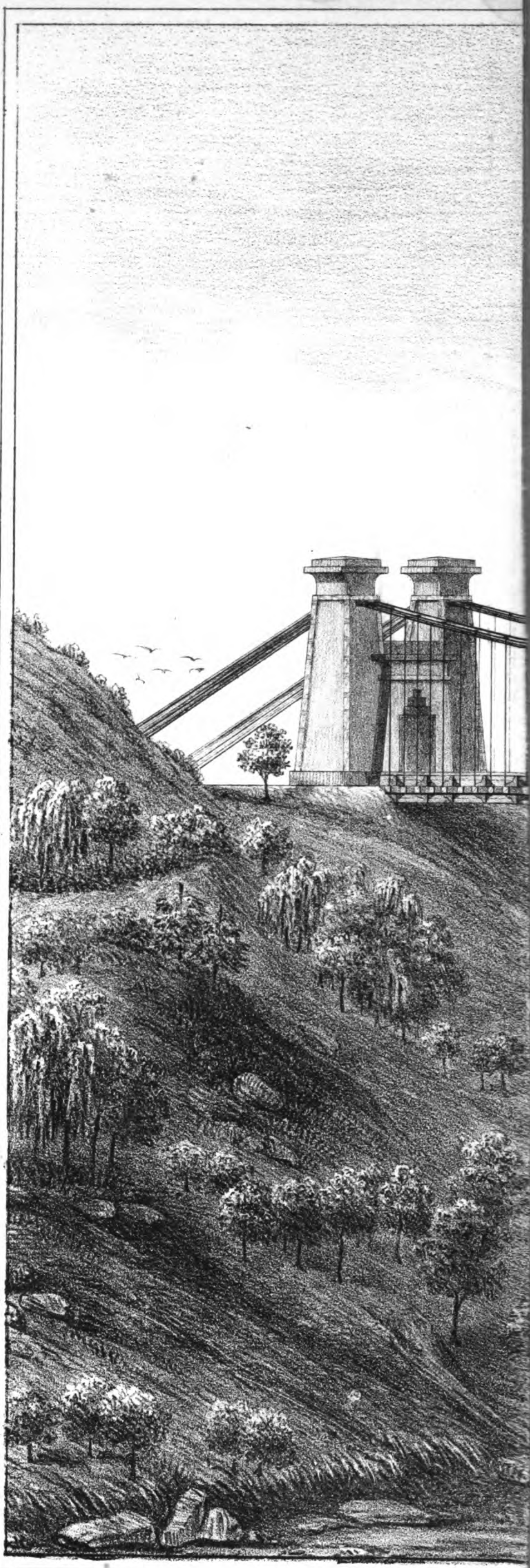
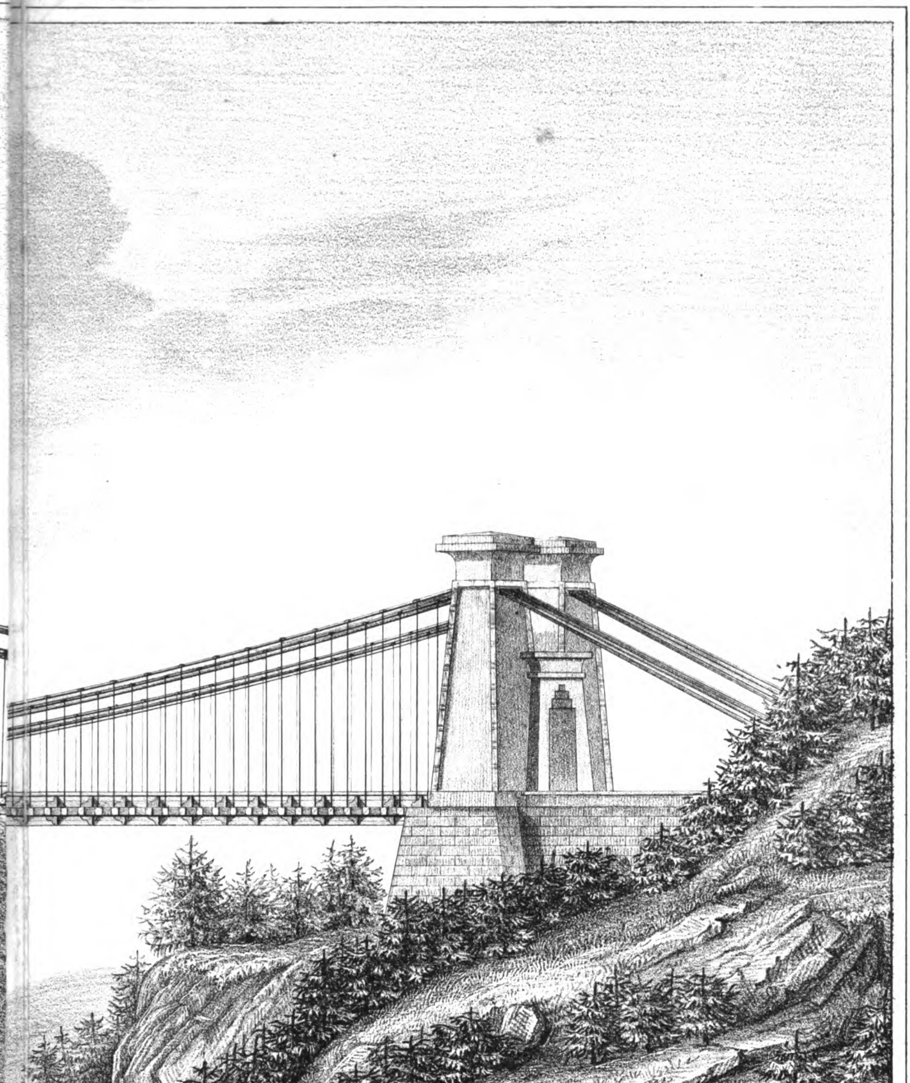


Drawn by Joseph D. Koecker, Architect.



Lith. of P. S. Duval, Ph.ª

REPORT

ON A

RAIL-WAY SUSPENSION BRIDGE

ACROSS THE CONNECTICUT,

AT MIDDLETOWN,

WITH A PROPOSAL FOR ITS CONSTRUCTION,

TO A

COMMITTEE OF THE CITIZENS OF HARTFORD,

BY

CHARLES ELLET, Jr.

CIVIL ENGINEER.

PHILADELPHIA:

JOHN C. CLARK, PRINTER, 60 DOCK STREET.

1848.

PROPOSAL

For the Construction of the Bridge described in the following Report.

THE bridge represented in the accompanying plans, and described in this report, is intended to possess strength sufficient for the passage of trains composed of twenty first class locomotive engines, and as many tenders, filling the bridge from end to end, and weighing in the aggregate 600 tons.

The flooring is to be placed 140 feet above the river, and the navigation left entirely unobstructed.

The bridge is to be upheld by 24 cables, composed each of 1000 strands of No. 10 iron wire.

The masonry is to be throughout well finished, and of a substantial and durable character.

The work is to be finished in two years from the time of its commencement, and to be proved, on its completion, by running over it trains of 600 tons, or greater weight.

I hereby offer to build such a bridge, in conformity with this report and the detailed plans by which it is illustrated—stipulating only for the privilege of introducing such modifications as will improve its character

—for the sum of $300,000; the amount at which the cost is herein estimated.

The contract may prescribe the usual guards for the protection of the Company, if these are deemed sufficient; but if not, it may provide that no advances shall be made to me until the work is in a condition to permit locomotive engines of 15 tons weight to run safely over the bridge, at the highest attainable velocity; at which stage of its progress I shall be paid one-half of the whole cost, or $150,000; the remainder to be held by the Company until the final completion of the edifice, in conformity with the plan herein set forth, and until the structure is proved to possess the promised capability.

I will also agree to build a bridge of 850 feet span on the same site, for the same gross sum, or $300,000.

In the event that the first of these proposals is accepted, I will make a reasonable deposit in the hands of the Company, as an earnest of my intention to begin, and press the work forward, as rapidly as they can wish, to its completion.

CHARLES ELLET, Jr.

REPORT

ON THE

Proposed Suspension Bridge across the Connecticut,

AT MIDDLETOWN.

THE question referred to me by a Committee of the citizens of Hartford, for a professional opinion and report, is—

The practicability and probable cost of constructing a Suspension Bridge competent for the passage of locomotive engines and trains over the Connecticut river at the "Narrows," below Middletown; the flooring of the bridge being elevated high enough above the river to permit the passage of the tallest masts beneath it, and the whole structure to be of "a durable and substantial character, equal to the present and future wants of a great rail-way thoroughfare."

The proposition to build such a bridge has originated in an Act of the Legislature of the State of Connecticut, authorizing the construction of a "drawbridge," on a low level, at a point a short distance above the wharves of Middletown, and some twenty miles below those of Hartford, from the effect of which the citizens of Hartford anticipate great injury to their property and commerce.

The facts of the case are these:—

A bridge of some sort, across the Connecticut, is desirable for the accommodation of a rail-road intended to connect Boston and New York, which it is the wish of the projectors and proprietors to lay upon the best line that can be found between the two cities, so that the through-trips may be made in the least possible time. This best line would cross the Connecticut on a high level below Middletown; and one of the original plans of the road seems to have contemplated such a location. But, subsequently, this location was abandoned, and the right was asked for and obtained from the Legislature, to construct a bridge above Middletown, on a low level, and on a plan which completely stops off the navigation, excepting at a single point where provision is to be made for a draw.

In this state of things, a committee of the citizens of Hartford, actuated by a common and deep desire to protect the navigation of the stream, to which their city owes its original existence, and in a great degree its subsequent prosperity, have asked a professional opinion and estimate of the practicability and cost of constructing a SUSPENSION BRIDGE, of which the flooring shall be elevated high enough to permit the largest vessels to pass under it at full sail, and which shall so span the river as to leave its trade and current uninjured.

If this can be done, they represent that their prosperity will be unimpaired by the enterprise of their neighbours; the great public, for whose benefit this rail-way is intended, will be relieved of the necessity of making an ascent and descent, amounting together to 100 feet, in every trip over the line; and that by reducing the grades, a saving of time will be effected, and the public convenience and welfare, so far as they depend on the construction of the Air Line Road, will be promoted, without injury to them or complaint from any.

My views on a bridge of this character, and my estimate of its cost, are set forth in the following

REPORT.

In presenting a design for a rail-way bridge over the Connecticut, I am aware of the difficulty which is almost always encountered in attempting to show the practicability of constructing a great work on a plan which has not yet been submitted, in all its features, to the test of practical experience.

In past times such an attempt could scarcely have hoped for success; for men then approached cautiously and by very slow steps, to the most important truths.

But it is our privilege to live in a period, and just here in an atmosphere, where all claim the right to judge of the feasibility of every useful project; and, fortunately for the present purpose, in a portion of this country where most persons are fitted by education and intelligence to decide upon the facts and the testimony.

I approach my subject, therefore, with confidence; intending to draw no conclusion that does not rest on established facts, and is not legitimately deduced from premises that are apparent to the common sense of men. And I shall endeavour to use no argument more difficult of comprehension than that which is deduced from the assumption, that, if one wire will bear a weight of 1500 pounds, ten thousand such wires will sustain a weight of ten thousand times fifteen hundred pounds; that if one pound will produce a given depression in a single strand, it will require ten thousand pounds to produce an equal depression in ten thousand similar strands.

With this explanation, we may proceed to the examination of the plan of the work proposed.

GENERAL DESCRIPTION OF THE BRIDGE.

The plan which I have presented for this structure, represents a wire suspension bridge, of which the span, measured from centre to centre of the abutments or supporting towers, is 1050 feet.

A work equally safe, and, it is believed, in all respects as economical and advantageous, might be erected with a span of 850 feet; but it would involve the necessity of raising an abutment 140 feet high, and consume more time in its execution than the plan now presented.

The height of the upper side of the flooring, or grade line of the road, is 140 feet above the low water surface of the Connecticut,—leaving space sufficient between the water and the platform, for the passage of the tallest masts in all conditions of the river.

The width of the platform between the parapets is 20 feet,—sufficient to admit the future introduction of a double track rail-way, although the plan contemplates for the present but a single track.

The height of the eastern abutment will average about 65 feet; the rock on which it is founded rising at this point, 75 feet above low water.

The western abutment is about 10 feet in height, and rests on a substantial foundation of earth and gravel, at a height of 130 feet above low water.

The towers which support the cables rise 65 feet above the road-way, measuring from the grade line to the point of suspension; but the masonry is carried up 10 feet above the bearing point, for the sake of architectural effect.

The thickness of the towers at the base is 30 feet, in the direction of the axis of the bridge, and 70 feet transversely thereto. In the former direction, they are pierced with an arch-way 20 feet wide and 34 feet high, through which the engine and train enter upon the bridge.

The style of the architecture of the towers is Egyptian, and all the work is of massive proportions.

The flooring will be upheld by 24 wire cables, each of which will contain 1000 strands of No. 10 iron wire.

These cables rest on cast iron saddles at the summits of the towers, which move on rollers calculated to yield with the contractions and expansions of the wire, due to atmospheric changes.

The deflection of the cables below the bearing points is 60 feet. Their length will be 1300 feet.

The weight of each lineal foot of the bridge between the bearing points of the cables is 4000 lbs.

I propose now to demonstrate that a bridge of these proportions, will possess strength and stability sufficient for the safe passage of locomotive engines and heavy freight trains, and be, in all respects, fully competent for the severest rail-road duties.

OF THE STRENGTH OF THE CABLES.

To the mind that has not reflected upon this subject, and is not familiar with works of this description, the proposal to suspend a bridge which is to be traversed by locomotive engines and heavy trains, on strands of wire, may appear to be exceedingly rash and hazardous.

The evidences of its practicability must therefore be set forth in more than the usual detail, and all the points on which doubts can be supposed to rest will need to be separately and distinctly examined.

In pursuing this course, it is to be proved—

1. That the cables will be strong enough to bear

the weight of the bridge itself, and the additional weight of the transitory loads that may pass over it:

2. That the flooring will be firm enough to resist the pressure of passing weights without injurious bending:

3. That there will be no dangerous or inconvenient horizontal oscillation, due either to the action of the wind or to any other probable cause:

4. That the cost will not exceed some reasonable limit, justified by the object for which the bridge is intended.

The first, and obviously the most important of these questions, after admitting the importance of the work, is that which determines the strength of the cables that uphold the bridge.

As already stated, these cables are composed each of 1000 strands of No. 10 iron wire, and there will be twenty-four of them, containing in the aggregate 24,000 strands.

A strand of No. 10 wire weighs the 1-20th of a pound for each lineal foot, and if sound and of good quality will bear about 1500 pounds avoirdupois before breaking. In the bridge it will sustain 500 pounds permanently and safely.

The absolute strength of one thousand strands—the number composing one of the cables—will therefore be 1,500,000 pounds, or 750 tons.

The aggregate strength of the twenty-four cables which uphold the bridge, will be 36,000,000 pounds, or 18,000 tons.

Experience teaches how we may multiply fibres of flax, or threads of the silkworm, until we obtain strands sufficient to form a cable that will bear the heaving of a ship of war; how we may multiply particles of clay or sand until we form a dyke that will sustain the pressure of the ocean; and it is by the same process of accumulating material and strength, that we can bring together strands of wire, until we are capable of supporting any load of matter that, in human affairs, can need to be resisted.

But it is not the intention, in the present case, to deal in mere generalities. The subject before us is a beautiful scientific problem, and must be treated with all the severity which is due to such questions.

It is stated as a fact, proved by my own repeated trials, and which it is in the power of every reader to test and confirm, that such a strand of wire as is here specified, will break with a load of about 1500 pounds. But to exhibit this tenacity, the wire must be formed from iron of good quality and properly drawn.

These cables of 1000 strands each will be about five inches in diameter, and will weigh respectively 65,000 pounds, or 32½ tons.

To compare the strength of one of these cables with that of more familiar objects, it may be observed that 200 pounds is considered to be beyond the force exerted by a draught horse in his daily work.

The strength of a single cable is, therefore, equal to the tug of 7500 horses, when drawing with united power; and the aggregate strength of the twenty-four cables will be equal to that of about 180,000 horses, or a team extending over a line of some 500 miles.

But still such computations do not prove the sufficiency of the cables; they show only that they are strong in comparison with certain other things. We have yet to compare their power with that which will be needed to sustain the heavy timbers of this bridge, and superadded thereto, the action of a column of freight cars filling the platform of the bridge from end to end.

OF THE LOAD TO BE SUPPORTED BY THE CABLES.

The load which the cables of this bridge will be required to sustain, will consist of three distinct items, viz: their own proper weight, the weight of the flooring which they uphold, and that of the transitory loads which may come upon the flooring.

The weight of the cables is immediately deduced from the dimensions already given, and amounts to - -	1200 lbs. per lin. foot.
The weight of the timber in the flooring is determined from the plan, and is - -	2200 „ „
The weight of the suspenders and other iron work supported by the cables, is - -	150 „ „
To which is to be added for flagging or ballast, - -	450 „ „
Making for the total permanent load, - - -	4000 lbs per lin. foot,

measured along the horizontal line connecting the points of suspension.

The length of the flooring is 1000 feet, and the total permanent weight of the suspended portion of the bridge is, in round numbers, 2000 tons.

In determining the weight of the transitory loads which may come upon the platform, a prudent economy would suggest the propriety of examining the character of the transportation likely to pass over the bridge.

It is estimated, in the official report of the Company, that the present tonnage along the line of the road which will cross the bridge, will amount to - - - - - 7050 tons.

To which is added, in the report, 80 per cent. for the conjectural increase, - 5640 „

Producing for the probable future annual tonnage, - - - 12,690 tons.

exclusive of certain agricultural productions, live stock and lumber prepared for market.

This is given as the official estimate; but in preparing for the accommodation of the trade of any extensive district of country, it would be prudent to look forward to a much greater business than this, where the estimated amount is intended to control the proportions of any important structure.

If we assume 30,000 tons of freight per annum for the business that will pass over this bridge, in addition to the usual complement of passenger trains to be found on other successful lines, we will approximate more nearly to what ought to be the future trade, to justify the construction of the rail-road.

If this amount of freight is carried over the bridge in 300 days, there will be an average daily movement of 50 tons in each direction, or more than quadruple the quantity estimated by the Company.

For the conveyance of this freight, we may allow 16 tons for the engine, 9 tons for the tender, 30 tons for the cars, and 50 tons for the lading, and we will obtain aggregate trains of 105 tons.

If the present purpose were to prepare a plan simply compatible with good economy, such is the calculation which it would seem advisable to make, in obtaining a business basis on which to compute the strength and cost of this structure.

But, in the case before us, it is deemed expedient to adopt a plan fully equal to all the present and probable future wants of a great rail-way; and we must therefore treat this part of the subject on a much broader ground.

In adjusting the dimensions of the bridge discussed in this report, it is assumed not merely that the flooring may be loaded with gross trains of 105 tons, but that it may be covered any number of times daily with a column, 1000 feet long, of loaded freight cars, filling the track from one abutment to the other, and moving at the ordinary speed of such trains.

Indeed, in computing the strength of the cables, a still more liberal view of the subject has been taken, and the load upon the bridge has been assumed to consist of *a column of the first class locomotive engines*, each of 20 tons weight, and followed by their respective tenders, each tender being of 10 tons weight.

The flooring of the bridge would contain 20 such locomotive engines and 20 tenders, or gross loads of 600 tons.

Now it will be observed, that the present actual freight along the line of the proposed road, which will cross the Connecticut, is 7050 tons per annum, with the exclusion of certain commodities of little moment; and that it is only by assuming, in the first place, that all the trade is accommodated by a single daily train, and that the tonnage will be more than quadruple the estimated amount, that we can obtain average gross loads of 105 tons. And after this, for the sake of giving ample room, it is assumed, for the basis of the computation upon which the proportions of this bridge are adjusted, that the work must sustain gross loads six times as great as this, which is itself quadruple the official estimate of the actual traffic.

By assuming that the flooring is covered by a weight equal to one train of locomotive engines and tenders daily, in each direction, we prepare for accommodating a trade twenty-four times as great as the estimated traffic: and by running only two such trains daily, the bridge will be adequate to the passage of about fifty times the estimated tonnage.

If, now, to the permanent weight of the bridge, - - - - -		2000 tons,
We add the weight of the transitory loads, say 20 locomotives of 20 tons each, or - - -	400 tons,	
And 20 tenders of 10 tons each, or - • -	200 ,,	
	——	600 ,,
		——
We shall have for the total weight,		2600 tons,

or 5200 pounds per lineal foot, to represent the load upon the cables.

Now, the cables must not only be strong enough to support this load, but they should be adequate to its support for centuries, with every reasonable chance of being unimpaired by the strain.

The load which these cables are to uphold, is, as above stated, 2600 tons; but this weight, drawing across the line of the curve, acts with a certain mechanical advantage, and produces a tension much greater than the absolute weight.

The methods of calculating this strain are entirely perfect, and may be relied on as practically and theoretically accurate.

The rule here laid down for computing its value may be submitted directly to experiment, and verified in the most conclusive way.

The tension is composed at each point of two parts —that which is vertical, and therefore just equal to the weight upheld at that point; and that which is horizontal, and depending on the form of the curve assumed by the cables.

The vertical component at each point of suspension is half the weight of the bridge and load, or 1300 tons.

The horizontal component is equal to the vertical component multiplied by half the span in feet, and divided by twice the deflection of the cables in feet.

To obtain this value in tons, we will observe that half the span is 525 feet, and twice the deflection is 120 feet. The vertical component is 1300 tons. The horizontal component is, therefore,

$$\frac{1300 \times 525}{120} = 5687 \text{ tons.}$$

The resultant of the horizontal tension, 5687 tons, and the vertical weight, 1300 tons, is—

$$(5687^2 + 1300^2)^{\frac{1}{2}} = 5834 \text{ tons.}$$

This is the strain against which provision is to be made—no less than 5834 tons, or 11,668,000 pounds.

The strain produced by the weight of the bridge acting across the line of the cables, is, therefore, more than double the actual weight supported.

But it has been stated that each strand of sound No. 10 wire is capable of sustaining any tension less than 1500 pounds. There will, therefore, be needed to balance the draught on the cables produced by the weight of the bridge thus loaded,

$$\frac{11{,}668{,}000}{1500} = 7779 \text{ strands.}$$

But the proposed cables consist of no less than 24,000 strands, or more than three times the number really necessary to support the tension to which they will be subjected.

In other words, it is assumed that the bridge is loaded from end to end with 20 tons locomotive engines, and 10 tons tenders; and *the cables are then made strong enough to bear more than three times their own weight, three times the weight of the bridge, and three times the weight of twenty first class locomotive engines and twenty tenders.*

Again, let it be observed that these are the facts which control the estimate of the cost of this bridge: That estimate is made for a work intended to bear safely and permanently, freight trains of 600 tons; while it is very obvious that the road is destined almost exclusively for passengers and valuable merchandise.

An engine of twenty tons, with its tender and eight or ten passenger cars, or a gross load of 100 tons, will probably be regarded on this line, for a long time to come, as an extraordinary train; and indeed all that a sound view of judicious economy could well prescribe as the ground-work of the plans intended for its accommodation.

But it is the wish of the Committee to present a plan for a bridge of ample power for any rail-way duty in this country. This plan has been controlled by that wish. It will remain for the rail-way company, in carrying out the details, to reduce the work and the cost down to what is really necessary for their purposes, leaving the extravagant excess to be provided for by posterity.

OF THE STIFFNESS OF THE BRIDGE.

It will hardly be doubted now, that the cables proposed for this bridge will possess ample strength to afford every reasonable assurance of their perfect safety. Nor will it be doubted, either, that such cables can be manufactured, since *they have been made* both of larger and smaller size. There is, in fact, no more difficulty in making and adjusting one of 5000 strands, than one of 500 strands.

But the fitness of the structure for the purposes in view does not rest solely on the strength of the supporting wire; for the bridge must not only be so strong that it shall not be broken down under the weight of the trains, but it must also be so firm that it will not be dangerously or injuriously bent under the engines which are to pass over it.

This division of the subject is fortunately susceptible of the same rigid analysis as that which has already been considered.

A suspended chain is flexible, and yields more or less to every weight that is applied to it; but it yields in accordance with certain laws, and the amount of its flexure may be calculated in ordinary cases with any necessary degree of precision.

These calculations are not speculative or conjectural, but absolute and certain. They depend on those established principles of mechanics which have been confirmed by the experience of centuries, and upon which all the computations of art equally rest.

There is no need of proving their accuracy here by any mathematical process, for the results can be stated in advance, and verified by experiment.

It is true that the observation and the calculation will not always agree precisely, with our uncertain means of measurement. The calculation is precise and positive, while the observation is only an approximation.

In a suspension bridge nicely constructed, and of which all the elements are known, the change of figure or depression of the central point, due to the weight of a single individual, or the variation of one degree in the temperature of the air, can be computed within a fraction of a hair's breadth.

The eye will not detect quantities so small, and they can only be rendered perceptible by a nicely adjusted instrument. But these motions take place, although unobserved, and are just as sensible to the computation as if they were produced by the weight of a locomotive engine.

In determining the effect of given forces in changing the figure of the flooring, there are three causes of movement which must be separately considered.

1. The depression caused by the alteration of the figure of the curve, the drawing up of the flanks, and the simultaneous sinking of the centre.

2. That due to the extensibility of the material—the elongation of the wire consequent on the additional tension produced by the additional weight.

3. The drawing up, or closer approximation to a straight line, of the stays or guys.

In ordinary cases, embracing the structure under consideration, the first of these three quantities is by far the greatest; so much the greatest, indeed, that the others are hardly worthy of consideration in comparison with this one.

It is also to be observed in these investigations, that there are two classes into which such questions may be divided, viz: those in which the concentrated weights producing the movement are small in comparison with that of the body put in motion, and consequently, in which the depression of the central point is also small in comparison with the primitive depression of the curve; and those in which these weights and movements are comparatively large.

In bridges of great span, as the proposed bridge over the Connecticut, the weight of an engine and tender is but some 30 tons, and the flexure of the curve, or the droop of the cables, in the ordinary condition of the structure, is many feet; while the weight of the bridge itself is 2000 tons, and the movements produced by the action of the heaviest engines will be usually but a few inches.

The questions which arise in this investigation belong, therefore, to the first of these classes, and the rules which will be laid down in this report, for determining the value of these movements, are to be taken as applicable only to this class of such questions.

Further—but without meaning to confine the application of these rules strictly within the limits here given—it may be stated generally, that where the sagitta of the curve is not less than the twentieth part of the span, and where the weight placed in the centre of the arch, is not greater than the twentieth part of the weight of the suspended portion of the bridge, these rules may be applied with entire confidence. But if we transcend these limits, by making the moving weight materially greater, or the original flexure of the curve materially less than the proportions designated, the depressions which actually have place will vary appreciably from those indicated by the calculation.

One of the most important problems that will occur to an engineer, in arranging the plan of a bridge of this character, is to ascertain the bending of the flooring which will be produced by placing a given weight, such as a locomotive engine, in the centre of the arch.

In computing this depression, he will assume that the flooring possesses no rigidity whatever beyond that which is due to the simple weight of the material of which it is composed. In other words, that the framing offers no resistance, and that the timbers are as flexible as a chain of the same length and possessing the same weight.

The amount of this depression, under these conditions, may be computed by the following simple process:—

Multiply the sagitta, or deflection of the curve of the cables in feet, by the weight in tons placed in the centre of the flooring, and divide the product by twice the weight of the bridge, in tons.

The result obtained by this process, will express the deflection in feet, under the supposition that the timber possesses no stiffness, and adds nothing at all to the strength or rigidity of the platform.

For an application of this rule, we may assume that a locomotive engine, of 20 tons weight, is placed in the centre of the flooring of the Connecticut river bridge.

The calculated deflection would then be

$$\frac{60 \times 20}{2 \times 2000} = \frac{12}{40} \text{ of a foot,}$$

or the flooring would be depressed three inches and six-tenths.

But the bridge is planned with a view to preserve a camber or arch in the flooring, of two feet, at midsummer, when unloaded; and it would therefore require about seven such engines to bring the centre down to the horizontal line.

It is unnecessary to attempt to prove, that a depression of four or five inches in the flooring of a flexible bridge, one thousand feet long, would produce no injurious effect—for that fact is demonstrated practically by every suspension bridge in existence. The Fairmount bridge sinks three inches and a fourth under a load of two tons, and is depressed by heavier weights six or eight inches many times daily, not only without injury, but without exhibiting any movement that would be in the least degree inconvenient under a railway train.

On the completion of the Freibourg bridge, it was frequently loaded, by concentrating people, horses and artillery on the flooring, until the central point was depressed *more than three feet*, without causing any injury to any part of the structure.

A wooden bridge, or any other bridge supported by a rigid framing, can rarely bend over one or two inches without suffering injury that will ultimately cause its destruction. But it is the peculiar merit of the suspension bridge, to yield slightly to the pressure of a passing weight, and return at once to its true position on the removal of the disturbing force. And this process may be continued thousands of times, with the certainty, known in advance, that the movement will occur, and that the structure will recover its place immediately on the withdrawal of the weight. It is no more injured by being depressed a few inches, than a flexible chain, stretched between two fixed points, is injured by a force which draws it slightly into another position.

But such is not the case with any other description of bridges. The bending of an ordinary wooden bridge proves the working of the joints, and shows that it will sooner or later be racked to pieces. The integrity of such a bridge depends on the stiffness of the framing, and that stiffness must be preserved or the bridge will fall. [See Note A.]

But we have seen that a 20 tons engine will depress the flooring of this bridge 3½ inches, allowing nothing for the rigidity of its framing. And this amount of bending, it is concluded, could do no shade of damage, because it takes place daily on other similar bridges of much shorter span and does them no injury.

The flexure of this bridge, produced by the passage of a 20 tons engine, is less than that to which an ordinary steamboat is constantly subjected, without starting a timber or opening a seam. On the western waters of this country, boats 150 feet in length are frequently bent *ten or twelve inches* in crossing over shoals, without apparent detriment to their hulls or machinery. Yet this is a case in which a slight motion would be comparatively dangerous—for if the bending exceed what is due to the elasticity of the material, the joints must open, and the boat will sink.

But in this bridge there are no seams to open, no frames to become disjointed, or other danger to be apprehended; and the greatest possible movement of the flooring, due to the action of a single locomotive engine is less than that which actually takes place in the hulls of many approved boats, at almost every change in the position of the cargo.

The depression of the flooring of this bridge, under the weight of a 20 tons locomotive engine, is too small to be detected by any but a practised eye, carefully placed to observe it. It is much less important than the oscillations and heavings of the cars in passing from one sill to another on any line of rail-road in this country.

The apprehension, therefore, that the bending of the bridge will present an impediment to the progress of the engine and train is entirely groundless. There is no sudden angle formed in the flooring, but the slight depression that really has place is diffused, in all cases, over at least half the length of the span. [See Note B.]

It has been already stated that the Freibourg bridge, a very slight structure, was repeatedly bent three feet by concentrating heavy weights on the platform. But on comparing the proportions of the Freibourg bridge with those of the work before us, it will be observed that the weight which would depress the former three feet, and which the calculation shows to be more than thirty tons, would produce a depression in the latter of only six inches.

It must surely be clear, then, that if a depression of more than 36 inches produced no injury in the weaker bridge, a depression of six, or any less number of inches, could not be hurtful to the stronger work.

The Freibourg bridge was bent more than three feet without injury, and this one might also be bent an equal or a greater amount, without the slightest cause for apprehension. But to bend the flooring of this bridge three feet—assuming still that the timber framing would present no resistance—would require the concentration of a load of 200 tons in the centre of the arch, or ten locomotive engines of twenty tons each, to be piled one upon the other at that point.

This is a trial that few, if any, wooden bridges would bear: they would not only bend, but be broken in two; while on the bridge proposed, the only effect of the concentration of such a weight would be to increase the strain supported by each strand of wire about 50 pounds. But these strands would each bear an increase of nearly 1000 pounds, or 20 times this amount, before approaching the breaking point.

It thus appears that the effect of a weight which would crush any timber bridge that has yet been built, would be only to depress the flooring of this work an inconsiderable amount; and the moment the weight was removed, the flooring would return uninjured to its place.

When speaking of a depression of three feet in the centre of the arch, we are assuming an unheard of load —a weight of ten of the first class locomotives piled up on the centre of the platform. But no such load can be collected there. In practice the cars are stretched out upon the track, and a train of 200 tons would spread over a space varying from 500 to 800 feet.

Now there is a remarkable difference to be observed between the effect of a weight occupying the centre of the bridge, and that which would be produced by the same weight stretched along a considerable portion of the platform, in the manner of a rail-way train.

As an example of this difference, we may allude to the test weight placed on the flooring of the Fairmount bridge—a work which was slightly built and intended only for common travel, and on which no extraneous means are applied to add to that stiffness which it derives from its own inertia.

This bridge, as is shown by computation and experiment, is depressed 3¼ inches by a load of two tons; or, by the rule laid down and verified by observation, it is about eight times as flexible as that in the plan before us. It would be bent just about as much under the weight of a loaded cart and one horse, as the heavy rail-road bridge, proposed for the Connecticut, would be under that of a 20 tons engine.

Yet, notwithstanding this flexibility under the action of small weights placed in the centre of the arch, that structure was publicly proved by placing on the platform *two columns* of loaded carts, each containing as much stone as the horses could pull upon the bridge, and drawn up as near together as they could stand, while the foot-ways were at the same time filled with people. With this weight, due to 39 carts, horses and loads, and probably reaching 120 tons, the depression of the flooring was not visibly greater than is frequently produced by placing three or four such teams in the centre of the arch.

After standing some time on the bridge, this train was started off simultaneously. No injury resulted to the structure, no motion was produced which would have been hurtful, if inconvenient, had the double train of carts been a rail-way train; and the flooring immediately assumed its proper camber when the weight was withdrawn.

Let it not be supposed that it is the intention to represent this light and comparatively feeble bridge over the Schuylkill, as at all proper to be used, in its present condition, for modern rail-way purposes. It is wholly unfit for any such application. The example which it furnishes is intended only to illustrate the single fact, that although a small weight placed in the centre will produce a perceptible movement, a very great weight may be stretched along the flooring without causing any considerable increase of flexure.

The bridge which we are discussing will be five times as heavy as that at Fairmount, for each lineal foot, or fifteen times as heavy in the aggregate; and will require, as will be hereafter shown, eight times the weight to disturb it; and will be no more shaken by a twenty tons engine, than the other by a two and a half tons cart.

The rules upon which these computations are made, have been stated approximatively; but it may well be asked upon what authority they are laid down, and how their accuracy is to be verified.

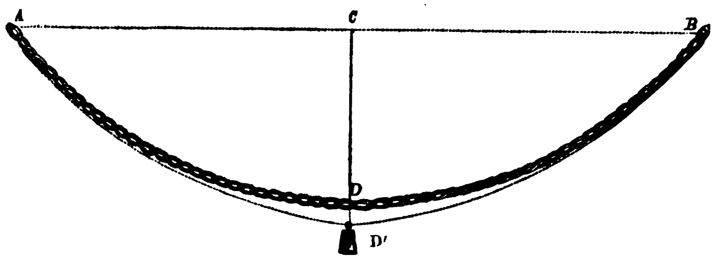
The scientific reader is referred, for a complete and beautiful analysis of this whole subject, to the "Mémoire sur les Ponts Suspendus," par M. Navier, late Chief Engineer in the *Corps Royal des Ponts et Chaussées,* and a distinguished member of the French Academy of Sciences.

But the complete investigation involves some very difficult and complicated mathematical formula, and will therefore engage the attention only of professional readers.

It is, however, fortunate, that the principal laws may be presented in a very simple dress, and in a shape which will permit their accuracy to be conveniently tested by every one.

Let any person, curious in these matters, take a chain of any length or size, and suspend it between two fixed points, A, B.

Let the number of links in the chain, as suspended from A to B, be counted. Let the distance, C D, showing the deflection, be also measured, by ascertaining the number of links which represents that distance.



Then let any number of links of the same chain be suspended to the point D, and that point will be found to have been depressed thereby the distance D D′.

Now, to calculate this depression, D D′,—

Multiply the number of links in C D, by the number suspended at D, and divide by twice the number of links in the whole chain from A to B. The quotient will be the distance, D D′, expressed in links.

The length of a link is the distance from the centre of one link to the centre of the next one to it.

This rule may be applied to all cases within the limits assigned, and approximatively to many cases beyond those limits; and it will always exhibit results which coincide very closely with experiment, if the experiment be accurately made.

It matters not what the size of the chain may be; from the finest watch chain up to the heaviest cable, or cable bridge, this rule will hold good, and be accurate enough for almost all practical purposes, until the bridge is stiffened by timber or other trussing, when the actual movements will become less than those exhibited by the calculation. Indeed, in nearly every case, within the limits specified, the errors which exist in the computation are on the safe side—since the calculated depression is generally a fraction greater than that which really occurs.

Now, let it be observed, that according to this rule, the depression produced by a given weight will be less and less as the weight of the chain becomes greater and greater.

Consequently, *if we double the span*, or put two chains in place of one, or double the weight of the links in the same chain, leaving all other things the same, the depression will be reduced one-half. In other words, the stability of a suspension bridge of great span depends mainly on its weight.

We must bear this fact in mind—that it is essentially *weight* which gives solidity and firmness to the structure. It resists by its inertia, and its inertia is in proportion to its weight.

To apply this principle to bridges, we have the case of a small foot bridge formerly stretched across the Schuylkill at the Falls, and sustained by six strands of wire. This work was exceedingly light, and it was also exceedingly flexible; so flexible, it is said, that few persons could cross it without fear.

The Fairmount bridge, of about the same span, and over the same stream, does not bend injuriously under the heaviest teams and droves of cattle, and has sustained safely more than 100 tons.

Now, why did the foot-bridge bend fearfully under the weight of a man, while the Fairmount bridge sustains safely the weight of two thousand men?

It is simply because the Fairmount bridge is heavier than the other—heavier, indeed, when thus loaded, as compared with the weight of a four-horse team, than the slight foot-bridge, as compared with that of a man.

If this is the reason, and this the principle, why may we not extend the application to cases of higher importance; and by making a bridge ten times as heavy as that at Fairmount, make it capable of bearing a twenty tons engine as lightly as the other bears a two tons cart, and capable of bearing the action of a train of 1000 tons as easily as the other bore a train of 100 tons?

There is no difficulty in this. All we require is more material, judiciously applied.

But have we provided that material in this plan?

The cables of the Fairmount bridge were composed of about 2500 strands of No. 10 iron wire, and those of the bridge before us will contain *twenty-four thousand strands of the same wire.*

To move the Fairmount bridge, or send a vibration through it, 135 tons must be put in motion. To disturb the bridge which it is proposed to build at the "Narrows," 2000 tons must be displaced.

But the relative stability of the two works is greater even than their relative weights, per lineal foot, would indicate; for the cables hang much more loosely on the Fairmount than is proposed for the Middletown bridge—another element in such computations.

OF THE STIFFNESS OF SUSPENSION BRIDGES AS DEPENDENT ON THE FORM OF THE CURVE OF THE CABLES.

The stiffness of the bridge depends, as already observed, mainly on the weight, when the proportions are constant; but when the weight is the invariable quantity, the stiffness depends mainly on the form of the curve which the cables are permitted to assume.

For example:—If we have a bridge of any given weight and span, in which the deflection of the cables is any given amount, and place a given load in the centre of the arch, and note the depression; then draw the cables more tightly, so that the deflection is reduced to one-half its previous value, and apply the same weight, we will find the depression also reduced about one-half.

The tighter the cables are drawn the more stable will be the structure, until we approach the point where the increased tension due to the load causes an elongation in the material itself, of which the cable is composed, sufficient to compensate for what is otherwise gained in stability.

The total deflection, due both to the change of figure and the elongation of the material, is a problem which only comes up with any interest, when the proportions of the bridge transcend the limits assigned for the application of the rule already given.

In these cases, when they occur, the results may be obtained with all desirable exactness, and over a wider range, by the application of a not very complicated formula. (See Note C.)

But, apart from these questions, which involve the extensibility of the material, and keeping still within our limits, it will be observed that the depression produced by a given force is directly as the original deflection. Hence, when we compare the movement which takes place under the action of a given weight on the Fairmount bridge, with that which will result from the same weight on the Middletown bridge, we must take into consideration this difference in their respective proportions.

Each foot in length of the Middletown bridge is five times heavier than a foot in length of the other. From this cause, therefore, the movement of the Fairmount bridge, consequent on the application of a given force, will be five times the greater.

But the deflection of the cables in the Fairmount bridge is 60 per cent. greater, in proportion to their span, than the deflection of those in the Middletown to the span of the latter work. From this cause, also, the stiffness of the latter will again be 60 per cent. greater than that of the former.

The combination of these two elements shows that the Fairmount bridge will be bent *eight inches* by a weight, which, on the proposed bridge, would produce a movement of but *one inch*. And we have already seen, that a train of more than one hundred tons, drawn by horses over the rough planks of the former, produced no injurious effect. It is clear, then, that a bridge, of which the cables are nearly ten times as strong, and which is eight times more stable, cannot be injuriously affected by the same weight, which in fact exceeds that of the ordinary trains likely to traverse the proposed road.

We have now gone through this branch of the subject, and have given full evidence of the sufficiency of the bridge proposed, so far as the considerations of strength and stability are at issue. This evidence is presented in the most conclusive form, by laying down rules for computing all the essential strains and motions, to which the work will be subjected in rail-road service: by showing how the accuracy of the rules may be tested, and inviting the experiment to prove their correctness: by giving the calculated deflections under given circumstances, and comparing them with the observation, and showing that the results fully confirm the calculations: by extending these computations from the finest guard chain up to the heaviest wire bridge in the country, and showing its confirmation throughout. (See Note D.)

OF THE EFFECT OF SPEED.

We have not yet made particular allusion to the effect of speed; and it may perhaps be supposed, that the oscillations produced by trains in motion are not reached by the methods of calculation presented, and that this bridge, however it may be adapted to the support of stationary weights, may not be applicable to the high velocities contemplated on the proposed "Air Line Road."

On this head, it might be sufficient to compare the loss of time incident to slackening up the speed of the engine while passing over a space of 1000 feet, with that which would be consumed by crossing on the low level, at a sacrifice of 100 feet total ascent and descent.

By reducing the speed on the bridge to the rate usual on long wooden bridges—or from 25 miles down to some 5 miles an hour—the loss of time in crossing at the Narrows, would be less than two minutes.

But the loss of time in merely crossing the drawbridge above Middletown, due to the same reduction of speed, would be 3½ minutes, or as the bridge is nearly twice as long, the loss of time would be nearly twice as great. But, in addition to this advantage on the score of time, the high level avoids the delay consequent on a total ascent and descent of 100 feet at every trip, besides the occasional delays incident to the simultaneous approach of vessels and trains at the same passing point. The advantage in time is, therefore, all in favor of the high level.

But there is another consideration. It is an error to suppose that the depression of the bridge is greater when a body of a given weight is moving along it, than when the same body is resting quietly on the platform. Careful experiments have been made on the Fairmount bridge, which seem fully to prove that the depression produced in the flooring by carts moving over the rough planks, is *considerably less* than that produced by the same carts when standing quietly in the centre of the arch.

I have caused a spirit level to be placed on the shore near the bridge, and the height of the flooring to be accurately ascertained; then, two carts, of which the total weight was four thousand pounds, to be brought on the bridge, and stood opposite the apex of the curve, and the corresponding depression accurately noted.

The same carts, horses and loads, were then driven over the bridge in the same relative position, and the depression again noted.

The depression of the bridge was less when the carts were in motion, than when they were at rest on the flooring.

Similar experiments have been tried on the flexure of rail-way bars, by placing an accurate instrument half way between the bearing points of ordinary T rails of different patterns, and observing the deflections produced by the drivers of locomotives at rest, or moving over the rails at moderate and high velocities.

In this case, the depression was not less when the engine was running, but, so long as the fixtures remained secure, appeared to be essentially the same as when the weight was standing quietly on the bar.

Similar experiments have been tried on a wire cable 1160 feet in length, stretched across Niagara river, and used as a ferry, by suspending a small car to sheeves, which traversed along the top of the cord. The oscillations of this cord, at the point of suspension of the car, were almost too small to appreciate, while no difference could be observed between the depression occasioned by the car, when at rest and when in motion.

OF THE STIFFNESS OF THE TIMBER IN THE FLOORING.

In all that has preceded, the computations and conclusions have been based on the supposition, that the flooring of the bridge is entirely flexible, and without strength, acting as it would act if the girders were sawed through and through in numerous places along its length. And it has been shown, that in this hypothesis the bending would be so small under the heaviest weights, that the platform might be traversed safely by rail-way trains of extraordinary size.

But this flooring is not so divided, and so entirely feeble; it is on the contrary a very strong and rigid structure.

The arrangement of the timbers is shown in the annexed engraving.

Joist or cross beams, 12 inches wide by 24 inches deep, and 28½ feet long, are suspended from the cables at every 5 feet, measured along the platform.

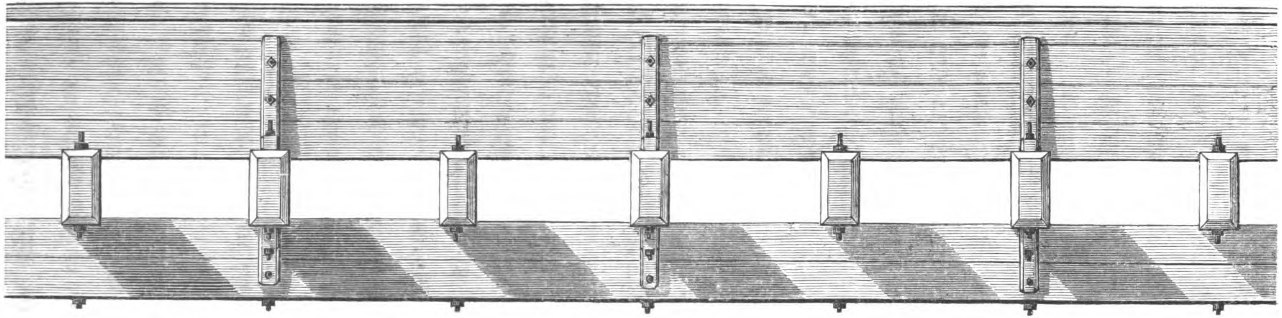
At the distance of ten feet from the centre, on each side of the bridge, is raised a heavy parapet, or wall of timber, four feet high and 12 inches thick. These parapets are built so as to constitute of themselves heavy girders, running from one end of the bridge to the other, and distributing the effect of every load over a considerable portion of the flooring.

They are each composed of a string of 12 inch square oak timber, laid on the cross joists, upon which they are fitted by a gain of two inches. They will be 40 feet long and properly scarphed at the ends.

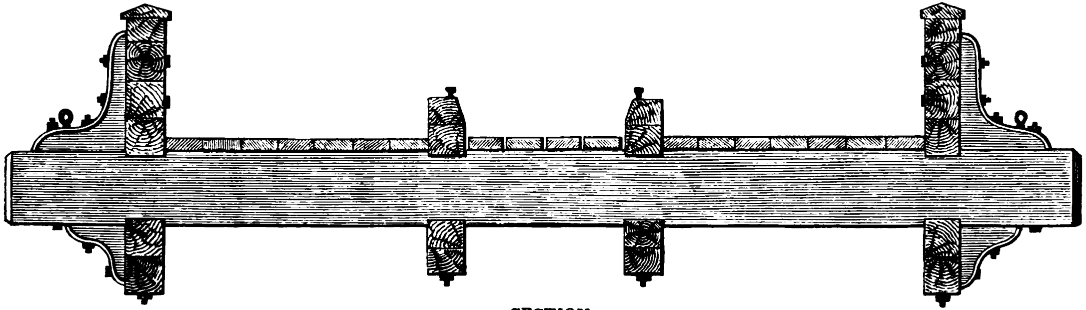
On top of these timbers, and parallel with them, is placed a second course of the same size, closely fitted to, and breaking joints with the former, with which they are united by tree-nails. On top of these last timbers is laid a third course of the same size, and secured in the same way to the lower courses.

On top of this third course is laid another string, 12 by 8 inches, still breaking joints with, and tree-nailed to the lower courses.

PLAN OF FLOORING AND PARAPET.



ELEVATION.



SECTION.

The whole is covered with a four inch cap or coping, breaking joints as before and secured to the preceding courses. To preserve this parapet in its vertical posture, and guard against lateral movements, staunch wooden knees are bolted on the outside, both to the parapet by horizontal bolts, and to the cross joists by vertical bolts.

Directly under each of the parapets is placed a longitudinal girder, formed in the same way, but composed of only two 12 inch square timbers, which break joints with each other, and are let into and fitted upon the under side of the joist by slight gains cut in the upper side of the girder.

Heavy iron screw bolts are finally driven through the parapet, cross joists, and lower girder, by means of which the whole are drawn and secured firmly together.

The rail-way track occupies the centre of the platform; the rails are supported by girders formed of two courses of 12 by 9 inches stuff, breaking joints with each other, and let down upon the joists, as already described for the parapets; and the platform is still further stiffened by similar girders corresponding with the line of the rails on the lower sides of the joists.

The platform is then covered with three inch oak plank. The rail-way track with flagging.

There will be 35 cubic feet of oak timber in each lineal foot of the flooring.

No calculation is presented here of the strength of this platform, or the resistance which it will offer to the weight of the trains; but it is submitted to the practical reader to decide, whether a flooring bound together by such girders, firmly secured at the ends to the massive abutments by staunch iron ties, and thoroughly bolted in the manner here specified, will not offer *some* resistance.

It will be recollected that the centre of the arch cannot descend, or yield to a weight placed there, without drawing up the flanks; and the flanks cannot rise without bending this timber framing.

Still, no estimate is made of the value of this stiffness, or of the reduction in the movement which might be expected in consequence thereof. The bridge is strong enough, and stable enough, for all the purposes of this rail-way, without counting on any collateral aid.

OF THE EFFECTS OF THE WIND.

It is not difficult to show by direct computation, based on the measured force of wind during violent storms, that no danger is to be apprehended to this structure from any such cause. But we have examples enough to spare us the trouble of the investigation.

The effect of the wind is not, as might be supposed, to produce a horizontal oscillation in the flooring. This movement is prevented by the mode of suspension, which swings the bridge in the manner of a hammock, so that it is guyed or stayed by its own weight, and by means of the very cables that uphold it. These cables do not swing in vertical planes, but are inclined from the summits of the towers towards the axis of the bridge, and act as constant and effectual lateral supports.

The only motion that is ordinarily perceptible in high winds—and which is manifested, perhaps, more remarkably in the Menai than in any other suspension bridge—is a vertical oscillation, or waving of the flooring, produced by the upward pressure of the currents of air passing at high velocity under the bridge.

The flooring of the Fairmount bridge is 30 per cent. wider than that proposed for the Air Line road; and the wind consequently acts on the former with 30 per cent. more power than on the latter, in producing this motion. But, on the other hand, the flooring of the Middletown bridge is four times as heavy as that of the Fairmount, and it resists, consequently, with four times as much power.

The effect of the wind is not at all hurtful on the Fairmount bridge, and it cannot therefore be injurious on a work which offers four times as much resistance, and on which the force applied is a great deal less.

The width of the Freibourg bridge, of which the flooring is more than 800 feet long, is almost precisely the same as that of the work proposed. The wind, therefore, acts upon both with nearly equal power. But the proposed work is nearly six times as heavy as the Freibourg, and consequently opposes the same force of wind with six times as much resistance.

In fact, all fears on this score for a well constructed bridge are entirely groundless, whether the span be long or short.

COMPARISON BETWEEN THIS AND OTHER SUSPENSION BRIDGES.

To be able to form a better judgment of the relative strength of the bridge here proposed, and that of other well known structures, it will be useful to bring their principal dimensions together.

The nearest approach to this work is perhaps the Freibourg bridge, a structure which measures 889 feet between the points of suspension. This remarkable edifice was designed exclusively for common road purposes; and though forming part of one of the highways leading into a city of eight or ten thousand inhabitants, it is very slightly and cheaply built.

Its weight is 740 lbs. per lineal foot, and no outlay has been permitted in any part of it for the purpose of adding to the stiffness due to its weight.

This bridge is upheld by four cables, each formed of 1056 strands of wire, and containing, altogether, 4224 strands.

In the rail-way bridge under discussion there are to be *twenty-four thousand strands*, or nearly six times as many.

But the Freibourg bridge was twice crossed on the day of its inauguration, by 300 soldiers in rank, marching to military music; a weight of about 20 tons concentrated in a point, and striking the platform with the momentum due to the height of the tread.

On the previous day the flooring of the same bridge was occupied by about 2000 people, also marching in procession, and keeping time to music.

The weight on the platform, at this time, must have been at least 120 tons; but it was not concentrated in a point, as before, and it produced no damage or inconvenience, although it occasioned a very sensible horizontal oscillation.

Now the load sustained on this occasion was considerably greater than that of the heaviest freight trains likely to pass over the Air Line road, while the bridge proposed for the Air Line road is nearly six times as strong, and seven times as stable as this. No doubt can therefore be entertained of the sufficiency of the proposed work.

The next most important of the existing structures of this description, is the Menai bridge, concerning the fitness of which, for rail-way purposes, there has been some discussion among gentlemen distinguished in England both by official eminence and well merited reputation.

It is not necessary to discuss that question here, though it cannot be denied that there are peculiarities in this work so evidently calculated to impair its applicability to rail-way service, for which it was never intended, that its rejection by the engineer of the Hollyhead road should occasion no surprise. The weight of this bridge is 2483 pounds per lineal foot, and the span about 13½ times the sagitta.

The Middletown bridge, as designed, will be 64 per cent. heavier, and for that reason 64 per cent. more stable than this; and the ratio of the span to the deflection of the cables 30 per cent. greater, and the structure from this cause also 30 per cent. stiffer.

In other words, by carrying out the computation, it is found that a weight which would depress the flooring of the Menai bridge *seven inches*, would depress that at Middletown but 3⅓ inches—making the calculation with reference only to the weight of the bridge and the form of the curve.

But there are other arrangements which influence the stability of the Menai bridge in an extraordinary degree, and produce a depression greatly exceeding that which this computation will exhibit. The chains which pass over the supporting towers of that work rest, as these do, on cast iron saddles, which move upon their summits and relieve the masonry of all appreciable horizontal strain. But the stays which pass from the saddles to the anchorage are of extraordinary length—considerably exceeding, in their total development, the whole length of the supporting chains.

The consequence of this feature of the plan is obviously a very great increase of deflection caused by the straightening out of these guys, as well as by the stretching of such great length of material, when extraneous loads are brought on the platform. When the weight comes on the flooring, the guys yield, the saddles move, and the supporting chains of the bridge are necessarily lengthened. A movement here of only one inch on a side, produces a depression of *five inches* in the centre of the arch, in addition to the depression already considered.

The Menai bridge, although substantially built, and as the first great structure of the kind, a remarkable work, is by no means well adapted to conversion into a rail-way bridge—needing a considerable addition to its weight, heavy longitudinal girders for the purpose of distributing the pressure of concentrated loads over a greater length of platform, and a total change of the method of staying, to reduce the range of the movement of the saddles.

Another bridge, which has also acquired some little, but most undeserved notoriety, in consequence of the arguments which have been drawn from it adverse to the adoption of suspension bridges for rail-way purposes, is a small bridge over Tees, on the Stockton and Darlington rail-way.

This work was formerly used for the passage of rail-way trains, but was found to be utterly inadequate to the duty, and was replaced by another under the direction of Mr. Stevenson, an eminent English engineer.

In a report to the directors of the Hollyhead railway, Mr. Stevenson has attempted to justify the expenditure of some two millions of dollars in the erection of a tubular bridge over Menai, by an argument based on the failure of this insignificant structure.

The work which failed was an ordinary suspension bridge, possessing no more strength than was proper for ordinary road purposes, and built, or applied, apparently without any knowledge of the principles upon which this whole question turns.

But what is curious in this matter is the fact, that the bridge by which this imperfect structure was replaced is itself a suspension bridge, but stronger, heavier, better secured, and throughout more judiciously planned for the locality.

The weak and slender bridge failed, because it had not material enough either in the flooring or chains, and because the chains hung too loosely to prevent hurtful oscillations.

The second work succeeded, because the structure is heavier, the chains drawn tighter, the iron girders well bolted down, and sensible measures taken to secure success.

The second bridge, though firm enough for security, also oscillates considerably under the heavy engines in use on that great road; but it might easily have been made still stronger, still heavier and still firmer.

Without meaning to justify the extravagant expenditure that is encountered in the tubular bridge over Menai—three-fourths of which could have been saved by a substantial suspension bridge—we must look with some indulgence upon the feeling that prompts an able man, conscious of his power, to strike out a new path to distinction and seek for argument to justify it. We must judge of such things, too, with an allowance for the peculiar views which prevail in England, where engineers, directors, and even stockholders, are prone to encourage extravagant outlay, for the purpose of excelling in magnificence and originality, and where those practical views of economy and usefulness which here constitute the criterion of excellence, are less stringently enforced than on this utilitarian soil.

ESTIMATED COST OF THE BRIDGE.

We have now gone over every branch of this subject, which appears to be essential to the establishment of the entire feasibility of constructing a safe and sufficient rail-road bridge, across the Connecticut at the point in question. It remains only to ascertain the probable cost of the work, that we may be able to judge whether the advantages of the structure are sufficient to justify the expense of its erection.

On this head, also, we have ample experience, and there is no part of the edifice of which the cost may not be estimated with sufficient accuracy for the security of a contractor, or the necessities of a company.

The cost may be stated to be as follows:—

Estimate.

1,560,000 pounds of No. 10 iron wire, including the cost of manufacture, raising and adjusting, at 10½ cents, - -	$163,800
45,000 pounds of No. 12 wire in the suspenders, at 12 cents, - - -	5,400

220,000 pounds of bar iron, in anchorage, at 7 cents, - - - - - -	15,400
35,000 pounds of bar iron, in bolts, for flooring and parapets, at 7 cents, -	2,450
60,000 pounds iron castings, for saddles, rollers, plates, &c. &c. at 4 cents, -	2,400
35,000 cubic feet of timber, in the flooring and parapets, including framing and raising, at 30 cents, - - - -	10,500
1,000 cubic yards of rock excavation, in levelling foundations, at $1.00, - -	1,000
1,500 do. in fastening chambers, at $4.00,	6,000
5,600 perches of masonry in the Egyptian towers, at $5.00, - - - -	28,000
14,000 do. in abutments, and fastening walls, at $3.00, - - - - - -	42,000
	$276,950

Or, making still further allowances for contingencies, the round sum of $300,000. (See Note E.)

This estimate is sufficient to cover every expense that can reasonably be expected to occur, and leave ample margin for the protection of the contractor. It may be regarded as the proposal of the writer for the work, if a contract should be desired.

CONCLUSION.

It is to be borne in mind, that the structure to which this estimate applies is of extravagant proportions, and far exceeding in strength the real wants of the Company. A bridge abundantly sufficient for all the duties of the Air Line Road, can be erected for little over $200,000; but, as before stated, the Committee desired to have a plan prepared for a bridge of the first order, and equal to all the duties of a great rail-way.

But taking the structure as it is, with all its excess of strength and weight, the cost would appear to be small in comparison with the evils which will be entailed on the city of Hartford, and all the country bordering the Connecticut, from Middletown to the head of navigation, by the adoption of the plan proposed by the Rail-road Company, and resisted by the great interests which it threatens. These evils will consist—

1. In the injury to the navigation consequent on the construction of the bridge, and the effect of that injury upon the commerce and value of property, as far as this injury may reach.

2. The loss of time to all who may hereafter traverse the Air Line Road, by the necessity of a total ascent and descent of 100 feet at every trip of every locomotive passing over the line.

3. The injury to the public, consequent on delays at the draw, which might, of course, be avoided by the higher level.

These are evils which certainly ought only to be encountered under manifest and absolute necessity. No ordinary consideration could justify a company in violating the vested rights of a population of more than 100,000 inhabitants, or putting their common earnings and inheritances in jeopardy. No ordinary considerations could justify a legislature in giving the sanction of LAW to such a violation.

But does that necessity exist in this case? Can it exist, when a structure which involves none of these risks, and none of these certain or contingent evils, can be built for a sum utterly insignificant in comparison with the value of the injury apprehended from the work proposed?

It is vain to urge the necessity of the measure on the ground of the impracticability of the alternative plan—a high bridge at the Narrows. Its practicability can be established by its achievement long before the rail-way will be in a condition to use the work.

It cannot be, then, on the basis of public necessity, or public convenience, that this new road will be permitted to impede the most important entrance into your prosperous city, or to stop up the principal avenue of your commerce and thrift.

The *necessity* does not exist, and the superior convenience is attained by adopting a high level, which leaves the navigation open. There is no motive here, founded on public utility, or defended by the public interest, which can sanction the placing of any impediment in the channel of this stream. And it is not to be supposed, therefore, that the Legislature, under such circumstances, will consent to relieve this Company, important as its intentions may be to the general welfare, from a trifling outlay, at the expense of Hartford—sacrificing existing vested rights of known and real worth, interests that have been built up by years of industrious enterprise, to any speculative object, however laudable, of which the actual value is yet to be submitted to the test of experience.

The great highways that lead into a city are the arteries which flow from the fountains of its wealth; and it is the characteristic of modern legislation to open these channels through hills and over valleys, that the products of the widest possible areas may pour through them into the markets which the cities furnish. The generous emulation which grows up between neighbouring towns promotes that result, and quickens all the elements of prosperity and trade.

To stop up or impede these channels—to cut off the natural inlets of wealth, which have actually given existence to the cities and sustained their growth—are measures which might have been entertained in an earlier age and under more arbitrary governments. But in this country, almost every effort having in view the obstruction in any degree of important navigable waters, has been resisted strenuously and desperately by the towns above the site of the contemplated work. It is, of course, they who are to bear the burden that can best judge of its weight.

Every application of the city of Wheeling for a bridge over the Ohio has been contested by Pittsburg, and successfully contested, until the present Company adopted the bold plan of spanning the stream by an arch of more than one thousand feet, placed quite beyond the reach of steamboats.

The application for the right to build a bridge at Cincinnati, having a pier in the water, has been resisted successfully by the river interest; and will doubtless continue to be resisted, until the applicants decide on a stupendous arch of 1400 or 1500 feet span, and study to promote their own great interests and most laudable wishes, without invading the existing and superior rights of others.

Albany has long sought to place a bridge over the Hudson, and has been desperately and successfully resisted by Troy; and this resistance will certainly continue until a plan is adopted which will attain this most desirable object, and at the same time protect the vast interests created by remarkable enterprise, at the head of that great navigation. (See Note F.)

The Schuylkill *was* obstructed for the convenience of a rail-way, which has added little or nothing to the commerce of the city, while it has annoyed and irritated a large population whose rights were unnecessarily impaired, and whose property was heedlessly injured.

The Susquehanna has not yet been obstructed by a bridge at Havre de Grace; but the application has been made and a contest has of course commenced between the petitioners and the village of Port Deposit. The interests above this bridge are comparatively small; but they are of great value to their owners, and so far have received the protection of their Legislature.

There are circumstances, most undoubtedly, where compensation could be made, in which some sacrifice of an existing interest may be justified for the obvious purpose of promoting a greater public good.

But yours is no such case as this. The land interest and the water interest—the interest of the public using the rail-way, and that of the greater public navigating the Connecticut—are here identical; for the plan that protects the navigation, and leaves the highway which Nature prepared without obstruction, is also that which offers the best line to the land travel; thus giving to the Legislature, the appointed guardian of their respective rights, the double motive for protecting both. Two such interests will certainly not be recklessly violated for any speculative object.

The navigation of the Connecticut above Middletown, is superior to that of the upper Mississippi or Missouri, or any of their branches. It is, in fact, superior to that of any river between the Alleghany and the Rocky Mountains, north of the Ohio. The water is deeper at its lowest stage, steamboats of greater draught traverse it, and the country through which it flows is more densely peopled, and the land more highly cultivated, than that which borders any of the western waters. And there is certainly no city or population which would seem to present a stronger claim upon the just protection of the Legislature and people of Connecticut, than the city and population of Hartford, the staunch opposer of this assault upon her prosperity.

But no party would now be so idle as to ask to place a draw-bridge across the Ohio or Mississippi; no law could be obtained for such an obstruction, and nothing is hazarded by the assertion that such a nuisance would be immediately overthrown, if placed there under the colour of any law. The bridges that are established on those streams, must be placed high enough to clear the steamboats, and must leave the channel open.

These views are submitted with more than the interest which usually attaches an engineer to a professional subject. The wrong which has been threatened, the danger which is still pending over your prosperity, are so manifestly the result of inadequate reflection, and so easily and cheaply to be obviated, that it would be difficult to refrain from the expression of an opinion on that head.

Trusting that these evils may be averted, and your commerce and rights, and all the grave interests of the public protected,

I have the honour to be,

Gentlemen, your ob'dt serv't,

CHARLES ELLET, Jr.
Civil Engineer.

Philadelphia, April 23d, 1848.

POSTSCRIPT.

Since receiving the first proof of the foregoing report, I have seen a copy of a pamphlet, entitled, "A Reply to the Statement of the Citizens of Hartford, &c.," in which I find the following passage:—

"The Hartford statement, with great want of can-"dour, endeavours to communicate the impression "that a rail-road suspension bridge is feasible here, "by asserting that such a bridge, for the same pur-"pose, is in progress of erection across Niagara river, "with a span of 800 feet. And also that a suspension "bridge is being built across the Ohio, at Wheeling. "As to the latter, it is sufficient to say, that it is not "designed for rail-road use; and in respect to the "former, the public ought to know that it is incom-"plete (a single cable only having as yet been stretched "across the chasm, on which the architect is able to "swing across in a basket without breaking it down), "but further, that the entire project is not only looked "upon as chimerical, *but the capital itself is not sub-"scribed.*"

To so much of this extract as is merely intended to discredit a noble enterprise, in which I have embarked my reputation, and, to a considerable extent, my property, I do not deem it essential to offer any reply.

There has been opposition to that work also, and there are parties who have supposed that their interests would be promoted by representing it as "chimerical;" and this misrepresentation has been a greater obstacle to the Company, than any they will ever find in the natural difficulties of the undertaking.

The assertion that "the capital itself is not subscribed," is a very great error, and one which I regret to be compelled to say, rests on no foundation whatever. *It has all been subscribed,* and the Company have entered into a solemn contract with me for the execution of the work, by which they stipulate to furnish the funds as fast as I need them. The work is now in full progress.

Among the Directors and Stockholders are some of the wealthiest and most influential citizens in Canada West and Western New York.

C. E. Jr.

NOTES.

NOTE A.

There are few wooden bridges of which the deflection is less than one inch under the weight of an ordinary locomotive engine and tender. I have caused various experiments to be made on this subject, and have been favoured by intelligent engineers with their observations—which prove that a deflection of one inch under heavy engines is almost universal in bridges of only 130 or 140 feet span.

A depression of $1\frac{1}{2}$ inches is frequent, and from two to three inches occasionally occurs.

A wooden bridge of 100 feet span is ordinarily more strained by a weight which produces a depression of one inch, than a suspension bridge of the same span would be under a depression of a foot; or one of a thousand feet span by a depression of many feet.

A depression of one inch in a bridge of 100 feet span is just as important as one of 10 inches in a bridge of 1000 feet span.

NOTE B.

It can only be in extreme cases, where very heavy trains are conveyed, that the change of grade due to the flexure of the bridge could be an object of any moment; and never until the inclination surmounted by the engine, exceeds the maximum grade ascended by the same engine on other parts of the road.

In the centre of an arch of great span, the flooring offers, comparatively, little resistance; but near the ends, where secured to the abutments, its stiffening effect is greatly increased.

In a weak bridge, or even in a strong one, overloaded, the first difficulty would be experienced in passing from the bridge to the abutment; but, even in very flexible structures, this trouble may be in great measure counteracted by the arched form of the flooring.

NOTE C.

The following is the formula alluded to in the report, which being an approximate result obtained by developing a series, and suppressing the higher powers, must be applied with caution, and not much beyond the limits assigned; and in the application care must be taken not to vitiate the results, by introducing the elasticity of the links in an ordinary chain. Represent by

h, half the span of the arch;

l, one-half the length of the cables, from the apex to the anchorage;

f, the deflection;

a, the cross section of the cables in square inches;

p, the constant weight of the bridge per lineal foot;

π, the weight placed in the centre of the arch and causing its depression;

δ, the value of this depression.

We shall then have this approximate formula,—

$$\delta = \frac{\pi}{4}\left(\frac{f}{p\,h} + \frac{l\,h^2}{900\,a\,f^2}\right)$$

to express the depression of the central point, due at the same time to the change of the figure and the extension of the material of the cables.

NOTE D.

It was the intention to offer, in a note, some cases of this sort; but the experiment is so easily tried by every reader, that it is deemed unnecessary to swell the report for that purpose.

NOTE E.

The quantity of masonry exhibited in this estimate is greater than would be really necessary for the execution of the work. The object not being to limit the cost to any very low figure, considerable latitude has been taken in adjusting the proportions, with a view to symmetry and effect.

The price affixed to the masonry of the abutments and wings may appear small; but as a considerable portion of the work consists of a massive wall which supports nothing but the rail-way track, it will, I doubt not, be found sufficient.

NOTE F.

There is, perhaps, no place in this country where the erection of a bridge across a navigable stream can be sustained by as great an interest, and as many important considerations, as at Albany. But the people of New York have hitherto respected the prior rights of Troy, and prohibited the obstruction of the navigation, to which that flourishing city owes its existence and prosperity. Nevertheless, the want of a bridge at Albany is becoming annually more imperative, and on the completion of the Hudson river rail-road, and the numerous great lines and tributaries progressing in the West, a bridge *will be made* across this stream, on some plan which will leave its navigation free.

It is perfectly practicable for all the rail-roads to maintain a high level at Greenbush, and crossing on a suspension bridge, raised entirely above the masts of all the shipping—leaving the whole channel clear—land their passengers in the heart of the city, and in a station worthy of the great interests that would be there concentrated.

In this case, as at Middletown, the same plan would obviate a considerable portion of the ascending grades, leading up from the river in each direction, and by promoting the common interests of the several roads and the city of Albany, justify a combination of all their strength to effect the object.

The cost of such a work would certainly be large, but nevertheless, it must, sooner or later, be encountered.

Ellet

Report on a railway suspension bridge ...