REPORT
ON THE
Niagara Railway Suspension Bridge
FINAL REPORT

—OF—

JOHN A. ROEBLING,

Civil Engineer,

—TO THE—

Presidents and Directors of the Niagara Falls Suspension and Niagara Falls International Bridge Companies.

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To the Presidents and Directors of the Niagara Falls Suspension, and Niagara Falls International Bridge Companies.

Gentleman:

It gives me great pleasure to be enabled to report the Niagara Suspension Rail Way Bridge complete in all its parts. The success of this work may now be considered an established fact. The trains of the New York Central, and of the Great Western Rail Road in Canada, have been crossing regularly since the 18th of March, averaging over 30 trips per day.

One single observation of the passage of a train over the Niagara Bridge, will convince the most sceptical, that the practicability of Suspended Railway Bridges, so much doubted heretofore, has been successfully demonstrated.

The practicability of the Suspended Railway Bridges of large spans, was a practical question of great importance to the country, intersected as it is by numerous large rivers and deep gorges, at a depression far below the general surface of the surrounding country.

The free and unobstructed navigation of our great rivers, which are to be crossed by Railways, also demanded a new class of viaducts, such as will safely pass the Locomotive with its train at one bound, and
at an elevation, that will leave no obstruction to the sailing, and steaming craft below. The great rivers of this continent will no longer offer an insurmountable obstruction to the formation of uninterrupted lines of Railways. At the completion of the road to the Pacific we shall possess continuous lines of Rail of over 3000 miles extent, over which, if desirable, cars loaded with treasure at San Francisco, may be passed to New York without breaking bulk.

The subject of Suspension Railway Bridges was indeed a question of great importance. A Rail Road is now being constructed through the central part of the State of Kentucky, known as the Lexington and Danville line which, with its extension to the State line of Tennessee, will from the connecting link between two great networks of Railways, north and south, of such an immense extent as can only be found on the North American Continent. This important connection will have to be abandoned, if a Suspension Railway Bridge of a single span of 1224 feet, now in course of construction, across the Kentucky River, which, there forms an abrupt chasm of 300 feet deep, cannot be accomplished.

The Kentucky River, the Niagara, and many others, which have been ploughing their courses through limestone formations, will not admit of any other mode of crossing but by a Suspension Bridge. Tubular as well as Arch and Truss Bridges are in those localities impracticable.

While the European Engineers are engaged in the construction of short lines of Railways at such enormous cost, that in most cases the capital invested, yields no remunerative dividends, the task of the
American Engineer is to lay down thousands of miles with extensive bridging, at a cost which would barely suffice in Great Britain to cover the expenses of preliminary proceedings.

The work which you did me the honor to entrust to my charge, has cost less than $400,000. The same object accomplished in Europe would have cost 4 millions without serving a better purpose, or insuring greater safety. The mixed application of timber and iron in connection with wire, render it possible to put up so large a work at so small a cost. When hereafter, by reason of greater wealth and increased traffic, we can afford to expend more on such Public Works, we shall construct them entirely of iron, omitting all perishable materials. We may then see Railway Bridges suspended of 2000 feet span, which will admit of the passage of trains at the highest speed.

As regards the success of your work, more has been accomplished than was promised. The idea of a perfectly rigid structure, such as tubular bridge, was never held out. The Niagara Bridge possesses all the stiffness that is wanted, and much more than is actually needed for the safe passage of trains. It is gratifying to notice the entire absence of all such vibrations as would easily be noticed, or would eventually prove a source of destruction. There is no Bridge in the world, neither of stone, cast or wrought iron, which is free from all vibrations. The effect of the concussions of a fast moving train may be sensibly felt miles off through the solid earth, while buildings of brick in the immediate vicinity of a Rail Road are very perceptibly shaken. Sitting upon a saddle on top of one of the towers of the Niagara Bridge during
the passage of a train, moving at the rate of 5 miles an hour, I feel less vibration than I do in my brick dwelling at Trenton, N. J., during the rapid transit of an Express Train over the New Jersey R. R., which passes my door within a distance of 200 feet. I will further remark that the Land Cables are not at all affected by the passage of trains; the very slight vibrations and concussions, noticeable in the superstructure, are not transmitted over the towers. This fact is gratifying, as it will insure the durability of the masonry. The stiffness of the lower floor has been a matter of general observation, ever since its opening in June last. Strange as it may appear, a number of loaded teams produce more motion than results from the transit of a train. But for the rumbling noise over head, such transit would not be noticed by persons on the lower floor.

Suspension Bridges have generally been looked upon as *loose fabrics*, swung up in the air, as if for the very purpose of swinging. Repeated failures of such works have strengthened this belief. My success in the construction of suspended aqueducts, however, should have been deemed a strong argument against it, at least by professional men. This fact should have cautioned them against forming hasty conclusions upon a subject, which they had but partially investigated. I have built five such works, and two of them of large capacity and great extent, which have all proved successful, and are to all intents and purposes as rigid as stone or cast iron aqueducts. The principle of Suspension is certainly much easier applied to Aqueducts than to Railway Bridges, but still these works require a degree of solidity and stiffness, which, as
was at the time reasoned by the Profession generally, could not be obtained. But some non-professional men saw much clearer than professional men, and so the thing was done. A good deal of the same sort of reasoning, which was made use of against Aqueducts, was equally directed against Railway Bridges, but with no better success, as the result shows.

Professional and public opinion having been adverse to Suspended Railway Bridges, the question now turns up what means have been used in the Niagara Bridge, to make it answer for Railway traffic? The means employed are: Weight, Girders, Trusses and Stays. With these any degree of stiffness can be insured, to resist either the action of trains, or the violence of storms, or even hurricanes; and in any locality, no matter whether there is a chance of applying stays from below or not. And I will here observe, that no Suspension Bridge is safe without some of these appliances. The catalogue of disastrous failures is now large enough to warn against light fabrics, suspended to be blown down, as it were, in defiance of the elements. A number of such fairy creations are still hovering about the country, only waiting for a rough blow to be demolished.

Weight is a most essential condition, where stiffness is a great object, provided it is properly used in connection with other means. If relied upon alone, as was the case in the plan of the Wheeling Bridge, it may become the very means of its destruction. That Bridge was destroyed by the momentum acquired by its own dead weight, when swayed up and down by the force of the wind. The weight of a Suspension Bridge should not bear too small a proportion to the
transient loads it is calculated to support. The smaller the transient weight is in proportion to the weight of the structure, the less disturbance such passing loads will cause in its equilibrium. When a train enters the Niagara Bridge, it produces a slight depression upon that part of it. But this depression cannot take place without a corresponding rise at the opposite end. The greater therefore the weight of the structure, the less its equilibrium will be affected by transient weights. This is certainly plain, and will appear so to the most careless observer. Consequently a high wind, acting upon a suspended floor, devoid of inherent stiffness, will produce a series of undulations, which will be corresponding from the center each way. And from this follows the necessity of introducing the principle of the triangle, so as to form stationary points and thus check vibrations, and restore balance. The effect of trains has to be met in the same way by the application of the triangle, either in the form of stays or trusses, or both. Undulations, caused by wind, will increase to a certain extent by their own effect, until by a steady blow a momentum of force may be produced, that may prove stronger than the cables. And although the weight of a floor is a very essential element of resistance to high winds, it should not be left to itself to work its own destruction. Weight should be simply an attending element to a still more important condition, viz: stiffness. Before enlarging upon the subject, I will here remark, that an engine and tender of 34 tons weight, together with one passenger car, crowded with persons, making a total load of about 47 tons, caused a depression in the center of 5½ inches. This flattening of the camber is partly
owing to an actual elongation of the cables, and in part to the disturbance of the equilibrium, the weight in the center causing the ends next the tower to rise. But suppose the superstructure to possess no inherent stiffness at all, and together with the cables to be perfectly flexible, then the depression, caused by the above weight, would be much greater.

Let \( x \) represent the deflection of cables in feet.

\[
\frac{x}{w} \quad \text{the weight in the center in toms,}
\]

\[
W \quad \text{the weight of the whole structure,}
\]

then the formula \( \frac{x}{2w} \) will give the depression, produced in the center, in feet. Substituting now 59 feet for \( x \), 47 for \( w \), and 1000 for \( W \), we shall have

\[
\frac{59 \times 47}{2 \times 1000} = 1.386 \text{ feet.}
\]

But the actual depression, as observed by an instrument, was only 5\( \frac{1}{2} \) inches or 0.45 feet. The difference of 0.936 feet, therefore is owing to the inherent stiffness of the structure. A single Engine of 23 tons weight, including tender, caused a flattening of the camber in the center of 0.3 feet. The formula applied to this case, would give a depression of 0.678 ft. or 0.378 ft. more. The above formula, however, does only consider the equilibrium of the catenary. Neither the elongation of the cables, nor the movements of saddles on the towers, nor the reduction of deflection of the land cables are here taken into account. To provide for all these movements, would exceedingly complicate the construction of a formula. The importance of weight however is rendered manifest, because it is shown, that depressions are indirectly as the weight of the structure, and directly
as the weight of the transient load, also directly as the deflection of the cables. The flatter the cables are, the stiffer they will be, but also less able to support a load.

In depending upon weight as guarding against a disturbance of equilibrium, such elements should also serve to increase the stiffness of the structure mechanically and not only statically. I object to weight, put on simply as loose weight.

In those discussions, which took place in Great Britain on the subject of Suspension Bridges, previous to the adoption of the tubular plan, for crossing the Menai Straits, a more thorough investigation of the subject would have led to the conclusion, that there is no inherent defect in the suspension principle, and that by simply adding to its weight, without providing any other means of stiffness, its adaptiveness to Railway traffic would have become clear.

The idea of absolute rigidity must be abandoned, when considering the practicability of Suspension Railway Bridges. We can only obtain a comparative degree of rigidity in any kind of structure, no matter whether it is a stone or cast-iron arch, iron or wooden truss, or a hollow wrought-iron beam. Such being the case, the next question is: what degree of rigidity is necessary for a safe passage of trains at certain speeds? Flexibility in a bridge is no objection, provided it offers no obstruction to its use, and is compatible with safety and durability. The Conway tube of 400 feet span, deflects 3 inches under a weight of 300 tons, placed in the center. How much would a tube of 800 feet span deflect under the same load, provided such tube had the requisite depth and strength?
Probably no less than 9 inches. When the Niagara Bridge is loaded with a freight train covering its whole length, and weighing about 326 tons, the camber is reduced 0.82 ft or nearly 10 inches. On removal of the load, the structure rises again to its former level. In the case of the Conway Tube the deflection is owing to the elasticity of the iron plates, composing it. In the Niagara Bridge the same cause produces the same effect, but in different directions, and under different circumstances. In the Tube one portion of the iron is exposed to tension, while a greater portion is exposed to compression. But the tensil power of wrought-iron is much greater than its resistance to compression. In a Suspension Bridge on the other hand, nothing but the tensil force of wrought-iron of a form and size, which insures the best quality, is employed. The tubular principle involves a great waste of material when compared to the suspension principle, and consequently, whenever great weights are to be supported over large spans, the first cannot successfully compete with the latter. In a country where the Engineer's task is to make the most out of the least, the Suspension principle will henceforth take the lead of the tubular, in all ordinary localities. For extraordinary long spans the tube cannot compete on any terms.

Every train that passes over the Niagara Bridge causes a certain depression, but this being far within the safe limits of the elasticity of wire, no injury results from it. Every train that passes through the Conway, or through the Britannia tubes, causes a depression. Now can it be said, that this deflection is an objection to the tubular principle? Certainly
not, because these deflections are far within the safe limits of the elasticity of the iron plates composing them. But tubular bridges are designed to be rigid, while Suspension Railway Bridges are designed to be flexible.

Next to weight as a means of preserving equilibrium the most important feature in the Niagara Bridge are the Girders which support the track. They are made of timber, and in connection with 4 lines of rails serve to distribute the pressure of concentrated loads. The efficiency of these girders became evident at the first trial. On the 8th of March, I made the first trial trip with an American built engine of 23 tons weight, with 4 drivers, placed but a short distance apart. The general depression in the center was 0.3 ft. But its passage was also accompanied by a local depression or slight flattening effect, which amounted to about 1 inch, extending over a length of 100 feet. Another American Engine of 22 tons weight produced nearly the same effect. I then made a trip with an English built Freight Engine of 34 tons weight, with six drivers, placed at a considerable distance apart, which owing to its weight being less concentrated, did not cause more of a local deflection than half an inch, but together with a loaded passenger car produced a general reduction of the camber in the center of 5½ inches. Without girders the trusses would not long resist the action of trains.

The Niagara Bridge of a span of 821 feet 5 inches, from center to center of towers, forms a slightly curved hollow beam or box of a depth of 18 ft., width of bottom of 24 ft., and of top 25 ft. The lower floor is used for common travel, while the upper is appropri-
ated to Railway business, and sidewalks. The two floors are connected by two trusses of a simple construction, so arranged, that its resisting action operates both ways, up as well as down. The suspenders are 5 feet apart. The beams of the upper and lower floor are connected by posts, arranged in pairs, leaving a space between for the admission of the truss rods. The ends of the posts are secured between the beams in a manner that no part is weakened, and that any amount of strain can be thrown upon them without injuring or loosening their connections. There are no joints to work loose. If the timber should undergo a further shrinkage, the truss rods will simply require tightening. The depressing action of any loads is by these posts transmitted from one floor to the other. From the end of each pair of posts a truss rod extends each way to the 4th pair of posts at an angle of 45 degrees. The rods therefore cross each other and form a diamond work. They are 1 inch diameter, their screw ends 1½ inch. The pressure upon any pair of posts is by these rods spread 40 feet apart. The nuts work on cast-iron plates, placed above or below the posts.

Without adding much to the weight of the structure, a surprising degree of stiffness has been obtained by the united action of the girders and trusses. They have fully realized my expectations. The pressure of an Engine and of a whole train of cars is so much distributed, that the depression, caused by a light freight or ordinary passenger train, is not readily observed. A freight train train of 12 loaded cars with a 25 ton engine, covers a little more than half the length of the floor. Its effect is more marked and
noticed, than either a smaller or larger train. When in the center, the result is only a flattening of the camber, but when near the towers, where the grade forms nearly a straight line, the depression is from 3 to 4 inches. A longer train of greater weight in proportion, disturbs the equilibrium less, as it covers a greater extent. Passenger trains of 15 long cars, which frequently cross the Bridge, make little impression observable by the eye. While the severe action of trains upon common arch and truss bridges, causes great wear and tear, I am persuaded that the woodwork of the Niagara Bridge will suffer much less.

My observations during the last month have not caused me to change this view, which I have always expressed.

The tubular or box plan of the Bridge has added much to its stiffness, vertically as well as horizontally. There is an entire freedom from all lateral motions during the passage of a train. It is a surprising fact, that half a dozen heavy teams on the lower floor produce a more perceptible horizontal motion, and a much greater jar and trembling, than is caused by a train of cars, moving at the stipulated speed of 5 miles an hour. The smoothness, evenness, and perfect level condition of the Rail Road tracks, partly account for this. While teams on the lower floor generally move forward outside of the center of the Bridge, the trains are exactly poised in the center. The great horizontal stability of the work is mainly owing to the powerful lateral bracing of the upper cables, which are suspended in a very considerable inclination. There is no reason to suppose that the durability of the woodwork of this Bridge will be less
than that of a common Suspension Bridge, serving for ordinary travel alone.

The next means of stiffness I have applied, are stays, above as well as below the floors. These as well as the suspenders are all made of wire rope, manufactured at my works at Trenton, N. J. There are 64 diagonal stays of $1\frac{3}{8}$ inch diameter rope, above the floors, equally distributed among the 4 cables. They are fastened to the suspenders by small wrappings, so as to form straight lines. Each of these stays represents the hypothenuse of a rectangular triangle of which the two cadets are formed by the towers and the floors. These two being solid and rigid in the direction of the lines they represent, by preserving the straight line of the stay and not allowing them to sag or deflect, we form as many triangles as we have stays. Now the triangle is the only geometrical figure whose corners cannot be shifted, consequently by keeping those stays under a good tension, we form so many stationary points in the flooring, as we have stays. But these do not only stiffen, they are also a great assistant to the cables. Their number being limited, and the cables possessing an abundance of strength, I did not continue them over the towers to the anchorage. They are secured to the saddles and allowed to move with them. No fear need be entertained, that they will pull the saddles forward. The friction of the cables in the saddles is at the lowest estimate equal to one third of the pressure. The constant pressure upon each tower is 500 tons. This would give 166 tons. The ordinary tension of each stay being about 4 tons, the united horizontal force of 16 stays applied to 2 sad-
dles is found to be about 56 tons, to which a resistance of 166 tons is opposed, without taking into account the curvature of the cables in the saddles, which will nearly double it.

To the underside of the lower floor 56 stays are attached, which are anchored in the rocks below, and occupy positions calculated to insure against horizontal as well as vertical motions. Their principal duty is to guard against the forces of winds, but at the same time they contribute materially to preserve the equilibrium of the structure during the passage of trains. Their usual tension averages about 2 to 3 tons. Considering their positions, their aggregate force, exerted upon the lower floor in a vertical direction, at a medium temperature, is less than 100 tons. In summer this force is less, in winter it is more. In the disposition of these stays, I have taken advantage of the ample opportunity this locality offers. There are bridge sites where this cannot be done, and where security against the force of winds has to be entirely obtained by over floor stays, and by the inherent stiffness of the structure. But the difficulty is no greater in one case than in the other. In all localities perfect safety against the force of winds can be obtained.

To present a fuller analysis of the work, I will review its various parts in the same course in which they were put up, and commence with the

ANCHORAGE.

The anchorage was commenced in September, 1852, and was formed by sinking 8 shafts into the solid Lime-stone rock, that here composes the upper-
most stratum of the cliffs. This layer is solid for a depth of 14 feet, underlaid by a lime-stone shale, which again is followed by a solid stratum. Three of the pits on the New York side are sunk to a depth of 25 feet. The fourth one south east is only 18 ft., where the rock proved very solid, and without any fissures. This shaft was not sunk deeper on account of the great influx of water and difficulty of bailing. In consequence the lowest link of that chain was omitted, and a greater hold given to the rest by reverse arches, thrown against the knuckles, also by the introduction of crossbars. With the exception of this shaft, all the others, on both sides of the river, have been sunk to an equal depth, 54 ft. below the Rail Road track. The surface of the rock on the Canada side being 10 ft. higher than on the New York side, the depth of shafts was increased that much, and the height of the masonry above reduced in proportion. Each shaft has a cross section of 3 x 7 ft., enlarged at the bottom to a chamber of 8 ft. square. The anchor chains are composed of 9 links, all of which are 7 ft. long, except the uppermost or last one, which is 10 ft. The first or lowest link is composed of 7 bars, 7 x 1.4 inches, and is secured to a cast-iron anchor plate by a pin of 3½ inches diameter, ground upon its seat. The next link is composed of 6 bars of the same size, and 2 half bars on the outside. The aggregate section of each is 69 superficial inches. From the fourth link on, the chain curves, and the section is gradually increased to 93 superficial inches. Four of these chains were manufactured of the best quality of Pennsylvania charcoal blooms by Everson & Preston, of Pittsburg, the other four were made at Napannock, Ulster
Co., N. Y., by Mr. Frederick Bange. They were manufactured out of Salisbury pig, puddled in wood fire. Both these irons can be depended upon for a strength of 32 tons of 2000 lbs. per square inch. I have tested them thoroughly by cutting up a number of extra bars and pins, and forging them over into various shapes. All the sockets attached to the ends of the wire rope suspenders and stays, which are very difficult to forge, and require the best quality of material, have been made of this Napanock iron.

The tension of the different links composing each chain, diminishes as they descend, the trains upon the vertical links being more than one-third reduced, in consequence of position, friction and hold in the masonry. The lowest link is secured to a cast-iron plate of 6 ft. 6 inches square, 2½ inches thick, at the edges, with 8 heavy ribs upon the lower side. The central portion through which the bars are admitted, has a depth of metal of 12 inches. Where a seam in the rock offered a good chance to form a solid bed, one half of the plate rests against it, and the other half against masonry. After securing the position of the plate and chain, the whole shaft was filled out with masonry laid in cement mortar and copiously grouted. Great care has been taken to grout the bars well. My experience has given me ample proof, that cement grout will take a firm hold of iron, and will affectually guard it against oxidation. The bars were well oiled with linseed oil, then painted twice with zinc paint and Spanish-brown. Where no solid face could be obtained, the roof of the chamber was cut out prismatically. The masonry resting upon the plate presses against this roof like a wedge. Large stones were
laid upon the knuckles, so that every joint has a hold in the masonry, above as well as below the surface of the rock. Above the rock, where the chain curves, each knuckle rests upon a cast-iron plate, bedded upon a large cut stone. This again rests upon one still larger or upon two flat stones, which distribute the pressure upon the masonry below. No labor has been expended upon the face work of the anchor-walls, but the inside has been faithfully executed to insure a strong job.

The aggregate section of the upper links of the four chains is 372 square inches, and their ultimate strength at 32 tons, equal to 11,904 tons. The strain upon the lowest link is at least diminished one-third, which leaves 7936 tons. This pressure on the New York side is resisted by a sheet of solid rock of no less extent than 100 ft. long, 70 ft. wide, and 20 ft. deep. This rock weighs about 160 lbs. per cubic foot. Now assuming only 200 lbs. of resistance in the solid rock, we have a mass of 140,000 cubic feet, opposing a force of 14,000 tons, without taking into account the weight of the superincumbent masonry and embankment. Admitting that the rock was full of fissures and seams, which is not the case, the entire safety of the anchorage is evident.

The great and very sudden changes of temperature, to which this locality is exposed, and also the intense cold, sometimes experienced in winter, made it necessary to enclose the whole length of the chains in masonry. The temperature of the iron is thus preserved more uniform. The chains end at the level of the coping, where they connect with the cables, which are also enclosed in grout and masonry for a length of
12 feet, the latter terminating in ornamental blocks above the coping. The strength of wire is not affected by sudden changes of temperature; no further protection of the cables therefore is required.

I will add here that the anchor plates were cast of a very strong, cold blast charcoal metal at the foundry of Oliver T. Macklem, Esq., at Chippewa, who supplied the castings for the whole work.

MASONRY.

This part of the work was given out in contract to Mr. John Brown, on the Canada side, and to Messrs. Latham & Gage, on the New York side. Its inspection was placed under the charge of the late Mr. George Watson, who fell a victim to the cholera last year. The base of the towers presents a rock face, the stone are large, and well bonded and bedded. The beds of the backing were all cut true, and all the stones were laid in a heavy bed of cement mortar, and the joints grouted. In the towers above, a uniform bond has been observed, all blocks being dimension stone. The backing was bedded with the same care as the face. To increase the solidity of this work still more, the upper courses were dowelled. The entire security of this masonry may be relied upon. Without expending much labor upon its appearance, nothing has been spared to secure its strength.

The base of the lower work at the level of the lower floor is 60 x 20 ft., pierced by an arch of 19 ft. wide, which forms the entrance to the lower bridge. Each of the four towers is 15 ft. square at the base, 60 ft. high above the arch, and 8 ft. square at the
top, therefore has a top surface of 64 square feet. The limestone, of which this masonry is built, will support a pressure of 500 tons upon every superficial foot, without crushing. While the greatest weight, that can fall upon one tower will rarely exceed 600 tons, it would require a pressure of more than 32,000 tons to crush the top course.

The base and towers on the New York side contain 1350 cubic yards, which weigh about 3,000 tons. Add to this the weight of the superstructure of 1000 tons, and we have a total of 4000 tons, in a compact and solid mass. For lateral stability, I have relied entirely upon this weight and the central direction of the forces, which act upon the top course. The inclination of the tangents of the suspension cables very nearly coincides with the angle of the land cables, consequently their united tensions will produce a vertical pressure through the axis of each tower.

As regards the apparent lateral pressure of the cables upon the towers, the danger is only imaginary and not real. The strongly inclined position of the upper or Rail Road cables, which insures that remarkable degree of lateral firmness so observable in the upper floor, appears to produce a lateral pressure towards the inside, which these small masses of masonry could not long resist. When however, the observer takes his stand either on top of the towers or back of the anchorage, in line with the anchor cables, he will discover, that all is right and as it should be. A medium line between the two anchor cables, when continued towards the river, will be found to correspond precisely with a mean line between the tangents of the two suspension cables, consequently, the
force growing out of the united tension of the cables, is bound to keep within a vertical plane, which descends through the axis of the towers. The horizontal projection of the cables on the plan, show the perfect safety of this arrangement. By connecting the towers by an arch, and forming a gateway, instead of isolated columns, the appearance of the want of lateral stability could have been avoided. But this would have changed the whole plan of masonry, and its cost would have been more than doubled, without adding to its safety.

The character of the anchor masonry is that of strong rubble, laid in cement mortar, no regard being had to outside appearance.

SADDLES ON TOWERS.

On the top course of each columns a cast-iron plate was laid down, well bedded in cement, 8 feet square, 2½ inches thick, and strengthened by three parallel flanges for the reception of two independent saddles. The top of the plate and the bottom of the saddles are planed off. Each saddle rests on ten cast-iron rollers, five inches in diameter, and 25½ inches long, turned off to the same size. They are placed close together. The ordinary pressure upon each tower being about 500 tons, makes each roller bear 25 tons. The object of these rollers is to admit of a slight movement of the saddles, whenever the equilibrium between the land and suspension cables is disturbed, either by changes of temperature, or by passing trains. The rollers were cast of a very close grained, dense and uniform metal.

Although a movement of the saddles is caused by a small difference of tension, no motion are thereby
communicated from the suspension cables to the land cables. A train moving at the rate of 10 miles an hour scarcely produces enough motion to be perceptible in the suspension cables, and none at all in the land cables. A single engine of 20 tons weight causes a movement of 1-32 to 1-16 inch. This conclusively proves, that in no case will a horizontal force of ten tons be directed upon one tower, in consequence of difference of tension between the suspension and the land cables.

The experimental freight train, which passed over the bridge on the 18th of March, and covered its whole extent, weighed 326 tons of 2000 lbs. each, and caused the saddles to move forward 0.041 ft. or nearly half an inch. The tension which results from this weight is 590 tons. Now according to my own experiments, which I have made with wires of 1000 ft. long, to ascertain their contractions and expansions, caused by changes of temperature, as well as by weights or tension, and which agree with those of Barlow and others, wire will stretch 1-10,000 part of its length for every gross ton of 2240 lbs. per square inch of section. The average length of the land cables and chains is 226 feet, their elongation caused by one gross ton per square inch, therefore is 266-10,000 = 0.0266 ft. The aggregate section of the 4 cables is 240 square inches, therefore the tension, caused by the above load is

\[
\frac{590 \times 2000}{240} = 4917 \text{ lbs.},
\]

and we find the elongation x

\[
2240 : 4917 = 0.0266 : x
\]

\[
x = 0.0583 \text{ feet.}
\]
Now the actual movement of saddles was 0.041 or 0.0173 less than calculation. Considering that the chains would only be partially affected, calculation approaches the fact very near. This examination also shows that the whole strain of the suspension cables must have been very nearly communicated to the land cables, and that consequently the towers were not exposed to any horizontal thrust.

CABLES.

There are 4 cables of 10 inches diameter, each composed of 3640 wires of small No. 9 guage, 60 wires forming one square inch of solid section, making the solid section of each cable 60.40 square inches, wrapping not included.

The construction of these massive cables required extensive and somewhat complicated arrangements. My patent machinery for the transmission of wires across rivers was employed. You have all become familiar with this process, which was carried on for two seasons. I will therefore confine my remarks to the principles of this operation only for the purpose of showing how a uniform tension and perfect work was insured. The appearance of the cables is not only pleasing, but their massive proportions are also well calculated to inspire confidence in their strength. The reflecting man however will naturally inquire: is this mass of wire put together so that the different strands bear all alike? Does each individual wire perform its duty, so that when exposed to a great strain, they will resist with united strength to the last? I can answer this question in the affirmative and can assure you, that the tension of these 3640
wires, composing each cable, is so nearly uniform that I feel justified in using the term perfect. The following remarks will explain more fully.

Each of the four large cables is composed of seven smaller ones, which I call strands. Each strand contains 520 wires. One of these forms the centre, the six others are placed around it. The 520 wires composing one strand are in fact one endless wire, obtained by splicing a number of single wires. The ends of strands are passed around and confined in cast iron shoes, which also receive the wrought iron pin that forms a connection with the anchor chains.

The strands were manufactured nearly in the same position, which they now occupy in the cables, with about one-third of their present deflection? this was for the purpose of increasing the tension of the wires, and to facilitate their adjustment.

All the preparatory operations, as oiling, straightening, splicing, and reeling, were carried on in an extensive shed, erected on the Canada side, back of the anchorage.—The mode of splicing you have frequently witnessed, and have noticed that the wire will break at any other point, before it gives way at the splice. Fourteen large reels were constantly kept supplied with wire, ready prepared or spliced for going into the cables. The machinery for plying the wires across the river was worked by horse-power. The adjustment of the wires in the centre of the span, was intrusted to two intelligent workmen, who were stationed on a platform, suspended by four wire ropes, about forty feet above the upper floor. Communicating all orders by means of signal flags, this whole operation went on very satisfactorily, occasion-
al interruptions from high winds, excepted. Owing to the influence of the sun, and the sudden changes of temperature of the wires on the opposite sides of a strand, during the progress of its manufacture, great care was required on the part of the men stationed in the centre. These, and other circumstances have all been properly attended to, and I feel confident that any difference of tension that may exist, does not exceed a few pounds per wire. The tension of one complete strand, was about fifty tons, or two hundred pounds per single wire. Two strands were made at the same time, one for each of the two cables, under process of construction. On the completion of one set, temporary wire bands were laid on, about nine inches apart, for the purpose of keeping the wires closely united, and securing their relative position. They were then lowered to occupy their permanent position in the cables. On completion of the seven pair of strands, two platform carriages were mounted upon the cables for laying on a continuous wrapping, by means of my patent wrapping machines. During this process, the whole mass of wire was again saturated with oil and paint, which together with the wrapping, will protect them effectually against all oxidation.

Five hundred tons of the wire used in the cables, were manufactured by Richard Johnson & Brother, of Manchester, in England, and contracted for, by Mr. James Cocker & Co., of New York. It is but justice to these parties, to state here, that they have faithfully observed all the stipulations the contract imposed upon them. My specification required, that the wire, when suspended between two posts, 400 feet apart, should not
break at a greater deflection than nine inches; also, that it should stand bending square over the jaws of a large pair of pliers, and rebending, without rupture.—The size of wire was to be twenty feet per pound, but subsequently modified to eighteen feet. The above test of strength corresponds to a tension of 1300 pounds per single wire, measuring twenty feet per pound, or to 90,000 pounds per square inch of section. The contractors, submitted a number of skeins for testing, which were all accepted. They then secured sufficient stock of the same quality of iron, to fill the whole order, and were thus enabled to insure a uniform quality throughout. On delivery, the tests were continued with the same favorable results. From a great number of tests, which varied but slightly, I found the average deflection, at which rupture took place, to be 0.683 feet, or a little over eight inches. The wire measures 18.31 feet per pound, and the above strength, therefore, is equivalent to 1640 pounds per single wire, or nearly 100,000 pounds per square inch. By this mode of testing, the wire is sure to give way at the weakest point. The above result, therefore, shows a remarkable uniformity in the iron, and great care in the manufacture of the wire.

Assuming the above average strength, the aggregate strength of the 14,560 wires composing the four cables, will be 23,878,400 pounds. But their actual strength is greater, because the above calculations are based upon a minimum strength of the individual wires.—The weak points of the different skeins, will not happen to meet all at the same point. Being closely, and very compactly bound together, they will greatly assist each other, and I am, therefore safe in estimat-
ing the strength of the cables beyond the result of the above calculation. We may assume their aggregate ultimate strength at 12,000 tons, of 2,000 pounds each.

Next to severe strains, repeated vibrations and concussions of great intensity, prove the greatest source of destruction to all kinds of metal. The more uniform and dense the iron is, in its grain or fibre, the greater will be its durability. Good wire is a very safe and reliable material, where great strains and vibrations are to be supported. Wire rope on inclined planes, where it is exposed to severe usage, and to an almost incalculable amount of vibration, lasts but a limited time. Its durability, however, will be found in direct proportion to the speed of its working, and to the consequent degree of vibration. Wire ropes of one and a quarter inch diameter, on such inclined planes as those of the Alleghany Portage, in Pennsylvania, where there is a speed maintained, of 7 to 12 miles an hour, and where the machinery is very imperfect, and always out of repair, will not last longer than 1½ to 2 years, and will pass about 300,000 tons, gross weight, over planes of half a mile in length, and rising one in ten. Ropes of less size, will perform five times the business, on the planes of the Pennsylvania Coal Company, and on the inclines of the Carbondale road, because treatment and machinery are so much better. Those in use on the inclined planes of the Morris Canal, are two inches diameter; draw loads of 100 tons, over inclinations of one in twelve, at a speed of 5 miles an hour and last, in consequence of perfect machinery and good usage, seven to eight years. I mention these facts, to show conclusively,
that the durability of wire rope and cable, is in proportion to usage. The same rope will last much longer under a heavy strain moving slowly, than it will under a light strain, moving faster. Of this fact, I have the most ample evidence. I have cited the experience of wire ropes on inclined planes, as an extreme, and by way of contrast. Suspension bridges should be built so as to be entirely, or very nearly exempt from vibrations. The cables and suspenders of the Niagara bridge, are sustaining but a moderate tension, far within their elastic limits, and may be considered as at rest.—They are also well protected against oxidation, and will consequently last an indefinite length of time.

In connection with this subject, I will cite another interesting fact. The small cables which supported the temporary bridge, put up under the superintendence of Mr. Ellet, and afterwards strengthened by Mr. Buchanan, had been exposed occasionally, to heavy strains, and to great vibrations. The wire originally, was very good; about the same quality as that in the new cables, and made by the same manufacturer. On removal of the old work, I tested it, and found its strength and toughness scarcely impaired; so little indeed, that I did not hesitate to work it into the new cables. Another fact is worthy of notice. The old cable measured from one and a quarter to two inches in diameter, and had been wrapped at intervals of about nine inches. The wire had been originally, well coated with linseed oil, and the cables afterwards, repeatedly painted with Spanish-brown or linseed oil, on the, outside which made them impervious to water. On taking them apart, I
found the oil inside, still in a soft condition, forming a tenacious varnish, and no trace of oxidation. These cables were put up in 1848, and removed in 1854; consequently had served six years. It is difficult to state how long this wire would have proved safe, if it had remained in the same situation, exposed to the same usage. The Wire Suspension Bridge at Frigburg, in Switzerland, the largest span in Europe, is still considered a safe work. It was completed about 1830. The roadway of the bridge is 808 feet long; weighs about 300 tons, and is supported by eight cables of five and a half inches in diameter, containing in all, about 4700 wires, No. 10. Its comparative strength is, therefore, much less than that of the Niagara Bridge, while it is frequently exposed to severe gales, and not secured against oscillations.

Wire cables, if guarded against oscillations, and not exposed to an undue tension, may be looked upon, as of indefinite durability. I have cited wire rope on inclined planes, as an extreme fact, regarding durability. Severe friction, short bending, constant vibration, high tension and frequent severe shocks, will soon wear out the best material. The more we can reduce these exposures, the greater will be its durability. The conditions of durability, are certainly most favorable to the cables of the Niagara Bridge. An instance of comparative great durability, is furnished by wire sofa springs, which, when made of good material, will not lose their elasticity, under fair usage, in a lifetime. As another very remarkable case of great durability, under the most severe exposure, we may refer to the wire strings of a piano, which are kept at a high tension, and in that state exposed to an almost
incalculable amount of vibration. Common wire would not resist this action twenty-four hours. Piano wire is therefore, made, either of the best steel, or of bars which form a good steel outside, and a fibrous iron inside, purposely manufactured. Good piano wire furnishes a very remarkable instance, how much strength, and what a high degree of elasticity can be obtained, by an improved quality of iron and steel. In this connection, I may also point to the great durability of steel springs, used for the support of carriages and Railroad cars. Their great exposure to severe vibrations and constant concussions, is well known; as also, their great durability. In all such cases of extreme service, it has to be well observed that the safe limit of elasticity is not exceeded, else the material will soon be destroyed. Bridges of half a mile span, for common or Railway travel, may be built, using iron wire for the cables, with entire safety. But by substituting the best quality of steel wire, we may nearly double the span, and afford the same degree of security.

STRENGTH OF BRIDGE.

Both ends of the bridge rest upon the cliffs, and are anchored to the rock. As far as supported by the cables, I estimate its weight at less than 1000 tons, which includes the weight of cables between towers, and the pressure of the river stays below. For convenience sake, I will assume this weight at 1000 tons of 2000 pounds each. By multiplying with the factor 1.81—see Appendix B, we find the tension of the cables, which results from this weight 1810 tons. Their ultimate strength was stated at 12,000 tons, therefore
their permanent tension is to their ultimate capacity, as 1810 is to 12,000, or as 1 : 6.63.

The sixty-four over-floor stays have an ultimate strength of thirty tons each, or 1920 tons in all. Their average supporting capacity is to their strength, as one to two and a half, or equal to 768 tons. With no loads on the bridge, their tension is about five tons each, consequently they relieve the cables 768-5 = 153 tons. But their principle service is to preserve the equilibrium of the structure under heavy loads, and to assist the trusses and girders. Being under that tension, and kept in a straight line, they yield but little, under passing loads. Their action is within the tangent of the cables, near the towers, where stiffness is most wanted. Being not carried back to the anchorage, they are of no assistance to the land cables.

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 fifty tons, and we have a total weight of two hundred and fifty tons, to which the bridge will be occasionally subjected. Ordinary passing loads are within this figure. The tension produced by this weight is 250 x 1.81 = 452 tons. Add permanent tension of 1810 tons, and we get 2262 tons, to which a strength is opposed, of 12,000 tons, or over five times, without counting upon the stays at all. Now the facts show, that the motion of trains and their speed, has no perceptible effect upon the cables, and will be, at any rate, greatly overbalanced by the assistance of the stays, consequently we may rely upon the unimpaired capacity of
the cables for support, and consider transient loads as at rest. There is a possibility of much heavier loads taxing the bridge occasionally, but this may not happen once in a year. A large crowd of persons and teams on the lower floor, while a heavy train is passing above, may add considerably to the above tension but there is an abundance of strength to meet it. What I consider of most importance to the durability of the cables is, the fact that their strength is nearly six times as great as their ordinary working tension, and equally important is the fact, that their strength will never be impaired by vibration. In calculating the strength of Suspension Bridges it has been customary to allow from three to five times of ultimate strength, for the support of a maximum tension. This is a good rule, provided the maximum load bears a large proportion to the weight of the structure. But if this proportion is small, as must be the case in Railway Suspension Bridges, it is a bad rule, as it allows too little strength for the permanent and ordinary tension.

There are 624 suspenders, each capable of sustaining thirty tons, which makes their united strength equal to 18,720 tons. The ordinary weight they have to support, is only 1000 tons. A locomotive of thirty-four tons weight, including tender, spreads its weight by means of the girders and trusses, over a length of no less than 200 feet. Of course the greatest pressure is under the engine, and is there supported by no less than twenty suspenders. If by any accident, a sudden blow or jar should be produced, the strength of suspenders will be abundant to meet it, Although the tension of the different suspenders is not
by any means as uniform as that of the wires in the cables, it being impracticable to secure a perfectly uniform bearing; their strength is so abundant, that they will easily resist a hurricane, should they ever become exposed to such a trial.

**EFFECTS OF HEAVY LOADS.**

Every train that passes over the bridge causes an actual elongation of the cables and consequently produces a depression. If the train is long, covers nearly the whole length of the bridge, and is uniformly loaded, the reduction of the camber or curvature or the tract will be uniform. If the train is short and covers only a part of the floor, the depression will be less *general* and more *local*, and will be the joint result of an elongation of the cables, and of a disturbance of the equilibrium. Depressions will be in *direct* proportion to the loads, and *indirectly* as the length of the trains. After the passage of a train the equilibrium of the work is restored, and it rises again to its former level. The elasticity of the cables is fully equal to this task and will not be impaired by the constant repetition of this process. Nor will the wooden superstructure be affected by it. The worst that can result is a certain degree of looseness either by further shrinkage or working, which can easily be corrected by tightening the bolts. My observations since the 18th of March, have confirmed this opinion.

On the last mentioned day the Rail Road floor was opened for business by passing an experimental freight train, composed of 20 full loaded cars, pushed by a 26 ton engine, from the Canada to the New York depot.
The gross weight was estimated at - 326 tons.
Tension of cables resulting, - - 590 "
Aggregate section of cables, - 240 sq.in.
Therefore tension per square inch, - 4917 lbs.
"  " of single wire, - 82 "
Average length of cables and chains, 1359 feet.
Elongation of wire per square inch caused by 2240 lbs., - - - 10,000
Elongation of cables by 2240 lbs., 0.1356 feet
From these data, now we can find the elongation of the cables caused by 326 tons,

\[
2240 : 4917 = 0.1359 : x \text{ and } x = 0.2983 \text{ feet.}
\]

The depression of the bridge, caused by the elongation is found by the following formula, see appendix C:

\[
X = \sqrt{\frac{3}{4} \left( Z^2 - Y^2 \right)}
\]

where \( Z \) expresses half length of curve, or 416 ft.
\( Y \) represents half length of chord, or 410.66 "
The deflection was, - - - 57.50 "
The elongation of the whole cable, - 0.2983 "
One half; - - - - 0.1491 "
Add value of \( Z \) - - - 416.0000 "

Gives value of \( z \) to be substituted in formula, 416.1491 ft.
The above quantities substituted, make

\[
X = \sqrt{\frac{3}{4} \left( 416.1491^2 - 410.66^2 \right)}
\]

or \( X = 58.34 \text{ feet.} \)
deduct former deflection, - - 57.50 "
And we get the depression caused by the load, 0.84 feet. The actual depression ascertained by the instrument was 0.82 feet.

Calculation therefore, and fact agree almost exactly. On the removal of this train the structure rose again to its former level. Ordinary freight, or large passenger trains cause a depression of 3 to 5 inches, which is as much the result of elongation as of disturbance of equilibrium. A short, heavy freight train will produce as much or rather more depression than a very long passenger, or empty freight train of greater weight, for the single reason, that the equilibrium is more disturbed by the short train than by the long one. To construct a Suspension Bridge which shall not sink under heavy loads, or by an increase of temperature, cannot be done. These motions are legitimate results of the nature of a Suspension Bridge, and are rendered harmless by its elastic properties.

**EFFECTS OF TEMPERATURE.**

According to my own experiments, which I have made with wire of 1000 feet long, their expansion caused by an increase of temperature of one degree is 1-146000 and for 100 degrees 1-1460. The average length of cables between the chains is 1227 ft. Therefore, their expansion from 100° is 1227-1460 which is equal to 0.8404 feet. Now suppose the deflection of cables at a temperature of 0° to be 57 feet we find half the length of catenary, by using the formula in appendix C.
Now substitute for X,  
for Y, or half the chord,  
\[ z = \sqrt{\frac{2}{Y + \frac{4}{3}X}} \]

57 ft.  
410.666 "

or \[ z = \sqrt{\frac{410.666^2}{410.666 + \frac{4}{3} \times 57^2}} \]

415.9009 ft.  

Now add elongation of half the length of cables, due to 100°  
0.4202 ft.

and we get half the elongated cable = 416.3211 ft.

To find deflection due to this elongation apply the formula for X in appendix C.

\[ X = \sqrt{\frac{3}{4} \left( \frac{Z}{Y} \right)^2} \]

Substitute for Z  
416.3211

and for Y  
410.6666

Therefore \[ X = \sqrt{\frac{3}{4} \left( \frac{416.3211^2}{410.6666^2} \right)} \]

59.25 ft.

deduct deflection at 0°  
57.00

difference arising from 100°  
2.25 ft.

Therefore a change of temperature of 100° causes a difference in the level of the floor of two feet three inches, which calculation very nearly agrees with my observations.

The lower floor or river stays have enough of slack or deflection to adjust themselves under these changes. The only difference will be, that they are tighter in winter than in summer, consequently that the equilibrium of the bridge will be less affected by passing trains in cold weather, than in warm.
EFFECTS OF HIGH WINDS.

The destruction of the Wheeling bridge by a high wind on the 17th of May last year, the greatest disaster of the kind on record, has naturally given rise to doubts as to the safety of Suspension Bridges generally. One of the scientific journals remarked at the time, that the failure of this bridge would appear to be conclusive evidence against the practicability of large spans. Although I would much prefer to leave this subject alone, I cannot conscientiously do so. It is my duty to establish the safety of the Niagara Bridge, which has already, and in the brief space of one month, become one of the greatest thoroughfares on this continent. I cannot do so without drawing a comparison with other works, and without pointing out the defects which caused the destruction of the Wheeling bridge, and on the other hand explaining the means of safety, which have been employed in the Niagara Bridge.

The Wheeling bridge formed a span of 1010 ft. from center to center of towers; the floor was 960 ft. long and 26 ft. wide outside of railings, its weight including cables was about 440 tons. The number of cables was 12, containing in all 6600 wires of No. 10. With the exception of two small stays under the floor at each tower, which appeared to be put up after the completion of the work, and were in a loose and ineffective condition at the time I examined it, there was no provisions in the whole structure aside from the inherent stiffness of the floor, which could have had an effect in checking vibrations. Owing to the provisions made for resting the cables on the towers by means of large rollers, and to the wire being
arrange in a number of small cables in place of one large one, is to be attributed the fact of the ready communication of vibratory motion from the suspension cables to the land cables. The motion caused by the transit of a single team, was readily communicated to the land cables. In consequence of this sensitiveness the great force to which the suspension cables were subjected on the 17th of May, was fully transferred to their connection with the anchor chains: the result was their failure on the Wheeling side. A competent eye witness stated, that the waves of the floor, caused by the wind, rose to a height of over 20 feet. This may have been exaggeration, but no ordinary strength of cables can long resist the momentum produced by such a weight falling even 15 feet. The destruction of that bridge was clearly owing to a want of stability, and not to a want of strength. This want of stiffness could have been supplied by over floor-stays, truss railings, under-floor stays, or cable-stays. If by these means no high degree of stiffness could have been obtained, they would at any rate have proved quite sufficient to check oscillations, and to keep them within safe limits. In the Niagara Bridge most ample provisions for stability have been made. The superstructure forming a hollow box, or beam of 24 ft. wide by 20 ft. deep, with solid girders of five feet depth, and effective trusses, possesses enough of stiffness, to resist the action of any gale. To be prepared however for the greatest emergency, there are 56 wire rope stays or guys attached to the lower floor, which are firmly anchored either to the solid rock of the cliffs, or to large masses of detached rock. Each of these ropes has an ultimate strength of 30
tons, they would therefore resist with aggregate force of 1680 tons. But owing to their inclinations they would probably not oppose a greater resistance than 1000 tons, if that pressure was vertically applied against the lower floor. The ordinary tension of these stays does not exceed two to three tons. Now the weight of the bridge without the cables, and stays, is 600 tons. To this add the anchorage at each end of the lower floor, which I estimate at 300 "

Resistance of cables in center, 100 "
Resistance of stays is, 1000 "

Total, 2000 tons.

Let us now suppose a hurricane expending its power upon the whole extent of both floors, and at the rate of 50 lbs. per superficial foot uplifting force.
The surface of the upper floor is 20,000 ft.
" " lower " 18,000 ft.

Total, 38,000 ft.
Pressure at 50 lbs. 1,900,000 lbs.

or 950 tons
to which a resistance is opposed of 2000 tons. No tornado however will act with equal force upon both floors at the same time, nor uniformly throughout their whole extent. Before the two floors were connected, I noticed, that while the lower one was sensibly affected by a gale, the upper one showed no motion at all; its force appeared to be expended below. Owing to the bend of the river, the Canada shore is well protected, while the opposite side is exposed from all quarters. Not the slightest motion from high
winds was ever noticed since the two floors were connected. The work has been frequently tested by the strongest gales that blow in this vicinity. I am also convinced that it will be proof against a hurricane.

The Tornado which on the morning of the 18th last month, made such havoc at the town of Niagara, and was also severely felt at Lockport and Rochester, did not expend its full force upon the bridge. Its vortex was either too much elevated, or too far north east. Only a severe momentary shock, accompanied by great darkness, was experienced and lasted but a few seconds. This shock did not produce the slightest perceptible motion. Tornadoes are believed to be whirlwinds on a large scale, produced by the struggle of two winds moving in opposite directions in the upper regions of the air. Impelled in the directions of the strongest wind, the two contending forces move on within the sphere of a double cone, the most violent action being at the union of the two bases. This view being correct, the Niagara Bridge can never experience the full force of a hurricane. The towers may come within the sphere of its action, but not the bridge itself. I mean to say, not enough to experience a great uplifting force.

EFFECTS OF THE TROTTLING OF HORSES, OR CATTLE, OR THE MARCHING OF MEN.

This is a subject which next to the effect of high winds is most important to be considered. The Niagara Bridge is a great thoroughfare for all kinds of stock. Drovers of cattle are, according to the regulations, to be divided off in troops of 20, no more than three such bodies, or 60 in all to be allowed on [the
bridge at one time. Each troupe is to be led by one person who is to check their progress in ease— they should start off on a trot. If these rules and regulations are strictly observed, the bridge will be spared much abuse. On several occasions I have noticed the injurious effect, produced by twenty heavy cattle under a full trot. Standing on the lower floor at the time, I could perceive no apparent motion in the bridge, but felt a most intense trembling and short vibration. If the cattle happen to move all on one side, outside of the center, the effect produced, is also lateral, and consequently severe upon the framing. The great inherent stability of the structure will so far resist this action as to prevent all such motions as would be readily discovered by the eye. But I will state here, that in my opinion a heavy train, running at a speed of twenty miles an hour, does less injury to the structure than is caused by twenty heavy cattle under a full trot. Public processions, marching to the sound of music, or bodies of soldiers keeping regular step, will produce a still more injurious effect. No bridge constructed without regard to stability, will long resist such tests. The best built Suspension Bridge, as well as all kinds of wooden or iron structures, not excepting tubular bridges, will suffer from this cause. The Covington Suspension Bridge opposite Cincinnati, with a single span of five hundred feet, erected last year, and since rebuilt, fell down under twenty cattle trotting over.

The above remarks have been made with a view to correct popular notions upon this subject, and also to draw your attention towards it, so that the Superintendent of the bridge may be directed to see the rules and regulations, already laid down, strictly enforced.
In conclusion I will state that the woodwork was entrusted to the charge of Mr. D. McKenzie, as master carpenter, who last year sustained a serious injury while removing the old wooden towers on the Canada side, and has been since assisted by Mr. L. Anson. The wire work and other parts have been attended to by Mr. David Rhule. During the first two seasons I was assisted by W. O. Buchanan, Esq., and latterly by J. H. Fisher, Esq., who is also acting in the capacity of Secretary to the Joint Board. To all these gentlemen I wish to express my obligations for their cordial and efficient co-operation in the execution of the works.

In reporting to you the final and successful completion of the Bridge, I would be doing injustice to my own feelings as a man, if I did not avail myself of this opportunity, to thank you publicly for the unwavering confidence, which you have always placed in my professional ability. When Engineers of acknowledged talent and reputation freely expressed their doubts as to the success of this work, a wavering of confidence on your part would have been but natural. But I am happy to state here, that in all my operations I have always met with a cordial support. It is a great satisfaction to me, that this work has turned out equal to my promise, and also to know, that on taking leave of you, the mutual confidence that exists, will not undergo any change.

Respectfully submitting the above, I remain

Gentlemen,

Your obedient servant,

John A. Roebling.
NOTE.

The Rail Road tracks are leased to the Great Western Railway Company, and the Contract requires that the Bridge should be inspected and examined by the Government Engineer of the Provinces of Canada, the Hon. H. H. Killaly.

The following is the certificate of that officer, addressed to the respective companies:

**Department of Public Works.**

Quebec, 31st April, 1855.

Sirs:—I had the honor a short time since to receive a letter from Mr. Roebling, requesting I would name a day on which I would meet him for the purpose of inspecting, and testing the Niagara Suspension Bridge. I have also had a communication from the Managing Director of the Great Western Railway Company to the same purport.

Having had repeated opportunities during the course of its construction of judging of, and observing the careful and scientific attention given to it, in all its details—the selection of the best of materials, of their respective kinds, used in it, and the severe tests to which it has been already subjected; I do not require any further proof to satisfy me of its stability and sufficiency for the purpose for which it is designed; nor do I conceive it necessary to require the Engineer again to go through the ceremony of testing it.

The respective examinations I have made of it, from time to time, the trials it has undergone, the ingenious and talented calculations made of its strength, &c., by Mr. Roebling, to which I have had access, convince me fully, that with due care in the mainte-
nance of it, it will be found a safe and permanent work, the principles, plan and details of construction of which, reflect the highest professional honor on that gentleman.

I am Sir, your obedient servant,

HAMILTON H. KILLALY,
Assistant Com' r of Public Works, Canada.

To the Presidents of the Niagara Suspension Bridge Companies.
APPENDIX A.

TABLE OF QUANTITIES.

Length of Bridge from centre to centre of tower, .... 821 ft. 4 in.
" Floor between towers, ......................... 800 "
Number of Wire Cables, .................................. 4 "
Diameter of each " .................................. 10 inches.
Solid Wire Section of each Cable, .................... 60.40 sq. in.
Aggregate " of the four Cables, .............. 241.60 "
Aggregate Section of Anchor chains, lowest links, .276'00 "
" upper links, .372.00 "
Ultimate strength of Chains, .......................... 11904 tons.
Aggregate number of Wires in Cables, ............... 14560
Average strength of one Wire, ......................... 1648 lbs.
Ultimate strength of four cables, ..................... 12000 tons
Permanent weight supported by Cables, ............. 1000 "
Tension resulting, ...................................... 1810 "
Length of Anchor Chains, ............................ 66 ft.
" upper Cables, .................................. 1261 "
" lower " .................................. 1193 "
Deflections of upper Cables at medium temperature, 54 "
" lower " .................................. 64 "
Average deflection, ................................. 59 "
Number of Suspenders, ............................... 624
Aggregate ultimate strength of Suspenders, ....... 18720 tons.
Number of Overfloor Stays, ............................ 64
Aggregate strength " ............................... 1920 tons.
Number of River Stays, ............................... 56
Aggregate strength " ............................... 1880
Elevation of railway track above middle stage of river, 245 ft.
APPENDIX B.

To find tension of cables:
Let x represent deflection.
y " half the span.
W " weight of cables and load equally distributed.
T " tension resulting,
and the following formula will give the value of tension.

\[ T = \frac{W}{4x} \sqrt{\frac{y^2}{4x+y}} \]

Substitute for x, 59 and y, 410.66, and

\[ T = \frac{W}{4 \times 59} \sqrt{\frac{2}{4 \times 59 + 410.66}} \]

or \[ T = W \times 1.81. \]

The tension of the cables therefore will be obtained by multiplying the weight W by the factor 1.81.

APPENDIX C.

The length of span and deflection being known, to find the length of the cable, calculated as a parabola:
Let y express half the length of span.
" x " deflection.
" z " half the length of cable.

Then \[ Z = \sqrt{\frac{2}{y + \frac{4}{3}x}} \]

The following formula will give deflection when length of span and of cable are known.

\[ X = \sqrt{\frac{3}{4} \left( \frac{z^2}{y^2} \right)} \]