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EXHIBITING A VIEW OF THE

PROGRESSIVE DISCOVERIES AND IMPROVEMENTS

IN THE

SCIENCES AND THE ARTS.

CONDUCTED BY

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Memorandum.

Dr Goring and Mr Henwood's Communications in next Number of Journal.

by at least 6°.75 Fahr. the average temperature of the ground at *Paderborn*, and this excess would melt a cube of ice, having a side of 934 feet. This heat is irrevocably withdrawn from the interior, and yet the thermal springs of *Paderborn* have sustained no diminution of heat from time immemorial.* Chemical processes, which could there give rise to such inexhaustible sources of heat in the youngest secondary formations, must be, or have been, carried on to a great extent indeed!

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 for the Encouragement of the Useful Arts in Scotland.†

Since this paper was sent to press, my attention has been directed, by Lieut.-Col. Blanchard, K. H., of the Royal Engineers, to an account of the destruction of the third arch of the chain pier at Brighton, inserted in the first volume of the Professional Papers of the Corps of Royal Engineers, containing observations made during the storm, and sketches of the appearance of the bridge on the spot, by my friend Lieut.-Col. Reid, who has since distinguished himself so much by his researches on storms, and who has now been so deservedly appointed to the governorship of Bermuda. This paper gives such a perfect confirmation of the views I have taken of the general nature of the vibrations that destroy suspension bridges and other slender structures of a similar nature, as to shew that the manner in which I have predicted that chain bridges are *likely* to be injured, is the precise way in which this suspension arch *was actually* destroyed, and that the remedy I have pointed out is the only one appropriate to the evil: indeed, so precisely does my view of the matter correspond to the fact, that Col. Reid's sketch of the Brighton arch, when in the

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* By far the greater number of the remaining copious springs, which rise on the western declivity of the *Teutoburger Wald*, are also thermal ones. Some, for instance, in *Lippspring* attain a temperature of 54°.5.

† Read before the Society on the 16th of Jan. 1839.

act of giving way, is identical with my illustrative diagram, Fig. .

It has, therefore, appeared to me, that I cannot give to the reader a better conception of the nature of the evils I have attempted to elucidate and remedy, than by presenting him with Col. Reid's sketches of the Brighton arch in the act of giving way, and after it had fallen, along with his own description of the event.

Fig. 1, Plate I, is a sketch shewing the manner in which the third span of the chain-pier at Brighton undulated, just before it gave way in a storm, on the 29th November 1837.

Fig. 2, Plate I, is a sketch shewing the appearance of the third span after it gave way.

"The same span of the Brighton chain-pier (the third from the shore), has now twice given way in a storm. The first time it happened in a dark night, and the storm was accompanied by much thunder and lightning: the general opinion of those who do not inquire into the causes of such matters was, that it was destroyed by lightning; but the persons employed about the pier, and whose business it was to repair it, were satisfied that the first fracture was neither caused by lightning nor by the waters, but by the wind.

"The fracture this year was similar to the former, and the cause evidently the same. This time, it gave way half an hour after mid-day, on the 30th of November 1836, and a great number of persons were therefore enabled to see it.

"The upper one of the two sketches annexed, shews the greatest degree of undulation it arrived at before the road-way broke; and the under one shews its state after it broke; but the great chains from which the road is suspended remained entire.

"When this span became relieved from a portion of its load by the road-way falling into the sea, its two piers went a little on one side, and the curve of the chain became less, as in the sketch. The second and fourth spans in these sketches, are drawn straight, merely to shew better the degree of undulation of the third span. These also undulated greatly during the storm, but not in the same degree as the third span. A movement of the same kind in the road-way has always been sensibly felt by persons walking on it on high winds; but on the 29th of November 1836, the wind had almost the same violence as in a tropical hurricane, since it unroofed houses and threw down trees. To those who were at Brighton at the time, the effect of such a storm on the chain-pier was matter of interest and great curiosity. For a considerable time, the undulations of all the spans seemed nearly equal. The gale became a storm about eleven o'clock in the forenoon, and by noon it blew very

hard. Up to this period many persons from curiosity went across the first span, and a few were seen at the further end; but soon after mid-day the lateral oscillations of the third span increased to a degree to make it doubtful whether the work could withstand the storm; and soon afterwards the oscillating motion across the road-way, seemed to the eye to be lost in the undulating one, which in the third span was much greater than in the other three; the undulatory motion which was along the length of the road is that which is shewn in the first sketch; but there was also an oscillating motion of the great chains across the work, though the one seemed to destroy the other, as they did not both (at least as far as could be seen) take place in a marked manner at the same time.

"At last the railing on the east side was seen to be breaking away, falling into the sea; and immediately the undulations increased; and when the railing on this side was nearly all gone, the undulations were quite as great as represented in the drawing."—*Lieut.-Col. Reid, R. E.*

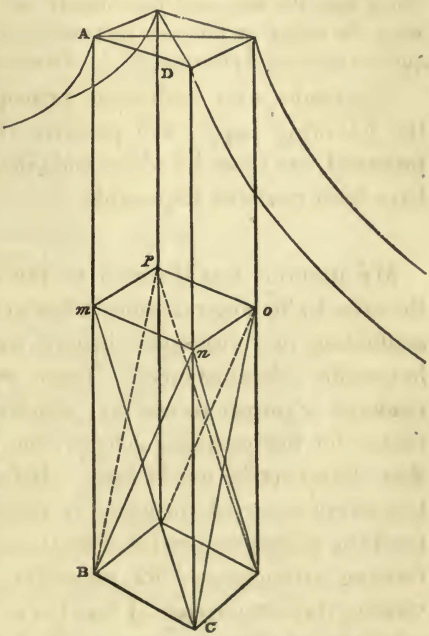
The reader who studies the principles I have explained in the following paper, will perceive that the remedies I have proposed, are those by which such destructive vibrations would have been rendered impossible.

My attention was directed to this subject, so important to the arts, by having occasion, a few years ago, to erect a timber scaffolding of considerable height, for experimental purposes, in peculiar circumstances. There were many reasons which rendered it proper to use very slender and very long pieces of timber for this purpose, so as to come near to the utmost limits that the structure would bear. Before it was removed a violent storm occurred, in which it suffered considerable damage from the vibrations produced by the action of the wind; and in forming arrangements for remedying these injuries, and preventing their recurrence, I was led to the examination of those principles of vibration from which I have deduced the practical maxims that form the subject of this communication. After detailing the circumstances which originally conducted me to these conclusions, I shall explain the principles on which they depend, and conclude the paper with some practical rules. Although the whole subject is very extensive, reaching to all the structures and mechanical arrangements in which vibration is to be prevented, I have here applied it principally to suspension bridges, not only on account of their national and com-

mercial importance, but also because, in these very light and slender structures, we are so near to the limit of possible strength, that the mere addition of weight to the parts, instead of strengthening, is certain to weaken them, by increasing the load to be borne, and the momentum of the mass, and so increasing equally the danger of oscillation instead of diminishing it; and therefore it is peculiarly necessary in this case to obtain the greatest possible strength to resist injury, with the smallest amount of weight. The means of doing this is, therefore, the principal object of this paper.

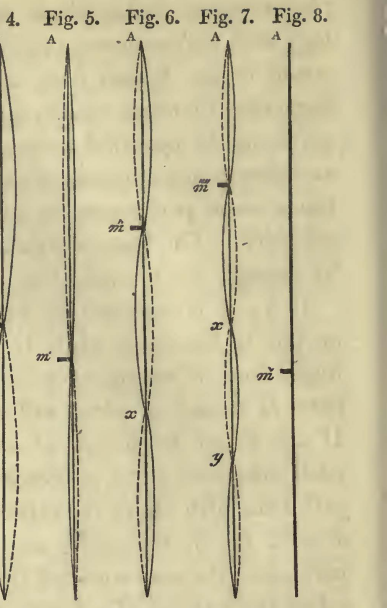
The original structure was of red pine scantling, 6 in. × 6 in., and about 80 feet high. Figure 3. will illustrate its construction. There are four beams cut from a log, as vertical supports at the corners; these being stayed in the middle by cross bars, and the whole diagonally framed for the purpose of stability and stiffness. A B C D is one of the sides of the framing, and the stays are at *m n o p*, the middle of the structure; and the top of the structure was fixed by ropes attached to surrounding trees.

Fig. 3.



This structure was perfectly adequate to the temporary purpose for which it was erected, and its extreme slenderness enabled me to watch the nature of its oscillations. The under part of the structure was sheltered by trees and high banks, while its upper part was exposed to the wind in every direction. When the wind began to act on the top of the framing, it produced an oscillation between A and *m*, as I have represented in fig. 4, and not only there, but it propagated a simultaneous and almost equal current of oscillation to the part B *m* below

the middle; and in like manner simultaneous oscillations were propagated through the whole structure with a continually increasing amount, until they at last injured it.



The method of cure which I adopted, was simply to alter the place of the cross bars at m, bringing them down, as shewn at m', Fig. 5, and this simple change was attended with remarkable results, inasmuch as the vibration was very greatly reduced, even though a larger portion of the upper division was thus left to the action of the wind without transverse support.

I next proceeded to make experiments upon the effect of altering the place of the support m. I placed it as in Fig. 6, at m''', one-third of the length from the bottom, and there were now vibrations as at first of great violence, only with a less range and with greater velocity, and it is most worthy of remark, that the point x, which was not fixed by any support, nevertheless remained stationary in the same manner as if it had been fixed.

The support being next placed at m'''', as in Fig. 7, being one-fourth part of the whole length of the beam from the bottom, the oscillations took place, as shewn in the figure, in four divisions, the points y and x at equal distances apart remaining stationary. The oscillations were less extensive and more rapid than formerly, but still of great force and duration.

Finally, it was ascertained that, by placing m the support at such a point, that its distance from the fixed points A and B bore to each other no simple proportion of length, the propagation and increase of oscillations are entirely prevented. Fig. 8.

Philosophical Explanation.—It is easy to account for these

phenomena on philosophical principles—the case is in close analogy with the phenomena of vibration in a musical string. The string of an Æolian harp, acted on by the wind, vibrates in numerical divisions exactly like this beam, and in doing so, it gives out the beautiful tones called natural harmonies; and by an intimate acquaintance with the principles of producing these tones, some performers on stringed instruments have attained celebrity. The laws of vibration of elastic cords, will explain by analogy the vibrations of the framings alluded to.

If A and B represent the two ends of a string which is struck or put in vibration, while it is prevented by a touch of the finger from vibrating at m, it will divide itself into two equal parts at m, each of which will sound an octave to the open note. If the finger be placed at m''', fig. 6, the string will divide itself into three parts, and each will vibrate in the tone which is called the fifth above the other. If, next, the finger be placed at m'''', fig. 7, the string will divide spontaneously into four parts, and the note sounded by each part will be that which is called the internal of a fourth from its predecessor. The next step taking one-fifth of the length of the string would stop it in five divisions, and the note produced would be that which is called an interval of one-third.

Now, the remarkable circumstance worthy of great attention in this inquiry is this, that, unless the vibrating body be fixed by a stop at one of these simple numerical divisions, 2, 3, 4, 5, it will either not vibrate at all, or through a very minute space only, and will return to rest almost instantly after the disturbing cause ceases to act, instead of continuing to perform equal timed oscillations.

Application to Suspension Bridges.—This case is in strict analogy with the case of the vibrations of a suspension bridge, and shews us the means of counteracting and suppressing its vibrations in the most efficient and simple manner.

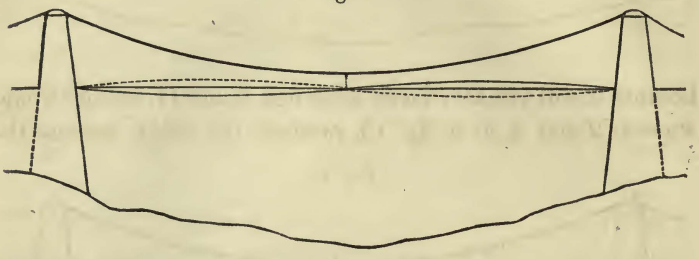
Every one who has noticed the vibrations of a suspension bridge in a gale of wind, must have observed that its oscillations are performed in a certain measured time, and are propagated from one part to another until the whole structure is in a state of equal timed vibration.

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 rising, it remains nearly stationary in the middle vibrating, in halves; again it will be noticed at another time vibrating, in three parts as in fig. 10, or in four parts as in fig. 11, and so on.

Fig. 10.

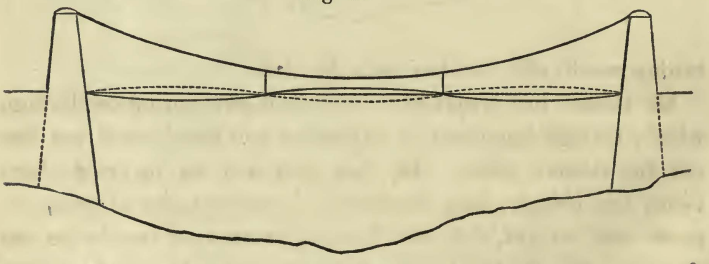
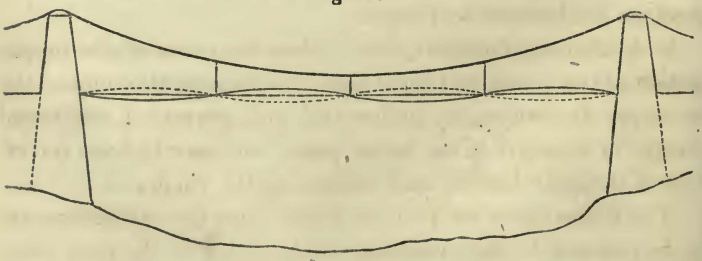


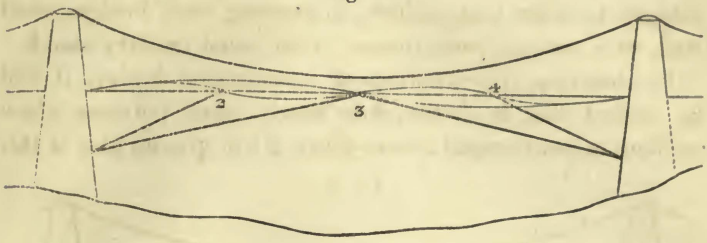
Fig. 11.



Now, in order to prevent these oscillations, it will be of no

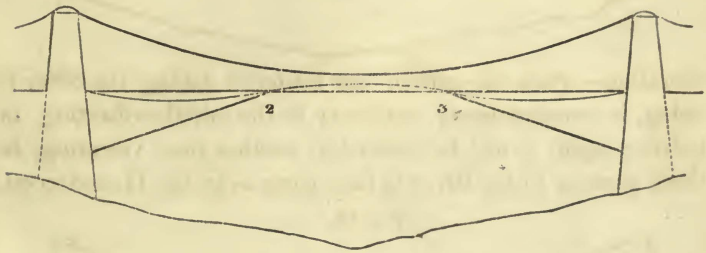
use to adopt the various methods of staying that have hitherto been adopted; it is of no use to carry a stay-chain to the middle of the roadway, fig. 12, nor even four stays as at 2, 3, and 4,

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, though ingenious, is expensive and heavy, and yet has not the desired effect. He has proposed an inverted chain below the bridge; but, besides the disadvantages of great expense and weight, this still leaves the cause of oscillation unremoved, for the whole will, in the manner already described, perform isochronous oscillations.

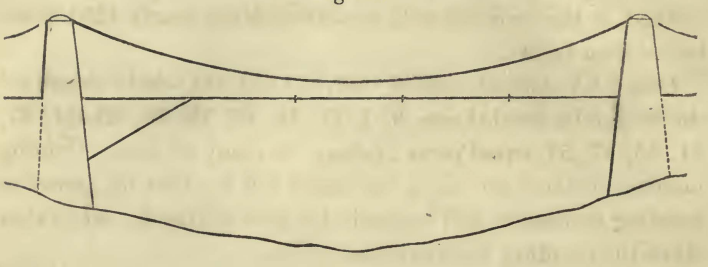
It is obvious, therefore, that, unless the cause of the propagation of continued and equal-timed oscillations throughout the structure be thoroughly understood and prevented, additional weight or strength given to the parts, will merely have the effect of uselessly loading and weakening the whole.

The following is the plan on which alone the oscillations are to be reduced to the smallest possible extent in the most effec-

tual manner. Suppose that stays may be placed below the bridge, as shewn in figures 12 and 13, we are to inquire how they may be best arranged so as to stop the vibration which the others do not. First, let us take one stay, and inquire how it may be most advantageously placed.

Case (1.) One stay. Fig. 14. Let the span of the bridge be divided into five equal parts. Then one stay to any one of these points will be as effectual as five stays, in reducing the extent of equal-timed oscillations. Also it may be thus placed, mul-

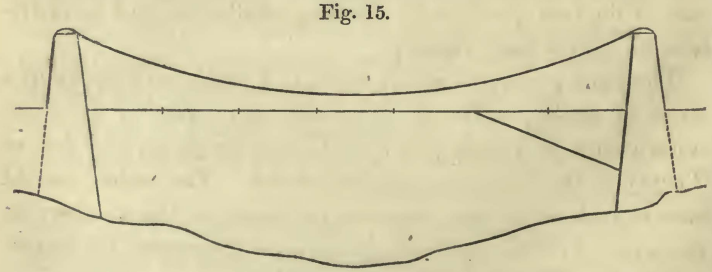
Fig. 14.



tiply the length of the bridge by itself, halve the product, and extract the square root—the resulting number gives that distance of the stay from one end, which will most effectually prevent the parts of the bridge from oscillating together.

Case (2.) Two stays. Let the first be fixed as in Fig. 14, then divide the length of the bridge into seven equal parts, a

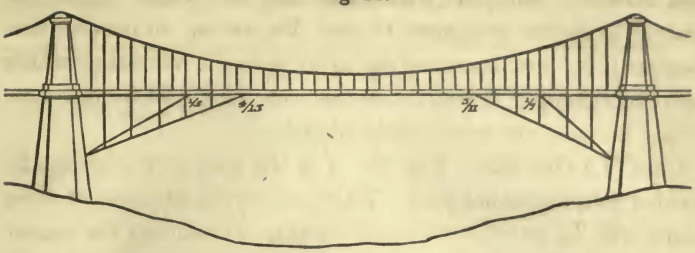
Fig. 15.



second stay to one of these parts will still farther reduce the oscillations in the proportion of 5 : 35.

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.

It is unnecessary to enter in this paper upon the practical details which will immediately occur to the civil engineer, and suggest themselves readily to the intelligent mechanical engineer. The stays should be similar in construction to the main chains of the bridge, but much lighter, and each link should be kept in the straight line by a suspending rod from the chain, continued from the platform, so as both to keep the stay in the best position for resisting oscillation, and to distribute its weight more equally.

The same principles which apply to a single arch apply to a series of arches, either in a wooden structure, or extensive stone arches, or a chain pier like those at Brighton, and that of Trinity in the immediate neighbourhood. The arches should bear to each other the porportion of some of the numbers in the series of dividers already given, so as to prevent the propagation of oscillations from one to another.

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.

JOHN SCOTT RUSSELL.

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