The Canadian Institute
from the Author

REPORT

ON THE

Clifton Suspension Bridge

AT THE

NIAGARA FALLS.

REPORT

OF

SAMUEL KEEFER

CIVIL ENGINEER,

TO THE

President and Directors of the Niagara Falls Suspension Bridge Company, and to the President and Directors of the Clifton Suspension Bridge Company.

PRINTED BY ORDER OF THE DIRECTORS.

BROCKVILLE, ONTARIO, MARCH 1st, 1869.

OFFICERS

OF

The Niagara Falls Suspension Bridge Company,

Under whom the Bridge was constructed in 1868.

Hon. **JOHN T. BUSH**, President,	CLIFTON PLACE, CANADA
DELOS DE WOLF, Esq., Treasurer,	OSWEGO, N. Y.
HOLLIS WHITE, Esq., Vice President,	NIAGARA FALLS, N. Y.
W. G. FARGO, Esq., Director,	BUFFALO, N. Y.
VIVUS W. SMITH, Esq., Secretary, Auditor and General Superintendent,	SYRACUSE, N. Y.

SAMUEL KEEFER, Chief Engineer.

Member of the "AMERICAN SOCIETY OF CIVIL ENGINEERS," and formerly Chief Engineer of the Department of Public Works of Canada, etc., etc.

Hon. **WILLIAM J. McALPINE**, Consulting Engineer.

President of the "AMERICAN SOCIETY OF CIVIL ENGINEERS," member of the "INSTITUTION OF CIVIL ENGINEERS," London, and formerly State Engineer of New York, and Engineer in Chief of the United States Dry Dock at Brooklyn, etc., etc.

Capital stock authorized under Charter from the State of New York,	$200,000 00
Capital stock authorized under Charter from the Dominion of Canada,	200,000 00
Total,	$400,000 00

REPORT.

To the President and Directors of the "NIAGARA FALLS SUSPENSION BRIDGE COMPANY," *and to the President and Directors of the* "CLIFTON SUSPENSION BRIDGE COMPANY:"

GENTLEMEN—

The bridge which I have had the honor of constructing for your joint Companies was so far completed on the 4th January last as to be opened on that day for public traffic. It has also been examined and approved for public use by the Government Inspectors appointed by the State of New York and by the Dominion of Canada. For your information I now submit the following particulars in reference to its construction:

The wonderful structure completed by Mr. Roebling in 1855—the only successful railway suspension bridge yet constructed—has for a period of fourteen years fully answered the purpose for which it was designed, *i. e.*, to form a connecting link between the Great Western Railway of Canada and the New York Central. The freight and passenger trains of both roads are continually passing over it, only limited to a walking pace, or speed of five miles an hour. Its span is 821 feet 4 inches.

Your bridge has been designed, not for heavy traffic, like the one below, but for the accommodation chiefly of the pleasure travel; for foot passengers, and for carriages employed by the visitors to the Falls, as well as for the local traffic between the five small towns, Chippewa, Drummondville and Clifton, on the Canada side, and Niagara city (so called) and Niagara Falls, on the New York side.

For this purpose it was assumed that the ordinary transitory load of passengers and vehicles passing over it at any one time would seldom exceed fifty tons, while on some occasions it might be as much as one hundred tons. My first design was for a load of 50 tons, but the bridge has been built of adequate strength in all its parts to sustain the greater load of 100 tons with safety. It has a single track of ten feet in width, affording ample room for a pedestrian to pass a carriage or sleigh at any point on the suspended roadway, and by the adoption of proper regulations for the use of it, as provided by the Canadian Act, will afford all the accommodation the public will require for many years to come.

Situated only three hundred yards below the American Fall, it is consequently exposed in winter to the spray from that Fall, drifting and freezing upon it. It was impossible to form any just conception of the extent to which it might accumulate during the winter months, or to decide positively beforehand whether it would endanger its stability or not. Indeed, the possibility of maintaining any bridge of so great span in such close proximity to the Falls, was only a matter of opinion. From this and other considerations, your Engineer was limited in expenditure, and the construction of the bridge was in some degree tentative, but he had no fears of the result. Having built the Suspension bridge over the Ottawa River, close to the Chaudiere Falls, which for a quarter of a century has stood in that exposed position without suffering the slightest injury from spray, he apprehended no danger from that cause.

From motives of economy, as well as to insure the speedy completion of the work, and an immediate return for the outlay, the bridge was built with a single track, and the towers constructed of wood. But the towers can at any time be replaced by stone or iron, and when this is done the bridge becomes a permanent structure; and by the widening of the roadway, and the addition of more ropes, all the accommodation that is needed can readily be provided. When the towers are covered with corrugated iron, as intended, and so protected against fire and the influence of the weather, they can be made to last for many years.

The bridge spans the gorge just below the cataract, commanding a view southward of both Falls, as well as of a portion of the rapids above them, of Goat Island and Table Rock. Northward the course of the river is traced for two miles down to the Railway Suspension Bridge, which, with the trains crossing it, is plainly visible from the new bridge. Here the river turns to the left and is lost to view.

The end resting on the right bank is situated in Porter's grove, at the foot of Niagara street, three hundred yards below the American Fall. The end resting on the left bank lands upon the main road running along the bank of the river, and is one hundred yards below the Clifton House, and three-quarters of a mile below the Great Horse Shoe Fall, on the Canada side.

The magnetic bearing of the bridge is S. 46 deg. E., or nearly South-east and North-west. It crosses the river at right angles to its general course at this point.

A section of the river on the line of the bridge gives a distance of 1190 feet from rock to rock, at the top of the cliff, and 850 feet at the water's surface. The rock on the left bank is 175 feet above the water, and on the right bank 180 feet. The American Fall is 164 feet. On the Canada side the rock is covered with two feet of earth. It falls off perpendicularly fifty-four feet to the debris which covers the foot, and slopes away to the water's edge. On the American side it is covered with twenty feet of drift (clay, sand and gravel,) which, when removed to make room for the towers, exposes a water-worn surface. Here the rock overhangs some ten feet, and the plumb line strikes the top of the debris at a distance of eighty feet from the surface.

Immediately beneath the bridge the river is 180 feet deep, and the current flows at the rate of four to five miles an hour. Its surface is mottled with foam from the Falls, and rippled by the eddies which indicate its depth and power.

From the surface of the rock to the top of the cliff, the ground rises eighty feet to the level of the table-land, and attains that elevation at a distance of a quarter of a mile from the river on either side, showing that before the river had excavated its channel through its rocky bed, it flowed in a valley of more than four times its present width.

GENERAL DIMENSIONS.

The span between the points of suspension, or centres of towers, is 1,268 feet and 4 inches. The deflection of the cables at centre, or greatest depression below the horizontal line, varies from 89 feet in winter to 92 feet in summer. The difference of three feet is owing to the effects produced upon them by changes of temperature, ranging through one hundred degrees of Fahrenheit.

The roadway is suspended at an elevation of 183 feet above the water on the Canada side, and 188 feet on the New York side, while the centre, according to the season, varies from 190 to 193 feet, there being a rise of four feet in the curvature of the bridge in summer, and of seven feet in winter. The tops of the towers being in the same horizontal plan, are therefore 105 feet high on the left bank, and 100 feet high on the right bank.

The length of the cables at medium temperature is 1286 feet between the centres of towers, 1828 feet between the anchor pins, where they are connected with the anchor chains, and 1888 feet in all, between the anchors embedded in the masonry on either side.

The prolongation of the cables under ground is effected by anchor chains of Lowmoor Iron thirty feet in length, in links of ten feet each, firmly built in hydraulic masonry.

THE OPERATIONS.

When I was appointed your Chief Engineer on the 17th June, 1867, the location had previously been made, and the work commenced by stripping the rock on both sides for the seats of the towers. Having fixed upon the line, and laid out upon the ground the positions for the towers and anchorages, and furnished plans and written instructions for the guidance of my assistant, by your request I proceeded to England in August, 1867, for the purpose of procuring the necessary material.

It was at first proposed to use steel ropes for the cables, and the choice between steel and charcoal iron was left to my discretion; but upon making enquiries in England, I was induced to relinquish the idea of employing steel. In a work so hastily undertaken, and proceeded with so rapidly, there was no time to institute the tests and enquiries necessary to settle the question as to the dependence to be placed upon it; and, as at the outset there was plainly no saving of cost, it was considered best to adhere to a material which up to this time had proved reliable.

Accordingly all the ropes for the bridge were made of the best charcoal iron wire. These and the tension plates for the underground anchor chains were manufactured in England to my order, and shipped for Canada before the close of the year, and I returned home in November.

During my absence the towers were framed and erected, and some progress was made with the anchorages. By your orders the works were suspended early in October, and were not generally resumed until the following month of May, 1868. Advantage, however, was taken of an ice-bridge formed in the month of February, for the taking across the two carrier ropes subsequently used for the erection of the bridge. This feat was accomplished with economy and dispatch, under the personal superintendence of your President.

The winter months were occupied by your Engineer at Brockville, in maturing his plans and making his calculations for the next season's operations.

It was first intended to use the Erie and Ontario Railway for uncoiling the cable ropes, but when it could not be leased, the ropes were spun out from a turn-table, upon a temporary platform, laid down for that purpose, where they were examined, cleaned, painted, strained and marked; and then run down the hill until the leading end, with the yoke attached to it, reached the anchorage.

The ropes had been so well saturated in linseed oil, that it filled up all the pores between the wires, but where exposed on the outside, the oil, in places, was rubbed off, and oxidation had commenced. When cleaned they received a good coating of paint, consisting of the red oxide of iron mixed with boiled linseed oil, and a second coat was added after they were suspended between the towers.

A base line of 1800 feet was accurately measured off upon the platform by means of a pine rod fifty feet in length, the same that had been used for measuring the base from which the span of the bridge had been determined.

In order that the levels for the bridge might be arranged with some degree of accuracy, it was necessary to know beforehand how much the rope would stretch when loaded with the bridge. There being no facts to establish the law of elongation in solid wire ropes of this description under different degrees of strains, it was determined by direct experiment.

For this purpose the weight of the rope itself, by its deflection between two supports 300 feet apart and moving freely on rollers, was used as a measure of the power applied to stretch it on the platform—the deflection being a function of that power. The rope when strained by its own weight between the two towers is subject, by calculation, to a strain of ten tons net. The elongation under ten and fifteen tons was noted. In this way it was satisfactorily ascertained that a power of ten tons produced an elongation of eight inches in 1800 feet of the rope. This result agrees very nearly with Mr. Roebling's experiments on single wires, according to which he found, that, "iron wire stretches 1÷10,000 part of its length for every gross ton of 2240 pounds per square inch of section."

Every rope was stretched upon the platform with a power of ten tons, and under that strain was marked at both ends and in the middle of the 1800 feet. When released from strain the recoil was measured. At the same time the state of the thermometer, then ranging from 95 to 115 deg. in the sun, (it being the hot month of July,) was observed and recorded. Then these elements: The initial elongation of 8 inches in 1,800 feet under ten tons strain—the marks under that strain, and the observed temperature reduced to a common standard of 110 deg., furnished the basis of a calculation by which the absolute length of each rope, under any degree of temperature and tensile strain could be definitely ascertained.

Having been marked under the same strain of ten tons, to which, by calculation, they are subject when hanging freely between the towers, and that force having stretched them 8 inches, then an additional strain of twenty tons would stretch them sixteen inches, and the ropes were accordingly cut so much shorter than the mark. The importance of this correction will be better understood when it is known that as the bridge is constructed the lines of curvature are always above the straight line, and are pleasing to the eye, whereas, if the ropes had not been so shortened, they would at certain seasons fall below it, presenting a reverse curve, at once offensive to the eye and injurious to the structure.

The carrier ropes having been raised into position on the tops of its towers, and set in large sheaves that prevented any lateral stress upon them, and other sheaves, in pairs, placed also on the towers, close alongside the saddles, the cable ropes were all successfully taken over in these, and on the carrier ropes, and were then cut, yoked, anchored and regulated to the same degree of deflection. After a second coat of paint, they were temporarily clamped in cable form.

While engaged in these operations, the Chinese Embassy visited the Niagara Falls, and by request of your Vice-President I had the pleasure of taking over the Ambassador and his English Secretary in one of the "buggies" used in the construction. This buggy, as you are aware, runs upon a single wheel upon one of the carrier ropes. I accompanied them from the East to the West tower, and back again, delighting his Celestial Highness with the sublimity of the view and the novelty of the adventure.

The carrier ropes, with the "buggies" and "cradles" running upon them, afforded the means of readily attaching the cable bands and suspenders, and as soon as this was effected, the hanging of the roadway was proceeded with as rapidly as possible. As the season advanced, the work was a good deal delayed by winds and rain, and the premature setting in of winter. Still, notwithstanding these hindrances, we succeeded in joining the framework of the floor at the middle of the bridge by the 15th October, and from that time forward, convenient and uninterrupted communication was established and maintained for the workmen between the opposite banks of the river. It was opened for traffic on the 4th January last. Deducting the time during which the works were suspended, we find that this, the longest-spanned bridge yet erected, has been constructed in twelve months of working time, which must be acknowledged a very short time for the accomplishment of a work involving every principle and demanding all the care and consideration of one of ten times the cost, especially under the difficulty of obtaining skilled labor, and of procuring materials from a distance.

Your board having wisely determined not to let the work by contract, the responsibility of selecting materials and directing the operations rested entirely with your Engineer. He considers himself fortunate in having secured the services of Mr. E. F. Farrington, as superintendent of construction during the most critical and important part, since the month of June, 1868, and by whom, with the assistance of an intelligent and faithful body of mechanics and workmen, his plans have been carried out to his entire satisfaction; and it affords him sincere gratification to be able to state that this difficult and hazardous achievement has been accomplished without failure or accident of any kind.

The cost of the bridge when completed, including purchase of land and preliminary expenses, will be about $150,000, U. S. currency.

Upon submitting my plans for your approval in April last, the Directors very naturally, and, as I thought, very properly proposed to have the opinion of the highest professional authority in America on such a bold undertaking. To this your Engineer cordially assented, and by mutual consent my plans and calculations were submitted to the Hon. William J. McAlpine, late chief Engineer of the United States dry dock in Brooklyn, State Engineer of New York, President of the American Society of Civil Engineers, &c., &c. By this reference your Board was at once assured, and your Engineer gratified, by the entire approval of the design by an Engineer of his acknowledged standing, sound judgment, and varied experience. At his subsequent visits the works themselves met his approval, and as evidence of his opinion his final report since the opening of the bridge is appended to this.

The inspection required by the charter from the State of New York was made by Judge Gardiner on the 16th January. That required by the Canadian charter was made by the Hon. Hamilton H. Killaly, C. E., M. A., late President of the Board of Public Works, Canada, on the 25th January. Copies of their respective reports are also appended.

It was a matter of great importance that the calculations for the strength of the bridge should be determined with perfect accuracy in accordance with clearly established scientific principles. Special attention was devoted to this branch of the subject, and it was very gratifying to me to have my calculations verified by an accomplished mathematician, the Rev. Edmund John Senkler, M. A. Cambridge, of Brockville, Ontario, who from his pure love of analytical investigations, requested the favor, and took upon himself the trouble of testing the results by independent methods

The following particulars in reference to the strength of the bridge are added for the information of the directors:

I.—THE LOAD.

The weight of the suspended portion of the bridge between the towers, including the cables, the roadway, the stays, stay braces, bridle stays, suspenders and guys is 263 tons of 2000. This constitutes the permanent load. The ordinary moving load, as before stated, is fifty tons, and the extraordinary load 100 tons. This is equal to the weight of 1300 people, or one man to every square yard of the platform; or it is equal to a load of thirty carriages and three hundred people. This is assumed as the transitory load. The permanent and transitory loads will not exceed 363 tons. This load is supported by the united strength of the cables and stays.

II.—THE CABLES.

There are two cables, one on each side of the bridge, descending to the level of the roadway at the middle, where they are twelve feet apart between the centres, while at the towers they are 42 feet apart—the sway on each side being fifteen feet from the perpendicular. Their vertical deflection at medium temperature is 91 feet, but in the plane of the swayed cable it is 92.22 feet. The horizontal projection of the cables or birds-eye view from above, represents the landward portions as tangential to the curve between the towers which is formed by swaying them in at the centre. The angle of depression from the points of suspension varies so little on either side of the towers, that the resultant of all the forces in both horizontal and vertical planes, produces only a direct vertical pressure upon the towers. The suspended system has in fact been so arranged as to exert no lateral strain upon them, except that which is unavoidable from the force of the wind, and this, it will be seen, is modified to a considerable extent by the manner in which the cables are inclined together at the centre, but more effectually met and neutralized by the use of stays and guys. Where the cables pass over the towers there is necessarily a movement of three inches arising from atmospheric changes; but the cables rest in cast-iron saddles which move freely upon rollers interposed between them and the cast-iron cap which crowns the summit of the tower, and in this way the irresistible force of contraction is eluded.

Each cable is composed of seven ropes, each rope of seven strands, and each strand of nineteen wires 0.155 inch in diameter, this size being between No. 8 and No. 9 of the Birmingham wire gauge. By a new process all the wires were drawn of sufficient length (1910 feet,) to make one rope without splice or weld from end to end. There are 133 wires in each rope, and 931 wires in each cable. The ropes are 2⅓ inches in diameter, 7¼ inches in circumference, and weight 54 pounds to the fathom. The calculated breaking strain of one of these ropes is 121 tons net. The guaranteed breaking strain was 100 gross tons = 112 net tons, and they bore the test of 108 tons net without fracture—the fastenings having given way under that strain.

When a solid rope of this kind is submitted to a dead pull, the central strand being straight, while the others are spirally arranged around it, it is the first to feel it, and would, were they all alike, be the first to break. To obviate this unequal stress upon the strands, it is usual to put a hempen core in ropes used for naval purposes. In our case a solid rope is wanted, and the central strand is made of softer wire than the other strands. The soft wire having greater ductility will stretch until the surrounding strands are brought to full tension, and they will then all pull evenly together.

If any one thinks it an easy matter to lay hold of a rope of 121 tons strength and fairly break it, just let him try it. He will find that all the fastenings heretofore used are either too complicated or too weak. The rope will render round the eye, or break in the splice or socket before the full power is reached. A piece of rope of this description was submitted for trial at the Liverpool testing machine at Birkenhead. The maker of it secured one end after his own plan, your Engineer the other. The former doubled one end round a cast-iron eye 14½ inches in diameter, and fastened it by means of four heavy screw clamps to the main rope. The clamps were made of 6 × 1½ inch iron, leaving six inches of space between them. This fastening had a very imposing look. Your Engineer had the other end fastened in a wrought-iron conical socket six inches long, 2½ inches in diameter at one end, and 3½ inches at the other. The end of the rope was drawn through this socket and protruded 1½ inches above its rim. The wires were separated and steel points driven between them, completely filling up the socket. Finally, the ends of the wires were bent and hammered down over them; this enlarging or crowning of the rope being intended to keep it from pulling out of the bell-shaped socket.

At the *first* trial, the clamps, under a strain of 36 tons, began to move towards the eye. At 50 tons they began to touch each other; at 57½ tons they were in two pairs, with 6 inches of space between them, and the eye had turned round 45 degrees. The trial could go no further. The other end stood firm, and the rope was uninjured.

At the *second* trial both ends were fastened in the same manner in sockets, but one of them pulled out under a strain of 88½ tons, owing to insufficient fastening.

At the *third* trial the rope bore a strain of 96½ tons gross, = 108 tons net, without breaking, but the end pulled through the socket, and the recoil injured it so much that the trial could not be repeated. This test gave 96½ per cent. of the guaranteed strength.

It was desirable, if possible, to find a mode of fastening that would give 100 per cent. of the strength of the rope. Having witnessed several experiments on spliced ropes of a smaller size, I found they always broke in the splice before their full power was reached. None of the methods heretofore used gave assurance of holding. On my return to Canada the following experiment was made: One end of a rope was fastened in the usual manner in a wrought-iron socket, the other end in a cast-iron yoke, and at every trial the end fastened in the socket was the first to give way. The result was decidedly in favor of the yoke. The yoke is simply an elongated eccentric, the least diameter of which is about twice the circumference of the rope, and the length about three times the diameter. There are two holes at the upper enlarged end, one of which is cylindrical, and of the same size as the rope; the other conical, into which the end is fastened as in the socket. The rope is passed through the cylindrical hole, then round the eccentric in a hollow groove, and then fastened in the usual manner in the conical socket.

The point of attachment being eccentric, near to one side of the yoke, it falls directly in line with the rope as soon as it is submitted to strain. The eye of this yoke is slotted to allow of a movement of six inches for adjusting the ropes when suspended. It is obvious, from mechanical considerations, that if the fastening in the socket end of the yoke is only 25 per cent. of the breaking strength of the rope, the rope must be fairly broken before the fastening will give way. But since fully 96½ per cent. can be counted on, as decided by the Birkenhead test, it is quite impossible for the fastening to yield before the rope breaks. Therefore, by adopting this plan, the full strength of the rope can be relied upon. For suspension bridges, more especially, the importance of this device can scarcely be overrated. The ropes were adjusted at the centre with the greatest facility by means of the slot, and with perfect confidence in the unyielding nature of the fastenings at either end.

At the anchorage the ropes are connected with the underground anchor chains by means of adjusting links of 4, 8½ and 13 feet in length of an uniform section of 6 × 1 inches. Three of the yokes are in the direct line of tension, two are thrown down, and two up, in order that all the ropes may be gathered into cable form and clamped as nearly as possible to the point of attachment. The solid sectional area of the cables is 37.8 square inches; that of the anchor chains 84 square inches. The aggregate force, or ultimate strength of both cables, 121 × 14 = 1,694 tons net; that of the Lowmoor anchor chains 84 × 32, = 2,688 tons net.

The ropes of which the cables were made were manufactured by R. S. Newall & Co., of Gateshead-on-Tyne, from wires drawn by Messrs. Richard Johnson & Nephew, of Manchester. Wires of 1,910 feet in length were made whole, without weld joint, or splice. The rods were rolled from the billets by one operation in less than a minute. Billets weighing 140 lbs., 15 feet long and 1¾ inches square, were heated to a white heat in a gas furnace, and passed through a series of rollers set close to the furnace, until they were gradually reduced to rods of No. 3, B. W. G. One end of the billet was in the furnace, while the other end was being wound upon the reel. The rods were then drawn through three holes down to the required size of 0.155 inch diameter.

As they were required to bear a tensile strain before breaking of 100,000 lbs. to the square inch, tests were made from time to time as they were run off, and a daily register was kept of the results, of which the manufacturers have furnished me a copy. By this register it appears that a few of the wires fell short of the specified strength, but that nearly all of them exceeded it. Some of these, it appears,' were drawn to so high a degree of tension as 120,000 lbs., as determined by direct weights and lever power, while by the hydraulic test the strength was much greater.

The ropes are beautiful specimens of the art of rope-making. For their size they possess a wonderful flexibility, and there can be no doubt of their having been fabricated of the best quality of material.

III.—THE STAYS.

While they serve to stiffen the roadway and prevent oscillations and undulations, the stays are a real support to the bridge. They form as it were, two rigid and powerful brackets extending out from either shore half-way to the centre, and cary one half the weight, and one-half the load; while they relieve the cables of half their duty, the two systems are nevertheless so arranged as to work in harmony—the primary object of the construction being, so to combine the two independent systems as to make them act in concert the moment a load comes upon the bridge.

There are twelve stays on each quarter, forty-eight in all. They are carried back to the anchorage, and secured there to the same anchors and in the same manner as the cables, save as regards the method of adjustment, which, for the stays, is effected at the other end by means of a nut and screw.

The longest stay is tangential to the curve of the cable at the point of suspension; the rest fall within this angle, and are attached to the platform at intervals of twenty-five feet. They are of various sizes, according to position and the stress they have to bear. The three outermost stays are made of 4¼ inch rope of 45 tons ultimate strength—the next six of 3¼ inch rope of 25 tons strength—and the last three of 3 inch rope of 18 tons strength.

The whole of the twelve ropes on each quarter are united with seven landward ropes, that are bound up into one cable of four inches in diameter, and reach from the anchorage to the towers, over which they are carried by saddles and rollers independently of the cables. The *three* largest ropes pass over the towers unbroken from the anchorage to the roadway—the next six are coupled, or yoked to three of the largest ropes on the river side of the towers, and the last *three* are joined to *one* of the largest ropes on the same side. The cast-iron yoke is used at both ends of the stays.

The aggregate strength of the whole assemblage of stays, 48 in number, is 1344 tons net. By the resolution of forces this affords 628½ tons of vertical lifting power.

Riverward, the stays pass in straight lines, directly from the saddle to the roadway, passing down the inclined plane formed by the suspenders, and to which they are seized at the crossings. Landward, they are stayed to the cables; and since contraction and expansion, under the various changes of temperature, must affect them equally, they must always preserve their same relative position, and consequently must always bear the same share of the load.

The mechanical advantage of employing stays in this manner is obvious, and the economy of the arrangement is conspicuous. One hundred and twenty tons of wire rope were employed in the fabrication of the cables, and only twenty-five tons in making the stays. Both carrying an equal load, and both strained to the same degree, it appears that one ton of stays is equal in effect to nearly five tons of cable!

Four stay-braces of three inch rope are placed horizontally between the cables, binding them together above the roadway to keep them from swaying about; and four bridle stays are attached to the cables reaching from the rock at the base of the towers to a distance of 110 feet out upon the cables, and serving to check vibration caused by the wind or by a moving load.

IV.—THE SUSPENDERS.

The suspenders are made of wire rope ⅝ inch diameter—two inches in circumference, and ten tons ultimate strength. Being placed five feet apart, there are 480 suspenders of 4800 tons ultimate strength, which is more than thirteen times the load they have to sustain. The ends are crowned in wrought-iron sockets, connecting above to the cable bands, and below to the tension bolts that pass through the floor beams and hold up the bridge. Towards the middle of the bridge, where the suspenders are short, all of less than twelve feet in length are made of solid rods of Lowmoor iron ¾ inch in diameter. All the tension bolts are terminated by a screw six inches long, to admit of adjustment.

V.—THE GUYS.

The overflow stays, by virtue of their inclined position, have a very good effect in preventing lateral movement in the suspended roadway, but the underfloor guys offer a more direct resistance to it. They check both the vertical and transverse motion. As far as both stays and guys reach, *i.e.*, half-way to the centre, there is little or no vibration. Beyond this the guys alone extend two-thirds of the way to the centre, and owing to their great length there must necessarily be some movement, but it is limited to the expansion of the material from changes of temperature, and to the sagging of the rope under different degrees of strain. Within these limits the wind can sway the platform, but it can do no harm.

The number of guys attached is fifty-four. Of these twenty-eight are on the upstream and twenty-six on the downstream side, the wind being stronger down than up the river. Some go out horizontally to the top of the cliff, some go down vertically, but the greater number occupy an inclined position, reaching down to large boulders embedded in the slope of the bank. In Spring it is intended to add a few more guys, stretching all the way to the centre, with compensating adjustment for changes of temperature.

These guys are made of the same size rope as that used for the suspenders. Atogether, they contain a reserve power of 540 tons, and offer a resistance of 260 tons to the wind, whichever way it blows; and yet, to all appearance they are mere gossamer threads, scarcely visible to the naked eye.

The ropes used for the stays, suspenders and guys, were manufactured by the Queen's Ferry Wire Rope Company, from wires drawn by Rylands Brothers, of Warrington. They were drawn from charcoal iron of the same quality as that used for the cables, and both at Birkenhead and Niagara Falls bore tests that were perfectly satisfactory. They are all of superior quality.

VI.—THE TOWERS.

On each side of the river are twin towers, constructed of white pine of superior quality. Each tower presents the outline of a tuncated pyramid, 28 feet square at the base, and 4 feet square at the top. They are placed 13 feet apart at base, and the roadway passes between them. They are 105 feet high on the Canada side and 100 feet on the New York side. They are built up of four timbers 12 × 12 inches in each corner of the pyramid, leaving a space of one inch between them for ventilation, through which the connecting bolts pass. Horizontal girths 9 × 12 inches bind them together at every ten feet in height, and above the roadway these girths extend all across, binding the two pyramids together into one tower. A series of heavy diagonal traces on all four sides, combined with the girths, and bottled together, serve to keep the posts fairly in line, and prevent any lateral bending or vibration. The lower ends of these timbers are stepped into cast-iron shoes, having cells for the reception of each post. The shoes are set in the solid sock in beds cut out fairly to receive them at right angles to the direction of the posts. The 16 timbers of the 4 posts all come together at the top, where they are crowned by a heavy cast-iron cap having 16 cells on the under side to receive them individually, and deep flanges on the upper side, forming channels for the reception of the saddles and rollers which carry the cables and stays. The timbers break joints with each other, and are firmly bottled together. Wrought-iron plates, 1-12th of an inch thick, with central dowels, are inserted in every butt joint. The posts are so firmly built and braced as to warrant their being considered in detail, as short square pillars or struts, having a breadth of base equal to one-fifth their height, and therefore not liable to bending under a heavy load. The mode of framing, too, cuts so lightly into the wood, that every single piece of timber of 12 × 12 inches may be taken as having an effective sectional area of 12 × 11, = 132 square inches.

The crushing force of white pine being about 5,000 lbs to the square inch, or 2½ tons net, the weight required to crush down one of the towers will be 132 × 32 × 2½, = 10,560 tons, or forty times the weight of the permanent load it has to carry.

The effective strength of pine is estimated at one-tenth of its crushing force, and hence the towers should be able to bear a load of $\frac{10,560}{10}$, = 1,056 tons. This is four times as much as the permanent load, and three times as much as both the permanent and transitory load taken together.

Should occasion require it, it will therefore be perfectly safe to take out any one of the four timbers of the eight corner posts and replace it by another, and the mode of framing adopted admitting of it, the change can at any time be made without much difficulty.

VII.—THE ROADWAY

At the centre, the curve of the roadway rises four feet above its chord in Summer and seven feet in Winter, there being a rise and fall of three feet due to the changes of temperature alone. The chord line is not in a horizontal plane. The end resting on the right bank is five feet the highest, but in so great a span the difference is imperceptible.

The two ends of the roadway are fixed to the rock on either side, but the middle must necessarily rise and fall the three feet just stated. The framing is therefore adapted to this variation. It is sufficiently rigid to resist the influence of a moving load and distribute it over 100 feet of the platform, but is not too rigid to yield fairly to the necessary changes in the position of its centre.

The platform is wonderfully stiffened by a light, yet strong reticulated truss on either side, 6½ feet deep, going down two feet below the road, and rising 4½ feet above it, forming at the same time a strong parapet for the protection of foot passengers.

The floor beams are of pine, 13½ feet long, and 2½ × 10 inches in the middle, bolted together in pairs, and suspended five feet apart between centres, the tension bolts passing down between them. They are notched upon the lower chord of the truss, which passes under them and are fastened to it by screw-bolts. The floor is made of two courses of Norway pine, 1½ inch thick. Between it and the floor beams there is a series of horizontal braces, acting with the floor to keep the bridge in line.

The upper chord is 6 × 7½ inches, made of two pieces of pine 3 × 6 inches, covered with an oak cap 7 × 1½ inches, breaking joints, and bolted together. Tension braces from the floor beams to this chord serve to keep the truss in a vertical position.

The lower chord is also made of pine 6 × 8 inches, in two pieces of 3 × 8 inches, and under them a wrought-iron channel bar 6 × ¼ inch, with flanges turned downwards two inches deep, and weighing 30 lbs to the lineal yard. These channel bars extend all across from shore to shore. The joints are fished with covering plates 15 × 5 × ⅜ inches, and eight screw bolts to each joint, the holes being slotted to allow for the contraction and expansion of the metal. This connection of wrought-iron under the truss gives it great additional stiffness, as well as tensile strength, and prevents the stays pulling the chord asunder.

To counteract the horizontal thrust of the stays, the lower chord is gradually enlarged from the point where the longest stay is attached, toward both towers. From 6 × 8 inches at the middle, it is increased to 8 × 8 inches at this point, and one inch is added to its width at every 60 feet until the lower chord is enlarged to 12 × 8 inches at the landings. Abutting blocks and transverse beams of oak are bolted to this part of the chord for the attachment of the stays and guys, and form, so to speak, a kind of stirrup in which the roadway rests.

Between the top and bottom chords of the truss is a series of diagonal braces and vertical tension bolts, binding these two members firmly together, through the oak cap and channel bar at top and bottom.

The cross braces are 6 × 2½ inches, with rounded ends where they abut against the oak prisms which are hollowed out for their reception, and by which the truss accommodates itself to the rise and fall of the roadway without racking the framework.

At the middle of the bridge, the weight of the cables, which here descend to the level of the roadway, is brought to bear directly upon it, and acts as an insistent weight to prevent it being lifted by the wind. At the point of osculation of the two reverse curves formed by the cables and the roadway, the floor beams are screw-bolted close up to the cables, and at every fifty feet of the 200 feet each side of the centre, a stud or pillar made of a two inch gas pipe, enclosing the suspender, is placed between the cable and the roadway. These studs serve to spread the inertia of the cables over 400 feet of the central portion of the bridge, combining it with the rigidity of the side truss to give stiffness to the roadway.

VIII.—THE ANCHORAGES.

The anchors are of cast-iron 3½ × 5 feet, weighing upwards of a ton each; pierced for the reception of the anchor bars, and having deep flanges on the back against which they are secured by steel pins. They are placed seventeen feet below the surface of the ground. On the Canada side they are embedded in the solid limestone rock which is horizontally stratified, and reaches to within one foot of the surface of the ground. A channel was cut through this rock just large enough to receive the anchor chains, and at the extremity, or lower end of this channel, a chamber was excavated for the anchors, and the jambs or shoulders against which they are fitted, were accurately cut out of the native rock, in a plane at right angles with the direction of the anchor chains. The sides and lower edges of the anchors have thus a firm and even bearing against a stratum of rock six feet in thickness, and the top bears against a large key-stone placed over the chains which, as it were, locks and bars the chamber door. The whole is built in with hydraulic masonry, and carefully grouted, so as perfectly to fill all cavities.

On the New York side the anchors are similarly set in a mass of solid masonry, the course of the chains being lined throughout with heavy cut ashlar so as to form a solid floor and cover for the chains, and by means of bond stones and the adhesion of the cement, to bind the whole mass together as one solid stone.

The body of masonry in both anchorages below the ground line on the New York side contains 530 cubic yards of masonry, and when completed by the two pedestals to be built above ground, each of which will be 30 feet long, seven feet wide, and seven feet high, enclosing the ends of the cable; the anchorages on this side will contain 630 cubic yards of masonry, and the weight of it will be 1415 tons net. But before the inertia of this mass can be overcome, an equal bulk of sand and gravel surrounding it would have to be moved, and the total resistance opposed to the direct strain of the cables and stays will not be less than 2400 tons.

On the Canada side, the anchors have a firm hold of the solid rock, and the resistance is incalculably greater.

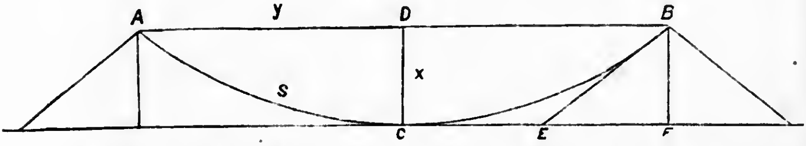
The weight of the bridge, and its greatest load, 363 tons, will produce a maximum strain of 705 tons upon the cables and stays, but one-tenth of this strain is thrown down vertically on the bearing stones where the cables enter the ground, by virtue of the change of direction of that point. Hence the greatest pull upon the anchors cannot exceed 634½ tons, and as this strain scarcely exceeds one-fourth of the dead weight opposed to it, it is apparent that the anchorages cannot be disturbed or in any way affected by the greatest tension of the cables and stays.

THE STRENGTH OF THE BRIDGE.

The cables, as they hung freely between the towers, before they were loaded with the roadway, formed a pure catenarian curve, the properties of which are well known to the mathematician; but when the roadway was added, which in any suspension bridge is much, or many times greater than the weight of the cables themselves, their primitive character was changed, and under the influence of an equally distributed load they assumed the form of a parabolic curve.

The difference between these two curves, in deducing the strength of the bridge, is inconsiderable, but in calculating the lengths of the suspenders, and fixing the curve of the roadway, it cannot be disregarded. The parabola gives the readiest means of finding them, and the lines it furnishes approximate more nearly to the curve of equilibrium. A foreshortened view of the bridge, as seen from either bank, brings out the harmony of these lines in a very agreeable manner.

THE CABLES.



To find the length of the arc $A\ C\ B$ considered as a parabolic curve:

Let $S = A\ C =$ half the arc.
$y = A\ D =$ half the span.
$x = D\ C =$ the depression of cables at centre.

$$\text{Then accurately, } S = \frac{y\sqrt{4m^2 + y^2}}{4m} + m.\ \log_e.\ \frac{y + \sqrt{4m^2 + y^2}}{2m}$$

The symbol $\log_e.$ standing for the hyperbolic logarithm.

By the equation to the parabola:

$$y_2 = 4\ m\ x,$$

$$\text{and } \frac{y^2}{x} = 4\ m \text{ — the parameter.}$$

The vertical deflection of the cables at medium temperature is 91 feet, consequently the swayed cables have an inclined deflection of 92.22 feet, and the length of the arc must be measured by this.

Substituting the values of x and y in the foregoing equation:

$$\text{i. e.—}x = 92.22$$
$$y = 634.17$$

we find that half the arc $S = 643.$ and $2\,S$, the whole arc

$A\,C\,B = 1286$ feet exactly - - - - (1.)

Similarly, if the deflection be taken at 90 feet vertical, the swayed deflection becomes 91.24 feet and the length of arc

$A\,C\,B = 1285.62$ feet exactly.

For a deflection of 92.22 feet the arc measures exactly		1286.00 ft.
For a deflection of 91.24 " it is		1285.62 "
Differences	0.98	0.38

Hence the increment of 0·38 in the arc, gives an increment of 0.98 to the deflection, and their ultimate ratio is as 38:98 (2)

The greatest tension upon the cables is at the points of suspension A and B.

Let y = half the span = 634.17 feet,
x = the vertical deflection = 91 feet,
P = total weight of the bridge, and its load equally distributed,
T = greatest tension upon the cables, resulting from the load P,

Then the curve of the cables being considered as a parabola

$$T = \frac{P}{4x} \sqrt{y^2 + 4x^2}$$

And by substitution

$$T = \frac{P}{4 \times 91} \sqrt{634.17^2 + 4 \times 91^2}$$

$$= 1.81\,P \qquad (3.)$$

That is, the factor 1.81, multiplied into the load P, equally distributed, gives the strain upon the cables at the point A. In other words, every ton laid upon the platform produces a strain of 1.81 tons in the line of the cables.

THE STRENGTH OF THE STAYS.

If E be the angle of inclination of the stays, *i.e.*, the angle $B\,E\,F$ at which they intersect the horizontal plane, then their effect in sustaining a given load varies as *Sin.* E—the smaller the angle the less their effect in giving vertical support. But to compensate for this difference, the strength of the stays increases in the inverse ratio. Three sizes of ropes are used, the longest being nearly three times the strength of the smallest. The angles vary from 16 to 67½ degrees.

As they are applied every one of the 48 stays is found by the resolution of forces to possess a lifting power varying from nine to fourteen tons, or from two to three tons effective strength.

The aggregate strain on all the stays is exhibited in the representative triangle of forces *B E F* (see the figure) deduced from the plans. The sum of all the breaking strains being represented by the line *B E* = 1,344 net tons, the sum of the horizontal thrusts against the abutments will be represented by the line *E F* =1,148.67 tons, and the aggregate lifting power of all the ropes will be represented by the line *B F* = 628.54 tons.

The same proportions hold good for all other strains less than the breaking strain. If *B F* = 1, then *B E* = 2.14, and *E F* =1.83. Let *B E* represent the entire weight (*P*) to be supported; then the strain upon *B E* will be 2.14 *P*, or

The average strain upon the stays = 2.14 *P* - - (4)

The bridge is supported by cables and stays. Taking these separately, the cables have to support,

1. Their own weight. By (1) $\frac{1286 \times 54 \times 14}{2000 \times 6}$ = 81 tons net
2. The weight of 634 feet of the central portion ot the bridge, including all the suspenders, the cable bands, tension bolts and washers, over the whole length - - - - - 79.60 "
3. The weight of the underfloor guys attached to the central part of the bridge, including a quarter of a ton strain on each guy to keep it taught 5.00 "
4. The weight of the bridle and horizontal stays between the cables, including a quarter of a ton strain on former - - - - - 2.00 "

Total weight resting on the cable, net tons =167.60 tons

The strain upon the cable produced by this weight is,

By (3) $167.60 \times 1.81 = 303.35$ tons - - (5)

The stays have to support,

1. Their own weight and attachments - - 18.00 "

2. The weight of the two landward quarters of the platform equal to one-half the roadway, minus the parts resting on the rock—say 556 feet in all 65.00 "
3. The weight of the guys attached to this portion, and a quarter of the strain on each of the inclined guys - - - - - - 12.40 "

Total weight resting on the stays - - 95.40 "

The strain produced by this load is,
By (4) $95.4 \times 2.14 = 204.15$ tons - - - (6)

The calculated strength of the cables has been thus determined.

The manufacturer's rule for ascertaining the strength of the best quality of wire rope heretofore made is as follows:

If W = weight per fathom of the rope in pounds,
B = its breaking weight in gross tons,
Then, making all due allowance for the lay,

$$B = 2\,w.$$

This rope weighs 54 lbs per fathom, and its breaking weight $B = 2 \times 54 = 108$ gross tons, $= 120.96$ net tons.

There is good reason, however, to know, from the superior quality of the material used in their fabrication, that the strength of these ropes is even greater than this. The wire was drawn to a specified tension of 100,000 lbs on the square inch, and the registry of tests proves that on the whole they greatly exceeded that limit. While the ropes were being made at Gateshead, I witnessed the breaking of one of the wires by direct weights and lever power. The guage was .154 inch. The weight per fathom .376 lbs, per yard .188 lb. It broke with a weight of 1,920 lbs. Since a bar of wrought-iron, one yard long and one inch square, weighs ten pounds, we have $\frac{10,000}{188} = 53.2$ wires of this size to the square inch, and the strength of the wire is

$$53.2 \times 1,920 = 102,144 \text{ lbs per square inch.}$$

The strength of the rope by this single test is therefore

$133 \times 1,920 = 255,360$ lbs = 127.660 tons.
Deducting 5 per cent. for rope making = 6.384 "
B = 121.295 "

It is fairly within bounds to assume that the breaking strain is 121 tons, and consequently the strength of the two cables is

$$121 \times 14 = 1,694 \text{ tons net.}$$

By the same rule the strength of the stays, at the lowest estimation, is as follows:

12 stays,	4¼ inch circ.,	20 lbs per fath.,	40 tons *B.S.*	= 480 gross tons
24 "	3¼ "	11 "	22 "	= 528 "
12 "	3 "	8 "	16 "	= 192 "
48 stays have an aggregate breaking strength of				1,200 "
			Equal to	1,344 net tons.

By (5) the permanent load exerts a strain on the cables of $\frac{1}{5.58}$ parts, between one-fifth and one-sixth their breaking strain.

By (6) the permanent load on the stays exerts a strain of $\frac{1}{6.58}$ parts, between one-sixth and one-seventh of their breaking strain.

And taken

Collectively,	on Cables,	on Stays,	
The permanent loads are	167.60 tons	× 95.40 tons,	= 263 tons
The resulting strains are	303.35 "	× 204.15 "	= 507½ "
The breaking strains are	1,694. "	× 1344. "	= 3038 "

Hence, the entire weight of the bridge, 263 tons, produces a strain in the line of the ropes forming cables and stays of 507½ tons, which is as nearly as possible *one-sixth* their breaking strength of 3038 tons—equal to 20 tons on each rope of 121 tons strength. This leaves a safe margin for the effects of the wind, the moving loads, and sudden accumulations of ice and snow.

The bridge having been designed for light traffic, and intended to be used under special regulations in regard to the loads to be admitted on it, as provided in the Act of incorporation, it may be considered safe if the permanent load does not exceed *one-fifth*, and the permanent and transitory loads taken together do not exceed *one-fourth* the breaking weight.

Let P = the weight of the bridge = the permanent load.
L = the greatest load admissable upon it.
T = the factor of tension in cables and stays produced by the permanent and transitory loads P and L.
B = breaking weights of cables and stays.

Then allowing a strain of 25 per cent of the breaking strains, the greatest load:

$$L = \frac{B}{4\,T} - P$$

By substitution for cables:

$$L = \frac{1694}{4 \times 1.81} - 167.60 = \text{ - - - - - - } 66.37 \text{ tons.}$$

and by substitution for stays:

$$L = \frac{1344}{4 \times 2.14} - 95.40 = \text{ - - - - - - } 61.37 \text{ tons.}$$

max. load on bridge - - 127.74 net tons.

While therefore a load of 127.74 tons equally distributed, would not strain the ropes more than 25 per cent of their full strength, there can be no doubt of their sufficiency to sustain safely the load of one hundred tons, for which the bridge was designed. In point of fact, in the course of construction, the cables were put to a test which is equivalent to this load. Before any of the stays, which carry one-half the load were stretched, before they relieved the cables of any part of it, the cables alone sustained for some weeks during the storms of autumn nearly the whole weight of the bridge. The dead weight they bore at such disadvantage, including their own, was 211 tons. Their deflection at that time being 88.80 feet, the strain produced by this load was 391 tons, equal to 28 tons upon each rope, the same as that of the maximum load of 100 tons. In this way, therefore, the cables have already been tested to the full strain of the maximum load.

THE EFFECTS OF TEMPERATURE.

It is assumed that under the modifying influence of the Falls, the greatest cold will not be below zero of Fahrenheit, and the greatest heat will not exceed 100 degrees by the same scale. The range of temperature provided for in the adjustment of the levels and the construction of the roadway was 100° Fah't.

The length of the cables exposed to atmospheric changes is 1800 ft. It is known by experiments that wrought iron expands .0012 parts of its length between the freezing and the boiling points of water, that is, between 32° and 212°, equal to a range of 180 degrees.

The expansion of the cables for 100° range of temperature is therefore $\frac{100}{180} \times 1800 \times .0012 = 1.20$ feet in the whole length.

By (2) .38 : .98 : : 1.20 : 3.09.

That is, the increase of 1.20 in the length of the cables will produce an increase in the deflection of 3.03 feet, which is the rise and fall of the bridge due to changes of temperature alone.

THE EFFECTS OF THE WIND.

It would seem as if every wind that blows rushes into the chasm crossed by this bridge with redoubled force. Winds that are but gentle breezes on the land strike the bridge with the force of a brisk gale, and a gale on land becomes a storm on the water. They press through the gorge as through a funnel, with increased velocity and power. Even in calm weather puffs of wind come up from the mysterious depths of the Falls as from the cave of Æolus, surcharged with spray, and then there may be seen, in sunshine, the new phenomenon of a rainbow both over and under the platform, describing a complete circle round about the bridge.

The bridge is undisturbed by ordinary winds, but in the course of construction there were severe storms that affected it to a considerable extent, until all the stays and guys were attached and brought to bear upon it. By these and by the cradle form of the bridge, the lateral force of the wind, tending to produce oscillations, is at once resisted and checked. The undulations from the upward pressure of the wind, and from transitory loads, are also checked by stays and guys as far as they reach, and beyond this, over the remaining space of 400 feet at the middle, it is counteracted by the vertical studs placed between the cables and the roadway, as before stated.

The prevailing winds are from the south-west. Coming from the open water of Lake Erie, they are likewise the strongest, and striking the bridge square upon its beam, act with much more power than any other. Allowing for a great storm, greater than any yet experienced in this locality, and next thing to a hurricane, and that it strikes fairly on one side, it will press with a force of 30 pounds upon the square foot, and exert a lateral power of 108 tons upon the whole length of the bridge. But the wind passing under the bridge has always an upward tendency. Then if the angle of incidence be taken at 45 degrees, its greatest effect, we find that while the lateral force on the side is reduced to 68 tons (as 1 to *Sin.* 45 *deg.*), it is also increased by the horizontal resultant of the pressure on the bottom by 140 tons, and hence the greatest lateral pressure will be 208 tons. To resist this disturbing force we have :

1. The inherent stiffness of the platform, fixed at both ends to the solid rock, and fastened at the middle to cables weighing 81 tons.

2. The cradle form of the bridge, the cable and stays being inclined at an angle to resist any lateral motion.

3. The weight of the entire suspended system, 263 tons.

4. The direct power of the guys, their united strength on each side being 280 and 260 tons respectively.

The upward pressure at the same angle of incidence will likewise be 208 tons. The platform, with the guys attached to it, weighs 156 tons, or 58 tons less than the lifting power of the wind; but the united strength of all the guys that hold it down is 460 tons, and the central half of the cables also presses upon it through the studs with a dead weight of forty tons.

I have now laid before your board a full and particular account of the bridge, exhibiting its strength and construction. To complete the design, there yet remain the following works, which can be proceeded with next Summer : The building of the four masonry pedestals for enclosing and protecting the anchorages; the covering in of the towers; the painting of the iron and wood work; the permanent seizing of the stays to the suspenders; the finishing of the approaches, and the division of the roadway by means of angle irons; the addition of one more stay and a few more guys, and a few other things of minor importance.

Before concluding, I have to thank the Directors for the very complimentary, and to me very gratifying resolution of the Board, passed unanimously at their last meeting of the 11th ult., a copy of which has been forwarded to me, expressing their entire satisfaction with the manner in which I have carried out the important work committed to my charge. I must also express to these gentlemen my grateful acknowledgments for the confidence they invariably placed in me as their Engineer from the time I first entered their service.

I remain,
Gentlemen,
Your obedient Servant,
SAMUEL KEEFER,
Engineer,
Clifton Suspension Bridge, Niagara Falls.

BROCKVILLE, 1st March, 1869.

[Copy.]

To the PRESIDENT AND DIRECTORS *of the* NIAGARA FALLS SUSPENSION BRIDGE COMPANY, *and to the* PRESIDENT AND DIRECTORS *of the* CLIFTON SUSPENSION BRIDGE COMPANY:

GENTLEMEN—

Your bridge being now ready to be opened for public travel, and completed in all particulars, except a few comparatively unimportant ones, I avail myself of this occasion to report to you in writing the results of my connection with the undertaking as Consulting Engineer.

In May last your chief Engineer, Mr. Samuel Keefer, invited me to examine the plans which he had prepared for the work, and I spent a week in carefully revising his calculations of the strains, and of the dimensions to meet those strains, and in the examination of the cables and ropes which had been prepared, and of the towers, then nearly completed.

At this time I expressed to you verbally the following opinion: That the plans had been prepared in the most complete manner, including the most minute details, and that they had been arranged of the most ample strength in every part to sustain the greatest load or strain to which they would be subjected under any circumstances, and four times as great as that which the heaviest contemplated load would impose.

I also found that the arrangement of the whole structure, and of its various parts, had been admirably adjusted so as to produce the desired strength with no unnecessary outlay.

The cables and ropes, which had been purchased by Mr. Keefer in England, from R. S. Newall & Co., were most beautiful specimens, and having been tested at Liverpool by the Government test, were of course perfectly reliable.

The anchorage was arranged admirably, so as to give to this important part of the work an extra degree of strength and security.

I also found that the towers had been made abundantly strong, and were arranged for stability and durability.

On my second and third visits in November, I found that the main portions of the works were nearly completed, substantially upon the original plan. At that visit I saw what must be regarded as a complete test of the cables. Nearly the whole weight of the structure was at this time sustained by them alone, without the aid of the stays (which now carry one-half of the load), and only a few temporary guys, and the structure subjected, in this imperfect condition, to the severe action of very high winds. Such a test is twice as severe as any Engineer would venture to subject the bridge to on a trial of its strength. During my present visit I have witnessed the effect of a terrific gale; and these examinations of the plans, and observations of the bridge itself, assure me of the correctness of the opinions of the strength of each part of the structure when completed (as it is now almost) as perfectly ample for safety under even extraordinary circumstances.

To Mr. Keefer is due the highest meed of praise for the perfection of his plans for the largest-spanned bridge in the world, and for the rapid and economic manner in which it has been executed. It alone would place Mr. Keefer among the highest in rank in the profession.

I am, very respectfully yours,

(Signed) W. J. McALPINE,
CONSULTING ENGINEER.

NIAGARA FALLS, N. Y., 25th Jan., 1869.

Express Printing Co., 14 East Swan St., Buffalo.