Engineers and engineering

Engineers Club of Philadelphia

ENGINEERS and ENGINEERING

Volume XXXIX

PHILADELPHIA
THE ENGINEERS' CLUB OF PHILADELPHIA
1317 Spruce Street
1922

ENGINEERS and ENGINEERING

JANUARY, 1922

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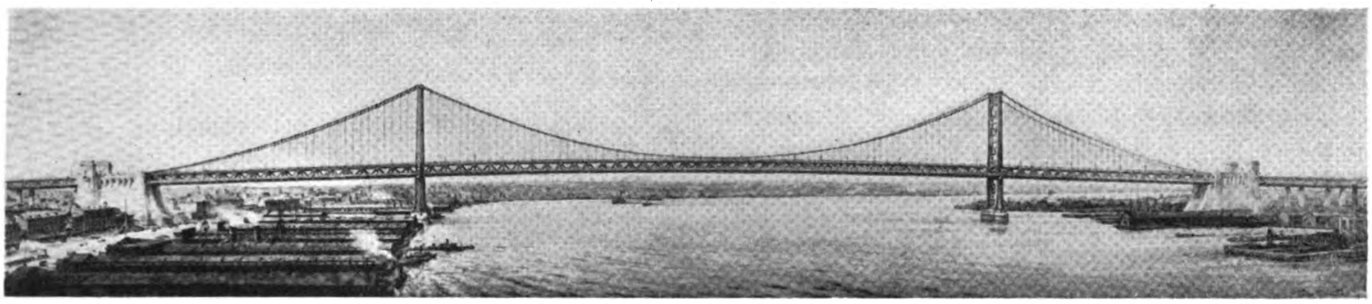
The Delaware River Bridge*



LONGER THAN ANY EXISTING SUSPENSION BRIDGE. THE MAIN SPAN ACROSS THE DELAWARE RIVER FROM PHILADELPHIA TO CAMDEN

The Delaware River Bridge center span will be 1,750 feet between towers, surpassing by 150 feet the longest suspension bridge in the world. It will mark an important advance in suspension bridge designs. The two cables supporting it will be 30 inches in diameter, each composed of 16,500 individual wires. The largest cable now in use is 20½ inches in diameter, while the far-famed Brooklyn bridge has cables only 15¾ inches in diameter. The bridge completed will have cost $28,000,000 and will be finished in time for use during the Sesquicentennial Exposition in 1926.

By Ralph Modjeski

Chief Engineer of the Delaware River Bridge Joint Commission

Ralph Modjeski is universally recognized as an authority on bridge design and construction and has been associated with numerous projects of large order. He was chief engineer in the construction of three bridges across the Mississippi River; the Thebes bridge at Thebes, Illinois; the McKinley bridge at St. Louis, Missouri; and the Harahan bridge at Memphis, Tennessee. He acted as consulting engineer on the Manhattan bridge project in New York City and as a member of the board of engineers of the final or successful Quebec bridge.

IN 1818, one hundred and three years ago, Philadelphia first began to dream of a bridge to Camden. The dream, with an occasional gleam of realization, continued until the present date when it is actually to become a reality.

In 1818 there was an island in the river between the Philadelphia and the New Jersey shores which was called "Smith Island." This was removed by dredging in 1893 thus increasing the gap between the two states instead of spanning it with a bridge.

At this time the plans for the main piers are barely completed and many of the important details of the superstructure still remain to be studied. It is, therefore, impossible to give more than a mere outline of what it is proposed to do and much of this will be a repetition of the statements made in the preliminary report of the Board of Engineers, published early this year.**

An Act of Congress of February 15, 1921, fixed the location of the bridge between Green Street, Philadelphia, on the north, and South Street, Philadelphia, on the south, to points opposite in Camden. This limitation, together with the necessity of placing no obstruction in the river between harbor lines, made it at once apparent that a span of great length, not less than 1,750 feet, would be required.

It will not be necessary to repeat the process by which the location at Franklin Square in Philadelphia and Pearl Street in Camden, was finally decided upon. The printed report referred to above gives all the details. Five locations were studied from all points of

*Address before the meeting of the Philadelphia Section of the American Society of Civil Engineers at The Engineers' Club of Philadelphia on November 7, 1921.

**Report of the Board of Engineers, June 9, 1921, portions of which were published in the July, 1921, issue of the Journal of the Engineers' Club of Philadelphia.

view—of cost, facility of construction, and as to the greatest benefit to the public and to the prospective users.

Cantilever vs. Suspension Type

For this great span, two distinct types are practicable—the cantilever type and the suspension type. For railroad bridges, with a single or double track, the suspension type is objectionable because of its greater flexibility and resulting wavelike motion of the cables and floor under concentrated loads. This objection does not exist for a highway bridge where the loads will be, generally, evenly distributed. The more lines of traffic the better will be the distribution.

In the Delaware River Bridge, six lines of vehicular traffic and four lines of rail traffic are provided for, besides two sidewalks, which gives in all ten lines of wheel traffic and two for foot passengers.

To determine positively, without recourse to the uncertain statements of text books, whether the cantilever or the suspension type would be more economical for the bridge in question, two complete general designs and estimates were prepared, one of each type. The cost of the cantilever design determined by these studies was two million dollars more than the suspension design, considering the main structure only. Other considerations, such as graceful lines, greater safety of construction and the fact that the suspension design lends itself better to subdivision of contracts, were taken into account in determining the choice.

The subdivision of contracts in the case of this bridge is of great importance, because of the fact that the funds will not all be available at once but will have to be appropriated from time to time. In the cantilever design it would be necessary to let the entire contract for the superstructure, a matter of about ten million dollars, at one time. In the suspension design, the superstructure may be let in the following separate contracts: the towers, the cables, and the stiffening trusses and floor.

Steel Towers Proposed

The adopted design contemplates steel towers placed on granite piers which will be founded on rock by pneumatic process. The caissons will be 70 ft. by 143 ft. in their horizontal dimensions and 40 ft. high. They will be filled with concrete and surmounted by crib work also filled with concrete. The construction of the caisson is a combination of steel and wood. The air chamber is of steel and the roof is supported by steel trusses running longitudinally and transversely. There are four wooden bulkheads in the air chamber to assist in supporting the weight of the caisson while sinking. The construction above the steel trusses is of wood.

The piers from a level 2 ft. 6 in. below ordinary low water, will be faced with granite and backed with concrete.

The borings thus far completed show the rock to be about 62 ft. on the Philadelphia side and 86 ft. on the Camden side, below mean high water.

Until comparatively recently it was considered necessary for suspension bridges to have massive masonry towers. Such was the Menai Bridge built about one hundred years ago and such were the old Buda-Pesth Bridge and the old Brooklyn Bridge.

At the time the Brooklyn Bridge was built, over forty-five years ago, it was without doubt a masterpiece of construction, but the science of engineering is progressing and many points of improvement have been introduced in the later designs of long span suspension bridges. The old masonry and the rigid steel towers required that the saddles carrying the cables over them, be placed on rollers. This was done in the Brooklyn Bridge and in the Williamsburg Bridge (New York). But later, when the Manhattan Bridge was built, greater knowledge of elasticity and properties of steel, led to the design of flexible towers for that structure. Thus the uncertain motion of the rollers of the old type bridge, which were not working in a satisfactory manner either at the Brooklyn or the Williamsburg Bridge, was obviated. Hinges at the bottom of steel towers were suggested for long span bridges in the endeavor to eliminate the uncertainty of roller bearings—but this is merely substituting one detail of very uncertain action for another.

Our eye accepts reluctantly the change from massive to slender towers, but it is merely a matter of education. This reluctance results in a temptation to disguise the real function of the towers by covering them with shells af masonry. Such shells, being useless, cannot be considered good engineering.

In the Delaware River Bridge, the bending at the top of the tower will be 21¼ in. towards the main span, and 15½ in. towards the anchorage under extreme conditions.

The anchorage piers will be masses of concrete faced with granite. The design of the anchorages presents more difficulties than any other portion of the bridge. Fortunately the rock at both anchorages is within reach, so that the complex effort of the cables on the masonry blocks will readily be taken care of.

Only Two Cables To Be Used

The backbone of the structure is the cable. It is proposed to have only two cables with 16,500 No. 6 wires in each. They will be approximately 30 in. in diameter. It is also proposed to study an eye-bar chain design in order, again, to determine beyond the opinion of text-books, which is better and more economical to use. The cables will also support the side spans in a similar manner to that of the Manhattan Bridge.

The reason for using two cables only is that the loads are distributed in a more definite and direct manner and that the details of the construction are

THE MANHATTAN SUSPENSION BRIDGE WITH A MODEL OF THE DELAWARE RIVER BRIDGE CABLE IN PLACE ON THE RIGHT HAND CABLE

simplified. Directness and simplicity should be the underlying and basic principles of all engineering. All three suspension bridges over the East River in New York have been built with four cables each. The Brooklyn Bridge cables are 15¾ in. in diameter, the Williamsburg Bridge, 18¾ in., and the Manhattan Bridge, 20½ in.

Three main questions have been asked about cables of the unusual diameter, of the Delaware River Bridge.

1. What will be the secondary stresses due to bending under load and temperature?

Assuming the cables as solid, all co-existing stresses will produce a stress per square inch of 79,800 lbs. on the wire. The direct congested load stress is taken at 72,500 lbs. per square inch, which means that the secondary stress will be about 10% in excess, an amount entirely permissible. The cables, however, are not solid and therefore the secondary stress will be considerably less.

2. What will be the efficiency of the cable as compared with the efficiency of the single wire?

A single wire hung from the towers, 1,750 ft. apart, with a sag in the center of 200 ft., will be subjected to a tension, due to its own weight, of 210 lbs., or 7,000 lbs. per sq. in. A variation of 1.1 in. in sag will increase or decrease this stress by 1,000 lbs. per sq. in. By the use of carefully adjusted guide wires, strung to the exact sag required at a given temperature, all wires are set to exactly the same sag and therefore are subjected to the same initial tension. This tension is sufficient to keep them taut without kinks of any kind. The longer the span the greater the initial tension in these wires. This initial tension is not disturbed by tying all the wires into strands or by wrapping the strands with wire into one cable. So that after the cable is completed and hanging free, every wire is stressed to the same amount. We now hang from it the stiffening trusses, floor, etc., and send live loads over the bridge. All which produces an elongation in the cable as a whole. Obviously, then, each wire must elongate by the corresponding amount. As we all know, the stress for a given elongation is proportional to the modulus of elasticity. A series of experiments has shown that the moduli vary from 26,500,000 to 27,800,000, a variation of about 5%. The stresses in the individual wires therefore cannot vary among them more than 5%. This means that if the cable is stressed as a whole to 70,000 lbs. per sq. in., some wires may be stressed to 68,250 lbs., and some to 71,750 lbs. per sq. in., but no wire should be stressed above 73,500 lbs. per sq. in.

The only factor which may tend to reduce the efficiency of the cable is the transverse pressure which the wires receive at the saddles and at the suspension points, when a transverse compression is exerted by the special castings which carry the suspender rods or cables. It is proposed to make special tests to determine how much, if at all, the strength of wires is affected by such a transverse pressure. We can only draw an inference from the action of ordinary steel cables or ropes working on sheaves, that the effect will not be material.

3. How can a wire cable be protected from rusting?

The Brooklyn Bridge cables were built of galvanized wires and have been in service forty-seven years. A recent examination of these cables, which was done by unwrapping the covering and prying the wires open with wooden wedges, shows that there has been no appreciable deterioration at any place. It is therefore believed that galvanizing affords a perfect protection for the wires and that the cables thus protected will last indefinitely. In the Manhattan Bridge, also, the wires were galvanized. The Williamsburg Bridge wires were not galvanized, but an attempt was made to protect them with linseed oil. The author recently examined the Williamsburg Bridge cables, and even with the lack of protection from galvanizing the wire seemed to be in very good condition.

Stiffening Trusses and Floor

The stiffening trusses of the Delaware River Bridge are arranged in three continuous sections, two in the side spans and one in the main span, expansion being provided at the towers only. It is planned to suspend them from the cables by means of eye-bars instead of wire ropes as was done in the former bridges.

The arrangement of traffic lines is quite different from any in the four New York bridges. A single 57 ft. roadway, which is only 3 ft. narrower from curb to curb than Market Street, Philadelphia, is placed in the center. There will be a surface car track on each side of this roadway on the inside of the trusses, and a rapid transit track on brackets on the outside of each truss. In the Manhattan Bridge the roadway is 35 ft. wide and the Queensboro Bridge roadway is 53 ft. 2½ in. wide, while both the Williamsburg and Brooklyn bridges have two roadways each much narrower than this.

The advantage of a roadway of single width over two roadways of half that width is apparent when we consider that vehicular traffic is practically all in one direction in the morning hours and in the reverse direction in the evening. On a single roadway with six lines of traffic, four or even five lines may be used for traffic in one direction.

An arrangement different from that shown in the preliminary report has now been worked out for the lateral bracing of the top chords of the stiffening trusses. The sidewalks are placed on the outside instead of the inside of the trusses, the overhead lateral bracing between the top chords is omitted and the top chords are stiffened first by curved gusset plates at each panel point connecting to the floor beams and second, by a horizontal truss placed immediately under each sidewalk. The elimination of the overhead bracing and the change in the position of the sidewalks will not only provide a clear view of the cables and towers but will also make travel over the bridge safer and more agreeable.

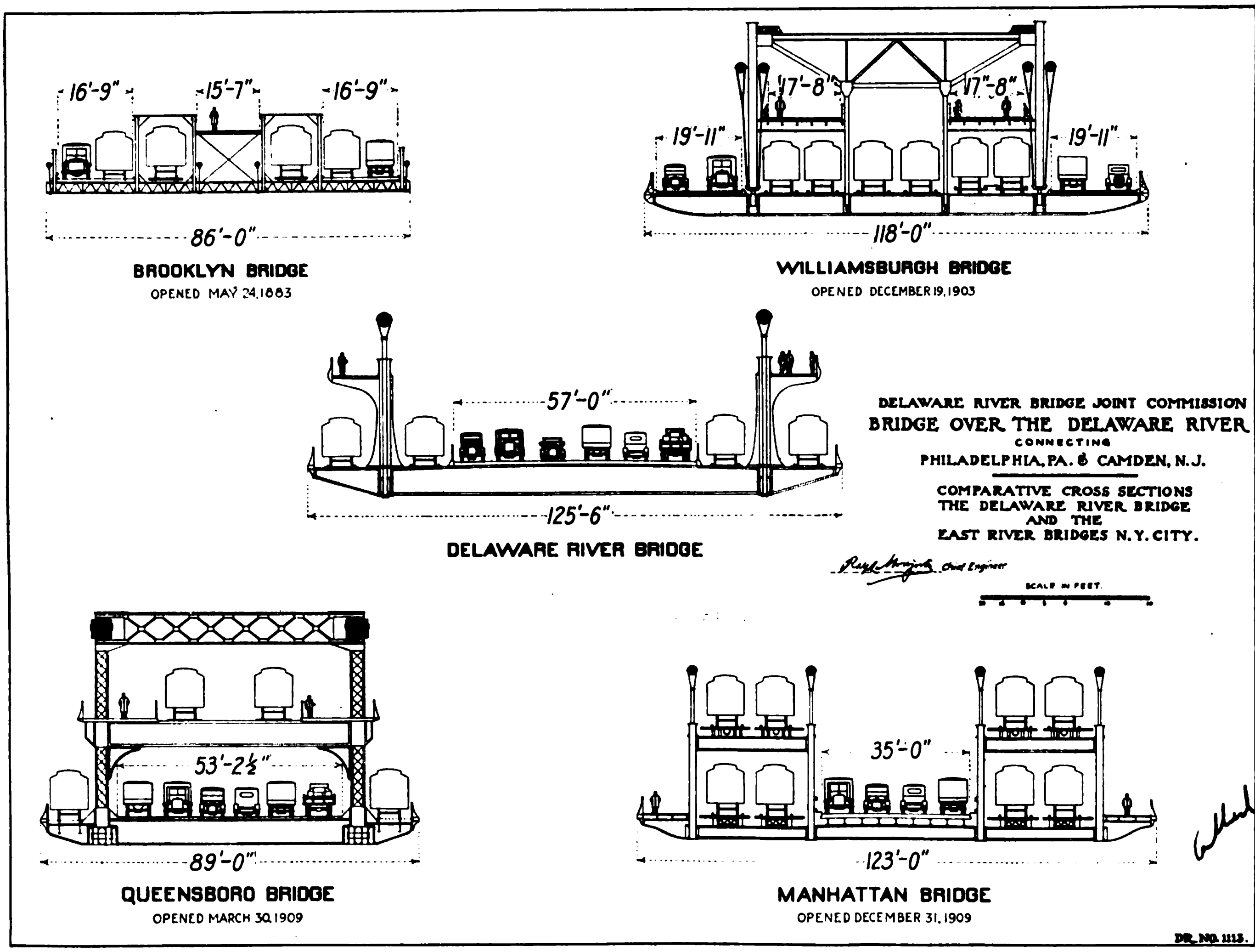


Plate I.—Comparison of Cross Sections—the Delaware River Bridge and the East River Bridges, New York City

Basis of Calculation

The following loading has been assumed for the Delaware River Bridge:

Two rapid transit lines....	4,000	lbs. per ft. of bridge
Two surface car lines.....	3,000	" " " " "
One 57 ft. roadway @ 70 lbs. per sq. ft...........	3,990	" " " " "
Two 10 ft. sidewalks @ 50 lbs. per sq. ft...........	1,000	" " " " "
A total of...........	11,990	" " " " "

The heaviest steel rail motor cars operated on rapid transit lines weigh, fully loaded with seated and standing passengers, 2,050 lbs. per lin. ft. The longer cars operated by the Municipal Railways Co. in New York weigh about 1,900 lbs. The elevated cars operated in Philadelphia by the P. R. T. weigh, fully equipped, 69,150 lbs. Allowing for a seating capacity of 50 and a standing capacity of 100 passengers, a total load per lin. ft. of 1,840 lbs. is obtained.

In adopting 2,000 lbs. per lin. ft. as the specified congested moving load per rapid transit track, ample provision has been made for high speed traffic.

The surface cars operated by the P. R. T. with a seating capacity of 53 and a standing capacity of 80 passengers weigh 1,230 lbs. per lin. ft. The "Hog Island" cars with a seating capacity of 46 and a standing capacity of 68 passengers, weigh 1,350 lbs. per lin. ft.

Allowing 1,500 lbs. per lin. ft. per surface car track as the congested load, provision has been made for a possible increase in weight of suburban cars.

Both rapid transit trains as well as surface cars cannot be operated without sufficient clear spacing between successive train units. It has been found that working speeds require a clear spacing between cars at least equal to twice the length of train or car. Thus the surface car load, under working conditions, will be nearer 500 lbs. per lin. ft. of track.

When local congestions occur on the main bridge a simple operating ruling keeps the cars spaced at an average of their own length. Such a condition would result in 750 lbs. per lin. ft. of track.

The average weight of forty-three types of fully loaded motor trucks was found to be 728 lbs. per lin. ft. and that of 25 types of passenger cars 312 lbs. per lin. ft. Allowing for six lines of vehicles over the bridge, three lines of motor trucks and three lines of passenger cars, a load of 3,120 lbs. per lin. ft. of roadway would result. The traffic count made by the Commission showed about 40% of the traffic to be motor trucks. In the above figures the higher ratio of 50% was assumed. Observations made at other places by engineers gave 500 lbs. per lin. ft. for a line of automobiles and trucks mixed.

For the design a congested load of 4,000 lbs. per lin. ft. of bridge has been assumed, an excess of 28%.

Thus the possible loads that may cross the bridge have been fully taken care of and also an allowance for a future increase in weight of vehicles has been provided.

This 12,000 lbs. per ft. of bridge therefore means congested loading; that is, the roadway filled with automobiles and trucks in close contact, the four tracks covered closely with cars filled to capacity with passengers, and the sidewalks carrying one pedestrian for each three sq. ft. Under this congested loading and under most unfavorable conditions of wind and temperature the stress in the cables will not exceed 72,500 lbs. per sq. in., or half the elastic limit. The stress in the towers will not exceed 27,000 lbs. per sq. in., or half the elastic limit and in the stiffening trusses 40,000 lbs. per sq. in., or less than three-quarters of the elastic limit. In the Manhattan Bridge it was calculated that under ordinary working load no portion of the stiffening truss is stressed more than one-quarter of the above unit stress or 10,000 lbs. per sq. in. The reasons for assuming a higher unit stress for the stiffening truss than for the other portions of the bridge are that should any one of the members fail there will be no serious consequence and that the maximum stress in the stiffening trusses would require a distribution of loading which is improbable; such, for instance, as the congested loading on one of the side spans and no loading at all on the rest of the bridge.

In arranging the track terminals it was considered of great importance that no tracks be allowed to block the free outlet of the roadway at the plazas. The experience in New York where criss-cross tracks and elevated roads are obstructing the circulation of vehicles in getting on and off the bridge, has led us to this better solution of the terminal arrangements.

VERBAL DISCUSSION

BY HENRY H. QUIMBY
Chief Engineer Department of City Transit, Philadelphia

It is evident that much expert thought has been given to the questions of both location and type, and there is little or no disposition among engineers to differ with the conclusions of the Board of Engineers and the action of the Bridge Commission in the selection of the site. Also we are, most, if not all of us, in accord with the recommendation of the suspension type of design whether the cables be of wire or of eye-bars.

The paper declares a preference for proximity to Market Street in Philadelphia, which certainly needs no argument to justify, and it seems a pity that conditions do not favor a site nearer than two and a half long blocks on the Philadelphia side, while the Camden end is even a greater distance from the Broadway station of the Pennsylvania Railroad, for as the bridge is located it does not hold out much promise of bettering accommodations for seashore travelers that now use the ferry, and as such traffic must be a very considerable portion of the ferry passenger traffic, and as there will always be pedestrian traffic originating between the bridge portals and the river, there may still arise a demand for a rapid transit tunnel under the river whereby continuous as well as direct transportation can be had.

In the planning of the car lines over the bridge was consideration given to the fact of difference in gauge of the tracks in Philadelphia and in Camden, neither being standard, and was any solution of the problem of through traffic suggested?

The bridge as a structure will have great interest to the public as well as to engineers, aside from its utility, because anything that transcends all others of its class is notable for that reason, and it will be of technical interest because we look for notable advances in the design of such an exceptional edifice. Large suspension bridges are so rarely built that very few engineers have a chance to design them, and the intervals of time between them are so great that, as in all branches of science, distinct development and improvement must be looked for.

The outlines of the bridge as shown are certainly graceful, though with the amount of dip given the cables a more pleasing elevation would be obtained if the bridge were raised about 50 ft. higher above the river, for people have a sense of suitable proportion between the height or the side area of a bridge truss and the area of the space below the bridge and above the ground or water. But the most ardent devotee of "Art for Art Sake" would hardly be so bold as to propose such a radical and uneconomical measure, although in the laying out of streets sometimes the public is condemned to perpetual detours at great economical waste of time and energy to secure plan lines whose curves of beauty can be seen and appreciated only when viewed from balloon or airplane.

The slender steel towers are entirely logical and in beautiful proportion when viewed in side elevation, and are no doubt the economical thing. Individual taste may suggest that the transverse bracing between the columns above the deck looks heavy in proportion to the columns, and it ought to be possible to get the necessary strength and rigidity of the bracing with smaller looking members and gussets.

Also it may be suggested that the gently tapering pilasters on the sides of the tower columns which stop off at the point of greatest transverse bending moments in the columns (about 14 ft. above the deck) might with advantage to appearance as well as stiffness be carried on down, and the outer car tracks be swerved enough at the towers to permit them to be so.

The stiffening truss in a suspension bridge always looks to the miscellaneous eye out of proportion to the cable carrying it, and this makes it desirable that the truss be as light in appearance as practicable and the cable as large as is justified. Also, if it is practicable to split the cables around the truss so that they could be dropped to or near to the lower chord of the truss at anchorages and at middle of span, it might be worth while both for appearance and to get a better dip to the cables.

For what concentration of live loading and on what theory of distribution is the stiffening truss designed, and was an assumption made of stiffness of the cables, and, if so, on what basis? Will it not be quite as convenient to construct two smaller cables, one directly over the other, either laced together or not? Some of the difficulties inherent in a very large cable would be avoided, and the eye of an observer would see less disproportion between the cable and the truss.

In designing the wire cables shown, what proportion of the total area of the wires was assumed as effective? If wire cannot be obtained in full length and each wire requires splicing, some section will be lost, and also presumably many of the wires will also be slack. Will welding of the wires not be more advantageous than the usual taper screw—splicing with sleeve nuts, both in giving greater effective section and greater facility for taking up slack? Where is provision made for temperature changes in length of trusses, and what temperature stress will be developed in the trusses due to the change of dip of the cables?

The change in cross-section of the bridge as shown on the screen from that shown in the published report of the board, whereby the overhead lattice transverse struts and horizontal bracing between the cables are eliminated, appears to be an improvement, certainly in the appearance of the bridge, and it may be in economy. The elevated footway over the river will be a delightful promenade in good weather, and if a seat could be constructed on it along the inside without too great expense, or a number of seats be placed there, the bridge would be an important adjunct to the activities of the Department of Welfare as a health resort.

What is the status of the fund for construction of the bridge? There is an impression that Philadelphia has not yet appropriated anything for construction—that its appropriation so far is available only for investigation, and that there is a hesitation on the part of City Council to make an appropriation for construction because the first such appropriation compels a reserve in the borrowing capacity of the city equal to the estimated total of the city's share for completion.

WRITTEN DISCUSSION*

IV **BY GUSTAV LINDENTHAL, MEM., A. S. C. E.**

EVERY unusually large bridge project offers new problems of construction, and it is a laudable although infrequent practice to offer up the plans for discussion by engineers before they are carried out. In this wise, more or less valuable views and experiences on the subject may be exchanged or contributed that may be of benefit to the project and so also to the whole profession. It is here assumed, that the plans for the Delaware River Bridge at Philadelphia-Camden to be presented at the meeting of the Philadelphia Section of the A. S. C. E., are the same that were published some time ago, and such comment on them, as herein offered, is intended to be in a helpful spirit.

The plans provide for a suspension bridge with wire cables and parallel chord stiffening trusses in vertical planes, of the type and arrangement in the Manhattan Bridge over the East River at New York. The middle span will be about 10% longer, but instead of four trusses there will be only two to carry the

(*) Presented by letter and partially read at the meeting.

floor construction. This is an improvement over the arrangement with more than two trusses, admitting greater certainty in the distribution of the suspended load and avoiding high secondary stresses in the floor system, due to unequal deflection of the cables.

The arrangement of the car tracks, two on each side of the roadway and descending on the approaches into subways, is also happily chosen. It will avoid the fouling of highway traffic with car traffic at the ends of bridge, which is a potent cause of congestion in the peak hours, mornings and evenings. The bridge will be found too small in a few years, and other bridges will have to be built as over the East River.

The location of the sidewalks over the rapid transit tracks, as now proposed, instead of over the surface tracks on the long spans, will do away with the ugly overhead bracing between stiffening trusses and thus afford an unobstructed view skyward between the supporting trusses.

While the general arrangement of the bridge is thus commendable, there are other features capable of improvement in the interest of the progressive art and science of bridge construction.

They relate first to the architectural aspects of the bridge and then to some of its constructive features.

Architectural Features

Any large bridge should be designed with a view to fine architectural appearance. That much at least is due to a civilized age and it is particularly important in a city bridge. Every large bridge, even when it is unsightly, has a monumental character from its very hugeness, and causes wonderment, but it should do more than that. It should also give the beholder a feeling of pleasure and enjoyment. That is the essence of architectural art and the more perfectly it is attained, the greater the merit of the work and the greater the regard for the sciences and the arts and their disciples, who create and leave it to posterity as a proof of culture and progress.

The studies in this case seem to have been confined to the cantilever form and the suspension form of bridge.

A cantilever bridge is the least adaptable to artistic treatment, but a large span can be given an imposing architectural appearance by the thoughtful engineer, through choosing a pleasing silhouette and by adroit differentiation of the bridge members so they will express in their form and massiveness the forces they resist. A satisfying aesthetic form for a very long cantilever span as in this case would, however, require the arching of the lower or compression line of the superstructure below the line of roadway, as was done in the two large spans of the Firth of Forth Bridge in Scotland, having about the same length as the river span in the Delaware Bridge. In the well-known Quebec cantilever bridge, the bottom edge of the structure also descends below the floorline, but unfortunately in straight lines, thus giving the bridge an amateurish appearance and unnecessary ugliness. It is regrettable that the graceful lines of the first Quebec cantilever design were not retained, because it was in its outlines and conception a meritorious design, but collapsed under its own weight; not enough metal had been put into it.

An arch bridge would have been the next in aesthetic value. From arch designs of nearly 3,000 ft. span (over the Straits of Messina) worked out in considerable detail, it is known, that arch bridges of very long span offer decided advantages over cantilever bridges, where the shores offer good abutments. But in the case of the Delaware Bridge, for which the Government required unobstructed width above the river, it was plain from the first that some type of suspension bridge would best satisfy local conditions. No time should have been wasted on a cantilever design.

It was then a question what kind of suspension bridge? One should think, that most any kind of suspension bridge would satisfy aesthetic demands, because the graceful curves of suspended cables, nature's beauty line, could not be spoiled by the callousness of man. But that such can be the case, was the experience in the Williamsburgh Bridge, the second bridge built over the East River.

No architect was consulted in the shaping of the bandy-legged towers or in the clumsy anchorages, nor were the stiffening trusses made sightly with any thought of forming a harmonious combination with the cables. The result is an unnecessary ugliness, which even the untutored mind beholds with surprise. That structure has the distinction of proving how unsightly even a suspension bridge can be made, if you try.

It should be the aim of the bridge architect designing a large suspension bridge, especially in city surroundings, to emphasize its monumental character in its most prominent feature, that is the towers. They should satisfy the innate desire to give dignity to the structure. It has found expression in all larger suspension bridges, some of them built a century ago. Stone was invariably used for the towers. To this fact all the old suspension bridges owe their reputation for beauty, whether it was of the rugged kind, as in the early English and American structures, or of the more refined and ornamental kind, as in some of the Continental suspension bridges.

The Brooklyn Bridge, completed 38 years ago, was the last suspension bridge with stone towers. The explanation is simple. High stone towers for very long spans are heavy and require big foundations, which are costly when they must be placed under water on deep rock. Metal towers are lighter and cheaper. But up to fifty years ago, cast iron was the only metal that could have been used as a substitute for stone towers and that only for limited heights.

Only after the iron rolling mills became capable of producing heavier rolled shapes, was it feasible to fabricate large metal towers of rolled iron and steel to take the place of stone towers. The designing of large metal towers as an art is therefore rather young and only few good examples of artistic metal bridge towers exist in smaller bridges.

From the aesthetic point of view, metal towers, no matter how finely designed, will never equal stone towers. The finest example of an artistic metal tower is the Eiffel Tower in Paris, which carries no load but its own weight. And yet as an architectural creation it does not impress the beholder with that feeling of dignity and majesty, which he experiences at the sight of any of the great spires in famous cathedrals. Although the highest inspiration of the architect, as also the cunning skill of the artisan will probably always prefer stone to metal as building material for monumental work, the modern architect is obliged to also use steel and iron. He must create his own precedents in that material, and a large suspension bridge is one of the occasions for it.

The writer held this view when, as Commissioner of Bridges of New York, he took charge of the East River Bridges nearly 20 years ago. But, he found, that he could do nothing in that respect during his short term of office. The Williamsburgh Bridge was building, the steel towers and anchorages were completed, the cables and its superstructure contracted for and in process of erection. For the Manhattan Bridge the narrow tower foundations were already sunk. Such was the case also with the Queensborough Bridge. The revised designs for all these bridges were fitted to conditions that could not be changed. These designs were either mutilated or thrown away by succeeding administrations, involving a loss of many millions of dollars. The mal-administration of New York City at that period has thus left its trace in its great bridges, readily discerned by engineers and architects. With better conditions of administration for the proposed Delaware Bridge, as far as the engineering is concerned, an unusual occasion is afforded for really good work if it is utilized.

An earnest effort should be made to design the metal towers for this monumental bridge on more artistic lines. The engineer who thinks merely of stresses must combine with the architect, who deals with artistic forms. The thousand foot Eiffel Tower already mentioned may illustrate the point. When in a discussion with a prominent structural engineer he had pointed out to him the beautiful lines and elegant details of that 1,000 ft. metal shaft as a fine example of French artistic skill, it was not a little surprising to hear him denounce that structure as wasteful and poor engineering of which no American engineer would be guilty. In fact, not long after an American design, a typical shop-creation, for a very high steel tower was published as an example of what such a structure should look like. Ugliness is rational beauty to minds who see merit only in geometrical figures and in cheap fabrication. It is not unusual for an engineer to be derided by his fellow engineers as wasteful and unscientific if he uses a few extra pounds of metal or a few extra yards of masonry to make his structure more durable or more sightly. And to listen to their doctrines of aesthetics would make a horse laugh. If such notions prevail, we may ask ourselves, to what purpose are our boasted academies of art and schools of architecture? We have no record of any such institutions existing for the benefit of the architectural geniuses in Greece and Rome, or among the God-inspired medieval cathedral builders of Europe, or among the ancient Babylonian, Indian and Moorish architects, whose wonderful work compels our admiration to this day. We know, that they did not get their inspiration from dry mathematical formulae, for they had very little of that, but they all had in them a spark of that creative supreme force and mind which moulds and directs the universe and with it that innate love for the beautiful, which like a flame tends always heavenward. The fine arts, which include architecture, will forever remain the true measure and index of human progress and intelligence. Future generations, wiser than ours, will judge our civilization by its achievements in monumental constructions, and for this reason we should feel it as a solemn duty and an obligation to the community, to do our best in that field. Viewed from that point, the towers of the proposed bridge do not present a good design. They are too much on the utilitarian principle of braced telegraph poles or derricks, holding up ropes. The few architectural touches and articulations in the surface of the columns and caps are not visible from a distance and do not relieve the unpleasant impression of naked utilitarianism. The steel towers should have at least four columns to express stability and power and should have a form and bracing for which the French School of Architecture for instance, furnished fine examples of artistic treatment in the Exhibition Buildings of the Paris International Exhibition in 1900. From designs studied in that manner a choice could be made, that would testify to the pride and good taste of opulent cities like Philadelphia and Camden, just as some of the fine bridges in Paris and London do for those cities.

Such towers should be provided with stairways or elevators to make the top readily accessible for sight-seeing. They would require a wider base, but not necessarily more expensive foundation, nor would they, on the whole, cost much more than the proposed towers. They would give the bridge its true monumental character and take it out of the commonplace. The towers should be fully designed and considered before the foundations for same are commenced. Because if the proposed narrow foundations were commenced, it would make the designing of more beautiful towers impossible. This happened in the case of the Manhattan Bridge, (of which the proposed structure is an imitation) where the narrow foundations prevented a design for monumental towers and a wider bridge. This bridge, only a few years old, is already too small, so that it is used only as a one-way bridge in rush hours, mornings and evenings. So is also the old Brooklyn Bridge.

As the high anchorages for the Delaware Bridge will be visible from a long distance on the river and from the shores, their silhouette and architecture should be fitted to that of the towers. That applies, of course, also to the suspended structure. Each has its proper share in the harmonious whole of a monumental bridge. The dominating feature, however, will always be the towers.

SOME CONTRUCTION DETAILS

A few words may be permitted on some of the constructive details, particularly the wire cables. Wire, because of its greater tensile strength than bars or rods, found early use in suspension bridges. French engineers (Dufour in 1823 at Geneva) were the first ones to use it, while English engineers (Telford 1820) had a preference for chains of iron, in the form of forged eyebars. The difficulty found in straining the wires with uniform tension made the French engineers cautious and so they preferred the method of construction which consisted in composing the wires into strands of parallel wires (occasionally also in the form of wire ropes). They were made on land. The strands hung side by side in vertical planes. The suspenders hung from crossbars on top of the strands and were lashed to them. This was also the construction of the first wire suspension bridge (1100 ft. span) built over the Ohio River (1846) at Wheeling by the French Engineer Ellett. The twelve strands for it were completed on land and hung on the towers. Shortly after its completion, a tornado turned the bridge upside down, John A. Roebling, who had already built a few smaller wire bridges, repaired the Wheeling Bridge. He disentangled the strands, and compacted them into two cables. Corroded wires in the anchorages were cut out and replaced. The bridge is kept in good repair and still in use, while most of the early wire bridges in France broke down from neglect and corrosion.

Roebling subsequently introduced the method of spinning the cables in the air and compacting the wires into cylindrical form by wrapping them with a continuous softer wire. This was the method followed in most American wire cable bridges. Only for two wire cable bridges over the Ohio River (at East Liverpool and Portsmouth), were the strands for the wire cables made on land.

All the early suspension bridges everywhere were built with flat catenaries, to which they owed their comparative rigidity in the absence of adequate stiffening frames whose office it is to prevent undulation in the cables and chains from loads and wind.

To this circumstance, flat catenary (1/16 to 1/13 of the spans) must also be ascribed the success of air spinning and compacting the wires under nearly uniform tension into solid cables, so that loose wires in them were rare and in small cables easily discovered and rectified. The last cables with flat catenaries 1/13 of the span, were in the Brooklyn Bridge. The wires were laid on a much flatter catenary than that in the bridge by moving the saddles on the stone towers toward the anchorages and thus increasing the tension in the wires during erection of the cables. This method was a great help to the better adjustment of tension in the wires before they were compacted. The four cables each 15¾" diameter, were completed in 21 months. The next largest cables in the Williamsburgh Bridge with about 1/9 deflection, were finished in 7 months, and the wire cables in the Manhattan Bridge, with 1/8 deflection, were finished in 4 months.

The successive shorter finishing times indicate the progress made in rapidity of cable construction, but it is a mooted question whether their quality as regards evenness in tension of wires is as good as in the Brooklyn and earlier bridges.

Many loose wires were observed during the compacting of the cables in the Williamsburgh Bridge near the towers, and they occurred also in the Manhattan Bridge. The compacting and wrapping machines starting from the middle and working toward the towers, compact the carefully laid wires so tightly that it would be impossible to pull out a single wire from the compacted portion only a few feet long. Loose wires can be adjusted in length only by cutting them and inserting a little turnbuckle splice with which to tighten the spliced wires if possible to same tension as the other wires. The trouble is however, that with all possible care in laying the wires, each adjusted in length with the guide wire, their length is constantly changing from changing temperature conditions in open air work, exposed to sun and winds. There always occur wires a few degrees warmer than others, producing local differences in tension and position in the same wire when in part already gripped in the compacted part of the cable. The compacted wires cannot slide on each other between the bearings on the towers, where they are held fast by their pressure. So the wires with less tension are forced together and compacted with those of higher tension and with different tensions lie side by side in the cable. But where the wires are not yet confined and compacted, they will bulge out, particularly as the compacting machines are nearing the towers. If the tension in the parallel wires at any one section of the cable differed even as much as 25 percent, it would mean no more than that some wires are stressed more than others, but that on the whole they are pulling together. The modulus of elasticity for the cables would of course be much lower than for the simple wires, but in the aggregate the entire cable section may have a sufficient margin of strength and safety. If the unequal tension in the wires can be controlled and kept between certain limits by careful work in the compacting of the cables, the total effective elastic strength of the cable, the only thing that counts, will be lowered, but still be high enough to include maximum stresses from loads and temperature. But this condition can be attained by simple methods only in smaller cables, in which the loose wires can be discovered and adjusted. As the diameter of the cable and the number of wires increase, such adjustment becomes increasingly difficult if not impossible.

The cables in the Manhattan Bridge, 21" in diameter, may be considered as the limit for such work and it is not at all certain, that the limit for safe air work was not already then exceeded. There exist no reports on the condition of the cables, during erection, except the observation of many loose wires forced into position by the compacting machines. If large cables could be uniformly loaded before being compacted with a large part of the suspended load, which would produce in the wires between bearings greater tension and stretch than that due to their own weight plus the elongation from the highest summer temperature and allowed to freely slide upon each other during their elongation and then compacted in that condition, then each wire in the cable between bearings would be under uniform tension although the many wires may differ slightly in tension one with the other. The aggregate strength of the cable would be brought nearer to the theoretical strength, which is equal to the sum of the wires. This method would require special preparation and would obviously be costly, and slow. A less effective alternative method would consist in starting the compacting machines on the empty cables from each tower down toward the center and ends, instead of the reverse, which is the accepted practice. The bulging of loose wires would then occur in the middle of the river span and near the anchorages instead of near the towers. Their adjustment and resplicing would occur at those parts of the cable where they have a surplus of strength and so would be less harmful. But the difficulty, if not impossibility, of reaching loose wires in the interior of a large cable would remain.

Engineers are therefore not lacking methods and means for making large wire cables of reliable strength, if they have to be made irrespective of cost, and if they have enough faith in their durability, which is not however justified to the extent of believing them as durable as eyebar chains. The engineer should prefer that construction, which for the same money is the best and most durable.

This leads to the subject of maintenance of cables. The best practice to preserve the wires against corrosion is undoubtedly galvanizing, i. e. covering them with a zinc coating. That practice was followed in the Brooklyn and Manhattan Bridges, but not in the cables for the Williamsburgh Bridge. The wires here were covered by a thick mineral oil paste expected to fill the interstices between the wires to make them water and air tight. That expectation was not fulfilled. Moisture condensed from the air penetrated the interior of the cable which was enclosed in a thin steel mantle. Corrosion started and repairs became necessary within a few years. Thick white lead paint filling up all hollow spaces is the best protection for that purpose.

But there is nothing permanently perfect in this world. As the zinc covering of wires may in the handling of them become abraised in spots or leave bare spaces, protection cannot be absolute. Some accidental strayed electrical current may find the weak spots and by electrolysis start corrosion in the electric opposite metals where it cannot be known or got at. In this connection we must keep in mind, that the great strength of the wire is in the outer layers of metal near the surface, which is the reason, why small wires are proportionately much stronger than large wires. If the surface corrodes away, the wire breaks easily. Several French suspension wire bridges hardly twenty years old, fell down some 60 to 70 years ago one after another rather suddenly, because there had been neglect in painting. The outside painting of cables can of course not stop corrosion inside and hold up a bridge. We see plain fence wire after a few years literally disappear like dust, particularly in smoke-laden air. Galvanized wire will last longer, but when corrosion after all gets a start, the wire seems to vanish even faster than plain wire. It is also so with tin roofs and tin cans.

The writer had been a strong advocate of wire cables for large suspension bridges for many years. They appeared to be an ideal method of construction for very long spans at lower cost than other bridge types. But when on closer study and observation he discovered the practical difficulties arising from greater span and larger size of parallel wire cables, he came to the same conclusion as other observing engineers, among them the late Geo. S. Morison, certainly a high authority. In his paper, (A. S. C. E., Vol. XXXVI 1896) on a study of a large suspension bridge, Mr. Morison had chosen for his 30 inch cables coiled wire strands, finished in the shops to accurate length and submitted to a proof-stress before erection, as preferable to cables with parallel wires.

The writer had about the same time examined into the practicability of fabricating wire links, (to be enclosed in a roomy shell of noncorrodable metal) with which to compose chains for suspension bridges. His first design for a suspension bridge at Quebec (1899) included that construction. The links were to be made of rectangular wire with corners rounded off, each link submitted to a proof-stress. They were guaranteed as to strength and quality under rigid specifications by the large wire firm, Felten & Guilliume in Cologne.

There would have been absolute certainty as to the strength of chains of this construction. This same firm as well as other firms manufacture several forms of patented coiled wire cables, which were used in suspension bridges of moderate spans, with great success. These were at first proposed also for the new Budapest suspension bridge in 1894. But the engineers for that bridge decided finally after long deliberation for chains of eyebars, cut out of wide plates. There are no plants in Europe for making forged eyebars. The finer architectural appearance of huge eyebar chains, and their greater durability were the final deciding factors.

The questionable condition and apparent uncertainty of strength of the large wire cables in the Williamsburgh Bridge induced the writer as Commissioner of Bridges for the City of New York, to avoid large wire cables in the plans for the Manhattan Bridge. The design provided therefore for chains of forged eyebars of Nickel Steel, which appeared to have many advantages over chains of wire links. That design was submitted to a board of five eminent bridge engineers and approved by them. Their report is published in Vol. IV, A. S. C. E. 1905, pages 89-93 (Report by Geo. S. Morison, C. C. Schneider, Mansfield Merriman, Henry W. Hodge, Theodore Cooper). In comparing chains and wire cables their first report to Mayor Seth Low sets forth:

"The chains have decided advantages in the accessibility of all parts for inspection and protection as well as in economy and rapidity of erection. They are to be preferred to wire cables whenever the cost of chains is not materially greater. The cost of eyebar chains and wire cables in this bridge would be about the same."

Quotation from the final report:

"We deferred our final report, relating to the quality of the material to be used for the eyebar cables until additional tests could be had and we should be satisfied, by correspondence with the leading manufacturers of structural steel, that the desired material could be obtained at reasonable price and in open competition...."

"In our preliminary report March 9th, 1903 we reported favorably on all features relating to the design of this bridge, subject only to the uncertainty of obtaining this quality of material. This uncertainty is now removed."

"In this final report, we unanimously recommend the adoption and execution of the proposed design of the Manhattan Bridge, as submitted to us by the Commissioner of Bridges."

The reason, why the Manhattan Bridge was not built on the approved plans is well known in the history of political corruption in New York. Before the contracts could be let, another City Administration was elected, which also changed the management of the Bridge Department. The approved plans were thrown away and new plans were made for a wire cable bridge costing several million dollars more than the chain bridge. No Board of Engineers was of course called in to report on these new plans, or compare them with those already approved. It was felt as a foregone conclusion, that, if done, the new plans would be rejected. The character of bridge management can be judged from the fact that the courts were appealed to by outwitted bidders to stop fraud in awarding contracts on manipulated bridge specifications. That a management of this kind would be very much concerned about the quality of the work or about progress in the art of bridges building was not to be expected and it is for this reason that we are without reliable scientific information or records on many details of erection and maintenance of the East River Bridges of that period. Among these are the actual condition and care of the big wire cables, erected in the unprecedented short time of 4 months, a very creditable performance, provided it was not at the cost of quality. Of this there is only rumor but no proof.

In any event, there is no reliable basis or safe precedent for a leap from 20 inch cables to 30 inch cables with parallel wires. It would be a great achievement, also most desirable, from the architectural point of view, to have big wire cables. In the writer's studies for the North River Bridge they would have been 60 inches in diameter. But it is one thing to design them and another thing to be assured of their safe obtainment.

That there are large secondary stresses in large stiff wire cables is now better understood, than when the East River Bridges were built, where they were not considered. The largest stresses from tension and bending occur at the towers just in that part of the cable, liable to have the most wire splices from adjustment of wires. Safe provision can of course be made for secondary stresses by increasing the cable section and leaving 150 to 200 ft. of cable at the towers uncompacted, so that the wires can slide on each other for that length to prevent excessive stresses from the bending of the cables. All this can be done, but it adds to weight and cost of cables and is poor construction.

In chains of eyebars no uncertainties of stresses can occur, as all lengths and fittings are done in the shops with great accuracy, which must be one of the determining elements in any great metal bridge. This feature was well considered in the design made for the Pennsylvania Steel Company for an eyebar suspension railroad structure at Quebec in 1910. In Engineering News (Nov. 23, 1911), the comparison of weight is given with the official equivalent cantilever design. The competition in this case did not decide the merit of any competing design as the contract was awarded to a cantilever structure not complying with specifications and therefore 30 percent lighter than any other design, including the so-called official design. The length of the river span (1756′) in this design was practically the same as in the proposed Delaware Bridge (1750′), therefore readily comparable for a layout, when transposed for the different load conditions and for the higher unit stresses, which would be justified with the present higher steels.

In this connection the report above mentioned on the chain design for the Manhattan Bridge as a carefully considered judgment from engineers of great experience and attainments is worth thoughtful consideration. In this report, made in 1903, the cost of eyebar chains and wire cables is mentioned as being about the same. It was based on nickel steel eyebars with 48,000 elastic limit and 85,000 ultimate strength. That was also the basis for the chain design for the Quebec Bridge 12 years ago. But since then progress has been made in the metallurgy of steel and large eyebars can be obtained of high steel with elastic limit exceeding 80,000 and 110,000 pds. ultimate. With such material an eyebar suspension bridge cannot help but be superior in quality to a wire cable design and also cheaper in total cost, when properly designed. It is surprising that improvements in the art are ignored and that no studies for chain designs have been made by which the merit and economy of the proposed wire cable bridge could be tested. That could probably be best done by a competition of designs, but not of the kind had on the Quebec Bridge.

Studies for a large bridge cannot be considered complete until every phase of it has been examined in the light of progressive scientific knowledge.

But in all or any designs for a large city bridge the architectural considerations should prevail for the reasons already stated. That much its builders owe to the public and our age.

CLOSING DISCUSSION

BY RALPH MODJESKI

Referring to the valuable discussion of Henry H. Quimby:

In the planning of the car lines over the bridge full consideration was given to the difference in gauge of the tracks on both sides of the river. No definite arrangement, however, can be provided until it is known whether both gauges or only one of them will be used on the bridge. As this matter will not have to be decided before two years some satisfactory solution will no doubt be found. This latter also applies to through-traffic arrangements. For further discussion of the subject the reader is referred to page twenty-three of the preliminary report on the Delaware River Bridge.

The transverse or sway bracing between the towers, when viewed on an engineering drawing showing the elevation without perspective, may appear heavy in proportion to the width of the columns. These columns on such a drawing are seen in their narrowest dimensions but a spectator will see the towers with their bracing in perspective only and no matter where he is placed he will see at least one tower in its greater width and he will also see the lacing of the top and bottom surfaces of the bracing which gives its members a relatively much lighter appearance.

Mr. Quimby's remark regarding the interruption of the pilasters on the sides of the columns above the deck is well taken; however, a study of this has been begun and no doubt it will be possible to modify it in the final design. But even if not changed, the nerrowed-down portion of the tower will be between the sidewalk above and the railway deck below and it will not be possible for any spectator to see that portion of the column at the same time as the wider section above. The actual strength of the column is, of course, taken care of at this point, by the addition of extra metal.

The appearance of the bridge would suffer materially if the cables were split and dropped to the lower chord of the trusses. The catenary curve would not appear continuous but interrupted by the camber line of the top chord of the trusses where the cables dip below it. Besides, it would mean the construction of two pairs of cables instead of two single ones, complicating the details and introducing greater difficulties of adjustment. No greater difficulties of construction are anticipated with the thirty-inch cable than were experienced at the Manhattan bridge with the twenty and one-half inch diameter cable. The two single cables are a more direct and simple solution, eliminating a large number of details and minor parts and many uncertainties of stress distribution. The same remarks apply to two smaller cables placed directly one over the other in place of the larger single cables. The increased number of parts, many of them subject to wear, and the introduction of elements of uncertainty in calculations would greatly outweigh any possible additional difficulties in the construction of a larger cable.

The stiffening trusses are designed for a working load of 6,000 lbs. and a congested load of 12,000 lbs. per ft. of bridge, placed so as to give the greatest stresses in the trusses. For the congested loading, which will occur if ever only on very rare occasions, higher unit stresses are assumed than for the working load. In order to obtain the maximum conditions some portions of the deck are assumed loaded with its maximum congested loading while other portions have no live load whatever. The distribution of this load between trusses and cables is such as will make the deflection of the trusses the same as that of the cable at all points. As the trusses are about four hundred times as stiff as the cables in bending, the stiffness of the cable is neglected in the calculations. The same also applies to the resistance of the tower to bending.

It is assumed that the entire area of the cable wires is effective; since the compacting of the wires in the cables is made from the towers down to the center of the main span and to the anchorage, there will be no loose wires on the towers where the greatest stress occurs. It is expected to eliminate the question of loose wires entirely by suitable mechanical devices but should any loose wires occur they will be at the center of the main span and near the anchorage where the total stress in the cable is least. The unit stress equal to one-half of the elastic limit of the wire is conservative enough to take care of any small imperfections in the manufacture.

Splicing the wires by welding does not seem advisable because of the effect of heat on the wire. This heat would tend to reduce its strength. The strength of the customary splice by means of sleeve nuts is about seventy-five or eighty per cent. of the strength of the wire. Since the wires are made in lengths of 2800 feet, there will be, on the average, fifty-nine splices in each ten feet of cable. The loss of efficiency of the cable as a whole, due to splices, will therefore be less than one-tenth of one per cent.

The provision for expansion of the stiffening trusses will be made at the towers. The advantage of this is apparent when we consider that the greatest motion of the trusses will occur where the suspenders are the longest. The temperature stress developed in the trusses due to the change in dip of the cables will vary at different points of the truss but approximately it will be from two and one-half to seven per cent. of the main stress, and will be provided for in proportioning the members.

The City of Philadelphia has appropriated $750,000 as its share of the construction. A small portion of this amount has been spent for preliminary work. It is ruled by the legal department of the City that balance of this amount is available for construction purposes.

Referring to the written discussion of Gustav Lindenthal:

Mr. Lindenthal speaks first of architectural features and later of some construction details ot the bridge under consideration. It seems to the author that construction details are first in importance and architectural features second, therefore he will take up these details first.

Frequent reference is made in the discussion to foreign engineers. Yet it is in this country that the greatest bridges, suspension and others, have been successfully built. Foreign engineers come here to learn our methods. We have a greater opportunity to build large bridges because of the greater number of important streams we have to cross. It is only natural, then, that the American Engineers should have more experience in such construction than their brothers across the ocean. It is stated that some wire suspension bridges in Europe broke down from neglect. That of course may happen to any neglected bridge.

The writer of the discussion evidently is not familiar with the manner in which the cables were compacted in the Williamsburgh and Manhattan bridges. The records in the Department of Bridges show distinctly that the compacting was done from

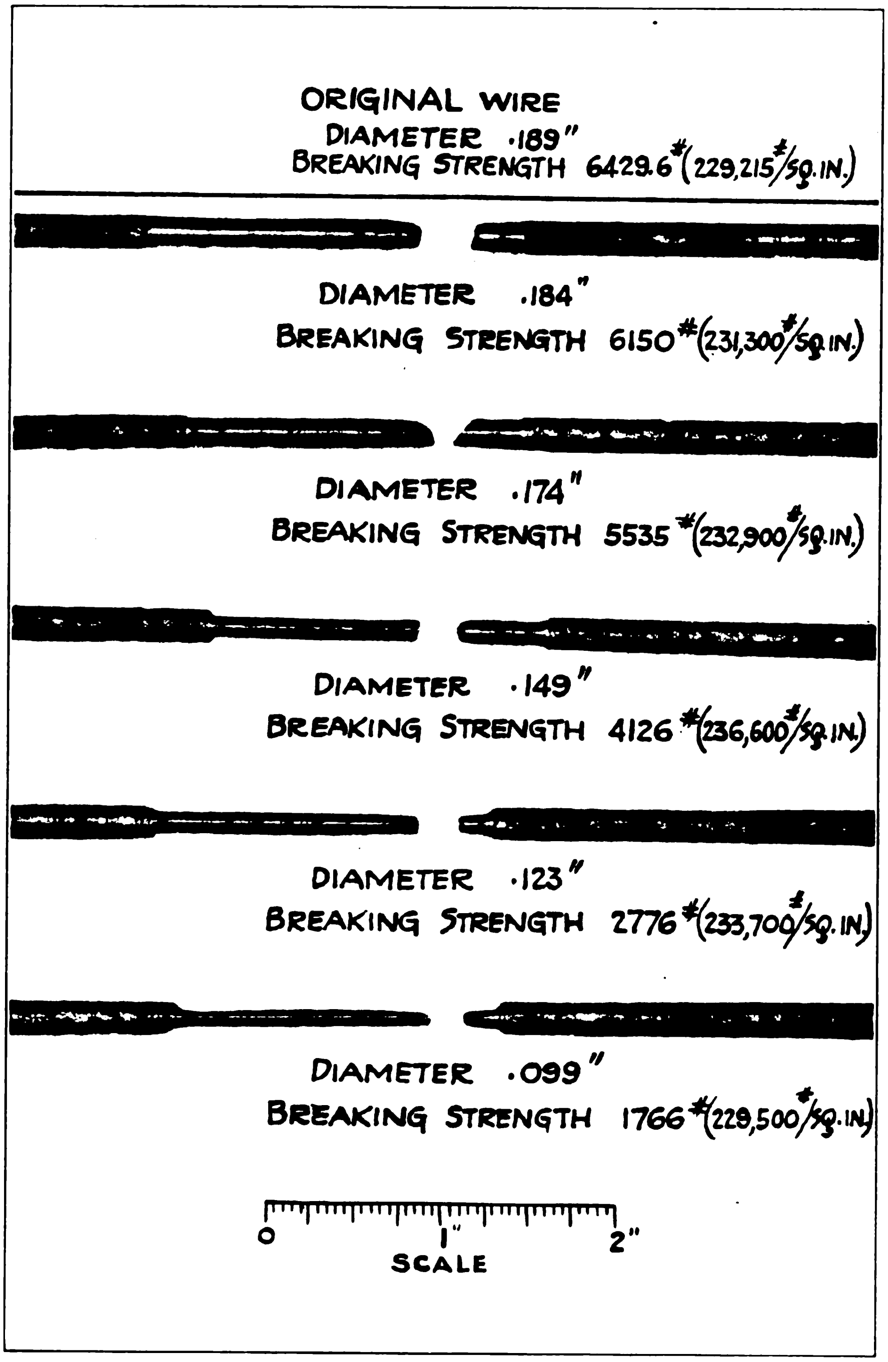


Plate II.—Tests Showing Comparison of Original Strength of Wire with the Strength After Removal of Successive External Layers

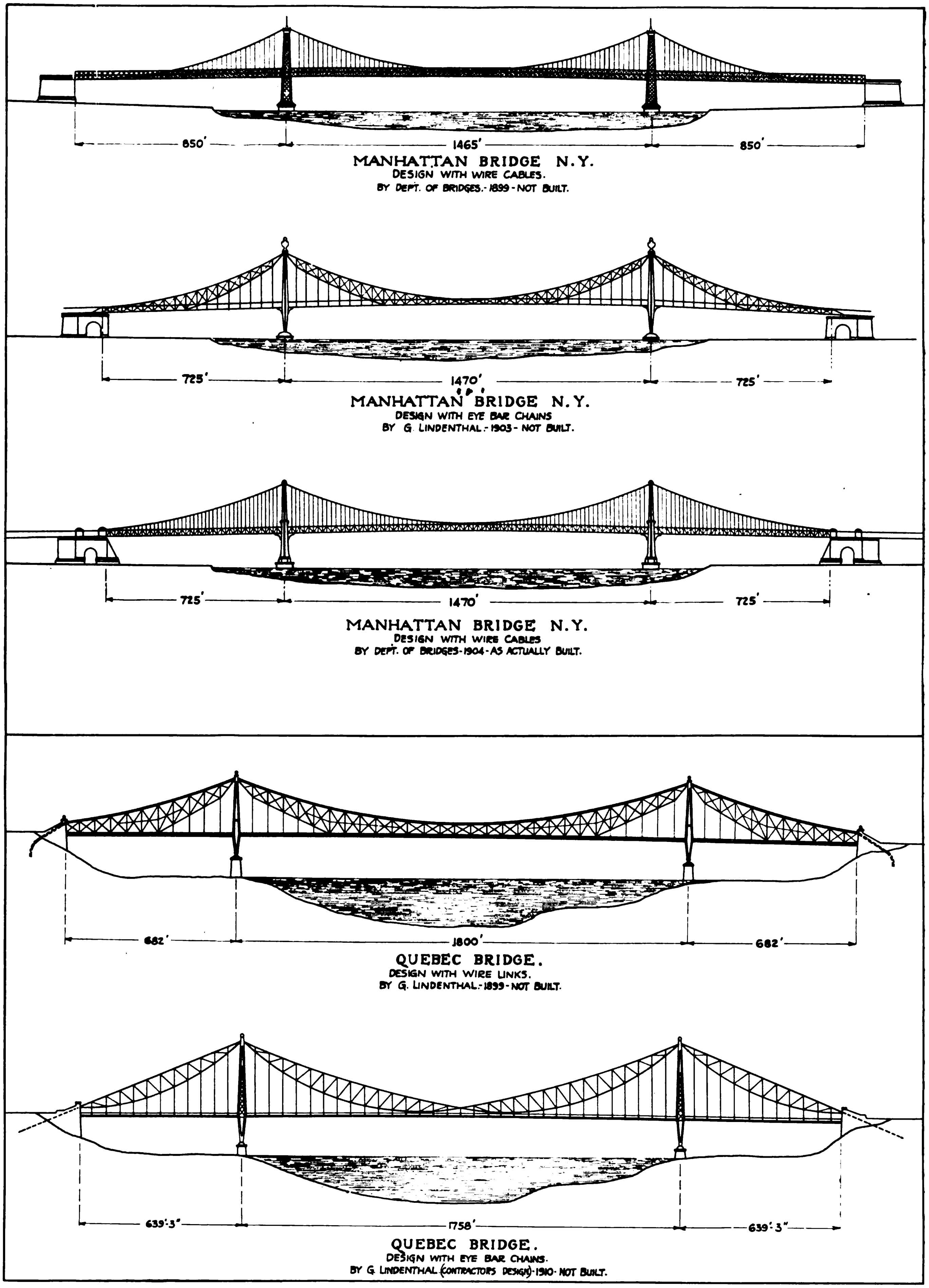


PLATE III—SUCCESSIVE DESIGNS FOR THE MANHATTAN BRIDGE AND TWO PROPOSED SUSPENSION DESIGNS FOR THE QUEBEC BRIDGE the towers down. They also show that there were no loose wires near the towers. The effect of temperature during the process of stringing of the wires will be appreciable in the Delaware River Bridge but can readily be obviated by simple means of sheltering from the direct rays of the sun. Generally speaking, each successive bridge of any type offers a field for improvement, not excepting long span wire suspension bridges. And we cannot look back to any eyebar suspension bridge even approaching the span length of the Delaware River Bridge, for reference. Such examples as we have of these, for instance the Point Bridge and the Seventh Ave. Bridge in Pittsburgh, are too small and have not been sufficiently successful to serve as a guide to design a 1750 ft. span.

The discussion points out the gradual shortening of the time of stringing the cables on the Brooklyn, Williamsburgh and Manhattan Bridges. This statement if not amplified is misleading. The shortening of time was due to improvement in methods and more and better machinery. On the Manhattan Bridge four strands of each cable were under construction at the same time or twice as many as on the Williamsburgh Bridge and four times as many as on the Brooklyn Bridge. The traveling sheaves made the trip from anchorage to anchorage in seven minutes on the Manhattan Bridge or one-half of the time required on the Brooklyn Bridge and seven-tenths of the time required on the Williamsburgh Bridge and the better means of access and improved machinery resulted in better workmanship.

The 20½″ diameter cable is declared in the discussion to be the limit. The much smaller cable of the Brooklyn Bridge also was considered as the limit at the time of its construction. In the Delaware River Bridge it is merely a matter of establishing another "limit." In this age of engineering progress it is not safe to pronounce anything to be the limit—but instead of that to apply science and ingenuity to utilizing the best materials to produce the best results.

It is agreed that the engineer should prefer construction which for the same money is the best and most durable. If he compares impartially the Brooklyn galvanized wire suspension bridge, the cables of which after more than 40 years of service are in perfect state of preservation, with the Seventh Ave. eyebar chain bridge in Pittsburgh which is greatly in need of repairs though of moderate span, he will hardly be in doubt as to which is best and most durable. The author examined recently the cables of the Williamsburgh bridge in which the wires had not been galvanized. The covering was removed and wooden wedges driven exposing the wires in the interior of the cable. No rust was found, although records show some slight corrosion in a few wires. This was due to the inadequate original covering and to the fact that the wires had not been galvanized. In this case, the repairs, which should rather come under the head of maintenance, consist of removing the canvas coating and the thin steel covering, cleaning the cables of all deleterious substances, pouring boiled linseed oil into the interior of the cables and serving or wrapping with No. 9 galvanized steel wire. The cables are then painted. A properly constructed cable, galvanized or not, is more proof against rust than a group of eyebars packed closely together on a pin. To illustrate this we should recall the International Railway Suspension Bridge over the Niagara River. When the increasing live loads required its replacement by the present bridge, the old cables were found in the same state of preservation as when placed there 50 years before and when cut apart the wires tended to return to their original coil. And these wires were not galvanized.

It was stated in the discussion that the great strength of wire is in the outer layers of metal near the surface. This is given as the reason for small wires being proportionately much stronger than large wires. This statement is entirely incorrect. The reader is referred to plate II showing results of a series of tests. The specimens were taken from the same coil and were turned down to gradually decreasing diameters with the following results.

	Ultimate strength per square inch
Average of 5 tests of bright wire .189″ diameter	229,215
Test on wire turned to .184″	230,625
Test on wire turned to .174″	232,873
Test on wire turned to .149″	236,626
Test on wire turned to .123″	233,619
Test on wire turned to .099″	229,425

In other words, wire that has been ground down to half its original diameter has the same proportional strength as the original wire. (*)

As to the cost of the wire cable design of the Manhattan Bridge the contract was let at a lower figure than the estimated cost of the eyebar design.

It is true that there is no precedent for a leap from 20 inch cables to 30 inch cables but no more is there any precedent for a leap from a 1000 foot eyebar span to a 1750 foot eyebar span. If one wants a precedent it is better to take for a starting point wire cable designs which more nearly approach the conditions and have proven satisfactory than designs of comparatively small eyebar chain bridges, some of which have been in themselves rather unsuccessful experiments, or eyebar designs of large spans which have been carried out on paper only.

Uncertainties in eyebar chain designs, especially in a braced chain, do occur—otherwise (for instance, in

(*) See also last paragraph of p. 199, Vol. X, A. S. C. E., July 1881, paper by L. L. Buck; also p. 129, Vol. XL, A. S. C. E., 1898, paper by R. S. Buck.