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# Report and plan for a wire suspension bridge proposed to be erected over the Ohio river at Cincinnati

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## Cincinnati, 1846

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# REPORT AND PLAN

FOR A

# WIRE SUSPENSION BRIDGE,

PROPOSED TO BE ERECTED

# OVER THE OHIO RIVER AT CINCINNATI.

BY JOHN A. ROEBLING,
CIVIL ENGINEER.

CINCINNATI:
J. A. & U. P. JAMES, WALNUT STREET.
JOHN OCHELTREE, PRINTER.
1846.

To ROBERT BUCHANAN, Esq.; JAMES TAYLOR, Esq.; PAUL ANDERSON, Esq.; JOHN K. McNICKLE, Esq.; REUBEN R. SPRINGER, Esq.; CHARLES A. WITHERS, Esq.

Gentlemen:

Agreeably to your request, I have investigated the project of constructing a *Wire Cable Suspension Bridge* across the Ohio river between Cincinnati and Covington, with all that care and attention to which, from its magnitude and importance it appears to be entitled.

The following report and accompanying plan are the result of my labors, and are respectfully presented to your consideration.

As one of the great thoroughfares of the country, and spanning one of the great rivers of the West, this bridge, when constructed, will possess great claims as a national monument. As a splendid work of art and as a remarkable specimen of modern engineering, it will stand unrivalled upon this continent. Its gigantic features will speak loudly in favor of the energy, enterprize and wealth of the community which will boast of its possession.

With the sincere desire that this noble and eminently useful project may receive that general support, which it so richly merits,

I remain, gentlemen, respectfully,

Your obedient servant,

JOHN A. ROEBLING,

*Civil Engineer.*

Pittsburgh, September 1, 1846.

# REPORT

ON THE

# CINCINNATI BRIDGE.

The object of the following report, is to explain the principal features of the accompanying plan of a *Wire Cable Suspension Bridge*, proposed to be erected over the Ohio river between Cincinnati and Covington, and to present such data to the consideration of the public, as to enable it fully to discuss the merits of the enterprise, and to decide, whether it is deserving of a general support, or not.

Whatever we undertake in opposition to public opinion, if that opinion is the result of a careful investigation, must turn out a fatal enterprise, and cannot succeed in the end. In this report, therefore, we will endeavor to be guided by truth and facts alone. We invite those who interest themselves, either for or against, to meet us in the same spirit, in those discussions, which no doubt will be carried on, before the public mind can rest satisfied.

In order to facilitate the examination of the subject before us, I propose to consider it under several distinct heads, arranged as follows:

1. General Remarks.
2. Location of Bridge.
3. General Description.
4. Anchorage.
5. Cables.
6. Suspenders.
7. Stays.
8. Floor.
9. Grading.
10. Practicability of proposed Work.
    - a. *Adequate strength of Cables and Stays.*
    - b. *Security of Anchorage.*
    - c. *Solidity of Foundation.*
    - d. *Stability of center Tower.*
    - e. *Effects of Ice.*
11. Comparitive merits of One or Two Spans.
12. Investment.
13. Construction.
14. Estimates.
15. Table of Quantities.

## I. GENERAL REMARKS.

The right of States bordering on the Ohio river, to grant charters for the erection of bridges over that stream, has been repeatedly and unqualifiedly negatived by those who are opposed to the erection of such structures. The opponents rest their arguments upon the ground, that the free and uninterrupted navigation of this river is a national object, paramount to any individual or state interest. And this, as a general proposition, is to be admitted as correct.

On the other hand, it appears but justice that the states should be allowed the right of forming communications across the river, accessible at all seasons, for the promotion of commerce and intercourse, provided such communications do not impede the navigation.

The time is not very distant, when millions of people will crowd both shores of the Ohio, and when the question of *bridging* will become highly important to the *landsman* as well as to the *riverman*.

A bridge may obstruct the navigation of a river in a twofold manner, either by the piers or the low elevation of the arches and of the roadway. But can we not decide upon certain limits, which will not only effectually guard the navigation against abuses in bridge-building, but at the same time admit the practicability of such structures in locations where they are really wanted? No fear need be entertained, that the right of bridging will be abused by every little community situated on the banks of the Ohio. In the first place, no bridge can be erected without a charter, which will not be granted without previously discussing the merits of the plan and enterprise. Secondly, the great expense of works, so constructed as not to interfere with the free navigation of the river, and which alone can be chartered by the states, will of itself be a sufficient check. No company will be willing to risk its capital in such a work without the certainty of a fair return, which can only be expected in locations, where there is a vast intercourse, and therefore a necessity for a bridge.

The idea of bridging the large rivers of the West, could not be entertained before the system of suspension bridges was fairly introduced. An attempt at this mode of building in the United States was made about forty years ago, when a number of chain bridges were erected upon a rude and insufficient plan. Although these attempts failed, they clearly demonstrated the practicability of the system. That no further efforts were made to perfect the plan, was not so much owing to the difficulty of construction, as to the great abundance of good timber in most parts of the country, which greatly facilitated the construction of wooden bridges, and reduced their first cost.

The solution of the problem of crossing large and deep rivers with great spans and at high elevations, was left to modern engineering. It has been fully solved by the application of the principle of suspension. Numerous structures of the kind have been reared in different parts of Europe, in the course of this century.

The suspension bridge across the Menai strait, in Wales, built by the English government, under the direction of Mr. Telford, is still considered a great national monument. This bridge is thrown across the strait in one principal span of 560 feet wide from centre to centre of abutment, and at an elevation of 121 1-2 feet above low water, the tide rising 21 1-2 feet. All classes of merchant vessels and steamers sail under it. When the erection of this bridge was proposed, the question of its interference with the navigation was considered by the admiralty. No objections were made to the proposed span and elevation of floor. The same subject has again and quite recently, occupied the attention of the English admiralty. The Chester and Holyhead Railway Company is about constructing a railroad bridge over the same strait, and is allowed to reduce the length of the two middle spans to 450 feet.

It would appear that spans of 400 feet are ample for all purposes of navigation. But there is no necessity of adopting this limit on the Ohio river. The construction of suspension bridges is now so well understood, that no competent builder will hesitate to resort to spans of 1500 feet and more, where localities may require it, and where the object will justify the expense. It may be observed here, that as a general rule, the expense of a superstructure will be in proportion to its span. Large spans will therefore not be adopted without necessity. There are locations, however, where a large span alone is practicable, as where expense can be saved by their adoption, in consequence of the reduction of masonry. The largest suspension bridge in the world, with spans of 1000 feet, is now being erected over the river *Danube*, at *Pesth* and *Ofen*, in Hungary, at an elevation sufficient to leave the navigation unobstructed. But it is on the great rivers of the *new world*, where this system of bridge-building will, in course of time, be fully applied and perfected.

The next consideration which is entitled to our attention, is the *elevation* at which the roadway or floor of a suspension bridge should be suspended above the river, so as to be not only above the reach of the highest flood, but to leave also the navigation unimpeded. The supposed want of height for the free passage of steamers has indeed been the most fertile source of opposition to the construction of bridges over the Ohio river. I propose to enter into the discussion of this question more at large, and I flatter myself, that the subsequent remarks will be sufficient to remove the fears of those who *honestly* believe all bridges to be fatal to the navigation. I should not countenance a scheme which was calculated to bring about results so disastrous. The remark has been made by the commander of a steamer, that he should consider any bridge an obstruction, even if erected at an elevation of two hundred feet. Such objections are, of course, beyond the reach of argument, and not deserving of any notice.

The floor of the contemplated bridge is proposed to be suspended at an elevation of 90 feet above *low water*, near the wharf, and at an elevation of 121 feet near the pier. From this we have to deduct 4 feet of framing below the floor, leaving 117 feet clear next the centre pier, and 86 feet next the wharf.

### THE HEIGHT OF CHIMNEYS OF STEAMBOATS.

| | | | | | | |
|---|---|---|---|---|---|---|
| *South America* | measures | 63 | feet above | water, with | 12 | feet joint. |
| *Eldorado* | " | 59 | " | " | 10 | " |
| *Wisconsin* | " | 54 | " | " | when | light. |
| *Clipper, No.* 2, | " | 64 | " | " | " | " |

The last named boat is the largest Packet now running on the Ohio river between Pittsburgh and Cincinnati.

The largest Packet on the Cincinnati and Louisville line, *Pike, No.* 7, has the following measurements, taken by myself:

| | |
|---|---|
| Hull, when light, measures | 4 feet. |
| Boiler deck measures | 15 " |
| Cabin deck " | 8 " |
| Chimney above deck measures | 42 " |
| Top of chimneys above water, | 69 feet. |

All elevations noted in this report, or in the plans, are referred to low water line, which is assumed at 63 feet below the high water mark of 1832, which mark is permanently exhibited at the corner of Main and Water streets, at Cincinnati. A depth of water in the river of 20 feet above low water mark is considered a medium stage; 30 feet is called high water; 45 feet is a flood, which seldom occurs. A flood of the height of 1832 may not be witnessed again in one hundred years: it should therefore not be considered in the question before us. When the river is running so high, navigation is extremely dangerous, particularly at night. All the wharves, warehouses and lower portions of towns situated on the banks, will be under water; no freight can be discharged nor taken in; business is entirely suspended for the time: therefore boats will, if possible, lie by in safety until the water has commenced falling.

Let us suppose the river to be 45 feet high, which is an unusual rise; this will leave 72 feet clear height near the centre pier. Pike, No. 7, measuring 69 feet, will therefore have 3 feet to spare in clearing the bridge. But most of those Packets which run in the lower trade, are provided with joints for lowering the chimneys, for the purpose of passing the arch over the Louisville canal. By lowering the chimneys, therefore, the largest class of steamers will be enabled to pass the Cincinnati bridge in the highest stage of water. It has been stated to me that the *Magnolia*, a boat in the lower trade, has chimneys 10 feet higher than Pike, No. 7; this steamer, however, seldom comes to Cincinnati.

The observation has been made, that for a series of years, boats have increased the height of their chimneys;—is it inferred from this, that no one could tell where they would stop? If it was established, that the growth of chimneys was in a direct proportion to the power and capacity of a boat, then the previous observation would be entitled to serious attention. But fortunately, the very reverse will be found to be the fact in future. Paradoxical as this may appear at first sight, it is nevertheless true, and will be assented to by those who have made themselves acquainted with the principles of the steam engine and of steam generators.

The steam engine has, in its main features, not been improved materially since the days of James Watt. This great engineer had investigated the nature of steam and its application to various movements so thoroughly, that he discovered almost all that can be discovered. He foresaw the extent to which the expansive action of steam could be usefully applied. His calculations have been verified by the astonishing results furnished by the working of the *Cornish* engines. The average effect of a high pressure engine, such as are in use on our western waters, where steam is worked under a pressure of one hundred pounds and upwards, and used expansively to some extent, does not exceed thirty millions of pounds raised one foot high, by the consumption of one bushel of coal. Now there are this day many engines at work in the mines of Cornwall, doing an average duty of over one hundred millions of pounds of water raised one foot high. What a vast difference! These astonishing results have been denied for a number of years by those engineers in Great Britain residing out of the mining districts. It is only a few years since the fact of the superior working of these engines has been generally credited, and considered as established.

But the question may be asked, how is it possible that this great discrepancy between the effects of steam on our western waters and those of Cornwall and other districts, has so long escaped the attention of the first mechanics of the day? It is difficult to attempt an answer. But it is sufficient to know the fact, that it *has* escaped them; and that those who are engaged in the construction of steam engines and of boilers, have yet a vast field left open for the application of their skill and ingenuity. If I am not misinformed, the credit of the present plan of boilers, as used on the western waters, is due to the late Oliver Evans. Although this plan is susceptible of great improvements, but little has since his time been added. The time, however, is fast approaching when the saving of fuel will become an important object. When we add to the first saving of expense of fuel, the additional power obtained by a machinery no more expensive, the saving of time, greater safety of the vessel from fire, reduction of firemen's wages, greater comfort of a boat where less heat is allowed to waste from the furnaces and boilers,—the aggregate benefit resulting from these improvements will be astonishing!

But it may be asked, what bearing has all this upon the bridge? I would answer this question by another:—why object to the bridge on account of the high chimneys? High chimneys are the strongest proofs of defective arrangements, they will disappear from our rivers sooner or later, as improvements advance. They are objectionable in every aspect;—if they could be forced from our rivers by some low bridge, it would be the greatest service which could be rendered to the navigation of our western waters.

The ostensible object of high chimneys on board of steamers is, to create more draft. Now, it is fully established, and generally known, that *economy in fuel is inversely as the rapidity of combustion*. And, on the other hand, *the escape of lost heat and unconsumed fuel up the chimneys, is in direct proportion to the draft*. These, and a few more points, are already better understood on our eastern waters, and in ocean navigation, where economy of fuel is a greater desideratum than here in the West. Chimneys on eastern boats are much lower than on western boats; they are still lower on ocean steamers, where high stacks are very objectionable. The question of an increased speed is there not solved by simply raising the chimneys and increasing the draft, but by other means, a little more creditable to science.

My remarks upon chimneys have extended beyond what was contemplated. But I had to enlarge upon this topic to meet those objections raised against the project in question, on account of these high chimneys. I am free to maintain, that, in future, the power and value of a boat will be estimated, not by the height of chimneys, as is now the case, but by their lowness. *Low chimneys on a powerful boat will be the best proof of a superior arrangement for the generation of steam*. But, as there are a number of boats still running which carry high chimneys, and as this fashion is likely to continue for some time yet, we shall be obliged to adopt in the construction of the proposed work, an elevation unnecessarily high. I have assumed an elevation of 121 feet at the centre pier as the maximum to which I can consent.

As an additional comment upon chimneys, I will add, that there is an easy method of raising and lowering them, which is practiced on most of the ocean steamers, and deserves to be known and applied on our western waters. Apart from the passage of bridges, or waste of fuel, high chimneys prove objectionable in other respects. They increase the surface exposed to head-winds, make the boat top-heavy, and are in danger of being knocked off, or becoming entangled among the branches of trees, when the boat is running near a shore. All these inconveniences can be avoided by arranging fifteen or twenty feet of the top for sliding. To effect this, the top of the outside, or stationary portion of the chimney, is made two to three inches wider than the rest, and its termination armed with a heavy cast-iron ring, to which four seats are cast for the reception of four little sheaves, which serve for the working of four chains, or wire ropes, for the support of the inside or moveable part of the chimney, and at the same time act as guides. Weights are to be attached to the outside portion of the ropes, to balance the weight of the sliding chimney. A very small force is required to raise or lower it, as the case may require. This plan will be a great improvement upon the old joint, although a little more expensive at first.

Another objection remains to be considered, which, at first sight, appears more formidable still than high chimneys. It is the passage of sailing vessels, built above Cincinnati, and sent to the ocean full rigged. On this question I have eased my mind by conversing with a competent and intelligent seaman. Capt. R. L. Browning, of the U. S. Navy, a resident at Cincinnati, has authorised me to state, that there is no necessity whatever to *step* the masts of a vessel, *before* she gets to New Orleans, for the purpose of towing,—and that her rigging, when put up, will only prove an impediment to her easy towing. This appears very plain and correct to a landsman, but I have cited *naval* authority to meet objections raised by watermen. The *barque* built last year at Marietta, and commanded by Capt. Lewis, measured 300 tons burden, and was 40 feet high from the water to the lower mast-head, according to Captain Browning. Vessels of that description, therefore, may, if they choose, pass the bridge in the very highest stage of water with the main-mast up. Nor will the bridge prove an obstruction to the passage of that large class of iron steamers constructed at Pittsburgh. These vessels will, when the works at Memphis are finished, have there the best opportunity of shipping their masts, which operation is not so easily performed at other places, where no machinery is erected for the purpose.

## 2. LOCATION OF BRIDGE.

During my visit at Cincinnati in May last, Mr. R. H. Rickey and myself made a survey across the river from Cincinnati to Covington, in line of Main street. The distance from the corner of Wharf and Main street on the Cincinnati side, to the corner of Garrard and Wharf streets on the Covington side, was found to be 1658 feet. This survey, for the present purpose, is sufficiently accurate, and as it is the only one I have made, I have adopted its profile for the plan, which is hereby submitted to your consideration. Although the line of Main street appears to possess some superior advantages, it does not follow that it has been definitively chosen for the location of the bridge. It may be observed here, that a bridge is perfectly practicable at any point of the city. The general wants of the community will have to be duly considered in the choice of a site, taking into consideration the degree of facility of construction offered by the different locations.

As the charter granted by the legislature of Kentucky leaves the location of the bridge entirely at the option of the Company, it is very important that the same liberal provision should be inserted in the charter to be obtained from the legislature of Ohio. It will be the interest of the Company to select the best location; and as their interests and those of the community are identical, the public will be best served if the Company is left entirely free in its choice. Where the business of the community can be best promoted,—wherever the greatest intercourse is likely to be, and where the approaches of the bridge do the least injury and offer the greatest accommodations,—there will be the most advantageous site.

A greater difference exists between the many sites which present themselves, with respect to the nature of the river bed, its width, and the form of the banks. On this, the engineer who plans the work should be necessarily consulted. The bank on the Kentucky side rests upon a stratum of limestone, which, from all appearance, extends across the river. If so, the foundation of the centre pier may be laid on rock. Nothing positive has been ascertained on this point, nor is it very important that there should be a rock foundation. If rock can only be found at a great depth, a pile foundation will be as safe, and much cheaper. Or a common timber foundation may prove sufficient, if the ground should be found favorable to it. As the river bed consists of gravel, its character will warrant the stability of almost any kind of foundation, provided it is always guarded against undermining by an extensive riprapping or stonefilling.

## 3. GENERAL DESCRIPTION.

The plan of the bridge, as has been remarked before, is adapted to the profile of the river bed, in line with Main street: the dimensions, therefore, have reference to that locality. The centre line, or axis of the bridge, is supposed to be located at a distance of 55 feet from the lower side of Main street. An open street, as a continuation of Main, would, therefore, be left between the lower return wall of the abutment and the houses now fronting the wharf, of 75 feet wide. The length of the bridge, from centre to centre of the abutments, is 1576 feet, total length, including approaches, 2070 feet. Two spans are proposed, which will meet in the centre of the river upon a gigantic stone pier, of 200 feet high. Three-fourths of the whole suspended weight of the bridge will be supported by this pier.

The river front of the Cincinnati abutment will be opposite the corner of Wharf and Main, and nearly in line with Wharf street. It will, therefore, not present any impediment to the current of the river when high. The houses fronting the bridge, will be protected by the return walls against the current. These walls extend from the abutment to Front street, leaving the latter entirely free. The length of abutment is 50 feet, the extreme width across the return walls, opposite Water street, will be 44 feet, and reduced to 38 feet at Front street. There will, therefore, be a space occupied on the public landing of 290 feet long by 44 feet wide, leaving the wharf between the abutment and the edge of the river entirely free and open. The approach on the Covington side is very nearly the same as on the Cincinnati side. The uniformity and symmetry of the two ends will add much to the splendid appearance which this great structure will present to the eye of the traveller who approaches the city by the river.

The tower in the centre of the river will, on account of its gigantic proportions, form the most conspicuous part of the whole structure. The total height of this masonry from the foundation will be over 200 feet, and 194 feet above low water mark. Its lateral dimensions are proportioned to its height. This structure has been planned with a view of obtaining the greatest stability, with the least amount of material, and with reference to the comparative expense of labor and material. Its main body consists of two solid walls of 12 feet by 20 feet on top, and 15 feet by 43 feet on bottom, carried up 200 feet, parallel to each other, at a distance of 45 feet apart from centre to centre, in the direction of the river. A connection is formed on the foundation and by two arches above. In order to increase the stability of these walls, they are strengthened by buttresses, which are 15 feet wide at bottom, 7 feet at top, and batter 14 feet. The cubic contents of this pile of masonry will be 12000 perch of 25 cubic feet each. No part of this masonry can be reduced with safety: it will be explained in another part of this report, how the stability of the whole bridge depends upon its proportions.

Each of the two spans measures 788 feet from centre to centre: the length of floor between the abutment and pier is 748 feet.

Two isolated towers of 30 feet high and at a distance of 30 feet apart from centre to centre, are erected upon each abutment, for the support of the cables. The latter rest in cast iron saddles, which are allowed to move on rollers, for the purpose of adjusting the tension of the land cables, as they contract or expand, either from changes of temperature or from loads. The castings which support the cables upon the centre tower, are stationary and not allowed to move.

The floor of the bridge, which is divided into carriage-way and two sidewalks, is to be composed of timber and plank, and to be suspended by means of two wire cables and a number of wire stays. The arrangement and construction of all these different parts will be more fully explained in the next paragraphs.

## 4. ANCHORAGE.

The end of each cable will be spread out in seven parts, which will connect with as many chains, manufactured in solid bars of the best hammered charcoal iron, similar to those which I applied on the Monongahela bridge and on the aqueduct at Pittsburgh. The plan of anchoring which I propose for this work will, in its main features, be but a modification of the plan applied at Pittsburgh. Each of the seven anchor chains will descend by itself through the masonry of the return walls, not in a straight, but curved line, the last link occupying a vertical position, and connecting with a cast iron plate of great strength, which supports the foundation of the superincumbent masonry. The whole arrangement will be such, that no unequal settling, which would slacken the one chain and tighten the other, can take place. In proportion to the magnitude of the forces, adequate means will be applied to meet them. These forces can all be accurately determined and estimated, and, therefore, be controlled with safety. As the success of the anchorage, however, depends much upon the resistance of the masonry, the necessity of a very careful construction of the return walls becomes evident.

## 5. CABLES.

The floor of the bridge is to be suspended to two wire cables, of 11.28 inches diameter each, by means of suspension rods. They will be prepared in the places in which they are to remain, and suspended in a somewhat inclined position between the roadway and the sidewalks. The formation of these cables is to commence after the completion of the masonry and of the anchorage. Arrangements similar to those used on the Pittsburgh aqueduct, but on a more extensive scale, will be made, and my patent machinery applied for the traverse of the wires across the river. Each cable will be composed of an assemblage of 5500 wires of one-eighth inch thick. When laid, they will be *wrapped* by wire of a smaller size, by means of my patent wrapping machine. A cable thus finished, presents the appearance of a perfectly round, smooth, and solid cylinder, which it greatly surpasses in strength. The success of the manufacture, although simple, depends entirely upon the intelligent observation of the workmen who have charge of it, and who should be willing, conscientious, and well trained by previous practice.

Wire of the size used in cables, is in the proportion of about one-half stronger than good bar iron of one inch square. Bar iron of a larger size, if not manufactured under the hammer, and of a selected material, is still weaker. Good wire of one-eighth inch thick, should bear at the rate of 90,000 pounds, and upwards, per superficial inch. Those who have experimented on the strength of bar iron, and have witnessed the rupture of large pieces of wrought or rolled iron, are aware of its *comparative* want of strength in such dimensions. It is, indeed, difficult to estimate the strength of large wrought iron shafts; to insure them, the greatest abundance of material has to be applied. The strength of iron will be found in proportion to its specific weight, and this in proportion to its density. The latter qualities are imparted to the fibres principally by mechanical action, either by compression or impact. In proportion as the size of iron is reduced under this process, will the tenacity of the fibres be increased. The process of wire-drawing appears to be peculiarly well adapted to consolidate the fibres and improve their tenacity. The finer the wire the stronger it is, but at the same time, the more expensive. But there is a certain size which yields the greatest strength at the least expense, and this is selected for bridge building. The average strength of good puddled iron, one inch square, may be rated at 50,000 lbs.; good hammered charcoal-iron, of the same size, will bear 60,000 lbs. and upwards. The strength of bar-iron varies very much, and greatly depends upon the quality of the bloom, or pig, from which it is manufactured. Another valuable quality of wire, which should be mentioned here, is the superior degree of elasticity it possesses over bar iron, and which is the result of the forcible compression of its surface during the process of drawing.

The English engineers have to this day refused the application of wire cables, in place of chains, for suspension bridges. The winters in Great Britain are less severe than on the continent of Europe, and in this country; there is, therefore, in that country less danger to be apprehended from the effects of intense cold than there is here. The reduced strength and sudden rupture of bar iron, in cold weather, cannot have escaped the notice of those who are in the habit of paying attention to such matters. Now it is well ascertained that the strength of wire is not affected, in an appreciable degree, by any changes of temperature which may take place in the atmosphere. The great safety and dependence on wire, in this respect, should alone be a sufficient reason to give it the preference over bar iron in the construction of suspension bridges. The fact, that wire cables are much safer than chains, appears to have been entirely overlooked in Great Britain.

The solid anchor chains, which I have employed on the Pittsburgh aqueduct, and on the Monongahela bridge, have been manufactured of a superior material, and with great care. On the Cincinnati bridge, however, I propose to continue the wire cables below ground for some distance, before they connect with the anchor chains, so that the latter may be altogether out of the reach of frost, and not exposed to any changes of temperature.

A cable is composed of a great number of strands. Admitting that a few unsound wires should, in spite of all care and vigilance, find their way into it, their number will be too small to affect the strength of the whole materially. We therefore obtain a combination of strength, which can be depended on for its uniform disposition. To guard the wire against oxidation, each single strand is coated with a durable varnish before it goes into the cable, and the latter is again saturated and copiously painted. No further precaution has been considered necessary for the preservation of those cables which have been constructed in Europe. But in order to insure their durability still further, and to improve their appearance, I have invented a machine by which a continuous *wrapping* of wire can be laid around, perfectly close and tight. Neither air nor moisture can penetrate a good wrapping, and if it is kept painted, no further precaution is necessary for the preservation of the cable. This improvement has been applied on the cables of the Monongahela bridge, as well as on those of the aqueduct.

The advantage of a well manufactured wire cable is, that while it lasts equally as long as solid bars, it possesses a far superior degree of strength, which can be depended on at all degrees of temperature. But in order to cause each strand to bear an equal share of the whole strain, the tension of the different wires must be exactly alike, and this is not so easily effected as might at first sight appear. To insure a perfect cable, much experience and judgment is required, and a constant vigilance and caution is to be exercised. Green hands cannot be trusted with any part of this delicate operation without being previously well instructed, and constantly watched duriug the progress of the work. It is not considered necessary here to enter into the details of construction, nor could the operation of a somewhat complicated machinery be well understood, without being illustrated by numerous drawings.

Before closing my remarks on the cables, I will explain the mode by which they, as well as the anchor chains, will be preserved under ground. The method usually adopted by European engineers in the construction of the anchorage of suspension bridges, for the passage of the chains or cables, is to form a hollow channel in the anchor-masonry or in the rock, as the case may be, and to leave this passage open for the free admittance of those persons who have charge of the structure, and whose duty it is to examine the fastenings from time to time. When I devised the plan for the Pittsburgh aqueduct, I had necessarily to depart from the old and long established mode of building. I could not, with any hope of success, resort to open passages and expect to keep the water out, while it was in the aqueduct. I therefore concluded to wall the chains in solid masonry, and to preserve them against oxidation, first by two coats of pure *red lead*, and secondly, by surrounding them completely, while the walls were carried up, with hydraulic cement. Pure calcined lead, mixed with boiled linseed oil, furnishes, as is well known, an indestructible paint. The oil may, in course of time, disappear, but the lead never will; it will preserve the iron against oxidation as long as it remains in contact with it. The hydraulic cement forms a compact body around the iron bars and the cables, impervious to air and water. And as it is left below ground undisturbed, its settling will take place slowly, but surely, and without shrinking. As a solid incrustation, the cement will afford an adequate protection to the chains, as well as to the cables. In addition to this, it is well known that a coat of lime or calcareous cement is a most effective preservative against rust. The greater affinity of oxygen for lime will prevent its combination with iron until the former is completely crystalized. Should moisture find its way to the iron, it will not reach it without passing through a large body of lime mortar and cement; it would, therefore, be rendered calcareous, and add another coat of lime to the iron. By the above method, it is proposed to insure the chains and cables underground against oxidation, and thereby to render that constant vigilance unnecessary, which otherwise would be indispensable for the preservation and safety of the structure.

## 6. SUSPENDERS.

The floor of the bridge, as has been remarked before, is suspended to the cables by means of suspenders, placed four feet apart, and made of the best charcoal iron. The thickness of these suspenders differs; they are to be of round iron, one inch in diameter within 200 feet from the centre tower, one and one-eighth inch in diameter within the next 100 feet, and one and three-sixteenth inch thick for the rest of the floor. They will all terminate at the lower end in screwbolts of one and one-fourth inch thick. All suspenders over 15 feet long are made in joints. Their connection with the cables is formed by straps, which nearly encircle them, in a manner similar to the plan applied on the Monongahela bridge. The reason of the reduced size of the suspenders near the pier is, because their tension will be almost entirely relieved by the stays.

## 7. STAYS.

On inspection of the plan, thirty lines will be observed on each side of the tower, descending from its summit to the floor in a diagonal direction; these indicate the stays which I propose to employ as an additional means of support to the floor, as well as one of the most effective means of guarding against vertical vibrations, and to check them when they do take place. Another, and a most important object to be accomplished by these stays, is to counteract the effects which heavy loads may have upon one span, while no load is on the other. In that part of my report where I treat of the practicability and safety of the structure, this action will be more fully explained. Each pair of stays, occupying a corresponding position on the two sides of the centre tower, is formed of one single *wire rope*. Each group of stays is divided into four parts, each part resting upon a separate saddle, on the summit of the tower. There are, therefore, eight saddles, each allowed to move independently of the other, on *rollers*, so as to regulate the tension of the several divisions of stays when they are affected by heavy loads, and in proportion as these loads proceed upon the floor. It must be observed, that the stays are to act entirely *independent* of the cables. The latter are stationary, fastened upon the summit of the tower, and not allowed to move. When one of the spans is overloaded its floor will be a little depressed, and consequently act upon the stays, which in their turn will yield a little, and in proportion tighten those on the other span, until the latter become so much strained by the resistance of the floor, that their tension will be balanced by the tension of the others. The effect upon the tower will be no other than a quiet vertical pressure, the *result* of the tension of the stays, directed through the centre of the masonry.

I am aware that several remarkable specimens of suspension bridges have been erected, where no use at all has been made of stays, while on some others they have been applied to an excess. Theoretical investigations, as well as experiments lately made, have convinced me of the utility of stays when judiciously applied. As regards their power to support, it may be observed here, that they can, in all cases, be applied to advantage, if not extended far beyond the limit of the *tangent* of the cables. The objection has been made to stays that they do not act in concert with the cables. This may be correct when applied to some bridges in Europe, where the floor, in consequence of a too light construction, too easily yields to the weight of a transitory load, and where the length of suspenders has been accurately determined for a *catenary* or *parabola*. The great assistance rendered by stays to cables, will cause the latter to sink at the centre and rise at the ends. The catenary curve of the cables will therefore be changed, the length of suspenders will not agree with our calculations, and we must resort to a practical mode of adjusting them. But these little difficulties are easily overcome, and the trouble will be amply rewarded by the greater perfection of the work. The few stays applied on the Monongahela, are fulfilling their object and add much to the stiffness and solidity of that structure. The system of stays proposed for the Cincinnati bridge, will not only increase its strength and stiffness, but also add much to its appearance.

## 8. FLOOR.

The floor will be constructed of well-seasoned white pine timber and plank, and will be divided into a roadway of 20 feet 6 inches wide, and two side-walks of 6 feet wide each. The distance across the floor, between the railings, will be 34 feet. The floor itself will be composed of two courses of plank, the lower course running in the direction of the bridge, the second course laid across. The first course on the roadway will be two and one-half inch white pine, the second course two and one-half inch white oak. The two courses on the side-walks will be two inches each, and of white pine. The bearers upon which the floor rests will be arranged in pairs of four feet apart from centre to centre. The roadway will be divided into two tracks, but so that the division will form no impediment to driving from one to the other. If, for instance, a driver on horseback, or a light carriage, wishes to be ahead of a heavy slow-driving team, they can turn out upon the second track and then return upon the first. The side-walks will be separated from the roadway by the cables, suspenders, stays, and fender-rails.

The plan to be adopted for the construction of the floor will, in its main features, be the same as was applied on the Monongahela bridge, but more perfect in all its parts, and, in consequence, more expensive. The rigid economy which had to be observed on the Monongahela, did not admit of some important improvements, which I contemplate to introduce on the Cincinnati bridge, and which are the result of long study and experience. The floor of the Monongahela bridge, when heavy teams are passing over it, is about as stiff and stable as a common wooden arch bridge of the same spans. The vibrations caused by more light and rapidly moving loads are greater, but not so great as to be very perceptible. A higher degree of stiffness will be required for the Cincinnati bridge. It does, however, not follow that the flexibility of the floor of a suspension bridge increases with the length of a span. There are means at the disposal of the engineer, which will enable him to impart to a large span a greater stiffness and more stability than is at all requisite for a smaller one. A transitory load bears a smaller proportion to the weight of a large span than to a small span. By disposing of this larger quantity of material in such a manner that every portion will add to the stiffness of the structure, it will become apparent why large spans can be made as stiff or stiffer than smaller ones.

The cables on the Monongahela bridge are four and a half inches in diameter, on the Cincinnati bridge they will be over eleven inches, or more than six times as heavy. Cables of this huge size compactly wrapped, so as to be nearly as rigid as a solid cylinder, will, of themselves, possess a stiffness which could not be overcome by the passage of the heaviest team in any perceptible degree. How much the stiffness of cables diminishes with their size was plainly observed by all those hands on the Monongahela bridge, who had been previously at work on the cables of the aqueduct, which are seven inches in diameter. The greater degree of rigidity which a wrapped cable possesses over a chain, constitutes one of its superior features. It may also be observed here, that one single cable possesses more stiffness than if divided into two, as is the case on the Freiburgh bridge in Switzerland. This work forms one single span of 890 feet long, and is supported by four cables, arranged in two pairs, one on each side. When the floor of a suspension bridge is set in motion by a heavy gale of wind or a hurricane, then the strength of the cables will be tested more severely than by any loads which could possibly be brought upon the floor. In this case lateral motion as well as vertical oscillations would take place, and then the superiority of one undivided cable over a number of cables would become apparent. The undivided cable would always resist with an undivided strength, while of those which are separated, one may be overstrained at a moment when the other is comparatively slack.

As regards the solidity and stiffness of the floor, I will further remark, that nothing will be omitted which is calculated to add to this much desired feature of a suspension bridge, without increasing its weight materially. It will be difficult to convince those who are skeptical on this point; they will however have to acknowledge that the Monongahela bridge possesses all the stiffness requisite for such spans. In place of convincing we can only persuade them to postpone their judgment until they shall have an opportunity of seeing it refuted on the bridge itself when finished. The plan of railing, devised for the Cincinnati bridge, will contribute much to its stiffness, and at the same time much improve its appearance.

Before dismissing the subject of the floor, the question of its durability should be considered. The principal material to be applied in its construction, will be white pine timber, with the exception of a few pieces of the upper floor of the roadway, which will be composed of white oak. We are accustomed to see all bridges covered with roofs. Even for aqueducts, to which roofs are a positive injury, they have been considered indispensable. That system of arching and trussing, which has been most generally approved for wooden bridges, renders framing of great depth absolutely necessary. On the rise of an arch on the depth of a transframe, its strength mainly depends. But high trusses and arches will only preserve their strength so long as they are kept in line and prevented from yielding laterally. When out of line their strength is lost. It becomes therefore important to connect and brace the trusses or arches laterally in the most effective manner. This is done at the bottom and at the top, the former serving for floor, the latter offering an easy opportunity for roofing. Thus the roof is in a manner an important part of the work, and rendered necessary to insure its stability and strength. Other modes of constructing wooden bridges have been extensively and successfully practiced for centuries in Europe, by which *roofing* is dispensed with altogether. It is true, that when green unseasoned timber is applied in the construction of such works, roofing will add much to its preservation. But at the same time, it cannot be denied, that the weather-boarding, as well as the roof, has in many cases favored the dry rot. As regards the appearance of covered bridges, we must acknowledge that their unsightly proportions always produce a bad impression, and in place of adding to the beauty of a landscape, often spoil the effect of the finest scenery. Indeed, it appears that this branch of architecture has thus far been entirely deprived of all chances of making a display of the beautiful and ornamental. The gloomy aspect presented by the interior of some of those very large structures involuntarily reminds us of a tunnel, with this difference, that the latter is cool and clean in summer, while in the former the air is dusty and suffocating. To these objections an open bridge is not liable.

To insure the durability of the timber to be used for the floor of the projected work, it should be well seasoned before it is put in. The beams, which form the most important part of the floor, will have to be planed on all sides and then receive two coats of boiled linseed oil and spanish brown, which, next to red lead, is the most durable of paints, and also the cheapest. All parts of the railings, as far as exposed, will be well painted. The floor will be crowned sufficiently for rapid draining. The first course of plank will be laid close and tight, and covered with a thick wash of newly slacked lime, upon which the second course is laid. The joints of the upper floor should be pitched. The lime between the two floors cannot wash out, and will effectually prevent rotting between the two courses. Whenever the upper course of plank is worn out and renewed, another coat of lime should be put on. If preserved in this manner, no fear need be entertained, that the timber will suffer from early decay. The tops of the beams will be particularly well painted, and as these timbers are exposed all around to a free draft, they will last as long as timber can last. The upper floor will wear out before it could be affected by the rot: it will be arranged so, that it will form an entire smooth surface, crowned in the centre, and sloping off on both sides, for the discharge of the rain through the openings in the side railings. No opening whatever or offset will be left in the floor where wet or dirt could collect and cause a rot. As the wind will have a fair sweep over it, its action will assist much in the cleaning, which should, from time to time, take place.

## 9. GRADING.

The practicability of attaining an elevation of 121 feet above low water, a height sufficient to clear the largest steamboats in all navigable stages of water, will be doubted by many, who will refuse to investigate the few simple data, upon which it depends. The levels of both banks of the river have been taken by Mr. Rickey and myself, sufficiently accurate for our present purpose.

It was stated in the fore part of this report, that the flood-mark of 1832 is 63 feet above low water. Now the curb-stone at the lower corner of Front and Main street is 59 feet above low water, or 4 feet below high water. From this level the grading of the bridge commences, and continues at the rate of 4 1-2 degrees, or 7.75 feet rise per 100 feet distance, to the centre of the abutment, a distance of 272 feet, when an elevation is attained of 80 feet above low water. The grading of the wharf at this point is 45 feet above low water, and therefore 35 feet below the floor of the abutment, and 14 feet below the curb-stone at the corner of Front and Main. While the wharf, therefore, descends 14 feet, the approach of the bridge rises 21 feet. A rise of 4 1-2 degrees will not be considered objectionable where one is accustomed to very steep gradients. To afford a comparison, I will observe here, that the pavement of the wharf below the abutment, drops at the rate of 9 1-2 degrees. The graded wharf on the Covington side, where the abutment will be located, rises 7 degrees. The distance from the centre of one abutment to the centre of the tower is 788 feet. If, therefore, the above grade of 4 1-2 degrees was continued the whole of this distance, we should overcome an additional rise of 61 feet, and therefore attain an elevation of 61 plus 80, or 141 feet above low water. In place of this, the grade of the bridge is reduced from the abutment to the tower gradually, until it approaches the tower at a level, and at an elevation of 122 feet above low water. The two spans, therefore, will sweep across the river in a curved line, which will improve the graceful appearance of the work.

It is certain that the wants of the navigation do not require an elevation of the floor of 122 feet. But it has been assumed here as a maximum, in case it should be considered necessary to resort to it. The estimates are based upon the above dimensions, and would, of course, suffer some reduction, if the elevation of the floor could be reduced.

## 10. PRACTICABILITY OF PROPOSED WORK.

It is the duty of the architect and engineer, when he is charged with the design of public works, to report previous to their execution, fairly, accurately, and candidly. Honesty of design will, next to knowledge and experience, most surely guarantee his professional reputation. This honesty will best be proved by full and candid explanations, exhibiting the weak as well as the strong sides of the proposed work. I intend to pursue this course in relation to the Cincinnati bridge.

It is conceded, in professional reports, that the practicability of a work is proved by a scientific demonstration. No works on Engineering, perhaps, afford as good an opportunity as a report on a suspension bridge, to make a display of scientific attainments. It is certainly worthy of remark, that no branch of engineering has derived as much aid from science as the art of constructing suspension bridges. As the report before us, however, is strictly a popular one, mathematical demonstrations must remain excluded. But on the other hand, it will be impossible to establish the practicability of a work of this kind, satisfactorily, without some demonstrations. I will, therefore, attempt to discuss the subject matter in as plain a manner as its nature will admit.

The security of the structure, and its ability to resist all forces which may be directed against it, will principally depend upon the

a. *Adequate strength of the Cables, Stays, and Suspenders.*
b. *Security of Anchorage.*
c. *Solidity of Foundations, and the*
d. *Stability of the Centre Tower.*

These various conditions of security will be considered in the following paragraphs:

### *a.* Adequate Strength of Cables, Stays, and Suspenders.

A bar of good charcoal iron, 1 inch square, as has been mentioned before, will bear a weight of 60,000 pounds; its weight is 3.38 pounds per foot run. A bar of the same size, and 60,000 pounds weight, will therefore measure 17,751 feet. From this it follows, that if we had a point elevated 17,751 feet, to which a bar of that length could be suspended freely, it would bear its own weight.

One pound of wire 1-8 inch thick, measures 20 feet, and if manufactured of good material, and of the right temper, will bear 1350 pounds, and more. From this it follows, that a length of wire of 27,000 feet would support itself, when freely suspended. Let us further suppose a wire, in place of being suspended at one end, suspended at both ends to two points 17,000 feet apart, and so that this wire will deflect 1400 feet, or about one twelfth of the distance, then the tension resulting from its own weight, will be equal to its strength. Any wire, therefore, freely suspended at both ends, within a distance of 3 miles, and with a deflection of about 1-12 of that distance, will bear its own weight without a rupture. But in this case the material would be strained to its ultimate capacity. Experience has taught that iron should not be strained beyond the limit of its elasticity. By the term elasticity, is understood the capacity of iron to contract its fibres again after the strain ceases which caused their expansion. Tension has the same effect upon iron as heat, but only in the direction of the fibres. The elasticity of bar iron is limited to one-third of its breaking strain. A bar of one inch square should, therefore, never be taxed with a greater weight than 20,000 pounds, or 10 tons. The amount of elasticity of wire, when compared to its ultimate strength, is much greater than of bar iron. Its degree of elasticity, as well as its ultimate strength, is likewise dependant upon its temper.

One-half of the weight which would break a wire, may be supported by it with safety, provided this weight is at rest, and causes no vibrations. A wire cable, therefore, freely suspended over a space of 1 1-2 miles, and deflecting 1-12 of this distance, will, with safety, support its own weight for any length of time. If we contract this distance, and thereby reduce the weight of the cable, we shall enable it to bear some additional weight beside its own. If there was any necessity for the construction of a span of 3000 feet, such a bridge could be constructed and rendered as safe as a span of 100 feet long. The practicability of such a work could not be doubted, it would only be a question of expense.

In determining the strength of cables, great allowance should be made for the support of vibrations. The weight of a floor, for instance, if set in motion by a hurricane, would cause a greater strain than would result from the greatest load which the floor is capable of holding. This shows the necessity of a stiff construction, capable of resisting high winds, If properly constructed, a suspension bridge should support the effects of a hurricane, which would destroy all other kinds of wooden bridges, and prostrate trees and houses. The yielding nature of the structure would save it, provided its stiffness was great enough to check undulatory vibrations.

The greatest strain which could be produced by a transitory load, would be caused by a body of soldiers marching over the roadway in compact file. The least allowance of room for one man in rank and file is 3 superficial feet. The roadway being 20 feet 6 inches wide, would contain an area of 20 1-2 superficial feet for every foot length. No marching could take place on the sidewalks; as they are separated from the roadway, they would be used by the officers in command. The average weight of a soldier, fully equipped, may be estimated at 150 pounds, which would make 1050 pounds for every foot length of roadway. Marching of soldiers, however, should never be allowed on any bridge, and should be strictly prohibited. They are to be ordered out of step, and allowed to move on promiscuously over the roadway as well as the sidewalks. In a crowd of people, moving freely, 4 superficial feet of area and 120 pounds of weight, is about a fair average allowance for one person. The spaces between the railings, as far as the floor can be occupied, measures 32 superficial feet for one foot length of floor. There would, therefore, be room enough for

8 persons who weigh 960 pounds. To be altogether on the safe side, we will allow 1100 pounds as the maximum load for every foot of floor. There is no other kind of transitory load which would be equal in weight to a crowd of people. Let us suppose, for instance, a herd of full grown oxen, occupying the whole area of the roadway. A large ox, weighing 1000 pounds, will occupy a space of 25 superficial feet; there is, therefore, not quite room enough for one head in one foot length of roadway. A herd of cattle will, therefore, not press as hard as a crowd of people. A heavy six horse coal team, loaded with 100 bushels of coal, will weigh altogether 7 tons, and occupy a space of 50 feet in length. Two teams alongside of each other, weighing together 14 tons, or 28,000 pounds, will cause a load of 560 pounds for every foot length of floor, therefore little more than one-half of the load caused by a crowd of people.

The following quantities will fully constitute the maximum vertical pressure which has to be supported by the cables and stays for every foot of length of floor:

| | | |
|---|---|---|
| Maximum transitory load, - - - - - - - | 1,100 | pounds. |
| Weight of 1 foot of floor, including all materials, - - | 1,100 | " |
| Weight of 2 cables and saddles of suspenders, - - - | 600 | " |
| Allowance for wet and snow in winter, - - - - | 200 | " |
| Total maximum weight, - - - - - - - - | 3,000 | pounds. |

The length of floor of each span between the abutment and town is 760 feet, and the maximum weight for this distance 1140 tons.

It will be observed, that the curve, in which the cables are suspended, does not form a complete catenary, but only a portion of it, which may be considered as being cut off at the abutment. If the curve was continued from the abutment until it rises to a point at a level with the summit of the town, which is 95 feet above the lowest point of the curve, then it would form a complete catenary with a chord of 1180 feet long and a deflection of 95 feet. Now let us suppose the horizontal length of the span to be equal to the chord of the full catenary, or 1180 feet, and the cables equally loaded at the rate of 1 1-2 tons for every foot, including their own weight, then it is evident that the tension of the cables would be the result of this load of 1770 tons, and which would amount to about 2,850 tons. But it is also apparent that the equilibrium of a catenary, or what is the same, the relative position of all points of a cable, will not be disturbed if we cut it through at some certain point, and secure this point *immovably*. Or in place of cutting the cable, we may support that point by an abutment, bend the balance of the cable over it, and anchor it in the ground, so as to resist the strain of the suspended portion with the same power it did previously, when in its original position. Thus, it would appear, that the cables of the Cincinnati bridge, although they have only to support a floor of 760 feet long, may be subjected to a tension resulting from a floor of 1180 feet long. Indeed, in place of terminating the floor at the abutment, it might be continued the remainder of the distance of 1180 feet, and without requiring any increase in the size of the cables.

The above is a correct exposition of a mathematical law, which I hope will have been rendered intelligible enough without the aid of analytical deductions. Those who have a desire of testing its truth practically, can easily do so by a simple experiment. We have, therefore, to base our calculations upon a fully developed catenary curve, with a chord of 1180 feet and 95 feet deflection. But the figure of this catenary will not be employed in its purity, but changed so that the ends for some distance will form tangents, or run nearly straight, while the curvature at the centre, and also the deflection, will be increased. The cables will be relieved, and consequently rise as far as the floor is supported by stays. Making our calculations for a full catenary, this will amount to 300 feet at each end, or 600 feet altogether. The length of the floor, as far as supported by the cables, is therefore reduced to 580 feet, for which the tension should be calculated. By introducing the proportions of the original full catenary into our calculations, we shall get a result too high, and shall, therefore, be on the safe side. The maximum weight of 580 feet of floor, cables, and maximum load, is 870 tons, and the tension resulting from this weight is found to be 1,427 tons. My practice is to allow 7 wires of 1-8 inch thick for every ton of maximum tension. The cables would therefore have to be composed of 9,989 wires; in place of this I have proposed to employ 11,000, as was stated in the 5th section of this report. At the rate of 7 wires per ton, each wire will bear 285 pounds, while it is capable of supporting a weight of 1350 pounds, or more than four times as much as the greatest tension to which it can ever be subjected.

| | | |
|---|---|---|
| The constant weight of 1 foot of floor was stated at - - | 1,100 | pounds. |
| Weight of cables and saddles, - - - - - - - - | 600 | " |
| Total, - - - - - - - - - - - | 1,700 | " |

The tension resulting from this *constant* load is equivalent to 161 pounds per wire, or not quite 1-8 part of the weight which would cause a rupture. On the Pittsburgh aqueduct, where the weight is nearly constant and uniform, I have allowed five times the quantity of wire, which would barely support it.

The above allowance for the strength of the cables, might indeed be considered extravagant. But we have to remember that this bridge will have to accommodate an immense traffic, and that it will stand foremost in the rank of such works, from its location as well as from its magnificent proportions. As it is calculated to last for ages, it will, in the course of time, become the greatest thoroughfare of the world, not even the London bridges excepted.

The stays which are to be employed next to the tower as an assistance to the cables in support of the bridge, will act in proportion to the *sine* of the angle of inclination. The further off from the tower they reach, the less they will be able to bear. It will be necessary here to introduce those simple calculations by which their relative strength is determined. It may be sufficient to state, that the same allowance of wire will be made for them which has been made for the cables. It now remains to consider the strength of the suspenders.

The maximum weight of one foot of floor, and load, was rated at 3000 pounds. The greatest tension, therefore, which a suspender of 1 3-16 inch in diameter will have to support, will be 6000 pounds. I need only remark that good charcoal iron of this size will bear 60,000 pounds, or ten times as much as the above weight. The reason why more strength is allowed in proportion for the suspenders than for the cables, is because the former are sometimes subjected to sudden vibrations and shocks, which are only confined to a small portion of the floor, and will never sensibly affect the cables.

The preceding examinations appear to authorize the conclusion, that the strength allowed for the stays, cables, and suspenders, will prove fully adequate for the support of the heaviest loads to which the bridge can possibly be subjected. But the question arises whether no other forces may be brought to bear against the cables but those resulting from transitory loads? High winds have, in several instances, proved destructive to suspension bridges. But in all those cases which are on record, it can be proved that the work had not sufficient strength, and that the injury was caused by the undulations of a very flexible floor, the rise and fall of which produced a succession of shocks, which broke the suspenders, and in some instances parted the chains. No accident of this kind is known to have taken place on a wire cable bridge. In a former part of this report I have explained the necessity of a stiff floor, which of itself will prevent short undulations. Lateral motions can never take place to a great extent on account of the inclined position of the cables, which, with their great weight and stiffness, will defy an ordinary storm. Let us, for instance, suppose a hurricane or a tornado, like those which sometimes have occurred on the lower Mississippi, the force of which has been estimated to be equal to about 30 pounds pressure upon one superficial foot. The outside vertical surface of the floor and railing, as far as exposed to the wind, measures 7 superficial feet for every foot of floor. The pressure of the air would, therefore, be equal to 210 pounds against one foot of bridge, or 159,600 pounds, or 80 tons, against one span. This is certainly a great force; but the great stiffness of the floor alone would be sufficient to resist it. As the ends of the floor will be firmly connected with the masonry, the strength of the timbers arranged in the line of the bridge, will be competent to resist a far greater force. But for the express purpose of guarding against hurricanes, a system of under-floor stays will be applied, calculated to check these injurious movements. It is true that a hurricane, such as was experienced at Natchez, might force the centre of a span a few feet out of line, but the yielding nature of the work would prevent any further injury. With a view of checking lateral vibrations of the cables, they will be connected by diagonal stays, made of wire rope.

The action of vertical currents of air upon the underside of the floor, will be effectually resisted by its great weight and stiffness. Admitting the up-lifting power of an under-current to act with a force of 30 pounds upon every superficial foot of floor, it would be resisted by a weight of 50 pounds, which includes the cables at the centre of a span, where they are firmly connected with the floor by the suspenders. It is not probable that a vertical current would act against the whole extent of the floor at once, and with equal power. It is more likely that its force will be directed against one portion of the floor, while the other remains at rest. An undulatory movement of the structure would be the result, but soon counteracted by its own stiffness.

### *b.* SECURITY OF ANCHORAGE.

The maximum tension of the cables was stated at 1427 tons. To resist such an enormous tension, equal to the weight of a frigate, may seem impossible to those who are not used to the application of great forces. But the most sceptical will not deny the practicability of resisting a large force as well as a small one, provided the means applied are duly proportioned to the magnitude of the object to be attained. The estimate of resistance afforded by the anchorage, has been made with a full appreciation of the forces to be opposed. Its certainty is based upon a simple and unerring calculation. It was stated in the 4th section that the end of each cable is to be divided into 7 parts, each to connect with an anchor chain. As these chains are curved about 65 degrees, their tension diminishes as they descend. In our examination of the strength of the cables we have allowed as the greatest tension to which the wire should ever be subjected, 20,500 pounds for every square inch of solid wire. In determining the requisite section of the anchor chains, which are to be constructed of solid bars, I propose to allow one superficial inch of section for every 14,000 pounds, or 7 tons of strain. The aggregate section of the chains will, therefore, be 1427 divided by 7, or 204 superficial inches. Each of the 14 chains will have a section of 14.57 inches; they will be composed of links, the links to be formed alternately of 4 or 5 plates, each plate to be 4 inches by 7-8 inch thick. The length of the plates will vary from 5 to 10 feet.

The object of curving the chains is to place the last link in a vertical position, and to assist their tension by their pressure upon the masonry. The strain of the last link will thereby be reduced about one fourth; the same section of iron will, however, be preserved throughout. A good quality of masonry, all to be laid in cement, is of course required, so that no appreciable settling will take place. The uplifting force of the last or vertical links being one-fourth less than the tension of the cables, is therefore 1070 tons: this pressure will have to be resisted by the weight of the superincumbent mass of masonry and embankment between the anchor or return walls. These walls, as far as they rest upon a group of anchors, descend 15 feet below the pavement of the wharf, and will average 31 feet high; they are 7 feet thick on bottom and 5 feet on top, and as far as they exert a pressure upon the anchors, they are 88 feet long. They contain, together with the buttresses, a quantity of masonry of 35,000 cubic feet, which, at 130 pounds, weigh - - - - - - 4,550,000 pounds.
The body of embankment between the walls is likewise supported by the anchors, and measures 88 feet long, 22 feet wide and 30 feet deep, and contains 58,080 cubic feet, which weigh, at 100 pounds, - - - - - - 5,808,000 pounds.

Total weight upon anchors, - - - - - - 10,358,000 pounds,
Or - - - - - - - - - - 5,179 tons.
To this must be added the resistance of the earth, stamped in outside, and which partly will adhere to the walls. We may safely estimate the total resistance at 6000 tons, which is opposed to a pressure of 1070 tons. It may be asked, why provide for such an abundance of resistance? In high water, the weight of masonry and embankment will be reduced about one-third. The depth of the walls is necessary, to render the foundations safe: their thickness could not be reduced much without endangering their stability, and the embankment between, which adds much to the weight, will cause no extra expense on that account.

### *c.* SOLIDITY OF FOUNDATIONS.

The greatest vertical pressure which the structure can exert upon the centre tower, will be equal to the weight of 1180 feet of floor, cables and load. It will be recollected, that this distance is the extent of the chord of that complete catenary, of which the cables form only a part. One-half of this span, or 590 feet, on each side of the tower, will fall to its support. The maximum weight of 1 foot of floor being 1 1-2 ton, including all, we find the weight upon the tower equal to - - - - - - - - - - - - - 1,770 tons.
The tower itself contains 12,000 perch, or 300,000 cubic feet of masonry, which, at 130 pounds, weigh - - - - 19,500 "

Total weight upon foundation of tower - - - - - - 21,270 tons.
The superficial area of the lowest course will measure 2,600 feet; this, divided in the above weight gives about 8 tons for every foot. This is far within the safe limit of the resistance of sandstone. The pressure upon the top course of the towers on the Pittsburgh aqueduct, is over 9 tons for every superficial foot.

But it remains to be examined, in case a timber foundation, or piling, should be resorted to, what degree of safety would be afforded by such a mode of building. It has been stated that the stratum of limestone, which, at low water, is exposed on the Covington side, is believed to extend all the way across to the

Cincinnati side; but at what depth remains to be ascertained. It will not be advisable, should the rock be very low, to excavate to it. This operation would greatly add to the expense of the work without insuring a greater solidity than can be obtained by other modes less expensive. If the side of the bridge was located on the lower Ohio, or on the Mississippi, where the bottom of the river is composed of a less solid and more shifting material, we should probably have to resort to a more expensive mode of building. Before the plan of foundation can be decided, the bottom of the river will have to be examined by boring, as well as driving experimental piles. Should the stratum above the rock be deep, and found to consist of compact clay and sand, covered with river gravel, I would not recommend excavation, but propose to lay upon the gravel a strong timber foundation, of about 100 feet long and 60 feet broad, to be composed of oak timber hewed 12 inches square, pinned together, the courses crossing each other, and to be carried up to low water line, where the first course of masonry is to be commenced. If such a foundation is well protected against the action of the current by an extensive stonefilling, sunk in cribs, which surround the pier, it will be as safe as rock. Timbers will be found perfectly competent to support the weight of the tower, that pressure being rated at 8 tons per superficial foot. I have made experiments myself, where I have directed a pressure of 30 tons upon a cast iron plate of 10 inches diameter, resting against a white oak block, without producing any marked impression upon the timber. An oak timber foundation will therefore easily resist the weight of the tower. We will now examine what security would be afforded by a pile foundation, in case this plan should be preferred. A sound white oak pile of 15 inches diameter, driven until it refuses, and either cut off short or prevented from bending laterally by other means, will, according to numerous experiments which have been made, and as the experience of executed works has amply proved, bear a weight of 50 tons with perfect safety, and for any length of time. As the aggregate weight upon the foundation is 21,000 tons, it would, at this rate, require 420 piles, driven home solid. Placing this number of piles 4 feet apart, from centre to centre, the whole pilage would cover an area of 90 feet by 50 feet.

From the above examinations we may conclude that, in all cases, we shall be able to obtain a foundation for the erection of the tower which will afford ample security.

It will not be important here to extend this investigation to the foundations of the abutments, which will have to bear a pressure much less than the weight for which the foundation of the centre tower has to be calculated. As these foundations will be laid on dry land, and probably above low water, less difficulty will present itself in their execution. A timber foundation may be advisable for the abutments, for the purpose of extending the bearing surface, and to prevent unequal settling. But as this timber will not be all the time under water, it should be laid in lime and copiously grouted. If completely immersed in lime, and if care is taken to consolidate the filling around the masonry by wetting and stamping, so as to make it air and water tight, no apprehension need be entertained that the timber will ever rot. During the re-building of the Monongahela bridge, an oak log was excavated from the embankment between the wing-walls, at a depth of 12 feet, which had been there 25 years, and was found to be perfectly fresh and sound, not even the bark affected. It may be well to observe that the material of the embankment consisted of a tough clay, impervious to water when well stamped.

### *d.* STABILITY OF CENTRE TOWER.

The conditions upon which the stability and security of the centre tower depends, will now be examined.

It has been demonstrated in the previous section, that the tower will be abundantly strong for the support of the vertical pressure which may result from the weight of the floor and of transitory loads. It is also clear, that so long as there is an equal weight suspended on each side of the tower, the result of these tensions will be directed through the centre of the masonry, and therefore will meet with ample support. But a condition of things may take place when the forces directed against the tower from the two spans, will be so unequal in magnitude that its stability may be questioned.

We will at once assume an extreme case, by supposing a maximum transitory load on the one span, while nothing is on the other. In this case, then, the tension of the cables, which results from the transitory load of one span, would exert a force against the summit of the tower which would not be balanced by an opposite tension, and would therefore have to be resisted by the strength and solidity of the masonry itself, or by other means. The tension of the cables, which results from the maximum transitory load, is 523 tons, and the horizontal tension directed against the summit of the tower, is 498 tons. It will be recollected that the load on the first 300 feet of floor next the tower, will be supported by the stays, and independently of the cables. The weight of 1 foot of floor is 1100 pounds; of the cables, 600 pounds; together, 1700 pounds, which gives, for 1100 feet, as far as supported by the summit, a total weight of 935 tons. Now, the friction of stone upon stone, the beds cut as usual, amounts to about 3-4 of the pressure. The resistance of the top-course, caused by its friction, would therefore amount to 701 tons, or 203 tons more than the horizontal tension.

The top courses will be constructed of the largest blocks of Dayton limestone, with beds cut perfectly true, and laid in the best cement. In the lower courses, where freestone will be employed, the cohesion of 1 superficial foot of cement may be rated at 2000 pounds, but it will be much less on the Dayton limestone, but certainly not less than 1200 pounds. The beds of the top courses measure 360 superficial feet, and will, therefore, resist with a force of 216 tons. If we add to this the resistance of the iron connections, which will be introduced, we shall get an aggregate resistance more than twice as great as the sliding force. It is evident that if the top courses are secure against sliding, those below will be still more so, as their resistance will be greatly aided by the weight of the superincumbent masonry.

It remains now to be examined whether the tower possesses sufficient strength to resist an *overthrow*. The proportions of this large body of masonry have been carefully studied, and are not the result of fancy. I have investigated other forms, but have decided in favor of the one proposed, which with the greatest strength unites the greatest economy. It will appear at a glance, that if there is any possibility of moving the tower, the point where it first will give way, will be at or near the level of the floor. If this point is found to be safe, the others above and below can be proved to be still safer. The investigation of this question will, of course, be predicated upon the best construction of masonry. No small blocks will be allowed to be used, either for face stone or backing; the latter will have to be fitted in, cut to the thickness of the course, and well bonded with the face. Numerous iron anchors and clamps will be applied inside, so as to increase the solidity of the masonry as much as possible.

The power of momentum, with which the horizontal force applied at the summit will tend to turn the tower on the side of the loaded arch, will be in proportion to the leverage, or the distance between the seat of the force and its fulcrum. The latter is supposed to be at the level of the floor, therefore 70 feet below the summit. The momentum of the throwing force is found by multiplying the force by its leverage, therefore

$$70 \times 498 = 34,860$$

The resistance opposed to this momentum, is caused by the weight of the masonry above the level of the roadway, and the weight upon the summit. The cubic content of masonry above the floor is 55,500 cubic feet, which, at 140 pounds, weigh - - - - - - - - 7,770,000 pounds,

| | |
|---|---|
| or, - - - - - - - - - - - - | 3,885 tons. |
| The length of floor of both spans, as far as supported by the summit, is 1147 feet, and its weight, including cables, at 1700 pounds per foot run, - - - - - - - - | 975 tons. |
| Total, - - - - - - - - - - - | 4,860 tons. |

Now, this weight will act upon the fulcrum with a leverage equal to the distance of the axis of the tower from that fulcrum, which is half the base of the tower at the level of the floor, or 16 1-2 feet. We, therefore, get the momentum of resistance

$$4860 \times 16.5 = 80,190$$

which is 2.3 times as great as the momentum of the throwing force.

The above method is the usual, and in fact the only one which can be applied in a question of *statical* equilibrium, as here presented. In this investigation, however, it will be observed that the masonry of the tower is considered as forming one solid body, which will turn around one of its edges without separating. But if we suppose a lifting force applied to the summit of the tower, great enough to raise the whole mass, we could not expect that the whole pile would stick together without parting at any place. It would undoubtedly separate, and most probably near the summit, where the cohesion of the cement would prove inadequate. The numerous vertical anchors which it is contemplated to apply, will not be sufficient to render the whole mass one solid body. It is, therefore, prudent not to rely upon the above estimate of strength altogether, and to make, if possible, some further provisions for the safety of the tower. But an ample addition of security will be afforded by the *stays*, whose principal office is to counteract, in a *direct* manner, the greater tension of the one span over the other, and at the same time, to check the vibrations of the floor. As far as the stays extend, they support the whole floor and loads. Now, when one span is loaded and the other not, the former will sink a little, and will thereby affect the stays more than the cables, because the latter, when under an increased tension, will drop much lower than the former under the same tension. The consequence of this will be, that the opposite stays on the next span will be tightened,—the saddles on the summit of the tower being allowed to move freely,—and as their tension increases, the resistance of the floor *will* increase in consequence of its great stiffness. The combined action of the stays upon the summit of the tower will only produce a vertical pressure.

Another additional means of security to the tower will be afforded by the lower floor stays, which connect the floor with horizontal anchors laid across the lower body of the masonry. They are likewise intended to diminish the vibrations of the floor, and of the cables next to the tower.

I am authorized to claim the conclusion that, with all those means of strength at our disposal, the stability of the great tower may be rendered secure against the greatest forces to which that structure can be exposed.

Before dismissing this subject, it may not be out of place to notice the plan which has been suggested, of constructing the tower of *cast-iron*. The superiority of this material over stone is no doubt founded upon the greater economy of construction, which, it is supposed, would result from its adoption. The preceding investigation, however, has clearly pointed out how much the safety and stability of the tower will depend upon its weight, and which would be greatly reduced by the adoption of cast-iron. In a structure of less magnitude, where we have but small forces to contend with, and at no great elevation, cast-iron might perhaps be advantageously employed for the construction of that portion of the tower which is elevated above the floor. It has been applied on the Monongahela bridge with happy success. Indeed, if the tower had to be constructed of cast-iron, we should be obliged to resort to a plan similar in principle to the one applied on the Monongahela bridge. It would not answer to fasten cables stationary to the summit; great objections would present themselves against the adoption of such a plan. Vibrations are the great source of destruction to most works. Small as they may be, when constantly repeated, they will cause a rupture at last. This would have to be apprehended principally in the winter season, when the strength of castings is so much reduced. But the greatest objection is the impossibility of so securing the base of a cast-iron tower upon any kind of foundation, that the unequal tension of the spans, when unequally loaded, would not move it with the immense leverage presented by its whole height. As its own weight would afford but little assistance to its stability, the base of a cast-iron tower would be its weakest point.

### *e.* EFFECT OF ICE UPON THE TOWER.

It has been stated to me, as an objection to the centre pier, that the discharge of ice from the mouth of the Licking, when this river runs high and the Ohio low, is seriously felt at the wharf on the Cincinnati side. The current of the Licking will, however, not strike the pier, when located at the lower end of the wharf, and if it did, would thereby be rendered more harmless to the shipping, without at all affecting the tower. On the other hand, it has been observed, that when those masses of ice, sometimes disgorged simultaneously from the Allegheny and Monongahela rivers and the lower tributaries of the Ohio, reach Cincinnati, they are much reduced, broken up and rotten, and seldom form such solid masses as may be noticed on the upper river. To render the effects of ice harmless, nothing more is required in this case, but what is usually applied as a protection to piers. An ice-breaker, constructed of timber and filled with rock placed above the pier, will be all sufficient. Advantage may be taken of the form of the tower to connect the ice-breaker so with it, that it cannot be dislodged. The breaker should be started upon the bottom of the river in form of a triangle, the base of which will butt against the main wall, and embrace the upper buttress. Its length should be about 100 feet, and the slope run up to 40 feet. The comb, or ridge, should be formed of one heavy stick of white oak, well armed with cast-iron corner plates. As the cakes of ice run up this ridge, they will break by their own weight, fall down and float off.

The space left between the two main walls composing the tower, are not intended to be left open; they might cause a lodgment of drift. Both sides will be closed by a heavy timber frame, planked over as high as the ice-breaker, and will then present a smooth unbroken surface to the action of the current.

## 11. COMPARATIVE MERITS OF ONE AND TWO SPANS.

When I first reflected on the plan of a suspension bridge at Cincinnati, and before I had attained that knowledge of locality which is indispensable to the design, I expressed myself in favor of one single span, and delineated the general features of such a structure. If the river bed was such that the foundation of the tower could only be obtained at a very great expense, and if the erection of a centre pier would prove an impediment to the navigation of the river, then a single span would be entitled to a preference. But as no serious objections can be made to a pier, and its foundation will not be attended with any very great expense, the plan of two spans should be adopted, provided it offers superior advantages over one span. The objection which can be urged against one single span, next to an increase of expense, is the great space which would necessarily be occupied by the towers and long return-walls on both shores. Such ground could be easier spared on the Covington than on the Cincinnati side. It would also be more difficult to attain that elevation of floor which is proposed. On the other hand, it is true, that a single span, without any pier, would appear to be more independent of the river. No fear, however, need be entertained that the masonry of the tower, if constructed as proposed, could ever be affected by the water. Its protection by an ice-breaker, which is easily kept in repair, its great weight, and the high elevation of the floor above the river, will, if the foundation is executed with due care, guarantee its safety. The reasons which decide in favor of two spans, are:

1. The greater adaptedness of the approaches to the locality and the local wants on the Cincinnati side.
2. The abutment and return-walls on the Cincinnati side will occupy less space.
3. They will also be further removed from the edge of the river, and leave the wharf under the bridge unobstructed.
4. If the site, proposed here, is chosen, the capacity of the wharf will, for all practical purposes, not be reduced.
5. It is easier to attain that high elevation of floor which is desired.
6. A greater section of waterway will be obtained by two spans than by one.
7. Saving of expense.

## 12. INVESTMENT.

Who has imagination and foresight enough, to foretell the number and the wealth of that people which, one hundred years hence, will crowd both shores of the Ohio at Cincinnati? Less than one hundred years ago the greater part of this Union of states was one vast unbroken wilderness, traversed by none but prowling savages and beasts of prey. On the spot where your city is now located, fifty years ago, no signs could be discovered of that civilization which is indispensable for the existence of the whites,—no sounds could be heard of that industry which our race has so vastly developed. Where now can be witnessed at each hour of the day, scenes of great commercial activity, the bustle of the arrival and departure of hundreds of travellers, there reigned, fifty years ago, the unbroken solitude of a dense forest. Where now the bosom of the Ohio is ploughed up and down by hundreds of swiftly moving steamers, conveying thousands of intelligent beings, transporting the products of industry and of the soil, and distributing the necessaries, comforts, and luxuries of life in all directions,—there, fifty years ago, you might have witnessed one of the first daring attempts of a crew of whites, undertaking a journey from the forks of the Ohio to New Orleans in a *broad-horn*, or an unmanageable flat-bottomed boat, anxious, at all times, to keep the middle of the river, to be out of reach of the ever-watchful Indian. You have all witnessed these great and wonderful changes; they astonish you less since you have participated yourselves, in this great move of civilization! Where, fifty years ago, the Indian trader hardly dared to penetrate, there your city stands now—a new city, emphatically—boasting of the proud name of the *Queen of the West*, the commercial emporium of three of the richest states in the Union! When each of these states will count fifteen millions of inhabitants, who will all contribute to the growth and wealth of your city, who will then define its extent and commerce?

The travel and intercourse between the two opposite towns and states, which are to be permanently connected by the work in contemplation, will increase in proportion to the general advancement and expansion. The additional thousands which are yearly swelling the population living adjacent to the bridge, will contribute to its revenue. The greatest part of the surplus products of the state of Kentucky, and those numerous droves of cattle and hogs, which are annually driven to Cincinnati, will all pass over the bridge and swell its receipts.

The preceding remarks may appear fanciful and visionary. Nothing, however, has been exhibited in prospective, that will not be outstripped by the reality of the next period to come. It is for such considerations that the work in question should be constructed with a view to last for ages. Investments are to be estimated according to their prospective value. Men of fortune, who wish to settle upon their children a certain and unfailing revenue, will here be offered a splendid opportunity.

It would be useless to attempt an approximate estimate of the probable revenue of the work. You are familiar with the daily intercourse between the two shores, to accommodate which three steam ferries are now employed. But as a new condition of things will be brought about by the completion of this bridge, it is confidently expected, that the first year's revenue will exceed the present aggregate receipts of the three ferries. An annual increase will, as the country and city improves, follow as a natural consequence. And as this work will be but little exposed to the dangers of the elements, and with a little care, and a very small annual expense, can be kept in a perfect state of preservation for centuries, the value of its stock will improve with its age. We may conclude, that no better scheme for a safe investment was ever presented to the capitalists of this country, than the contemplated formation of a joint-stock company for the erection of the Cincinnati bridge.

## 13. CONSTRUCTION.

The building of the Cincinnati bridge will be the work of three years. Two years will be required for the execution of the masonry; the superstructure may be completed in the third year. It will, however, require an energetic and systematic management to accomplish it within that time, and within the limits of the estimates. The most expensive part of the work will be the masonry; its erection will be rendered more difficult and expensive on account of the total want of a suitable material in the vicinity of the site. The Dayton limestone is transported forty miles by canal, and is the best material to be had within this distance. It is contemplated to employ this material for the facing of the centre tower as high as 30 feet from the foundation, and also to use it for the construction of the summit courses, and of the four small towers on the abutments. It has great claims as a good building material, when free of veins, and of a compact formation, but it is expensive to work. Its great hardness recommends it highly for the construction of the summit courses of the towers, and for the support of the anchor-chains, where a great pressure will have to be supported. It would, however, be difficult, and still more expensive, to procure that quantity of large blocks at Dayton, which would be required for the execution of the whole masonry. Not because it could not be had, but on account of that great waste of material of an inferior size and quality, which would necessarily have to be refused.

Since the project has been agitated, I have been anxiously employed in discovering other sources, from where materials can be had. The scattered quarries in the immediate vicinity of the city, appear to be scarcely sufficient to supply the demand for that small sized limestone, commonly used in the construction of cellar walls and foundations. This material can only be employed as *backing*, on some portions of the abutments and return-walls; nor can it be procured in large quantities at a time. It is only found scattered and in thin layers, and generally obtained by the excavations and levelling of the surrounding hills. It is indeed a remarkable geological phenomenon, that the Cincinnati basin should be entirely destitute of solid formations of rock, while the largest deposits make their appearance on the banks of the river, some distance above and below. Fortunately there is a point on the Ohio, about two hundred miles *above* Cincinnati, where there is an inexhaustible supply of a good quality of a coarse-grained *free* or *sand*-stone, which will furnish an excellent material for the masonry. My attention to this extensive formation, overlaying the bituminous coal measures, and which is found for some distance on both sides of the Ohio river between the Muskingum and Scioto, was first directed by the Hon. Mr. Ewing. The extensive bluff which forms the roof of the Pomeroy coal mines, is composed of this rock. It is of a similar quality, but not quite as coarse and hard as the material of which the top courses of the tower on the Pittsburgh aqueduct have been constructed.

A distance of 200 miles, for the transportation of this stone, may, at first sight, appear an insurmountable obstacle to its use. A closer examination of the subject, however, will prove that the location of the Pomeroy quarries is rather more favorable than those at Dayton, with regard to transportation. The river from Cincinnati to Pomeroy is deep enough at all seasons for tow-steamers, and free from those impediments which we meet further up. If one good efficient tow-steamer and about twenty strongly built stone flats are procured, well managed by a good crew, and if all the necessary machinery is erected at the quarries for loading large blocks, and the whole of this branch of business is carried on systematically and with sufficient capital, all the stone wanted may be delivered at a moderate expense, and without fail. In order to save expense in boating, and to facilitate the whole operation, all the stone blocks should be cut at the quarries, numbered and coursed, so that they can be put in their appropriate places when they reach the site of the tower, without any further handling.

The prices which I have allowed in the estimate for the execution of the masonry, are believed to be adequate, but not at all too high for that description of work which is absolutely required.

With reference to the construction of the floor, the necessity has been mentioned, in a former part of this report, of procuring a supply of timber at the commencement of the work, so as to allow it sufficient time for seasoning. It will not be necessary to enter into any details on the construction of the floor, as this has been already done in the 8th section. The framing, and all the wood work, which can be done beforehand, will be going on while the cables are being manufactured, and will be put up as soon as these are finished.

The observations I have made on the foundation of the centre tower, I do not wish to be considered as conveying a full idea of the plan of execution which eventually should be adopted. Nor can it be expected that a well digested plan should be proposed before the necessary examinations of the river bed have been made. It is also in consequence of the uncertainty of the plan to be adopted for the execution of this part of the work, that a considerable latitude should be admitted for the estimate of the cost of foundation. The system of operations which most probably will have to be pursued, are as follows: A coffer-dam will be constructed around the site of the pier of 110 feet by 80 feet in the clear, by driving 2 rows of piles, 25 feet long, 4 feet apart, the rows to be at a distance of 12 feet apart, the piles to be driven about 5 or 6 feet deep. Three rows of plates will be placed against these piles inside, and a double row of sheet piles driven against it all around, the top of the piles to be capped and cross-tied. The chamber is then to be filled with the best *puddle* which can be found near the river, and which should contain a large proportion of coarse sand, or should be mixed with it. If this work is commenced about the first of August, the coffer-dam may be raised about 15 feet above low water, this being about the height of an *ordinary* rise, which may take place in August and September. It is true that freshets may occur of 20 and even 30 feet high, but it would be unwise to make our preparation to suit a stage of water which but rarely occurs at this season, and if it does occur, will only last a few days. It would, then, be the best policy to stop the operations until the water falls.

A second coffer-dam, of about 10 feet height, will be constructed outside, by driving another row of piles around the first, at a distance of eight feet, which will be secured by caps and ties, and sheet-piled as before. This chamber will be filled by the material which will be obtained from the excavation inside of the large coffer-dam. By this increase of strength, this work will be enabled to withstand a high freshet without being carried off. The bailing, as well as the pile-driving, will be done by a steam-engine of 8 to 10 horse-power, which afterwards can be advantageously employed for raising stone, and other materials used in the construction of the tower. When the water is removed from within the coffer-dam, the excavation to the rock, or as far as necessary, will be commenced. Should a pile foundation be determined on, no bailing is necessary until all the piles are driven. As timber will, under water, last as long as stone, or any other imperishable material, it is proposed to use it, in place of stone, up to low-water mark, in case no pile foundation should be resorted to. And even in the last case, should the upper layer of the river-bed consist of a doubtful material, it will be good policy to excavate it between the piles, saw the latter off one foot above the level of the pit, put caps on, fill the space between with small stone and cement, and commence building with courses of long oak timber, hewn square, the different courses crossing each other, and bolted down with iron bolts. This timber-work will be superior to the best quality of masonry, and can be done much more expeditiously, which is a very great desideratum in such a case. To save expense in bailing, and to get out of danger, the masonry should then be carried up as rapidly as possible to the surface of the river.

As the nature of the river-bed is not of a very changeable and treacherous character, it is expected that some one of the modes mentioned above, will be found practicable. The execution of this work will be much favored by the shallowness of the water at the site of the tower.

## 14. ESTIMATE.

### FOUNDATION OF TOWER.

| | | | |
|---|---|---|---|
| 310 | piles for cofferdam, 20 to 25 feet long, hewed on one side, | $2.50 | $775 |
| | Shoeing, | 1.25 | 388 |
| 3,200 | feet of 12 inch square timber for caps and ties, | .09 | 288 |
| | Hewing, framing and putting up, | | 300 |
| 6,000 | feet of bands 12×6 inch. | .22 | 720 |
| 60,000 | feet, board measure, of 2 inch plank, | 10.00 | 600 |
| | Joining, sharpening and driving, | | 600 |
| 2,000 | pounds screwbolts, | .8 | 160 |
| 2,200 | cubic yards of puddle, | .50 | 1,100 |
| | Cost of steam engine and pile drivers, | | 6,000 |
| 420 | oak piles for foundation, 35 feet long, 15 inches at but end, | 4.00 | 1,680 |
| | Shoeing, | 1.75 | 735 |
| | Driving, | 4.00 | 1,680 |
| 60 | days bailing, attendance, fuel and repair of engine, | 15.00 | 900 |
| 800 | cubic yards of excavation between piles, to be deposited in the outside cofferdam, | .50 | 400 |
| 100 | perch of concrete between piles, | 5.00 | 500 |
| 1,200 | feet of oak timber, 12×15 inch., for caps, ready hewed, | .25 | 300 |
| | Cutting tenons on piles, framing cap and putting them on, | | 200 |
| 20,000 | cubic feet of oak timber, 12 inches square, in 4 courses, | .15 | 3,000 |
| 7,000 | pounds ragbolts, | .07 | 490 |
| | Cost of pumps, and keeping them in repair, | | 200 |
| 5 | flats for operating on river, | 100.00 | 500 |
| | Incidental expenses and accidents, | | 2,000 |
| | *Cost of Foundation of Tower,* | | $23,516 |

### MASONRY OF TOWER.

| | | | |
|---|---|---|---|
| 11,100 | perch of masonry, | $8.00 | $88,800 |
| 15,000 | superficial feet of extra cutting of summit courses, | .30 | 4,500 |
| | Cost of masonry of tower, | | $93,300 |

### MASONRY, &c., OF TWO ABUTMENTS.

| | | | |
|---|---|---|---|
| 15,000 | perch of abutments and return-walls, | $4.00 | $60,000 |
| 780 | " " towers, | 10.00 | 7,800 |
| 200 | " " cut stone arches on arches, | 8.00 | 1,600 |
| 40 | " " anchor blocks above ground, | 15.00 | 600 |
| 14,000 | cubic yards of excavation of foundations, | .10 | 1,400 |
| 10,000 | " " embankment between return-walls, | .15 | 1,500 |
| 7,000 | superficial feet of brick pavement on sidewalks, | .05 | 350 |
| 1,320 | superficial yards of stone pavement on roadway, | .60 | 620 |
| 5,000 | cubic feet of coping for return-walls, | .40 | 2,000 |
| | Cost of masonry of abutments, &c., | | $75,870 |

### ANCHOR-CHAINS.

| | | | |
|---|---|---|---|
| 102,000 | pounds of anchor-chains, | .08 | $8,192 |

## CABLES.

| | | | |
|---|---|---|---|
| 1,008,000 | pounds of wire in cables, | 0.11½ | $115,920 |
| 35,000 | pounds of wrapping, | .14 | 4,900 |
| | Cost of cables, | | $120,820 |

## STAYS.

| | | | |
|---|---|---|---|
| 150,000 | pounds of wire rope stays above floor, | .13 | $18,200 |
| 10,000 | " " " below floor, | .13 | 1,300 |
| | Cost of stays, | | $19,500 |

## SUSPENDERS AND FLOOR-IRON.

| | | | |
|---|---|---|---|
| 80,000 | pounds suspenders, | $0.07 | $5,600 |
| 40,000 | " wrought iron in floor, | 0.07 | 2,800 |
| 6,000 | " stirrups at end of stays, | 0.08 | 480 |
| | Cost of suspenders and floor iron, | | $8,880 |

## FLOOR.

| | | | |
|---|---|---|---|
| 96,000 | feet of oak, board measure, | $13.00 | $1,248 |
| 600,000 | " pine, " | 10.00 | 6,000 |
| 1,580 | " lineal framing of floor, | 3.00 | 4,740 |
| 1,580 | " of floor to put up, | 2.00 | 3,160 |
| 12,000 | " of clear stuff of pine, for railings on return-walls, | 15.00 | 180 |
| 1,120 | " of railing, to frame and put up, | .40 | 448 |
| | Painting beams and railings with 3 coats, | | 600 |
| 8,000 | pounds of spikes, | .05 | 400 |
| | Cost of floor, | | $16,776 |

## CASTINGS.

| | | | |
|---|---|---|---|
| 9,600 | pounds of bed-plates on summit of centre tower, 10 feet × 4 feet × 3 inches. | | |
| 8,000 | " for the two stationary saddles for cables. | | |
| 10,000 | " " eight small movable saddles for stays. | | |
| 16,000 | " " four saddles and plates on small towers. | | |
| 56,000 | " " 28 anchor plates. | | |
| 7,000 | " " 140 plates under chains. | | |
| 10,000 | " " bull-eyes for anchors in masonry. | | |
| 116,600 | pounds of castings, including fitting up and chipping, | 0.03½ | $4,081 |

## ICE-BREAKER.

| | | | |
|---|---|---|---|
| 8,000 | cubic feet of timber, framed and put up, | $0.15 | $1,200 |
| 6,000 | pounds castings, | .40 | 240 |
| 1,500 | cubic yards of stone-packing, | 1.25 | 1,875 |
| 3,000 | pounds spikes and bolts, | .07 | 210 |
| | Cost of ice-breaker, | | $3,525 |

## SUMMARY.

| | |
|---|---|
| Foundation of centre tower, | $23,516 |
| Masonry, “ “ | 93,300 |
| “ “ abutments, | 75,870 |
| Anchor-chains, | 8,192 |
| Cables, | 120,820 |
| Stays, | 19,500 |
| Suspenders and floor iron, | 8,880 |
| Floor, | 16,776 |
| Castings, | 4,081 |
| Ice-breaker, | 3,525 |
| Total cost, | $374,460 |

The above estimate, therefore, shows that the construction of the Cincinnati bridge may be accomplished for a sum of *three hundred and seventy-four thousand four hundred and sixty dollars.*

### NOTE BY THE PUBLISHER.

[The foregoing estimates of Mr. Roebling, having been made without a knowledge of the formation of the bed of the river, they contain provision for a large amount of expense which will not be requisite. Piles will be unnecessary, and cannot be driven in the bed of the river, it being formed of solid compact blue limestone; and the cost of a great part of the stone used, may be reduced by quarrying them on the banks of the river, near the place where they are to be used, and where stone of the best kind may be quarried at low water.]

## 15. TABLE OF QUANTITIES.

| | | |
|---|---|---|
| Length of bridge from centre to centre of abutment, | 1,576 | feet. |
| Total length, including approaches, | 2,070 | “ |
| Height of centre tower, | 200 | “ |
| Elevation of floor above low water at tower, | ~~101~~ | “ 121 |
| “ “ “ “ at abutments, | 90 | “ |
| Flood of 1832, above low water, | 63 | “ |
| Length of chord of catenary, | 1,180 | “ |
| Deflection of cables, | 95 | “ |
| Length of cables, | 1,890 | “ |
| Diameter of cables, | 11.28 | inch. |
| Weight of one foot of cables, | 275 | pound. |
| Number of persons who may collect on the floor, | 13,000 | |
| Number of cattle which may be on the roadway, | 1,600 | |
| Tension of cables, resulting from weight of floor and 13,000 persons, | 1,427 | tons. |
| “ “ cables and stays, “ “ “ “ | 2,300 | “ |
| Ultimate strength of cables and stays, | 10,500 | “ |
| Weight of tower, | 19,500 | “ |
| Weight of tower and floor with a maximum load, | 21,270 | “ |
| Pressure resulting from this weight upon 1 superficial foot of foundation, | 8 | “ |
| “ “ “ “ upon 1 pile, | 50 | “ |