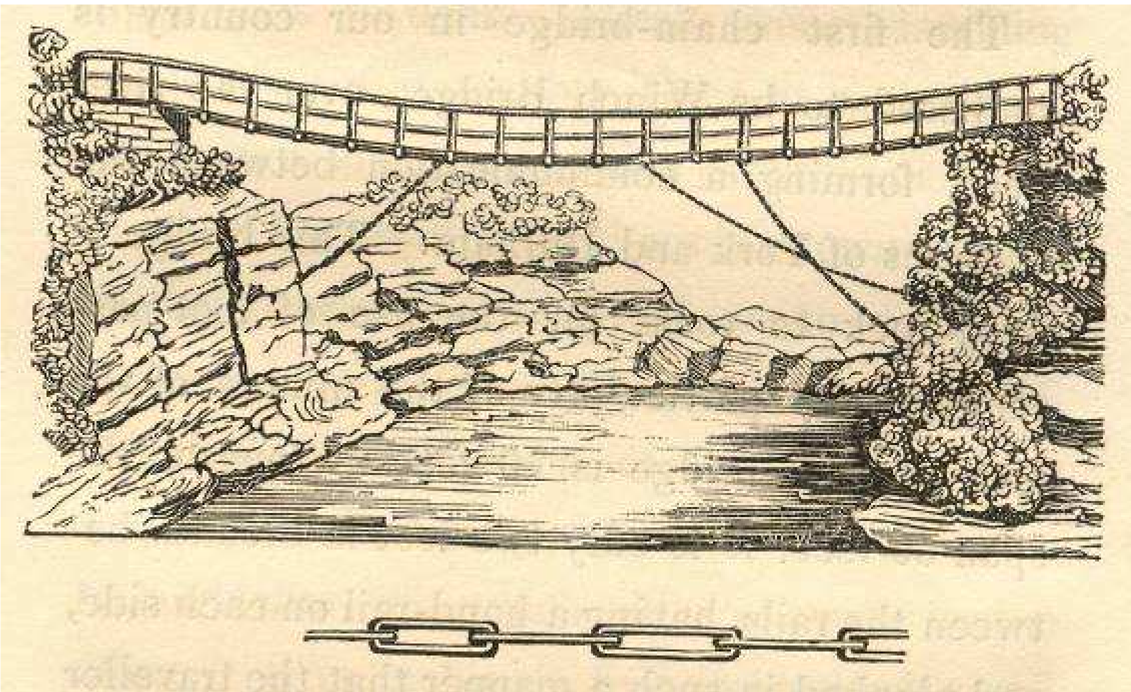
John Scott Russell's anti-vibration proposal for suspension bridge decks.

by

Professor Roland Paxton,
Heriot-Watt University, Vice-chairman PHEW.

Presentation at the Construction History Society's John Scott Russell bicentenary lecture at the Institution of Civil Engineers, Westminster, on 21.5.08.

BACKGROUND

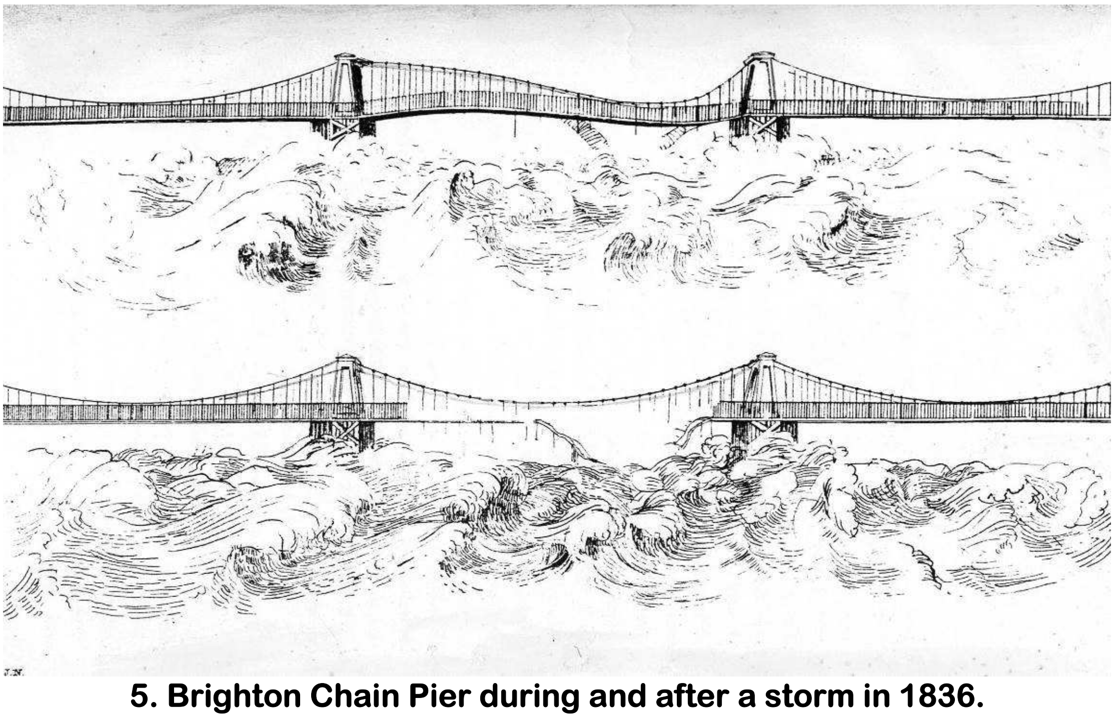


1. Winch Bridge Co. Durham c1741-1802, which, in 1824, *'even with bracing chains, yielded to every footstep'* (Cumming).

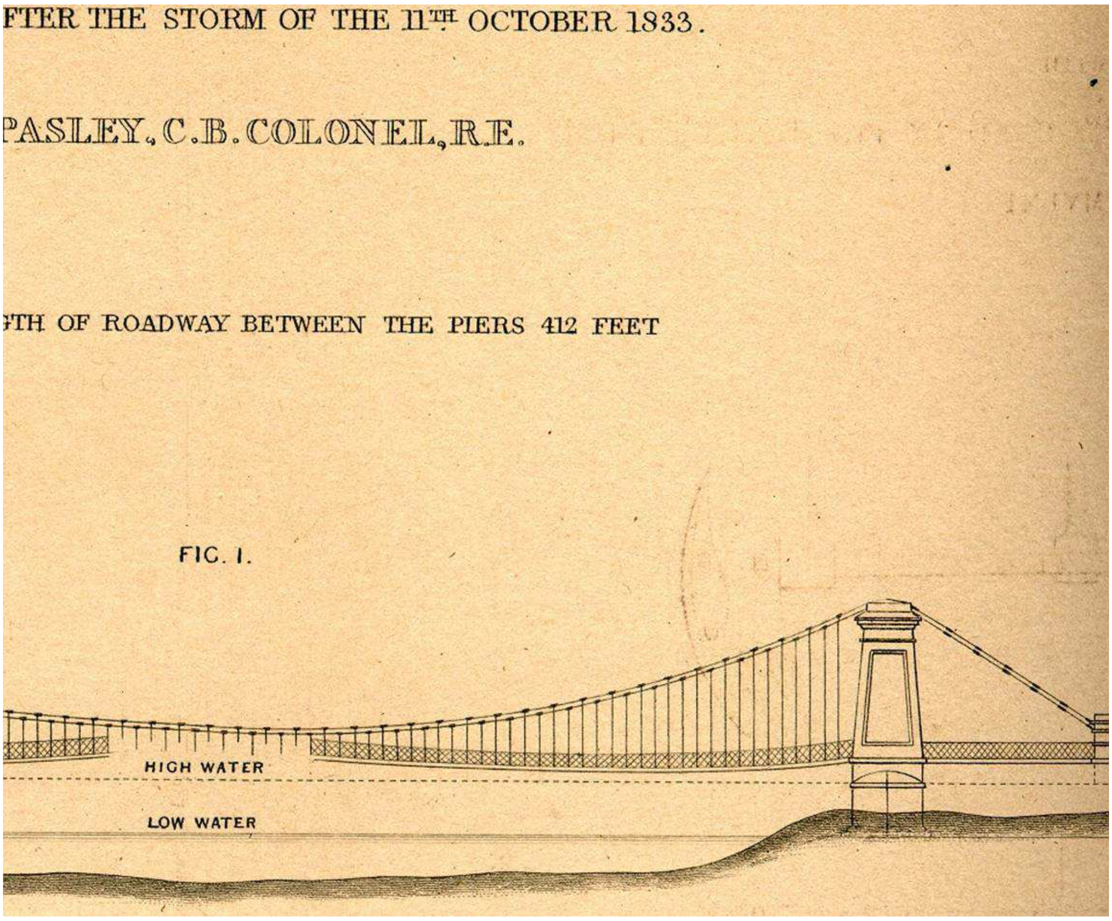
2. Brighton Chain Pier 1823 (Capt. S. Brown). Brown 's Union Bridge 1820) and Telford's Menai Bridge 1819-26, then had the world's longest spans, but their empirically and intuitively derived decks proved to be under-designed, particularly against strong winds.

3. Brighton Chain Pier wreck in 1833.

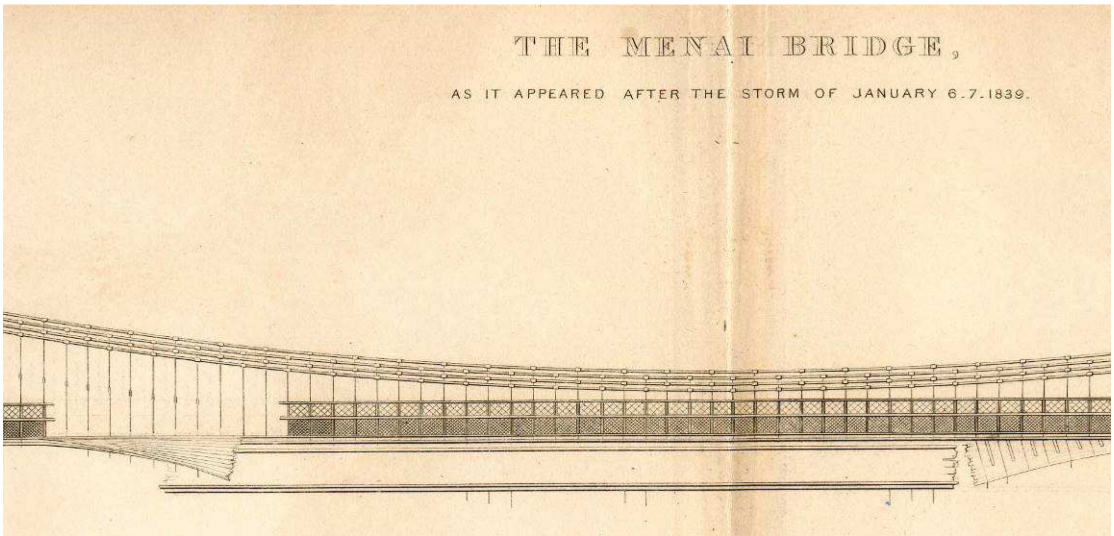
4. Brighton Chain Pier wreck in 1833 – another view.



5. Brighton Chain Pier during and after a storm in 1836.



6. Montrose Bridge 1829 (Capt S. Brown) in mid-October 1838.



7. Menai Bridge 7 Jan. 1839. One carriageway badly damaged. The central footway and most of the other carriageway remained intact.

SCOTT RUSSELL'S PROPOSAL

On the Vibration of Suspension Bridges and other Structures ; and the Means of preventing Injury from this Cause. By JOHN SCOTT RUSSELL, M. A., F. R. S., and Vice-President of the Society of Arts in Scotland.

(Read before the Society on the 16th of Jan. 1839.)

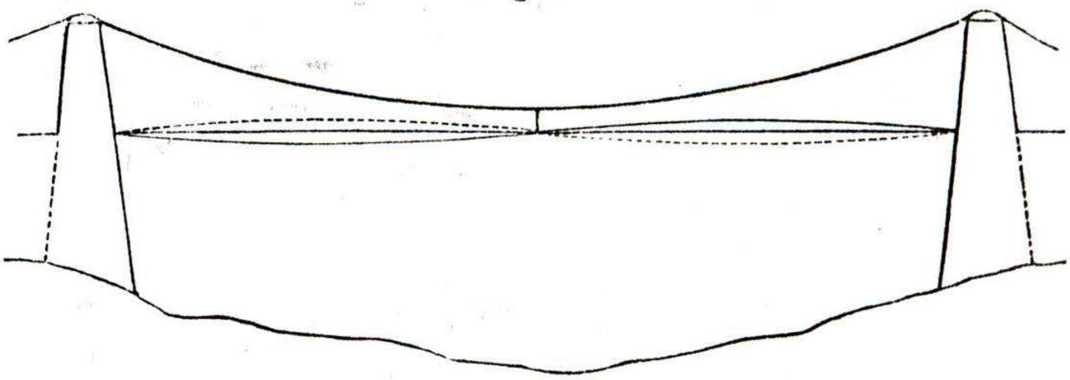
8. John Scott Russell's paper.

Then, 30-year-old Scott Russell was a naval architect (8 years later elected MICE). His paper had added topicality in being given only 9 days after the damage to Menai Bridge.

It is also matter of common observation, that any equal timed force, like that of soldiers marching in ranks, is the greatest trial to which such a bridge can be subjected. A suspension bridge near Manchester was destroyed by this means, and it has, therefore, been necessary for the curators of such bridges, to order that soldiers, in crossing such bridges, shall walk with unequal paces instead of the usual military march.

In observing the vibrations of a suspension bridge, it will be noticed that it divides into nearly equal portions which oscillate in nearly equal times—figure 9 will give an idea of this

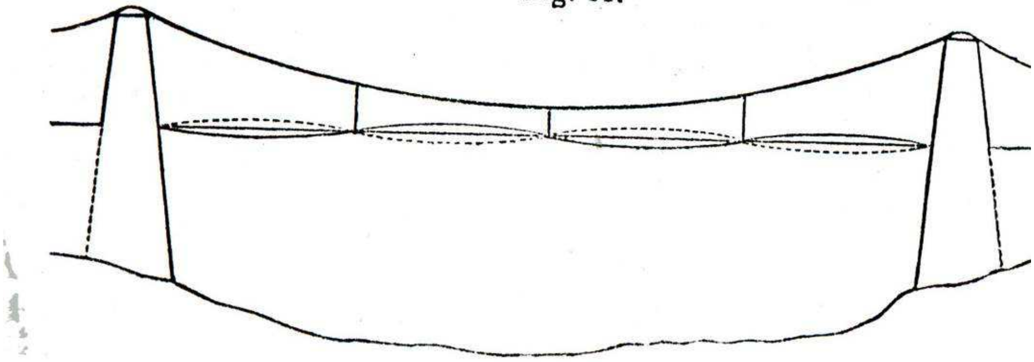
Fig. 9.



vibration—when one-half of the bridge is falling the other is

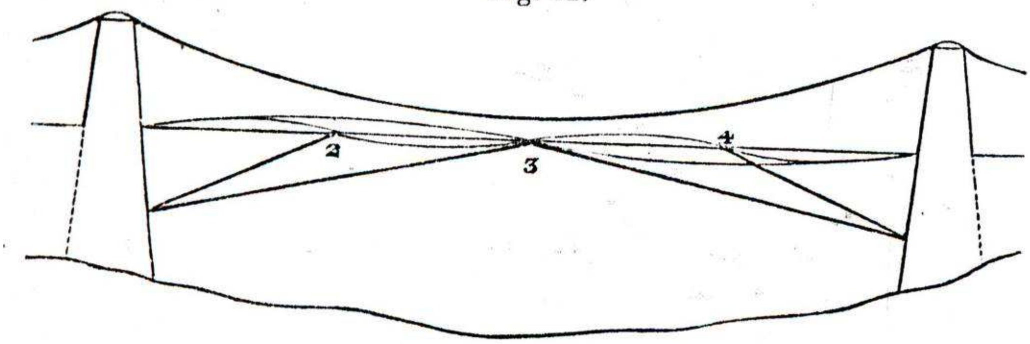
**9. John Scott Russell's paper 16 January 1839 – Fig. 9.
Simple longitudinal oscillation**

Fig. 11.



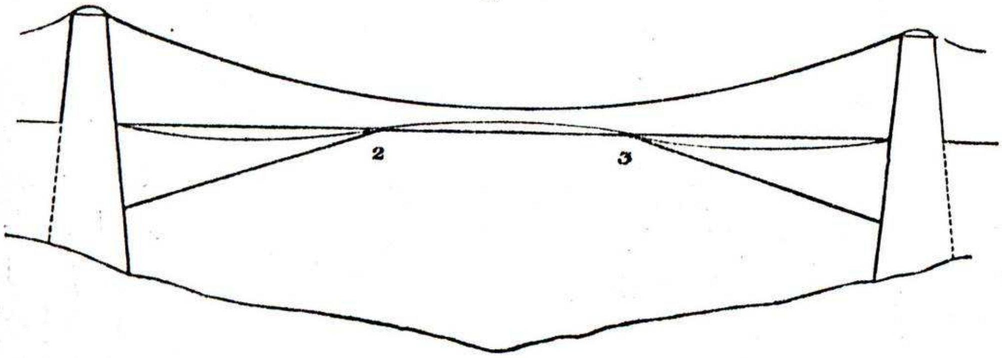
Now, in order to prevent these oscillations, it will be of no use to adopt the various methods of staying that have hitherto been adopted; it is of no use to carry a stay-chain to the middle of the roadway, fig. 12, nor even four stays as at 2, 3, and 4,

Fig. 12.



because it will vibrate exactly as at figs. 9 and 11, neither would stays at 2 and 3, as in fig. 13, produce the effect, because the

Fig. 13.



bridge would still oscillate as in fig. 10.

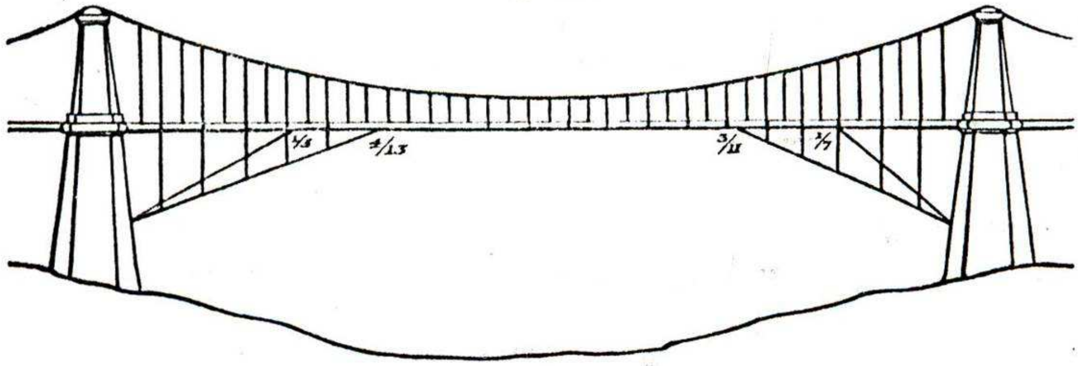
Mr Brunel has proposed a method of preventing oscillation,

which is 'expensive and heavy but has not the desired effect . . . for the whole will perform isochronous oscillations'

10. John Scott Russell's paper 16 January 1839 – Figs 11-13.

Case (3.) Four stays. Let the whole length of the bridge be successively divided into 5, 7, 11, and 13 equal parts; then let a pair of stays be fixed on each side, at one of each of these

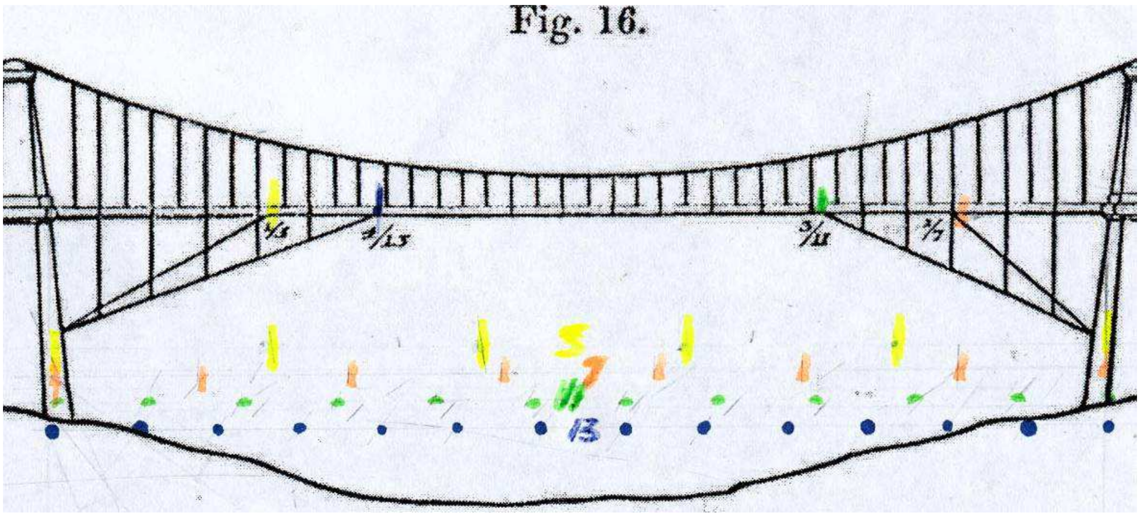
Fig. 16.



sets of divisions, and the oscillations will be less with the four stays in figure 16, than with the four stays on the old method, in the proportion of 4 to 5005, being nearly 1251 times better than before.

Case (4.) Any number of stays. Let the whole length of the bridge be divided into 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 51, equal parts; taking as many of these dividing numbers as there are stays, the result will be, that the power of resisting oscillation will be found by multiplying by each other all of the dividing numbers used.

11. John Scott Russell's paper 16 January 1839 – Fig. 16.



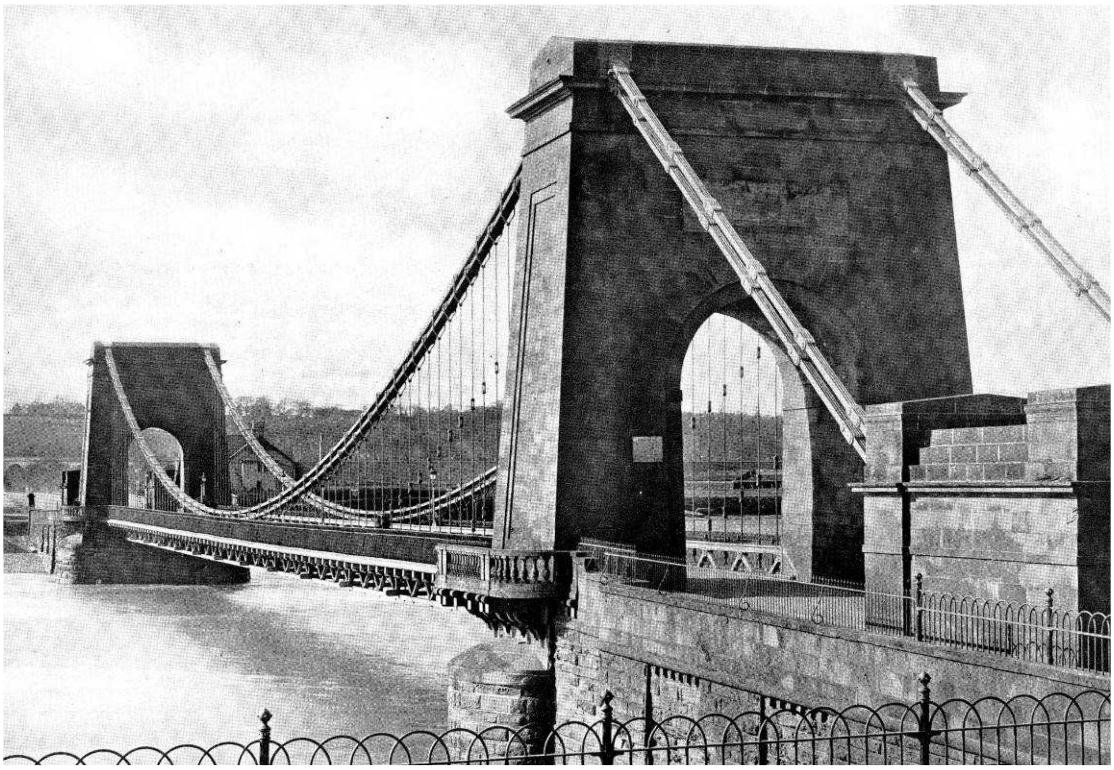
12. Fig. 16 showing the span divided into 5, 7, 11 and 13 equal parts restrained by straight stays. The idea, although limited to linear oscillation and without quantification of forces and temperature effects, is attractive, but how would it have worked in practice?

Stays in platforms, viaducts, and all wooden structures, when intended to prevent oscillations, should be placed at distances not perfectly equal, but in the proportion of the series of numbers already given, and all structures intended to prevent oscillation should be found on the same principle.

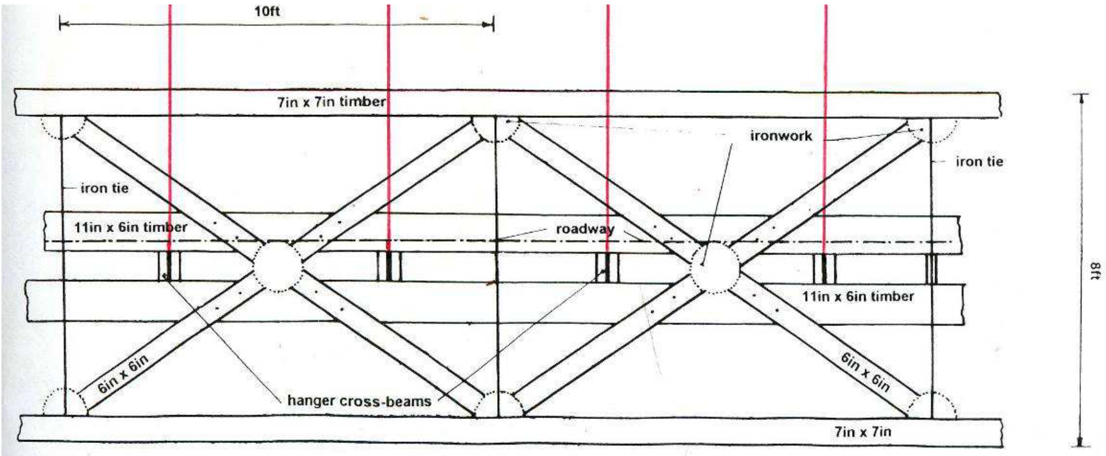
21 Coates Crescent, 16*th Jan.* 1839.

13. Conclusion of J.S.Russell's paper, of which the meeting reporter wrote:- ***'it was shown by some beautiful experiments that the tendency of such structures is to oscillate in equal portions like the string of a musical instrument in sounding harmonics, and that the great object in mechanical structures was to stop these vibrations, whereas in musical strings it was to continue and increase the vibrations, the principles were the same but the plans to be followed were opposite'*****.**

SUBSEQUENT DEVELOPMENTS IN DECK DESIGN



14. Montrose Bridge, refurbished c1841 (replaced 1931).
Note timber trussing extending vertically above and below the deck.
There was also robust lateral bracing.

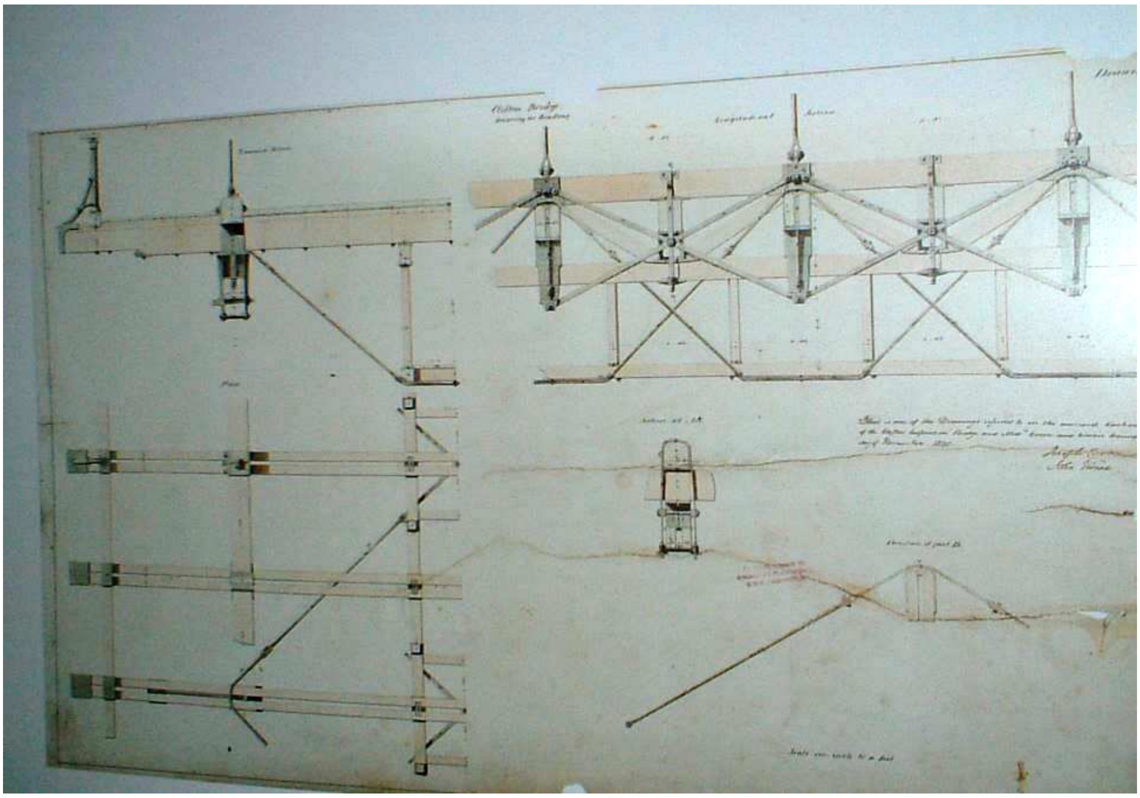


Montrose Suspension Bridge – Sketch elevation of longitudinal truss designed by Rendel

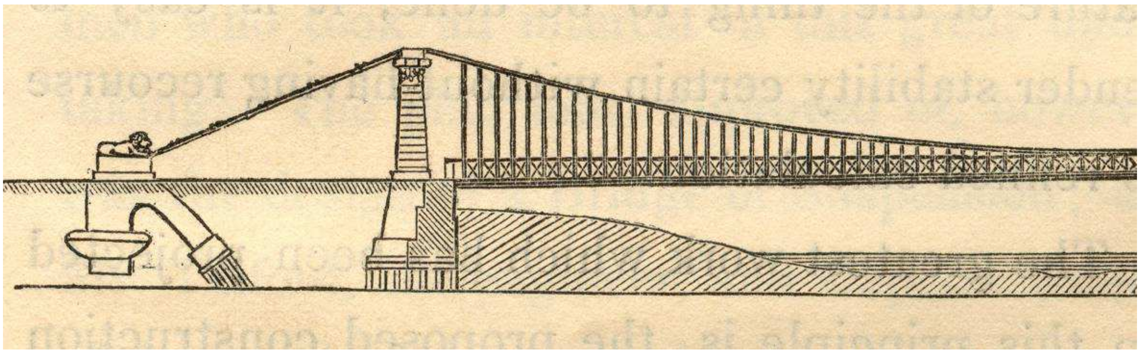
15. Montrose Bridge, refurbished c1841 (replaced 1931).

J.M. Rendel, the leading suspension bridge designer who had devised this arrangement, was against the use of stays and braces to counter roadway movement in principle, maintaining that wind forces should be resisted by the design of the structure (*Min.Proc.ICE*, 1).

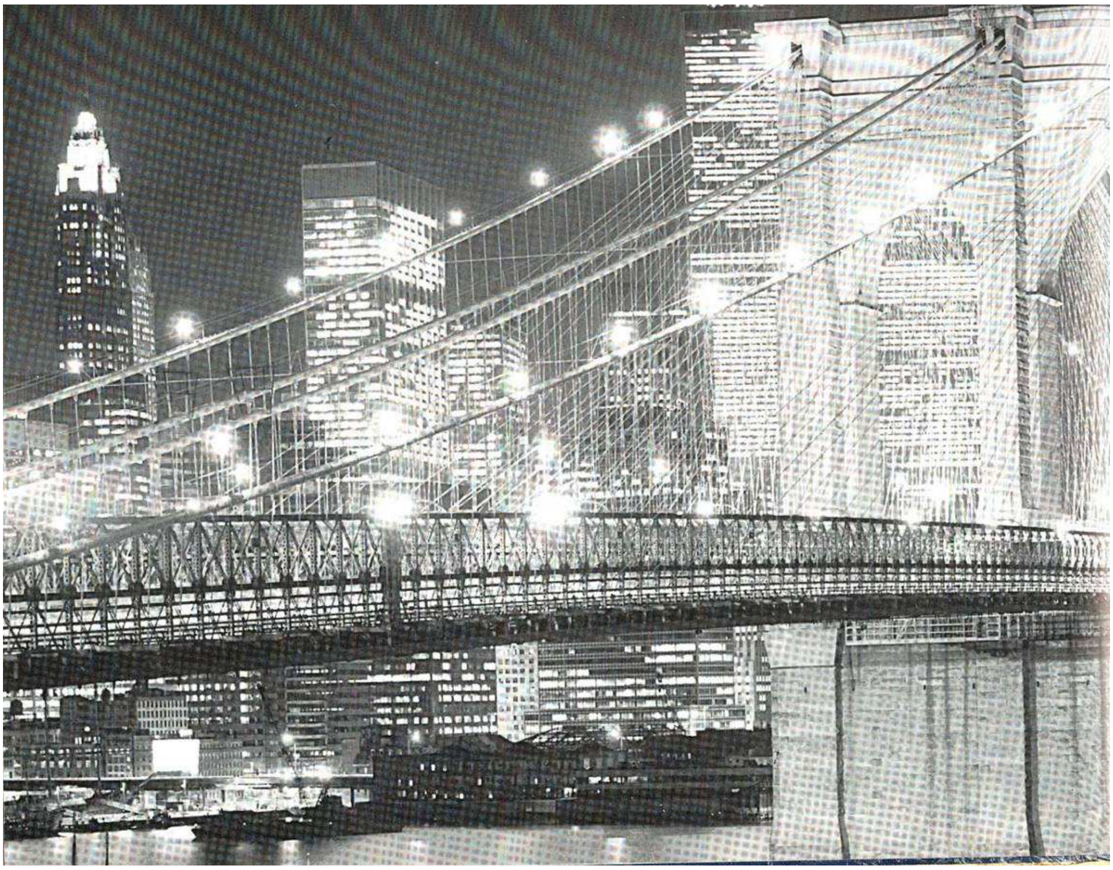
Clifton Bridge, completed in 1864 as a tribute to Brunel, has deck stiffening of similar form which was more robust than the never-tested, light, convoluted, arrangement proposed by Brunel 30 years earlier.



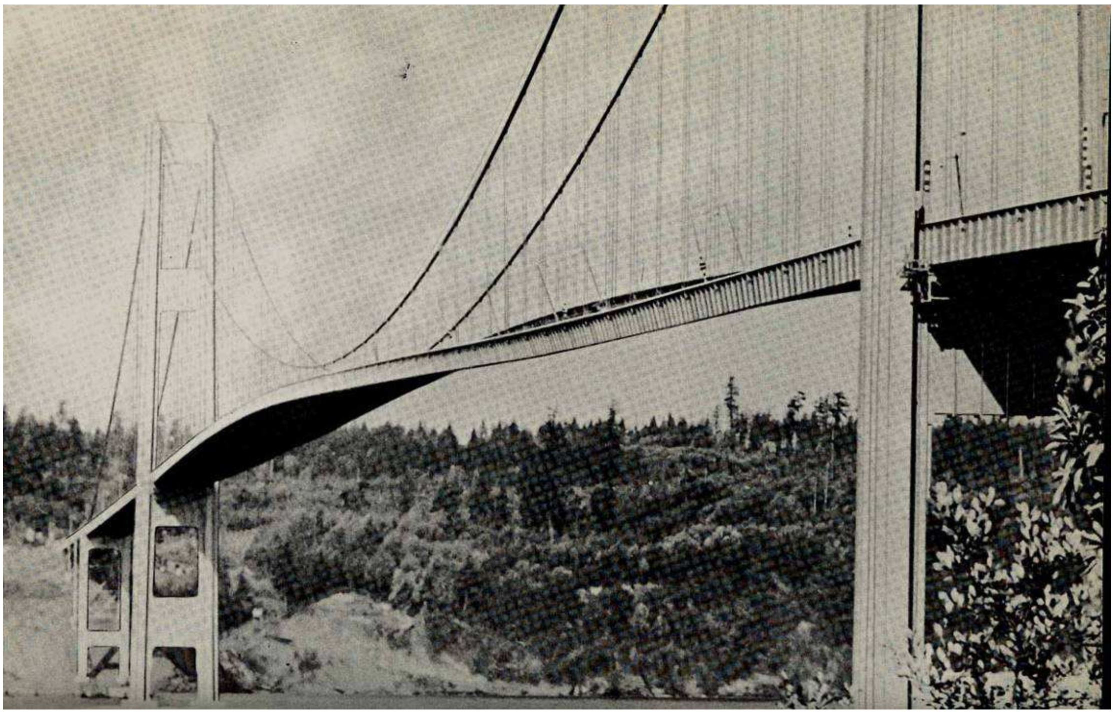
16. Clifton Bridge deck proposal (Brunel – early 1830s)



17. Paris Suspension Bridge (L.M.H. Navier), which fell when nearing completion in 1827 when the abutment balance weights proved too light as a result of in Navier's words,*'a little error in my calculations.'* Note the robust longitudinal trussing for which kihhe clearly saw a need, as in their earlier bridges had James Finley (USA) and W.T.Clark.

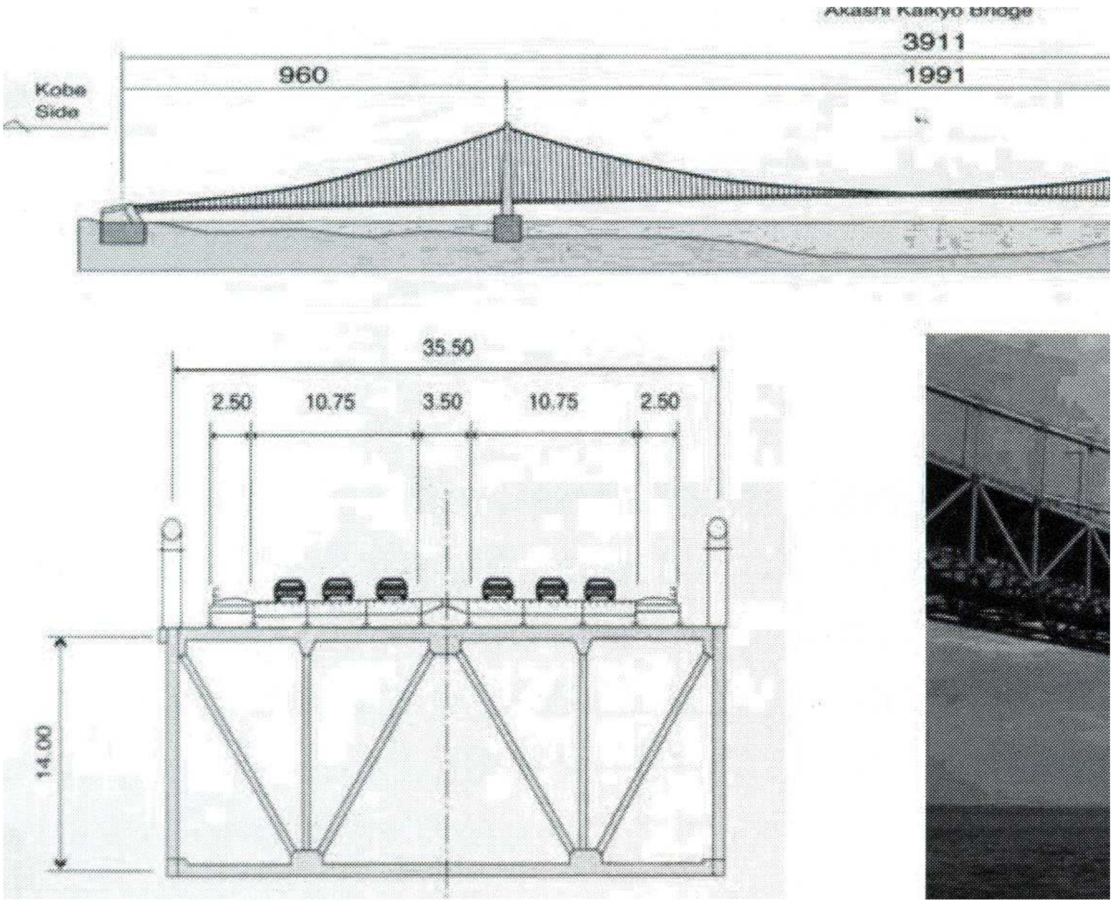


18. Brooklyn Bridge 1883 (J.A. Roebling) - note the substantial longitudinal trussing.



19. Tacoma Narrows Bridge 1940 – Note the departure from trussing and the huge torsional oscillation in a 42mph wind. The deck of its replacement stemmed from the pioneering work of Rendel and others.

20. Tacoma Narrows Bridge 1950 today. The Forth Bridge (1964) and Akashi Straits Bridge (1998) have decks stiffened by similar trussing.



21. Akashi Bridge, Japan, 1998 – Deck stiffening.

CONCLUSION

An idealistic novel solution to a problem, not fully understood more than 1½ centuries later as London's Millennium Bridge 'wobbled'.
Although with potential for safeguarding the unstiffened decks of its day, and well received at the lecture and in Scottish journals, the idea does not seem to have attracted the attention it deserved from contemporary designers.

The engineers who remedied the deck failures at Menai, Brighton and Montrose Bridges and their successors, as spans and deck loads increased, developed trussing as a more effective means than stays in accommodating the loading and stress complexities at work, including oscillation and temperature effects.

Nevertheless, in taking a theoretical approach to design in a largely empirical age, this paper was a step in the right direction.

In closing I invite you to reflect on Scott Russell's wonderful analogy with musical string oscillation in support of his ingenious lateral thinking! A lesson for today perhaps!

SOURCES OF ILLUSTRATIONS

1. CUMMING, G.T. *Description of the iron bridges of suspension . . .* London, J.Taylor, 1827. 42.
2. 'The Royal Palace and Suspension Chain Pier, Brighton.' London, E.Wallis, (1823).
3. WEALE, J. (ed) *Bridges . . .* London, 1843. Pl. 90.
4. Id. Pl. 91.
5. REID, W. Lt.Col. *Professional Papers of the Royal Engineers*, **1**, and ref. 8.
6. *Trans. I.C.E.*, **III**, London, 1842, pl. II.
7. Id., pl. XVI.
8. RUSSELL, J. Scott. 'On the Vibration of Suspension Bridges and other Structures; and the Means of preventing Injury from this Cause.'. *Trans. Roy. Scot. Soc. Arts.* , 1841, **I**, 304-314, pl. Also in *Edinb. New Philos. J.,* 1839, **XXVI**, 386-396.
9. Id. Fig. 9.
10. Id. Figs 11-13.
11. Id. Fig. 16.
12. Id. Fig. 16 with span divided into 5, 7, 11, and 13 parts.
13. Id. 314.
14. Late 19th century photograph in author's possession.
15. PAXTON, R.A. 'The early development of the long span suspension bridge in Britain 1810-1840.'. *Proc. Intl. Conf. on Historic Bridges,* Wheeling WV, U.S.A., Oct. 1999. Addendum. Sketch from a drawing by J.M. Rendel.
16. Author's photograph of a Brunel drawing at Clifton Bridge Visitor Centre, 2006.
17. CUMMING. Op. cit. 54.
18. DELONY, E. *Landmark American Bridges.* A.S.C.E., 1990, 93.
19. GIES, J. *Bridges and Men.* Doubleday & Co., New York, 1963. Fig. 33.
20. CORTRIGHT, R.S. *Bridging.* Bridge Ink, 1998, 62.
21. ISOHATA, H. 'The world's longest span suspension bridge at Akashi Straits, Japan.'. *Collected papers from a commemorative conference on the 250th Anniversary of the birth of Thomas Telford, 2 July 2007.* Royal Society of Edinburgh. 23.