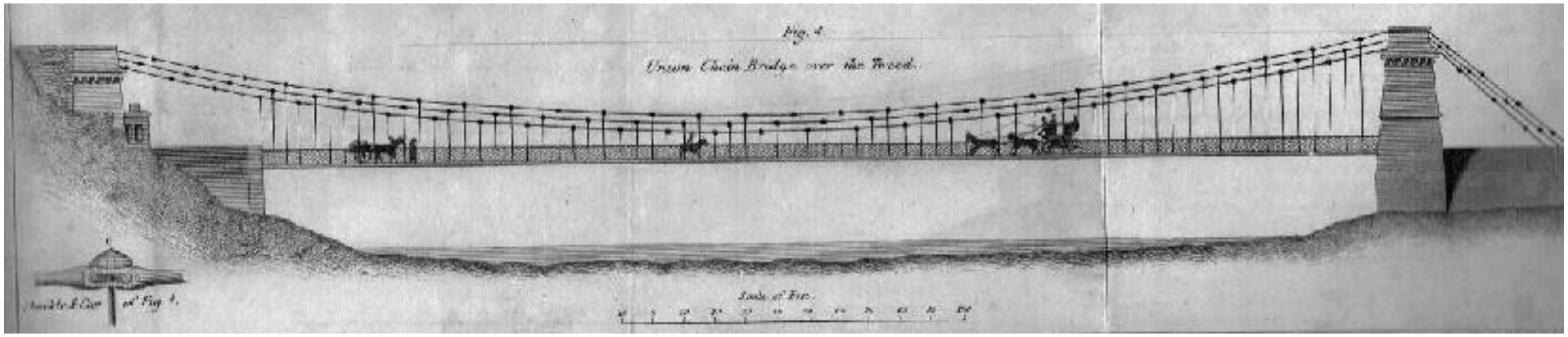
Civil Engineer and Historian

After starting his career with the Ordnance Survey, Professor Paxton qualified as a civil engineer and practiced for 35 years with large local authorities on the planning, design, and execution of highway, bridge, tunnel and drainage projects, retiring as a senior principal engineer. In 1990 he joined the staff of Heriot-Watt University, Edinburgh, in an honorary capacity. Since then he has represented civil engineering and conservation disciplines extensively in teaching, lectures, and research in the UK, USA, Scandinavia and Japan. His work attracted an MBE, and an Hon.D.Eng from Heriot-Watt University, complementing his MSc and PhD, These, and awards from the Association for Preservation Technology International, the American Society of Civil Engineers and Institution of Civil Engineers [ICE], enabled him to appreciate and promote the engineering significance of historic structures widely.

Professor Paxton served on the Royal Commission on Ancient and Historical Monuments of Scotland, and chaired the UK's Historic Bridge and Infrastructure Annual Conservation Awards Panel and the Forth Bridges Visitor Centre Trust. He initiated and acted as secretary/director for the Laigh Milton Viaduct Conservation Project, near Kilmarnock, which he bought for £2 and restored the oldest viaduct on a public railway for £1.1m. He is a Fellow of the Royal Society of Edinburgh, Trustee of the James Clerk Maxwell Foundation, Curator Emeritus of ICE Scotland Museum, Emeritus Member of the ICE Panel for Historical Engineering Works, which he joined in 1975 and chaired for 13 years, and Co-Patron of The Friends of Union Chain Bridge. His many publications include *Civil Engineering Heritage Scotland* [2007] and six articles relating to Union Chain Bridge.

1. Union Bridge, International engineering aspects and the explorative use of radar site investigation

Roland Paxton



The bridge as widely promoted in Robert Stevenson's 'Description of Bridges of Suspension' [*Edin. Phil. J.* **V.** 1821]

Union Chain Bridge deserves its now recognised international historic engineering landmark status because it began a new era in long span bridge development. By 1819, improvements in iron manufacture had made wrought iron economically viable for larger uses and the enterprising Captain Samuel Brown RN made the most of this opportunity to make high quality chains, at first for maritime use and then for bridge and sea-side piers. For Union Bridge he used his 1817 patent wrought iron, round, eye-bar links 15ft long by 2in diameter in 12 chains, deployed in a catenarian curve span of 437ft, from which he suspended by iron rods an 18ft wide roadway. When opened on 26 July 1820 Union Bridge had the world's longest and widest vehicle-carrying span and although weight-limited, is the longest-serving of its type. It cost about £7700 and took only a year to erect. A stone bridge with river piers would have cost at least £20,000. By c.1840, Brown went on to erect more than 20 spans. Union Bridge, the longest, and Brighton Pier were his finest achievements.

In reporting the bridge's opening *The Scotsman* on 5 August 1820 praised its '*superiority over a stone bridge, its advantages are incalculable; it will save to an extensive district of country seven or eight miles in going for their coal and lime*' [there were then no other road bridges over the Tweed between Berwick and Coldstream]. At the opening about 700 people surged on to the deck and civil engineer Robert Stevenson estimated their weight at 47 tons and that the total suspended weight of 147 tons induced about 370 tons of chain strain (9.8 tons sq.in). A 15ft eye-bar link tested at Brown's chain works sustained 92 tons (29 tons sq.in). Stevenson calculated the strength of the bridge at 1104 tons, '*a surplus of say 700 tons*'. With hindsight, its chains were stressed to nearly twice what came to be regarded as safe, its chain curvature dip of c. 27ft had about half the strength efficiency of modern practice, and it lacked counter-oscillation provision. Even so, the bridge was a landmark achievement. Its basic principle was correct for achieving the longest spans and its design shortcomings, applicable generally to early suspension bridges, were progressively addressed in later practice.

Brown's successful use of eye-bar links at Union Bridge encouraged Thomas Telford, then erecting Menai Bridge, overall length 1368ft not to use Donkin's more efficient but unproven composite iron cables and to develop, with William Hazledine at Plas Kynaston Ironworks, a chain on the eye-bar principle comprising 5 rectangular-section links in parallel, cross-bolted through drilled eye holes and with hanger tops bolted to inter-connecting links [Figs 1 & 2]. This form differed from Brown's practice of single lines of chains with forged eyes and hanger tops resting on, not cross-bolted through, a chain pair. Brown is not known to have claimed this infringed his patent. The longest span of this basic form was 702ft at Clifton Bridge [Brunel/Barlow/Hawkshaw 1864]. Other bridges using this form were Paris (1824), Conway (1826), Hammersmith (1827, erected and part-made by Brown), Danube Canal, Vienna (1828), Marlow (1832), Budapest (1849) and Tower Bridge London (1894), its

Fig 1 *- Union Brodge's 15ft long eye-bar links and connection*

Fig 2 *- Menai Bridge's 16 chains each of 5 cross-bolted links*

last major usage, apart from in Menai Bridge's reconstruction (c.1940). Brown's Kalemouth Bridge [Fig. 4] influenced Norway's Bakke Bridge (1844). Brown's application of chains to bridges was first promoted from 1813 by a 10ft wide 100ft span erected at his Millwall Works, London. It was examined and travelled over by leading engineers, including from France, Charles Dupin and Joseph Dutens who, impressed by its potential for 'spanning outstanding distances', published his drawing of it [*Mémoires*. Paris 1819. Fig. 3].

From 1820, Union Bridge's details were widely promoted in articles by Stevenson, by 1824 translated into German, French, and Polish. Also by Brown, noting 'it has given entire satisfaction' after 15 months use [*Edin. Phil. J.* **VI.** 1822] and via Taylor's *Architectural Library*. Details were also published by C-L. Navier [Paris 1830], and by Baron Charles Dupin noting, in his review of state-of-the-art British improvements, Union Bridge's link-changing apparatus and having 'oscillations inconsiderable and vibrations not inconvenient'.

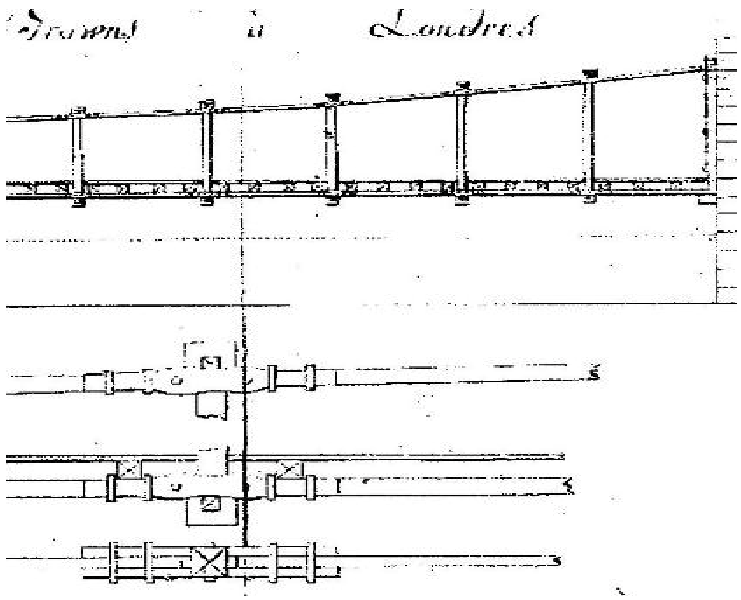


Fig 3 - Brown's works bridge 1813 [Dutens 1819]

Fig 4 - Kalemouth Bridge (c. 1830 - chains cross-bolted, timber trusses

Dupin in his *Voyages dans la Grande-Bretagne*. Paris 1824, London 1825, 1830], devoted a detailed double page engraving to Union Bridge [Fig. 5] and Newhaven Pier. Capt. Brown's reputation as a suspension bridge builder was at its zenith for about a decade after the opening of Union Bridge and would have continued had his 800ft span Clifton Bridge proposal of 1830, one of three finalists, been built. The success of Union, Menai and Hammersmith bridges by 1827 and wide publicity encouraged the building of suspension bridges. On the continent least 30 had been or were being erected by c.1830, mostly with wire cables, in France, Austria, Russia, Germany and Switzerland. Also one in India. Soon afterwards public interest in suspension

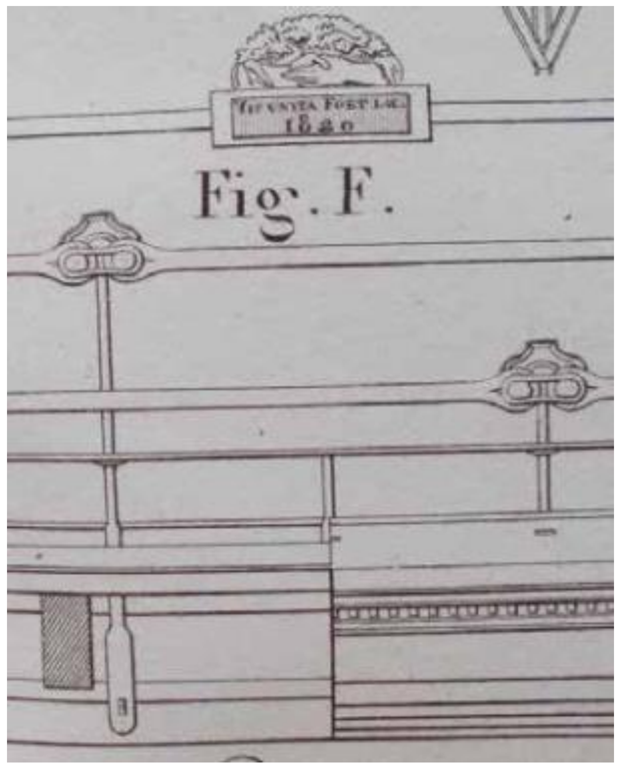


Fig 5 - Union Bridge - mid-span chain, deck and 'VIS UNITA FORTIER' plaque details [Dupin 1824] bridges waned as many at exposed sites suffered storm damage from severe oscillation, such as at Menai and Stockton Bridges and Brighton Chain Pier [Fig. 6]. From 1839, Rendel's 8ft deep timber trussing at Montrose, and that at Wheeling [Fig. 7], helped to counter this problem before the adoption of more efficient iron, and later, steel trussing (See pages 47, 52, 55, 68).

In the 'Hall of Fame' table below, Union Bridge features with other world record span bridges created at the frontiers of contemporary technology and design. Their achievement required engineers and contractors of outstanding skill, courage and determination. The table features many of the great names in long-span bridge building. It also shows that as spans lengthened, the use of iron eye-bar links in cables began to be superseded from 1835 by iron wire, and from 1883 at Brooklyn Bridge by steel wire, which is still present practice.

Brooklyn and Akashi bridges are highlighted as appropriate possible partners in any future 'twinning' arrangements.

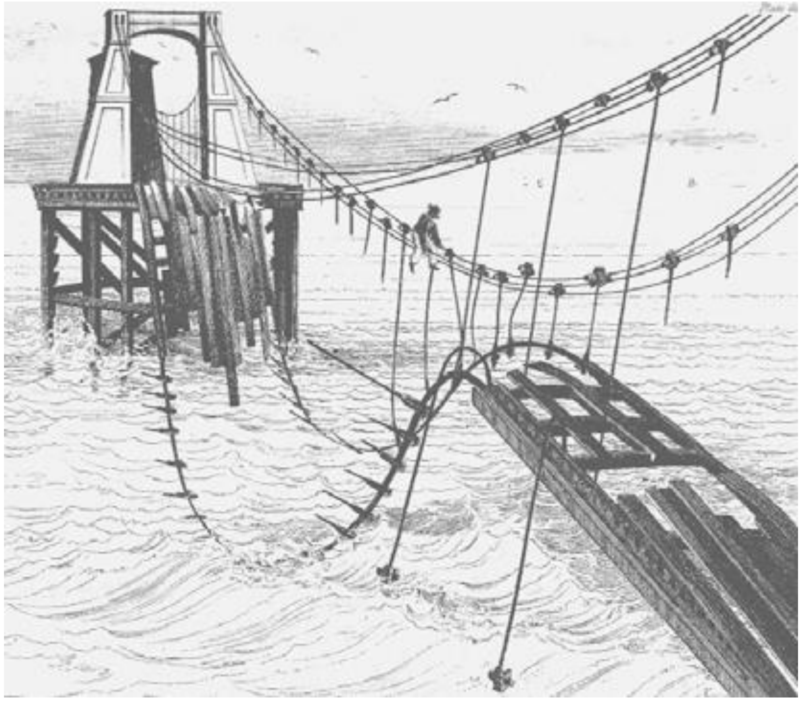


Fig 6 - *Brighton Chair Pier (1823-96) - damage in October 1833*
[Weale's Bridges 1843]

Fig. 7 - *Wheeling Bridge WV USA 1849 1010ft span – Upper part of longitudinal Howe type timber trussing (rehabilitated) seen by the author in 1999. Note the adoption of wrapped, parallel multi-iron wire, main cables.*

Name of Bridge, Engineer, Main Cables, Dates	Span (ft/m)
Newburyport, MA, USA (Templeman 1810, to Finley's patent modified, bar chain, replaced 1909) Finley designed 8 bridges erected by 1811 and later	244/74
Colossus, Philadelphia USA (Wernwag 1812–38, timber arch, iron-rod braced)	340/103
McCall's Ferry, PA, USA (Burr) 1815, timber arch, destroyed by ice 1818)	360/108
Union, UK (Capt. Brown & Rennie 1820, bar chain, 2t limit 2020)	437/133
Menai, UK (Telford/Provis/Hazledine1826, bar chain, renewed in steel 1940)	580/177
Fribourg, Switzerland (Chaley 1835, iron wire, replaced c.1924)	c.870/265
Wheeling, Ohio River WV, USA (Ellet 1849 – iron wire - Fig 7)	1010/308
Queenston-Lewiston, USA-Canada (Serrell 1851-64 wrecked, iron wire)	1040/317
Cincinatti-Covington, USA (Roebling 1867 – iron wire)	1057/322
Niagara-Clifton, USA-Canada (Keefer 1869-89 wrecked, iron wire)	1268/387
Brooklyn, USA (Roebling 1883, steel wire - bar chains in anchorages - see page 45)	1596/486
Forth, UK (Fowler/Baker/Arrol 1890, steel cantilever type)	1710/521
Quebec (Vautelet/Fitzmaurice/Modjeski 1917, zenith span of steel cantilever)	1800/549
Ambassador, USA-Canada (McClintic & Co.1929, steel wire)	1850/564
George Washington, USA (Ammann/Gilbert 1931, steel wire)	3500/1067
Golden Gate, USA (Strauss et al 1937, steel wire)	4200/1280
Verrazano Narrows, USA (Ammann/Brumer 1964, steel wire)	4260/1298
Humber, UK (Freeman Fox & Partners 1978, steel wire)	4526/1380
Akashi Straits, Japan (Satoshi Kashima 1998, steel wire)	6532/1991

Chronological table of the world's longest road/railway bridge spans exceeding 200ft/61m erected from 1810-2020 (see graph on page 64)
© Paxton (All are suspension bridges except for McCall's Ferry, the Colossus, Forth and Quebec bridges)

Fig 8 - *Wernwag's magnificent timber/iron rod 'Colossus' arch of 340ft span at Philadelphia 1812 (destroyed by fire in 1838)*

The table also gives other fascinating details of long-span bridge development. From 1800 this started in the USA with Finley, moving to Europe as Union Bridge's span eclipsed that of 'Colossus' arch [Fig. 8].

In the 1840s impetus returned to the USA, then alternated with Europe, then to Asia with Akashi Bridge.

I first recorded Union Bridge for the *Institution of Civil Engineers' Panel for Historical Engineering Works* forty years ago. My Interest in promoting its preservation quickened in 2013 when it was put on English Heritage's *History at Risk Register*. On 25 July 2014, in my lecture at the inaugural meeting of *The Friends of Union Chain Bridge* at Paxton House, I undertook to seek international recognition for the bridge from the American and Japan Societies of Civil Engineers [ASCE and JSCE] via a nomination from the Institution of Civil Engineers [total membership c. 300,000]. This was approved by ASCE on 7 November 2018. Since 1979 about fifty International Historic Civil Engineering Landmarks have been designated, "illustrating the creativity and innovative spirit of civil engineers. Almost always performed under challenging conditions, each of these engineering feats represents the achievement of what was considered an impossible dream." These include the Eiffel Tower, Thames Tunnel and bridges at Sydney Harbour, Victoria Falls (R. Zambesi), Menai, Brooklyn, Golden Gate, and the Forth Bridge. So, in bridge development terms Union Bridge is in great company! Its landmark plaque, to be dedicated later, reads:

INTERNATIONAL HISTORIC
CIVIL ENGINEERING LANDMARK
UNION CHAIN SUSPENSION BRIDGE 1820

UNITES ENGLAND [HORNCLIFFE] AND SCOTLAND [HUTTON] OVER THE RIVER TWEED USING WELSH IRONWORK MADE BY BROWN LENOX & CO., NEWBRIDGE.THE WORLD'S OLDEST AND THEN LONGEST SPAN ROAD SUSPENSION BRIDGE. USING 15 FT. IRON EYE-BAR LINKS IT COST ABOUT £7,700, LESS THAN 40% OF A STONE BRIDGE

ENGINEERS: CAPT. SAMUEL BROWN R.N. (1774-1853).
CONSULTANT: JOHN RENNIE C.E.
OPENED 26 JULY 1820 BY WILLIAM MOLLE W.S.
CHAIRMAN OF THE BERWICK & NORTH DURHAM TURNPIKE TRUST PRESENTED TO NORTHUMBERLAND

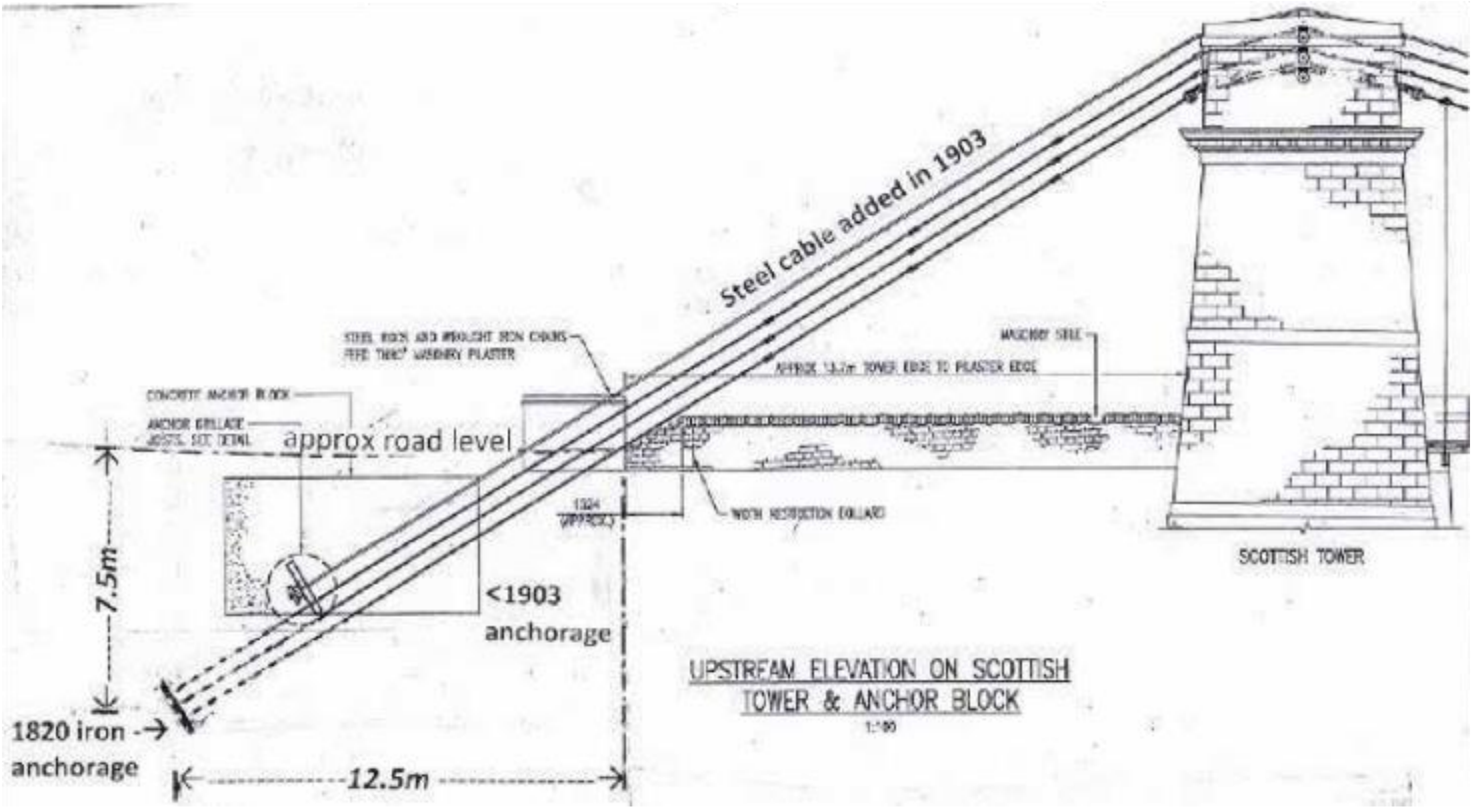


Fig 9 *- Scottish anchorage from our ADR study plotted on a Northumberland CC drawing*

Looking to the future. In 2018 the bridge provided the catalyst for a pro bono research study by Heriot-Watt University's Institute for Infrastructure and Environment via myself and Dr. Colin Stove of radar specialists Adrok Ltd, using its state-of-the-art equipment and techniques. Our objective was to promote knowledge of the bridge anchorages to inform its ongoing restoration, and bridge historians, by locating inaccessible Scottish anchors for which no drawings could be found. Using radar we scanned down 12m below the road surface and located iron ballast plates, into which the six chains on each side of the bridge were stopped at a depth of 7.5m [now refined to 6.9m) - Fig. 9]. This involved transmitting a radio beam into the ground and analysing changes to its characteristics as it passed to the receiver through materials having different dielectric constants. These were identified, particularly iron, by spectroscopy. This analysis offers the exciting possibility of applying Adrok's techniques more widely to monitoring the extent of internal damage and corrosion in reinforced concrete structures. The ballast plate model [Fig. 10], based on historical source data, compares closely with the radar image [Fig. 6 in Colin Stove's essay].

Fig 10 -
[L] Author's notional model of a 2-ton iron ballast plate 5ft x 6ft x 5in-2½in (about to be stone-laden to road level) which resisted a 185 ton total chain strain (9.8 tons sq. in) on opening day [Stevenson 1821].
[R] Underside of platform.

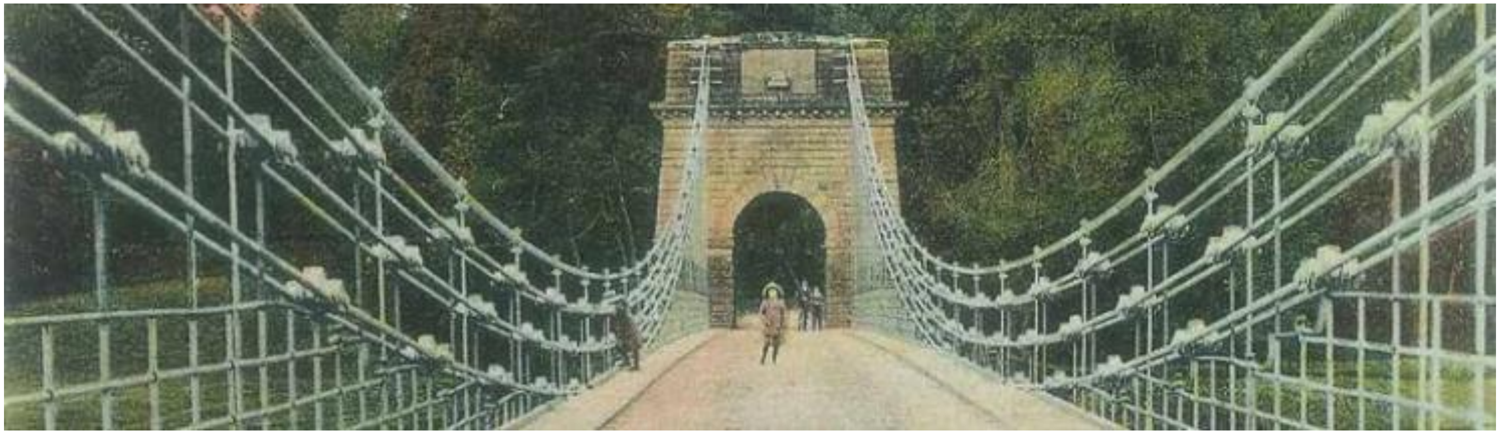


Fig. 11 - *The Bridge in 1904 with additional top cables. Capt. Brown's chains at and near mid-span still acted as a safety barrier, obviating the need for their part obscuration by railings. The 1820 deck at mid-span was 1¼ ft lower than shown here [Fig. 5]. Today's deck is 1 ft higher than shown here and, unless the 1820 or 1904 levels are reverted to, railings will be needed after removal of the cables. Note the original deck hangers incorporated into the railings which, with hindsight a poor design concept, now usefully exemplify 1820s practice.*

A delegation of eminent American civil engineers visited the Union Bridge in November 2018 to learn about the restoration plans and to gather information in connection with the Bridge's proposed designation as an International Historic Civil Engineering Landmark in which proposal the delegation, together with their Japanese and UK colleagues, were prime movers. Most of the party, together with other colleagues from the US, Japan and Norway, had planned to be present for the Bicentenary celebration including the presentation of the Plaque referred to in Professor Paxton's Preface on page 7.

L to R: *Colin Stove, Chairman, Adrok Ltd; Jerry Rogers, now Chair, ASCE History and Heritage Committee; Kathlie Jeng-Bulloch, City of Houston Public Works, ASCE delegate; David Gilbert, ASCE delegate; Bill Bulloch, ASCE delegate; Gordon Masterton, Chairman ICE PHEW; Edward Cawthorn, Friends' Secretary; Theodore (Ted) Green, past Chair ASCE H&HC; Sandra Purves, Chair ICE PHEW Scotland, SPAB representative; Roland Paxton, Friends' Patron; Greg Simpson, Bridge resident engineer-designate, Northumberland County Council; Robert Hunter, Friends' Chairman; John Home Robertson, Friends' Trustee. Photograph: Courtesy of group member David McGuigan, Chairman, ICE Scotland Museum.*