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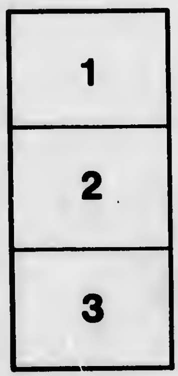
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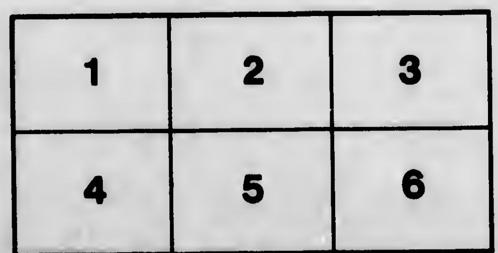
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A REPLY

TO

THE RECENT CRITICISM

MADE BY MR. EDWARD WASELL,

UPON THE

NIAGARA

RAILWAY SUSPENSION BRIDGE.

BY

W. A. ROEBLING, C. E.

NEW YORK:
S. B. LEVERICH,
105 FULTON ST.

1877.

Niagara Railway Suspension Bridge.

A REPLY TO THE RECENT CRITICISM MADE
BY MR. EDWARD WASELL.

Nearly twenty-two years have now elapsed since the completion of the Niagara Suspension Bridge. During this time scarcely a month has passed but the structure has been attacked, or criticised in a friendly as well as unfriendly spirit; but generally from motives not entirely disinterested. One fault is common to all the critics, viz.: their judgment is based on what they would do now, and not what they would have done twenty-six years ago.* These pamphleteers find their echo in the general press; and when, after a twelvemonth, the round of the country has been made, another one stands ready to repeat the farce. Among the latest of these productions is a modest little pamphlet by Mr. Wasell,

* In criticizing work built even so recently as 25 years ago, it should in justice be remembered that the era of iron chords, beams, angle irons, etc., had not yet arrived, and hence wood had to be used in situations where it would be considered inadmissible at the present time.

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of Digby, Nova Scotia, late Assistant Engineer on the Great Western Railway of Canada.

In his solemn warnings to the travelling public, predicting their early engulfment in the fearful chasm, he is apparently actuated by sentiments of the purest humanity; but when we turn to the preface of his pamphlet, we find that our author has blessed the world with still another form of suspension truss, and would particularly like to try it near Queenstown, some eight miles below the present bridge.

While mentioning this location I may add, that five years ago I had several consultations with Mr. Reed, Chief Engineer of the Great Western Road, concerning the project of a railway suspension bridge at that point, and even went so far as to make two estimates of cost, which, however, proved too high. It appeared to be the object of the Great Western to form a connection with the Ontario Lake Shore Road at this point. When this was abandoned, negotiations were commenced for the purchase of the Niagara bridge itself, but the financial embarassments of the Company put an end to these schemes.

With these preliminary remarks, I will pass to a consideration of the statements made by Mr. Wasell in his pamphlet. The first thing he gives (and upon which all his computations are based) is a table of quantities. In this he states that

The greatest rolling load is	—on railway - - -	470 tons.
" " " "	—on carriage way - -	160 "
	Total - - - - - - - -	630 "

Turning to Mr. John A. Roebling's published statements, I find he wrote as follows [italics are his own]:

"Trains of more than 200 tons weight will only cross the bridge experimentally, or at any rate but very seldom. Add to this a number of teams and persons on both floors, weighing in all about 50 tons, and we have a total weight of 250 tons, to which the bridge will be *occasionally* subjected. Ordinary passing loads are within this figure."

The experimental train passed over on March 18th, 1855, was especially prepared to cover the entire bridge, and was estimated to weigh 326 tons. This train consisted of twenty fully-loaded freight cars, pushed by a 26-ton engine. The load of 470 tons assumed by Mr. Wasell as the maximum load on the railway track, is almost equal to a train of locomotives, and is simply preposterous. If ever such a load *has* been taken across the bridge, it has been done surreptitiously, and with a design to injure it.

With regard to loads on the carriage-way, it is difficult to say how small they really are. The erection of the Clifton bridge took away nearly half the travel on this floor of the bridge; so that it is literally true that the "solitary horseman" is now the rule instead of the exception, as formerly.

To establish his assumption on this point, Mr. Wasell finds it necessary to pack the lower floor with people, next to subject them to a freezing temperature of 20 degrees below zero; and at last to blow upon them with a wind of sufficient force, to hurl them, and the locomotive over their heads, into the river below. The greatest load that was ever put upon the bridge to my knowledge, was 360 tons.* Assuming

* This was when the lower floor was packed full of spectators to view the spectacle of Blondin crossing the chasm on his rope. The crowding was allowed once or twice only, and was then stopped.

however that Mr. Wasell really believes, that the bridge is liable to be frequently called upon to sustain a passing load of 630 tons, let us see the light in which it places him.

It is a matter of history, that when the bridge was about half completed, it was leased (or rather given away) to the Great Western R. R. Co. This was owing to the want of faith in the work, on the part of some of the bridge directors. Mr. Wasell states that for a portion of the time that the lease existed, he was in the position of Chief Assistant Engineer on the Great Western, and therefore one of its executive officers. Hence this overloading must have been done with the knowledge and consent of himself and associates; and now he dares to charge the structure with weakness, which he himself has helped to produce, by loading it to *double the test load, and 2½ times the maximum load which it was built to carry.* Fortunately, by a decision of the courts, the railroad floor has been relegated to the Bridge company; and there is now an end to such outrageous overloading.

As a matter of fact, the portion of the load that has been substantially increased, is the weight of the locomotives. This has been gradually raised from 25 tons, up to 40 and even 45 tons. The effect of such a concentration of load has been, *not* to injure the cables, but to rack the trusses to pieces. The only present defect of the bridge is in the trusses, and it is these which require immediate attention. Had Mr. Wasell directed his criticism against this part of the work, he would have found in me an active supporter. The trusses are without effective upper and lower chords; it being originally supposed that the upper and lower floors would act in the sense of chords. This has been found to be a mistake; and the usefulness of the diagonals and posts (which would otherwise answer) is impaired by the defect. I have repeatedly called the attention of the Directors to this matter, and the fact of their paying no attention to my recommendations shows an almost unpardonable indifference on their part.

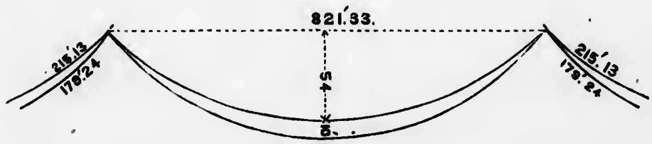
Passing on in Mr. Wasell's pamphlet, from the table of quantities given, we come to certain assumptions on which his criticism is predicated. These are:—

First Assumption.—That "each cable bears its due proportion of load." By which I suppose him to mean, that if two cables (under like conditions) bear a certain load, one cable will bear one-half of that load. This is an axiom. The result given under such assumption would be correct, if the *load* assumed had been correct. When the proper load is taken, the factor of safety will be over 5, instead of $3\frac{8}{10}$ as he gives it. For the test load of 326 tons, the factor was $4\frac{4}{10}$ for the upper cables, and 5 for the lower.

Second Assumption.—That "each pair of cables, whether upper or lower, carry their own particular load." That is to say, that the *upper* cables *alone* carry the railroad trains and receive the strain due to their entire weight; leaving the lower cables to carry only the light loads that ordinarily come on the lower floor. This would be perfectly true if the two floors were entirely disconnected; but as they are united it cannot be correct. This part of the subject may be considered further under the next head.

THIRD ASSUMPTION.—That "each pair of cables carries its own particular load, in addition to a large portion of the load due to the pair of cables above or below them." There is here a kernel of truth, but I shall proceed to prove that what Mr. Wasell exaggerates into a mountain, is nothing but a mole-hill.

Considering the case of the upper cable, we find the conditions to be approximately as shown in the following diagram, viz.: a central half span of 410 feet, with 54 feet deflection, balanced by a land span of 214 feet (or half length 107 feet) with a deflection of nearly 1 foot.*



The length of the central curve under these conditions is $829\frac{42}{100}$ feet, and of the curve of land span $214\frac{1}{100}+$. A full ordinary load on each cable, including dead and live load, is 745 pounds per foot, and as the factor of tension in this case is $1\frac{957}{1000}$ the total tension resulting is

$$T = 829\tfrac{42}{100} \times 745 \times 1\tfrac{957}{1000} = 1{,}209{,}265 \text{ pounds.}$$

* This is on the supposition that the land span be considered horizontal instead of inclined, which does not alter the effect of expansion, etc.

To balance this we have the land span weighing 203 pounds per foot, with a factor of tension = 27.83486, and

$$T = 214.01151 \times 203 \times 27.83486 = 1{,}209{,}267 \text{ pounds},$$

or the tensions in the two curves practically equal, and therefore no tendency of the saddles to move on

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The diagrams on pages 8 and 10 should be transposed. For the figures on page 9 read as follows:—

The deflection of the central curve then	=	56.314 feet.
The factor of tension in " " - - -	=	1.8875 "
And the total tension in " " - - -	=	1,166,320 lbs.
The deflection of the land span - - -	=	4.256 feet.
The factor of tension " " - - -	=	6.305 "
And the total " " " - - -	=	273,918 lbs.
The excess of tension in the centre span	=	892,402 "

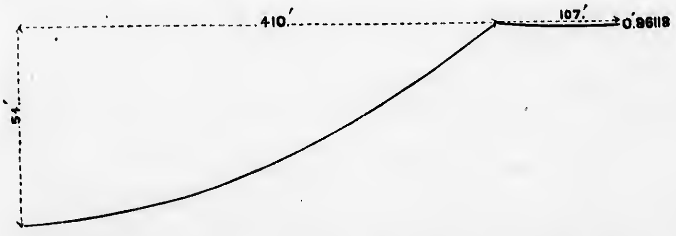
On page 12, in fifteenth line from top, for $\frac{1}{1000}$ read $\frac{1}{10000}$.

motion towards the centre, at once increases the deflection, and lessens the tension of the central span.

With a shortening of the cable (consequent on a lowering of the temperature) precisely the reverse of the action described takes place, and the saddles must move towards the land to equalize the tension. In this case, too, the motion will be *less* than the change in length of the land curve. If I assume, then, in the future discussion, that the saddles move in or out to the full extent of the lengthening or shortening of the land curve of the cables, I am entirely on the side of safety.

Mr. Wasell's criticism of the bridge is based altogether upon his apparent proof, that when the cables are exposed to a low temperature, it is impossible that the lower ones shall bear any considerable portion of the load on the upper roadway; (or, on the contrary, that when exposed to a high temperature the upper cables will not bear their proper load;) and not only this, but that owing to the rigid connections which he claims to exist between the cables, there will under a high temperature be a portion of the weight of the upper cables borne by the lower, and under a low temperature a portion of the weight of the lower cables borne by the higher.

Proceeding to actual facts, we find that the cables of the Niagara Bridge were all regulated at a mean temperature of 55° Fah.,* and at that temperature the deflections, spans, and lengths of curves, were as shown in the following diagram :—



* The floors were also united at that temperature; and as the lower floor had been used for over a year previous for a carriage-way, the upper floor was loaded with 600 tons of stone, to produce the same amount of stretch in the upper cables that had already taken place in the lower.

From this we get:—

Length of upper cables each $215.13+830.76+215.13=1261$ feet.
" " lower " " $179.24+834.52+179.24=1193$ "

Here we strike at once, one of the chief sources of Mr. Wasell's blundering; since he takes the lengths of all alike at "about 1,460 feet."

Suppose now the temperature to fall to 20° below zero, the changes in length will then be:—

	Land curve shortened.	River curve shortened.
In Upper Cable - -	0.111 feet - - - - -	0.427 feet.
In Lower " - - -	0.092 " - - - - -	0.429 "

This, as previously shown, will cause each saddle of the upper cables to move towards the land $\frac{111}{1000}$ feet, and each saddle of the lower cables to move likewise $\frac{92}{1000}$ feet, thus increasing the spans to $821\frac{555}{1000}$ feet and $821\frac{517}{1000}$ feet respectively. The lengths of curves of the river spans will be shortened to $830\frac{313}{1000}$ feet and $834\frac{91}{1000}$ feet respectively. The final effect of these changes will be to diminish the deflection of the upper cables to $52\frac{8}{100}$ feet, and of the lower cables to $62\frac{47}{100}$ feet, making the distance between them $10\frac{39}{100}$ feet, or 4¾ inches more than it was when first adjusted.

Suppose, on the contrary, the change to have been to + 130° Fah., we then have the cables elongated by the same amount that they were in the other case shortened; and the final effect will be a deflection of $55\frac{81}{100}$ feet in the upper cables and $65\frac{46}{100}$ feet in the lower cables, or the distance between them $9\frac{65}{100}$ feet. This makes the total difference in distances, between the cables $\frac{74}{100}$ feet = 7/8 inches, for these extreme cases. Mr. Wasell only makes it 7¾ inches, the difference being due to the unfavorable supposition we have made, that the saddles move to the full amount that the land spans elongate.*

Now allowing Mr. Wasell's argument full weight, let us see what it amounts to. At the time of greatest cold, we have found that the distance between the cables is $\frac{39}{100}$ feet more than the normal distance; and it is manifest that more load will be thrown on the upper cables in consequence of this increase. The question, then, to consider is, how much will it be necessary to *take off* of the lower and place upon the upper cables, to bring them again into equal bearing?

Experiments show that iron wire extends $\frac{1}{1000}$ of its length per square inch of section, for each gross ton of weight added. If, then, we add 18 tons of weight to each of the upper cables, the strain in each will be increased $35\frac{46}{100}$ tons. This increased load will cause the curves of the land spans to each increase in length $\frac{127}{100000}$ feet, and the curve of the centre span to increase $\frac{49}{1000}$ feet; and the final effect will be to increase the deflection of the centre span by $\frac{222}{1000}$ feet, making it $52\frac{302}{1000}$ feet. But when we place 18 tons more load on each *upper* cable, we by so doing diminish the weight on the *lower* cables; thus causing a diminution of tension of $30\frac{42}{100}$ tons in each. This diminished strain will cause the curve of each land span of the lower cables to shorten 0.00908 feet, the

* On the unallowable supposition that the saddles are *fixed* on top of the towers, the difference in distances between the cables for the extreme range of temperatures taken, would be but 4½ inches.

curve of the middle span to shorten 0.0423 feet, and as a result the centre of the lower cables to rise $\frac{15}{100}$ feet, making the total deflection $62\frac{32}{100}$ feet. The difference between the total deflections of the lower and upper cables will then be $10\frac{2}{100}$ feet, or but *one-fourth of an inch in excess of the mean difference.* We learn, therefore, that the transfer of only 18 tons gross (= $20\frac{16}{100}$ net tons) to each upper cable, is sufficient to counteract the effect of a temperature of 20° below zero.

It remains yet to be shown, what the actual strain in the upper cables will be under these conditions; and here I will use the load assumed by Mr. Wasell. He places

The total dead load at - - - - - - - - - -	900	tons.
" " moving load at - - - - - - - - - -	630	"
Total - - - - - - -	1530	
Load on each of four cables if all bear alike then =	382	tons.
Add the load transferred to each upper cable at 20° below zero - - - - - - - - - - =	20	"
Total load on each upper cable - - =	402	"
Total tension resulting from this load will be 402×1.95 - - - - - - - - - - - - - =	788	tons.
Ultimate strength of one cable - - - - - - =	2657.6	"
Consequent factor of *safety* = $\frac{2657.6}{788}$ =	$3\frac{4}{10}$	

This is a very different matter from the low factor given by Mr. Wasell, viz., $2\frac{2}{10}$, and shows that even when we assume the *monstrous load he has given, we find the bridge to be safe; the total excess in strain caused by a change from mean to extreme temperature* *either way, being but* $\frac{39 \cdot 2}{2657 \cdot 6} = 1\frac{1}{2}$ *per cent. of the total strength of the cables;* so *small* does this fearful bugbear become when critically examined.*

In this investigation no allowance has been made for the strength of the long stays. The safe supporting power of these is 150 tons in the aggregate, or about one-tenth of the load assumed by Mr. Wasell. The factor of safety of the whole bridge, therefore, under this extreme load, on the supposition of equal bearing on all the cables, would be about 4. I admit that these factors are smaller than is usual in such structures, but have already shown that the true factors under all ordinary loads, and even the extraordinary test load applied when the bridge was opened, are fully up to the best engineering practice of the day.

If the upper cables were strained to their breaking point, they would have a deflection of 65 feet, or eleven feet more than that of their mean position. Under the test load of 326 tons, the deflection was only 9⅝ inches, returning to its original amount on the removal of the load; thus showing that the limit of elasticity had not been reached. In this

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* I am unwilling to allow that even this small difference in strains actually occurs. The connections of the cables to the floors is not such as to allow any such action as the author claims. When by lowering the temperature there is a tendency to an increase of the distance between the cables, the cradling of the lower cables will be increased, that is they will swing nearer together; and that of the upper cables will be diminished by their separatnig a little, so that finally, the vertical distances *between* the cables will remain the same. The reverse action will occur when the temperature is raised.

A very casual inspection of the Bridge will make the truth of this statement manifest to any observer.

connection it is proper to state, that the material in a suspension bridge is in the best possible state (being always in tension) to bear its load; and can safely be loaded to much nearer its full breaking strength than where exposed, as in many other structures, to strains first of tension, and then of compression. Experiments prove this beyond all question; and it is an element of economy for which Mr. Wasell gives no credit.

I have thus far shown that the writer has fallen into error, first, in his assumption of load; and second, as to the length of the cables. Thirdly, that by making no allowance for the self-adjustment of the system (by an increase or diminution of the cradling of the cables) he induces a condition of things which cannot possibly exist; and finally, that even on the supposition of fixity of position, the elasticity of the material in the cables allows of but an insignificant increase of strain in either pair of cables before the other comes into full bearing; the final conclusion being, that even under the most extreme conditions of temperature and load, *no danger is to be apprehended to the structure.*

I propose, in closing, now that I have disproved the defects claimed by Mr. Wasell, to show that the design for the Niagara bridge has some positive advantages, which are derived from what he considers a faulty construction.

It would have been very easy to have arranged the land cables so as to compensate exactly for the differences in deflections in the main span; but the upper ones were made longer because one anchorage had to come behind the other (to accommodate other more important structural conditions), thus requiring a certain space independently of other considerations. It was necessary to give the cables such relative positions that the final resultant of the various lines of pressure in the towers should intersect their bases as near the centre as possible. By tracing the various planes in which the several cables lie, it will be found that this result is reached by the plan adopted as near as may be. It was this ingenious arrangement that permitted the use of those slender obelisks which now form the towers of the bridge; whereas any deviation would have necessitated double the amount of masonry, besides a connecting arch at the summit, coupled with a threefold expenditure of money.

A second advantage of the design is, that the cables are attached to the superstructure with its moving loads, in such a way as to give the *greatest amount of stability*. The centre of gravity is low enough to avoid all top-heaviness due to the load on the railroad floor. With a higher centre of gravity, lateral oscillations would occur, and the chances of de-railment would be very great. There would have been no difficulty in suspending both sets of cables at the same deflection, either on the level of the railroad or of the lower floor, at a sacrifice, however, of the advantages already named. If suspended at the railroad level, the pendent truss and lower floor would oscillate from side to side under the influence of the wind, besides increasing the aggregate tension in both cables, which would have to be met by higher towers or heavier cables. On the other hand, to suspend them at the lower level would be the height of folly, as the high centre of gravity would destroy all stability. The relative grades of railroad and common road were also such as to enforce the use of the upper floor by the railroad.

A third advantage of the design consists in this: that cables of the same span but different deflections oscillate in different times, and with different wave lengths; hence, when a pair of such cables are attached to a structure, the oscillations caused in one by a load or the wind, tend constantly to neutralize those caused in the other, and to produce a state of rest. In conclusion, I quite agree with Mr. Wasell that "the suppression of facts so intelligible, and of such vital importance to the travelling public would [indeed] be criminal"; but the facts, on examination, have dwindled to such diminutive proportions that, in my judgment, and I trust that of the public, they do not yet justify the building of Mr. Wasell's "Improved Trussed Girder Bridge," either at the Falls or any other point on the Niagara River.

W. A. ROEBLING.

NEW YORK, *Nov. 28th*, 1876.