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THE MUNICIPAL ENGINEERS
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THE MANHATTAN BRIDGE.

BY ALEXANDER JOHNSON,* M. M. E. N. Y.

WITH DISCUSSION BY
ARTHUR S. TUTTLE, WILLIAM J. DUNCAN, GEORGE A. TABER, GARDNER L. VAN DUSEN, MARTIN GAY, GEORGE R. FERGUSON, AND ALEXANDER JOHNSON.

It is not the writer's purpose to present herewith a paper on the Manhattan Bridge. Such paper will later be prepared, when the construction of the bridge is completed and its full use as a highway for traffic is instituted. However, for the information of the Municipal Engineers a few of the more interesting matters connected with the construction of the bridge may be set forth.

It is the fourth bridge built across the East River and marks the close of a remarkable bridge building epoch in the history of the City, beginning in 1895 and continuing through the construction of the Williamsburgh, the Queensboro and the Manhattan Bridges. An era of tunneling under the river ensues, to be followed doubtless by more bridge building, when the present bridges and the tunnels are taxed to their capacity or do not conveniently serve the localities now more sparsely peopled, but with future possibilities of being centers of population.

In 1898 the City began the undertaking of the construction of the Manhattan Bridge. Late in 1899 there had been adopted a general plan for a wire cable suspension bridge with steel towers, masonry anchorages and approach structures of steel viaduct construction. It was to extend from the Bowery and Canal Street in Manhattan to Willoughby Street, between Prince and Gold Streets, in Brooklyn. The bridge of to-day extends from the Bowery and Canal Street in Manhattan to Nassau Street and the Extension of

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Flatbush Avenue in Brooklyn. In line with this first general plan were let the contracts for the construction of the tower foundations in Brooklyn and Manhattan, one in 1901 and the other in 1902.

The original general plan of 1899 was superseded in 1903 by a plan for a braced chain suspension bridge. The tower foundations, already contracted for, were adapted to the newer design by additional masonry. Effort was made to introduce desirable architectural treatment of the structure as a whole. Not much could be said in favor of the "lines" of the original plan and it was wisely determined that in the newer plan stern static requirements should be made to combine with beauty of outline.

Controversy arose as to the relative merits of the wire cable and the braced chain suspension bridge, delaying progress in construction. A change in the City administration set aside the braced chain design and in 1904 evolved a new design, haply the final, for a wire cable suspension bridge, which design is carried out in the bridge as it stands to-day. Out of all the controversy, now historic, and by reason of it, has risen the best bridge of its type in the world, a nobly pleasing structure and a highway of capacity second to no other in the world.

As stated before the Manhattan Bridge extends from the Bowery at Canal Street, Manhattan, southeasterly to the Flatbush Avenue Extension at Nassau Street, Brooklyn. The main bridge is a suspension bridge supported by four wire cables hanging in vertical planes stiffened by four trusses, and consists of one river span and two side spans. The cables are supported on steel towers fixed to masonry piers and are anchored in masonry. The approaches on either side of the river are of steel construction, consisting of seven through riveted Warren truss spans supported on concrete piers faced with granite. The Manhattan Plaza or entrance to the bridge will occupy two entire city blocks bounded by the Bowery, Canal Street, Forsyth Street and Bayard Street. The Brooklyn Plaza will occupy two city blocks bounded by Jay Street, Sands Street, Bridge Street and Nassau Street. As these plazas will provide access to the bridge for railway traffic as well as for vehicular and pedestrian traffic, the construction required upon them has not yet been undertaken and cannot very well be until it is known what railway companies are to use the bridge and how.

PLATE 5.
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JOHNSON ON THE MANHATTAN
BRIDGE.

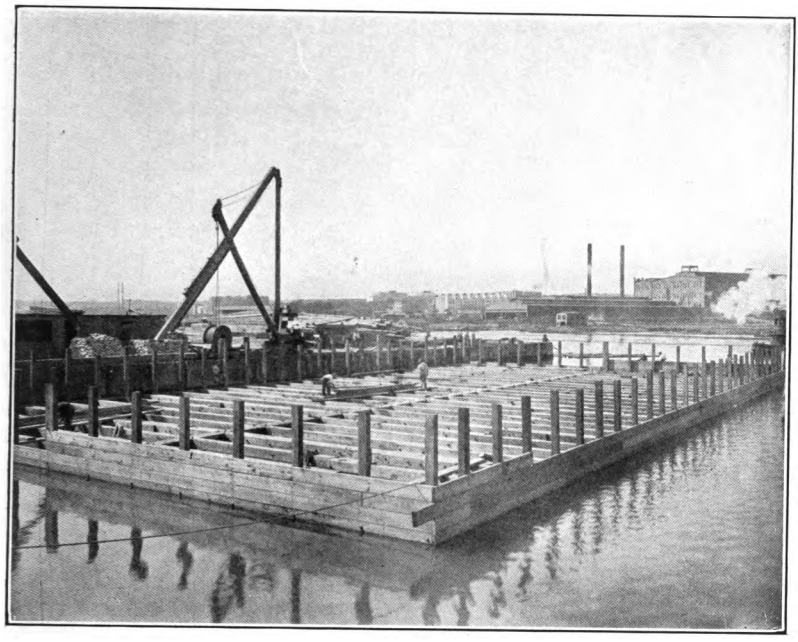

FIG. 1.—PONTOON UNDER CONSTRUCTION.

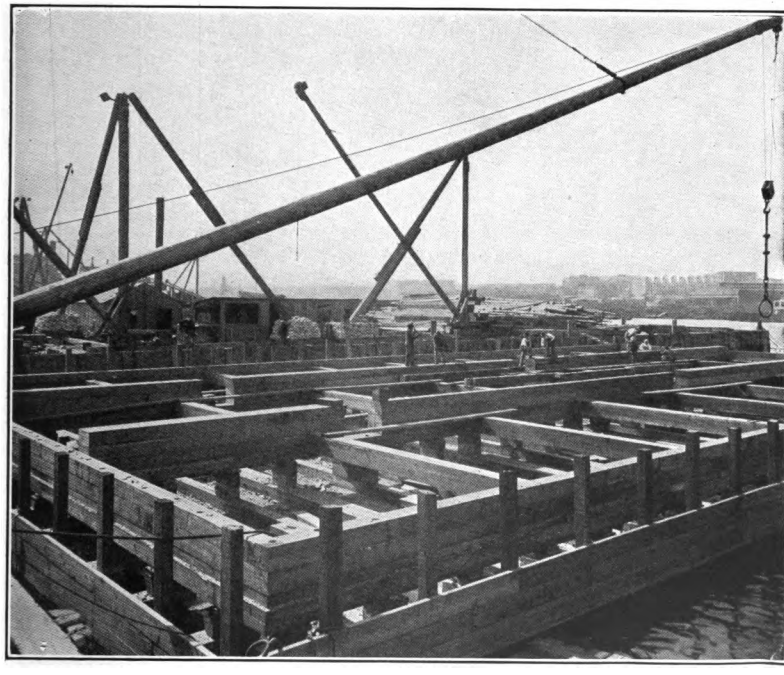

FIG. 2 —CAISSON UNDER CONSTRUCTION.

The bridge, including plazas, has a total length of 6 855 ft., divided as follows: The river span, 1 470 ft. and two side spans each 725 ft., making the total length of the suspended structure 2 920 ft.; the Manhattan Approach is 2 067 ft. long and the Brooklyn Approach 1 868 ft. The Manhattan Bridge is, therefore, third among the suspension bridges of the world in length of river span, it being exceeded by the Williamsburgh Bridge with a river span of 1 600 ft., and the Brooklyn Bridge with a river span of 1 595 ft. 6 in. In every other sense it is a larger bridge than these and of far greater capacity for traffic.

The clear height of the river span for a channel width of 400 ft. is 135 ft. above mean high water, at highest temperature and with the span loaded.

The width of the bridge over all is 120 ft. On the main or lower deck are two footwalks each 11 ft. wide, bracketed outside of each of the outer trusses, the main roadway, 35 ft. wide, extending along the axis of the bridge between the two inner trusses, and four tracks in pairs on either side of the roadway and within the inner and outer trusses. There are two upper deck structures on one level, extending the entire length of the bridge and its approaches, supported by the pair of trusses on each side of the roadway. These provide four more railway tracks in pairs. Eventually there will therefore be in use eight railroad tracks, one roadway and two footwalks.

The railway tracks on the lower deck can be utilized for subway traffic, affording transit between Manhattan and Brooklyn for lines operating the Brooklyn and Manhattan Loop Line, so-called, the Canal Street subway, a possible subway north and south on the Bowery, and the Fourth Avenue (Brooklyn) Subway. In this connection it may be remarked that carrying subway trains out of the ground and lifting them over steep grades through a vertical distance of sometimes over a hundred feet for the purpose of dropping them through the same distance, within the limits of the length of a bridge, appears at best as a makeshift for something that would be better, namely, tubes under the river. If the question be asked as to what would use these lower deck tracks if the subways do not, the existing surface car lines now operating in both Manhattan and Brooklyn and possible additional surface car lines suggest the

answer. The volume of traffic between the two boroughs over existing lines which may be extended is sufficiently great to warrant them the use of the bridge, leaving for future subway routes, existing for the most part as yet only on paper, the use of tubes to be constructed for them, making possible the immediate utilization of existing means of traffic to meet immediate needs, and providing as well for future needs. It is not contended that subway trains should be kept off the bridge altogether, but that operation of them thereon should continue only until the City can divert subway traffic into extensions underneath the river, thereby reducing grades to be traversed, diminishing the chances of accident, lessening costs of operation and increasing efficiency of service. However, the bridge can and will provide four tracks for subway trains. These tracks are practically finished now, except on the Plazas, and will be ready before the subways connecting with them.

While it is thus proposed to utilize all of the lower deck tracks for subways, the surface cars, operating trolley or conduit, may use the four upper deck tracks. These will, of course, have to climb from the streets at the plazas to the bridge deck on track supporting structures of steep grades.

When the track arrangement on the bridge structure was originally determined upon it was assumed that the lower deck tracks would be used by the street surface car lines and the upper deck tracks by elevated railroads. The opposition to further extension of elevated railway structures in the older and more congested sections of the City renders it unlikely that elevated railway trains will ever operate over the bridge on the tracks originally intended for them. It is possible to connect with the elevated railways of Brooklyn in such manner as to bring their trains across the bridge on the lower deck tracks and into a subway in Manhattan. Such arrangement would require extension of the existing elevated railway structure in Brooklyn streets to the bridge plaza.

It has been estimated that with all of the eight tracks on the bridge in use, the railway traffic capacity per hour in one direction will be 180 000 passengers.

The construction work on the bridge was divided into seven principal contracts, as follows:

1. Brooklyn Tower Foundation, let in 1901, completed in 1902.

PLATE 6.
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JOHNSON ON THE MANHATTAN
BRIDGE.

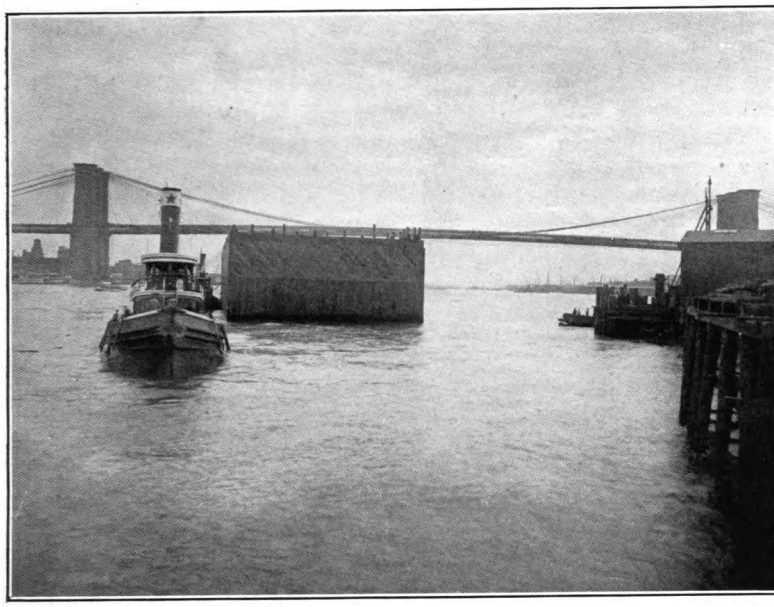

FIG. 1.—CAISSON BEING TOWED IN AT PIKE SLIP.

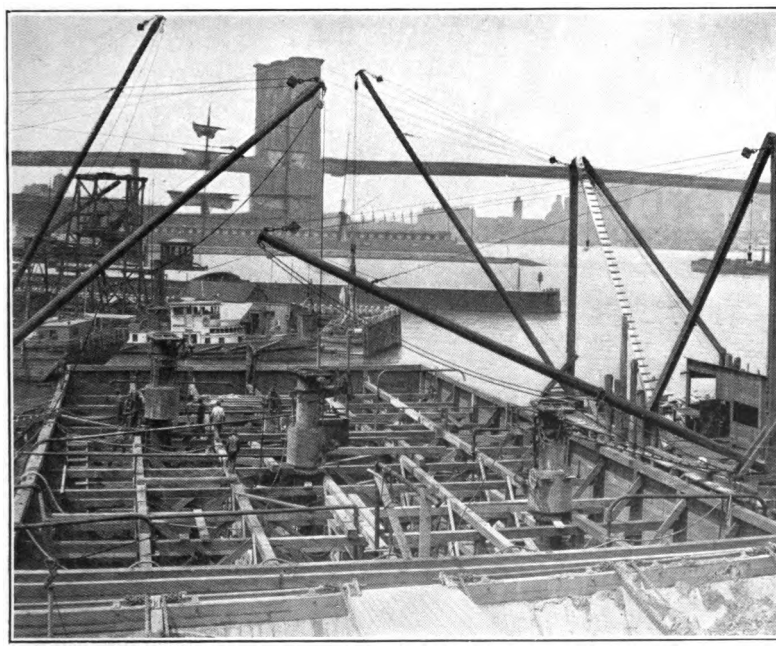

FIG. 2.—CAISSON IN PROCESS OF SINKING.

2. Manhattan Tower Foundation, let in 1902, completed in 1904.

3. Brooklyn Anchorage, let in 1905, completed in 1910.

4. Manhattan Anchorage, let in 1905, completed in 1910.

5. Steel Towers, Cables, Suspenders and Suspended Superstructure, let in 1906, completed in 1909.

6. Manhattan and Brooklyn Approaches, let in 1907, completed in 1910.

7. Roadway and Footwalk Pavements, Electrical Equipment, and Lower Deck Railway Tracks, let in 1909, in course of completion.

The principal contracts remaining to be let are those for the work to be done on the plazas and the installation and equipment of the upper deck tracks.

The tower foundations are practically alike for each side of the river. They are single piers consisting of concrete, limestone and granite masonry. They were carried by means of pneumatic caissons to elevation 91.85 ft. below mean high water in Brooklyn, and elevation 92.26 ft. below mean high water in Manhattan. The Brooklyn caisson rests on a bed of coarse gravel and boulders, the underlying bed rock being but 2 or 3 ft. below the cutting edge. The Manhattan caisson rests on a compact bed of sand and gravel. The underlying bed rock is from 8 to 37 ft. below the caisson. These caisson foundations are now carrying the total dead loads for which they were designed, and there has been practically no settlement of the Brooklyn foundation and a total settlement of about ⅝ in. in the Manhattan foundation. The maximum pressure under the foundations will be about 8 tons per sq. ft. Under ordinary conditions it will amount to about 6½ tons.

Each caisson was built chiefly of timber and departed from precedent in no essential features except size. The Manhattan caisson is 78 ft. wide, along the axis of the bridge, and 144 ft. long, on the line of the transverse axis of the bridge. The working chamber, divided by two bulkheads into three smaller chambers, was about 6½ ft. high. The timber roof over the working chamber is 2 ft. 9 in. thick. Above this, during construction of the pier, was a timber coffer dam about 50 ft. high. The caissons were built on pontoons located in the Harlem River. When the caissons had sufficiently advanced in construction to be launched the pontoons

were sunk and pulled away from the caissons, which were then towed to the bridge site and moored in position. Concrete above the roof and within the coffer dam was then built up, the caisson settling down into the river bed. Compressed air was then forced into the working chamber and as masonry was added above the roof, material from below was excavated and passed out, the finer material through blow-out pipes and the coarser material through locked shafts which extended upward through the roof from within the working chamber. When the cutting edges of the caissons had reached their final position the working chambers were sealed or filled solid with concrete. The laying of the uppermost courses of granite masonry above the water line to a height of about 32 ft. followed and completed the foundations for the steel towers.

The air pressure employed in the sinking of the caissons varied from 20 lb. to about 47 lb. per sq. in. The total cost of the tower foundations and the granite pedestals surmounting them was $1 125 000.

The anchorages are large masonry structures, one on each side of the river, located about 2 900 ft. apart. They enclose and contain the steel eye-bars and girders which form the anchors for each of the four bridge cables and also the steel anchors for the stiffening trusses at their points of support at the front wall of each anchorage. Each anchorage at its base is about 237 ft. in length and about 182 ft. in width, and at the level of the main deck of the bridge is about 184 ft. in length and about 152 ft. in width. The masonry mass rises to a height of about 103 ft. above street grade, but is finished off architecturally above this by massive granite colonnades about 40 ft. high. Transversely through each anchorage passes a public street, Water Street in Brooklyn, and Cherry Street in Manhattan. The street passage is through a full centered arch 46 ft. in span and rising to a height of about 45 ft. from the pavement. Connecting with this arch at right angles, and on the axis of the bridge, is a smaller arch of about 18 ft. span, forming a passageway through the front face of the anchorage. The most noticeable features in the Manhattan Bridge anchorages, in contrast with the anchorages of the Brooklyn and Williamsburgh Bridges, are the buttressed construction of the front wall and the fact that the cables supporting the bridge are not led into the anchorage through openings

PLATE 7.
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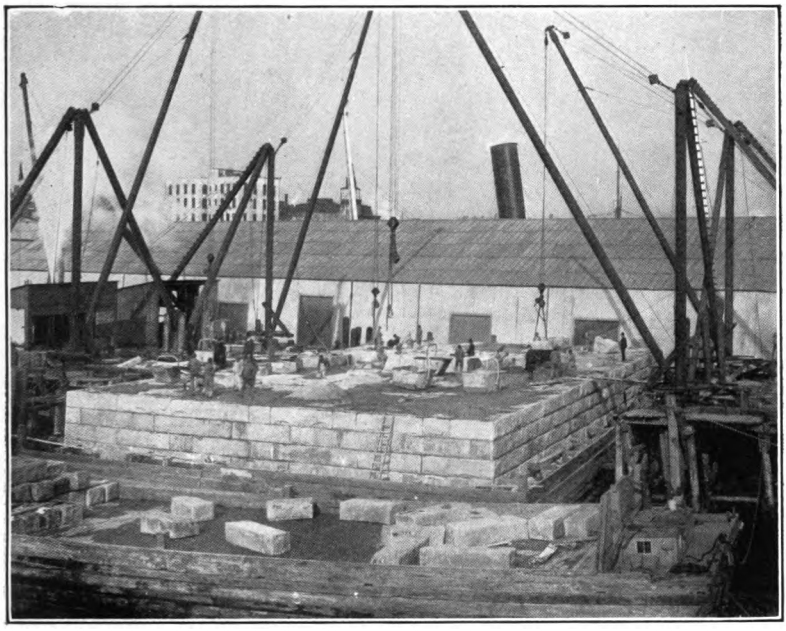

FIG. 1.—MANHATTAN TOWER PIER. FROM THE EAST RIVER.

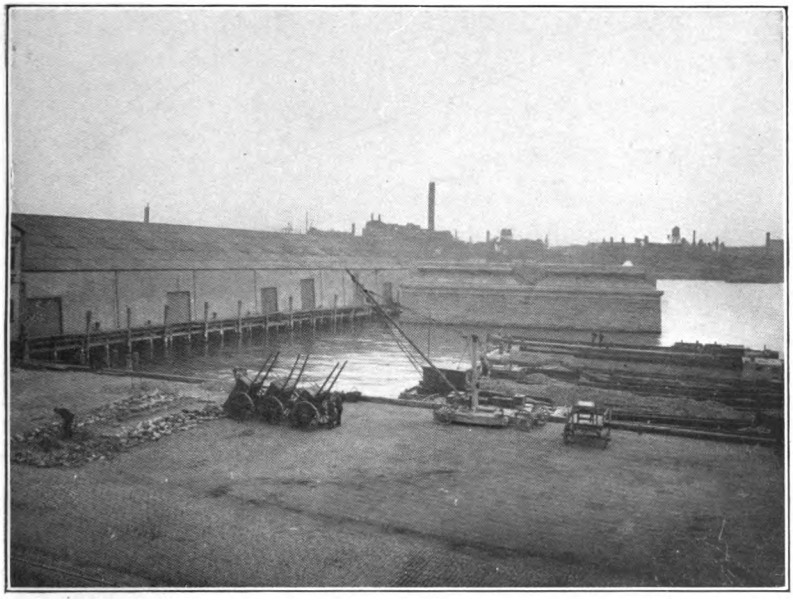

FIG. 2.—MANHATTAN TOWER PIER, FROM SOUTH STREET.

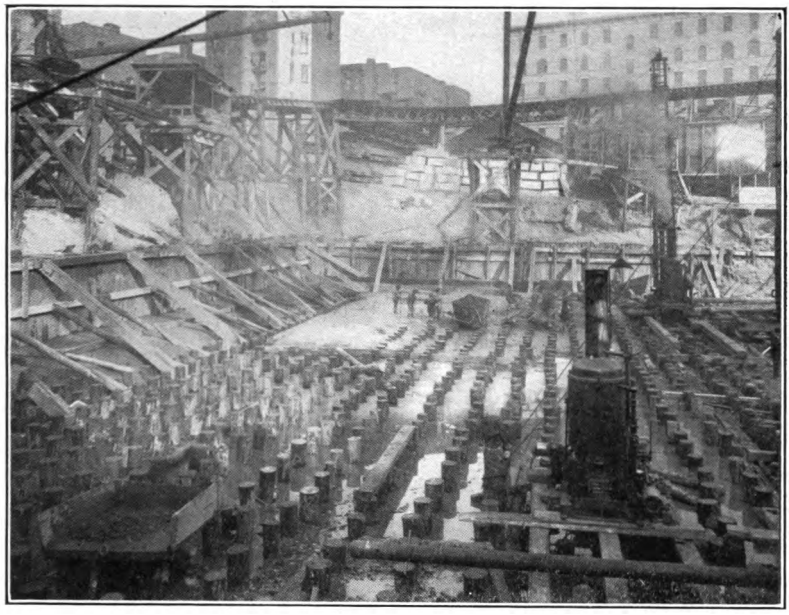

FIG. 1.—PILING AT WEST END OF MANHATTAN ANCHORAGE.

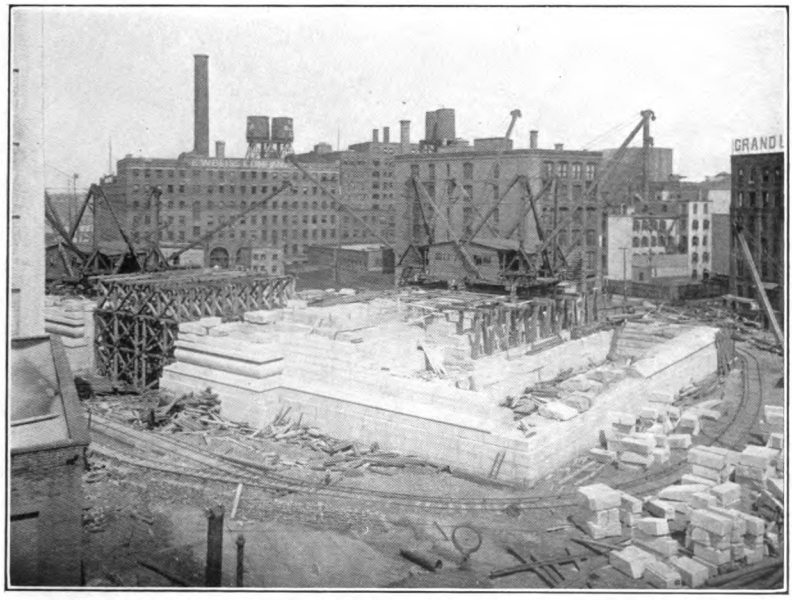

FIG. 2.—BROOKLYN ANCHORAGE, LOOKING NORTHEAST.

in this wall. These features are incidental to a controlling feature in the architectural design of the bridge, namely, that at no point between the anchorages should the cables intersect the line of the stiffening trusses. The cables, extending to the anchorages above the top chords of the stiffening trusses are supported at the front of each anchorage on cast steel saddles bearing on inclined granite pedestals. The buttresses in the front walls of the anchorages are in the planes of the main cables and buttress the pedestals over which the cables are deflected into the anchorages through the surface masonry at the top.

The exterior walls of each anchorage are of granite throughout, relieved by arches, buttresses, pilasters, cornices, balustrades and colonnades in such manner as to form a most pleasing architectural monument, inclosing the more prosaic though more vital construction within of stone, concrete and steel to which are secured the bridge cables.

The Brooklyn anchorage is founded on a bed of sand, gravel and boulders at an elevation of 12 ft. below mean high water. A few bearing piles were driven into this material. The Manhattan anchorage is founded on a bed of sand and on bearing piles at elevation 12 ft. below mean high water. The excavation required for the foundations was all open. On the bearing piles and bottom as cleared was deposited a solid mass of concrete up to the street level, making a masonry footing about 25 ft. thick. This, under the main arch, was reinforced with steel bars. Imbedded in the concrete to the front and rear of the main arch were large blocks of granite and limestone, roughly cubical in form and constituting so-called cyclopean masonry backing. Above the footing the outer walls of granite were laid as the deposit of concrete and cyclopean masonry backing within progressed. The rear portion of the anchorage, resisting the pull of the cables, is built up solidly. In this is imbedded, above water level, the anchor chain girders and the eye-bars forming the anchor chains to which are attached the strands of the wire cables. There are nine groups of chains to each cable, eight in four-strand groups, each composed of 32 eye-bars 9 in. by $1\frac{7}{16}$ in. and one in a five-strand group composed of 42 eye-bars 9 in. by $1\frac{7}{16}$ in.

The front portion of each anchorage, that which supports the

load of the cable saddles and their granite pedestals, is built up solidly through the section of each buttress, with concrete and cyclopean masonry. The middle portion of each anchorage, above the main arch, is divided into chambers, separated by concrete walls supporting concrete arch construction carrying the bridge roadways.

The time allowed the contractor for the construction of the anchorage was divided into two periods between which occurred the building of the bridge cables. The first division of the work involved construction of the rear portion of the anchorage up to elevation 83 ft. above mean high water, and of the front wall, buttresses and pedestals complete.

This arrangement was necessary in order to provide free space for plant and access to the anchor chains during the cable-making operations. Following these the anchorages were completed simultaneously with the completion of the steel spans.

The weight of each anchorage is 231 600 tons. The calculated pressure at the toe under maximum loadings will be about 7.5 tons per sq. ft.

The cost of the Brooklyn anchorage was $1 237 642.35, and of the Manhattan anchorage $1 258 671.50.

The steel towers, cables, suspenders and the suspended superstructure were all included in one contract, the largest of those let in connection with the construction of the bridge. The experience undergone in the construction of the Williamsburgh Bridge where the steel work from anchorage to anchorage was let in three separate contracts, viz., one for the steel towers and shore spans, one for the cables and suspenders and one for the suspended span, clearly implied the wisdom of embracing within the one contract the entire construction of the main bridge and eliminating multiplicity of plant, friction between separate contractors and possible consequent litigation with the City, while at the same time resulting in economy to the City. A very important result, was the gain in time to the City in that the fabrication of all the materials required was proceeding simultaneously and under one direction. This brought about an orderly and intelligent accumulation and erection of materials and fitted each step in the progress of the building of towers, cables and suspended spans in manner to overlap, where possible, succeeding steps, without intervals of time lost

PLATE 10.
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BRIDGE.

FIG. 1.—BROOKLYN ANCHORAGE, LOOKING WEST.

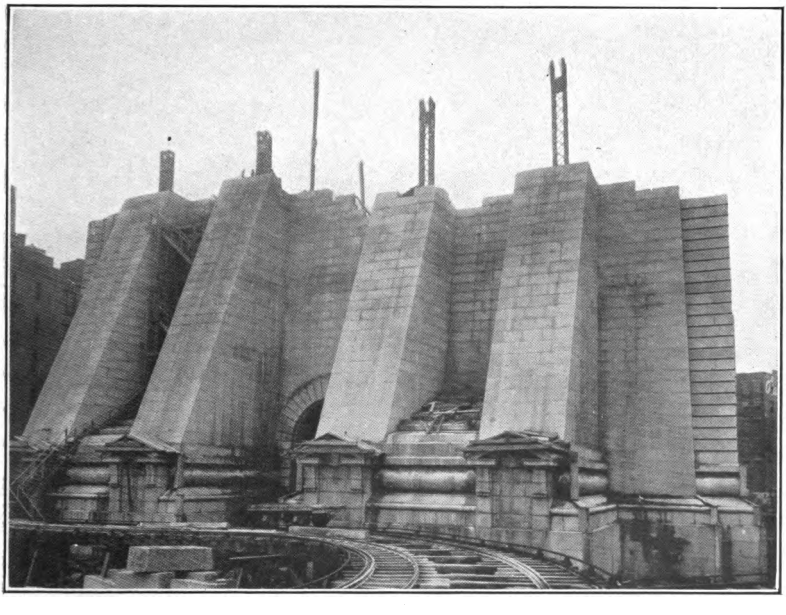

FIG. 2.—BROOKLYN ANCHORAGE, FRONT FACE, LOOKING EAST.

in one contractor waiting for another. In three years and four months there was fully completed the erection of 34 424 tons of structural steel and 8 000 tons of steel wire, suspender ropes and cable bands at a total cost of $6 584 234.83.

The steel towers rise to a height of 336 ft. above mean high water, and consist of four steel columns, one under each cable, braced together and arranged as a transverse bent. Each column is of cellular construction, opposite outer plates or webs being braced together at intervals by transverse diaphragms. The saddles at the top of the towers, on which the cables rest are fixed to the tower, unlike those on the Williamsburgh and Brooklyn Bridges, which rest upon movable bearings. The base of each tower is fixed. As the cables, under varying loads and temperatures, cause movement of the saddles, this movement therefore is taken up by the tower bending inshore or outshore, as the case may be. Under certain conditions of partial loading, and using the working live load of 8 000 lb. per lin. ft. of bridge, adopted in the design of the bridge, the bend at the top of the tower may amount to about thirteen inches, disregarding the resistance to bending developed in the towers themselves as the cable saddles tend to shift. Under similar conditions of partial loading, but using the congested live load of 16 000 lb. per lin. ft. of bridge, the total bend or deflection at the top of the tower may amount to about twenty-four inches. Under these latter assumed conditions, which are not likely to occur in the life of the bridge, no part of the tower would be stressed to more than 0.8 of the elastic limit of the material. Under the severest actual conditions likely to occur the stress developed will not exceed about 0.6 of the elastic limit.

Some very heavy sections were handled in the erection of the 6 250 tons of steel in each tower, the maximum weight being 62 tons. An ingenious feature of this erection was the method adopted by the contractor of supporting the derrick platforms or travellers. No false tower was required, the tower columns themselves forming literally a sort of track up which the travellers moved and by which they were supported as erection progressed. There were two of these travellers, one within each pair of columns. The platform extended inshore from the tower columns, and was supported by two brackets. At the platform level the bracket bore

on rollers which engaged the outstream side of a projecting middle section of the tower column, or where such section did not exist, as in the upper part of the tower, a heavy vertical timber bolted to the tower column. At the foot of the inclined strut of the bracket were rollers engaging the instream side of the projecting middle section. The center of gravity of the traveller complete was, obviously, outside the tower and inshore. The travellers were vertically supported by the projecting heavy gusset plates for the tower bracing. The lower or pedestal section of the towers was erected by floating derricks, and then followed the installation of the travellers, and the erection of the tower columns, the bracing, and finally the cable saddles.

Following the completion of the steel towers and as much of each anchorage as was required for the anchor chains and the support of the anchorage cable saddles, the construction of the bridge cables was undertaken.

There are four cables hanging in vertical planes and located 20 ft. and 48 ft. either side of the center line of the bridge. The wires in the cable are laid straight. There are 9 472 steel wires of 0.192 in. diameter in each cable, laid in 37 strands of 256 wires per strand. The strands are compressed together forming a solid cylinder and are covered with a close wrapping of soft steel wire. The diameter of the finished cable is 21¼ in. The length of each cable from anchorage to anchorage is 3 223.6 ft. Each wire is galvanized and then further protected by a coating of oil. At each panel point of each cable, corresponding to the panel point in the stiffening truss, is securely clamped a cast-steel cable band in which are grooves over which are looped two 1¾-in. galvanized steel-wire ropes, forming thereby four suspenders at each panel point. The lower or free ends of the suspenders are socketed with cast-steel screw-threaded sockets. These sockets pass through heavy steel plates in the bottom chords of the stiffening trusses, engaging large cast-steel nuts on the under side of the chords, forming thus the connection which secures the bridge to the suspenders.

At the tops of the steel towers the cables are supported on heavy cast-steel saddles 11 ft. long, at an elevation 321 ft. above mean high water. As before stated these saddles, one for each cable, are fixed to the towers. The main span of each cable, between

PLATE 11.
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JOHNSON ON THE MANHATTAN
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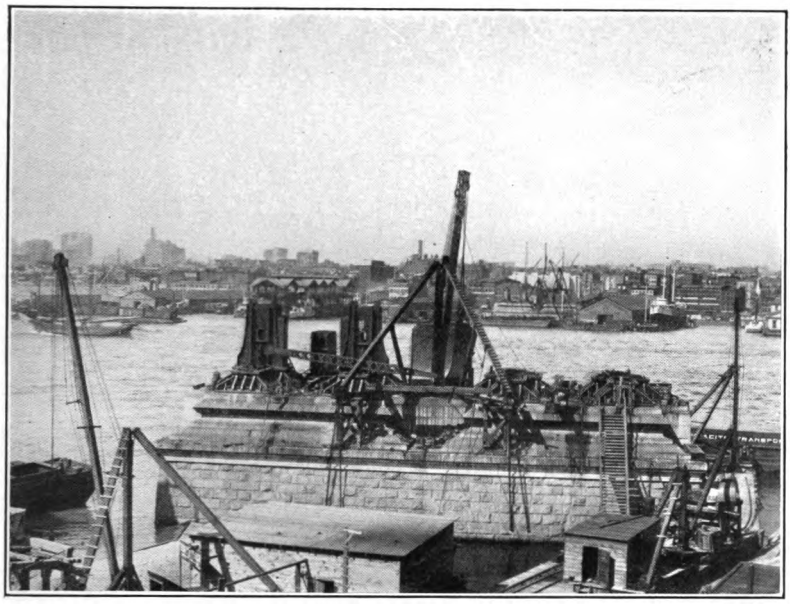

FIG. 1.—PEDESTAL IN PLACE ON BROOKLYN PIER.

FIG. 2.—ERECTING STEEL COLUMNS ON MANHATTAN PIER.

PLATE 12.
THE MUNICIPAL ENGINEERS
OF THE CITY OF NEW YORK.
JOHNSON ON THE MANHATTAN
BRIDGE.

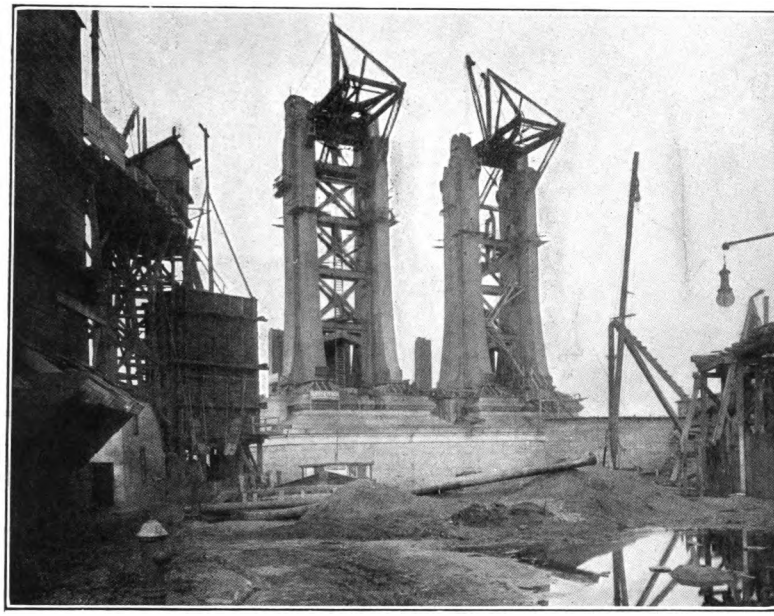

FIG. 1.—BROOKLYN TOWER, LOOKING WEST FROM WASHINGTON STREET.

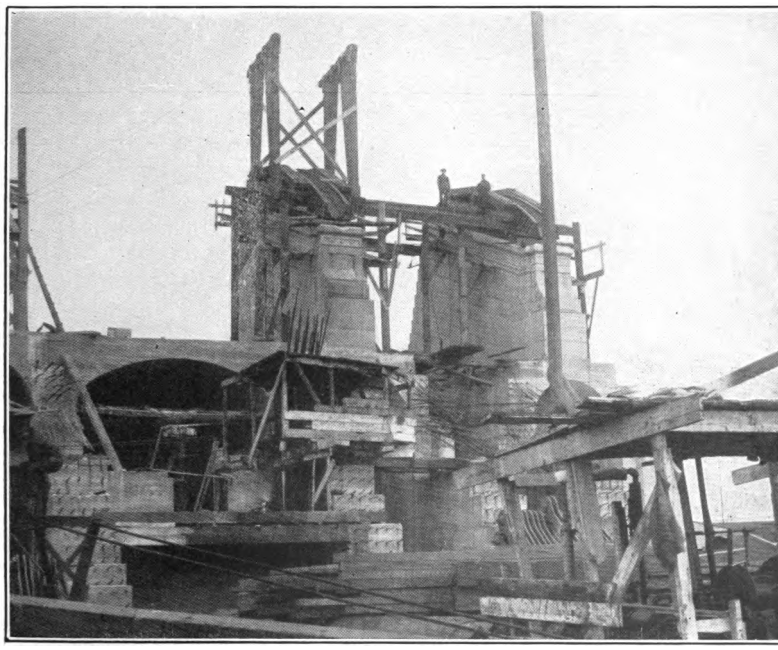

FIG. 2.—SADDLE CASTINGS AT ANCHORAGES.

towers, has a versed sine of 149 ft. at mean temperature and under the dead load of the structure. At the anchorages the cables are supported on cast-steel saddles 30 ft. long, inclined so as to deflect the cable from the catenary curve to the line of the anchor chain. The saddles at the anchorages are placed on cast-steel segmental rollers, taking up the movement of the saddles as caused by the cables. The cables are connected to the anchor chains in strands. The wires in each cable strand are looped over a cast-steel strand shoe, which is secured between two heads of the eye-bars in the uppermost link of the anchor chain by means of a steel pin.

The wire of which the cables are built is made of a high carbon steel, having an ultimate tensile strength in the finished wire of about 210 000 lb. per sq. in. and an elastic limit of about 135 000 lb. per sq. in. The maximum theoretical stress in the cables is about 75 000 lb. per sq. in. The actual maximum stress likely to occur will probably be within 60 000 lb. per sq. in. The breaking strength of each cable is reckoned at 30 000 tons.

The wire of which the suspender ropes were made was of the same quality as that used for the cables. Full size tests of socketed suspender ropes showed their ultimate tensile strength to be about 290 000 lb. The test pieces were 20 ft. long, and the breaks in them occurred within four to eight feet of the socketed end, without failure in the socket. The maximum load ever likely to be carried by one rope in the structure does not exceed 35 000 lb., about one-fourth of its elastic limit.

The stringing of cables was accomplished in a remarkably short time, compared with the only existing precedents, the Brooklyn and the Williamsburgh Bridges. The first cable wire was strung on August 1, 1908, and the last one on December 10, 1908. This satisfactory progress was due to the careful and exact preparations of the Contractor, based on the experience of his Chief Engineer who had already had intimate connection with bridge cables in the design and erection of the Williamsburgh Bridge cables.

Temporary suspension bridges, one for each pair of cables, each with two footwalks or platforms 8 ft. wide, one under each cable, and hanging about 4 ft. below the center line of the completed cable, were first constructed, leading from anchorage to anchorage over the steel towers. Each footbridge was supported on two cables made

up of four $1\frac{3}{4}$-in. steel wire ropes passing over the steel towers and anchored back at the anchorages. The footbridge construction was of light timber and was stayed by $1\frac{3}{4}$-in. and $\frac{7}{8}$-in. wire ropes anchored to the towers and anchorages. On each of the footwalks were erected nine small timber towers, about equally distant apart, for the support of sheaves over which the hauling ropes passed in their progress back and forth from anchorage to anchorage with the travelling sheaves, or spinning wheels, which drew out the individual cable wires and laid them in place. Timber towers were also erected on the tops of the steel towers, which guided the hauling ropes and travelling sheaves and furnished support for hoists which lifted and adjusted the cable strands into their proper positions in the saddles.

The plant used in stringing the cable wires was in general somewhat similar to that before employed on the Williamsburgh Bridge, but improved in detail and arrangement so as to more than double the working capacity. Work on each cable could proceed simultaneously, the hauling ropes and sheaves for each operating independently. The power plant required was located on the Brooklyn anchorage.

For each cable there was one endless hauling rope to which were attached the two travelling sheaves before mentioned. These travelling sheaves were so arranged that when one was starting from the Brooklyn Anchorage the other would be leaving the Manhattan Anchorage. As each sheave engaged a bight of cable wire there were thus laid four wires at one time in each cable, or when all the hauling ropes were working sixteen cable wires were laid simultaneously. When each bight or loop of wire arrived at the anchorage it was placed upon its proper strand shoe. During the operation of making a strand it was built somewhat higher than the final position required in the finished cable. This was accomplished by attaching each shoe a fixed distance above its final position to a temporary strand leg and also by carrying the strand in temporary supporting sheaves above the saddles on the towers and anchorages. The first few wires in a strand were carefully laid to a guide wire set to computed elevations and checked by observations with instruments. The balance of the wires were laid to these first wires. When all the wires of a strand were laid they were compacted into

PLATE 13.
THE MUNICIPAL ENGINEERS
OF THE CITY OF NEW YORK.
JOHNSON ON THE MANHATTAN
BRIDGE.

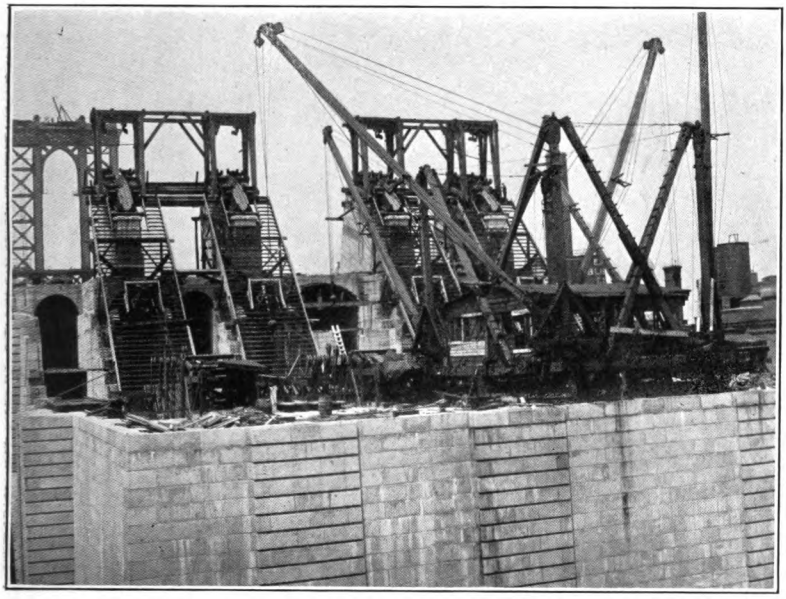

FIG. 1.—BROOKLYN ANCHORAGE.

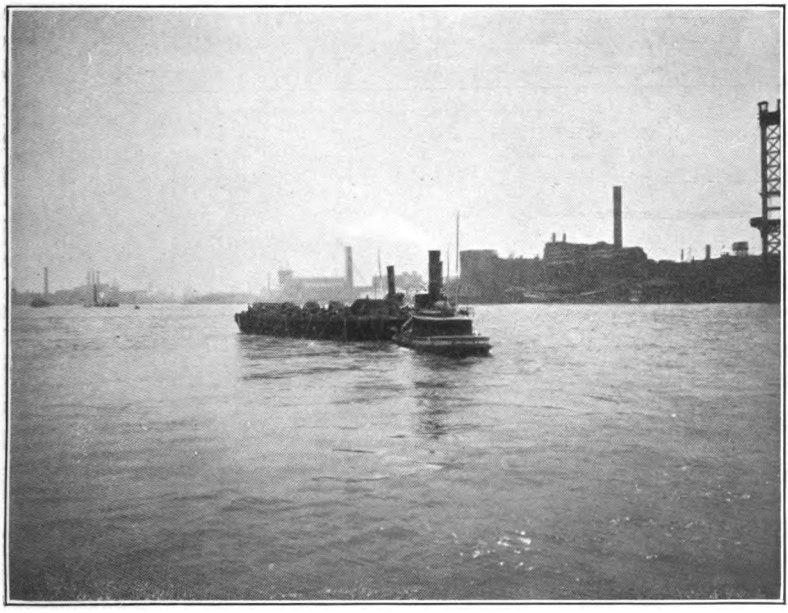

FIG. 2.—TOWING FOOT-WALK CABLE ACROSS THE EAST RIVER.

PLATE 14.
THE MUNICIPAL ENGINEERS
OF THE CITY OF NEW YORK.
JOHNSON ON THE MANHATTAN
BRIDGE.

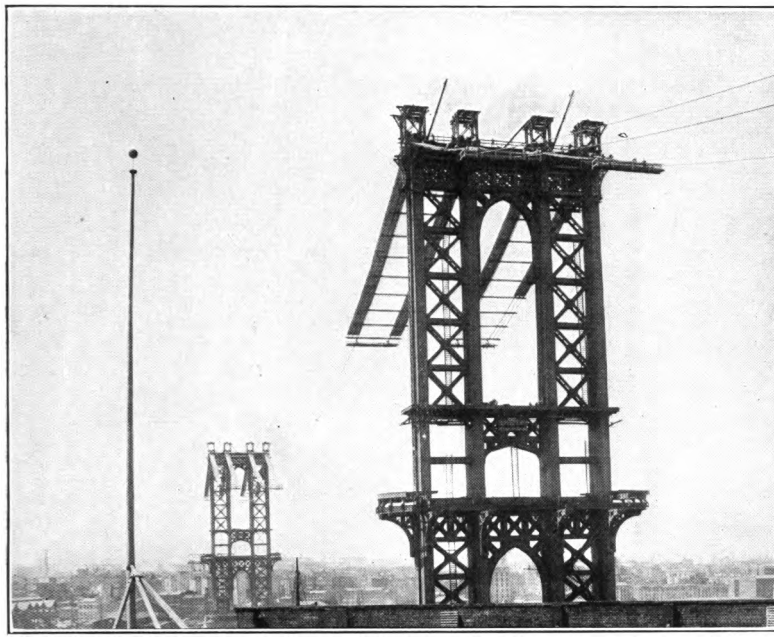

FIG. 1.—BUILDING THE FOOT-WALKS FOR CONSTRUCTION OF THE CABLES.

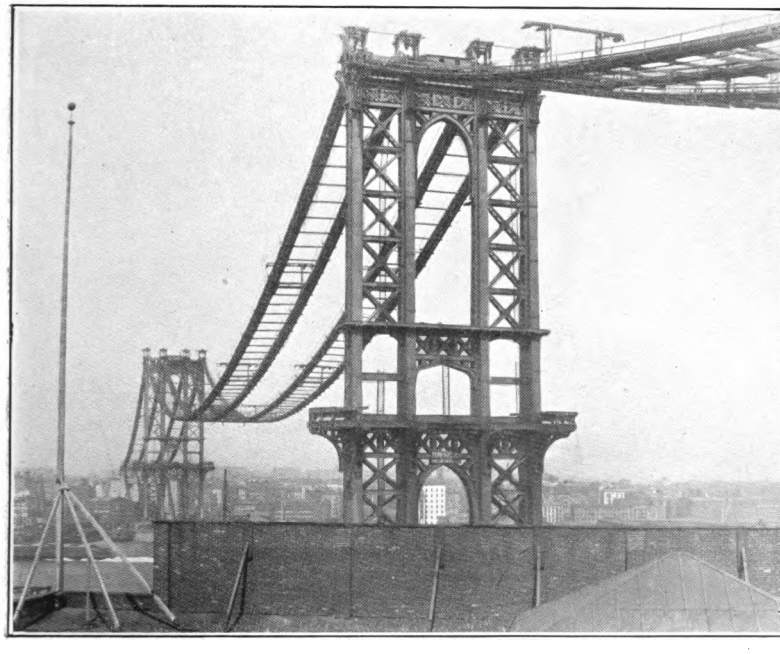

FIG. 2.—COMPLETED FOOT-WALKS, ON WHICH CABLES WERE CONSTRUCTED.

cylindrical form and seized at short intervals by several turns of wire. These seizings were temporary only, except within the anchorage, and were removed when the completed strands were compacted and rounded into the finished cable. Upon the completion of a strand, the strand shoes were let into their final positions between the eye-bar heads in the anchor chains and the strand was lowered into position in the saddles at the towers and anchorages, being carefully adjusted by means of shims at the strand shoes. The seven strands forming the center of a cable were compacted into a core cable, and the remaining strands were afterward compacted about this core. The cable bands and the suspenders depending from them were then put in place, and afterward the final protective covering of soft steel wire was wrapped about each cable between the cable bands, the ends of which were made water-tight by calking. Fixing hand-rail ropes into position and the application of red lead to all of the construction completed the cable-making.

At the wire mills the cable wire was drawn in lengths of about 3 000 ft. The lengths were spliced together into a continuous wire about 80 000 ft. long and wound on a large diameter shipping reel, the whole weighing about four tons. The wire splice consists of a sleeve $\frac{3}{8}$-in. in diameter having right- and left-hand threads, which engage cold rolled threads on the abutting mitred ends of wire. The field splices required were similarly made. Tests made of the splices developed never less than 95% of the ultimate strength of the wire.

Following the completion of the cables began immediately the erection of the suspended steel spans. The first step involved was the erection of the bottom chords, the floor beams, bottom laterals, main deck stringers, and vertical posts of the trusses.

This was accomplished by means of travellers moving away from the steel towers in both directions. There were in all twelve such travellers, six starting from each tower, three toward the center of the river span and three toward each anchorage. Each group of three travellers consisted of two equipped with one 25-ton derrick each, which erected the heavier members of the floor and moved out over the track stringers within each pair of trusses, and one equipped with a 7-ton derrick, which followed the other travellers.

moving out over the roadway stringers and erecting the lighter material. Erection was carried on so that the loads on either side of each tower and on either side of the center of the river span balanced each other approximately. Inequalities in the loadings and the consequent deflection of the tower were easily detected by means of two heavy plumb-bobs within each tower suspended on wires reaching from the top of tower to the base

When the erection of the lower or main floor of the bridge had been finished the travellers were moved back to the towers and then proceeded away from the towers erecting the web members of the trusses. These erected, the travellers worked back to the towers erecting the top chords of the trusses and the upper deck floors. They were then dismantled at the towers.

During the erection the steel members were delivered to the travellers by cars hauled from the towers over standard gage track laid on the floor as erected. There were fixed derricks at each tower which hoisted material from floats to the cars on the bridge deck.

When all of the principal members had been assembled in the suspended spans, and under the full dead load, the adjustment of the suspenders was commenced and continued until the trusses were suspended in their proper and required positions. The suspenders, before being placed over their respective cable bands, had been accurately cut to required lengths with corrections for stretch under temperature and the dead load, and the adjustments required were therefore relatively small. These were obtained by easing off or taking up the cast-steel nuts engaging the screw-threaded sockets at the ends of the suspender ropes.

The field riveting began after the first adjustment. With the final adjustment made the riveting of the trusses was completed in summer under the desirable condition of high temperature and consequent maximum deflection in the trusses. The rivets driven in the chord splices and in the connections of the diagonal web members to the chords were of nickel steel, of which material were fabricated the main parts of the chords and the diagonal web members, the chord splice plates and the gusset plates for the diagonal connections.

The construction of the steel viaduct approaches, extending from anchorage to terminal plaza on either side of the river, went on

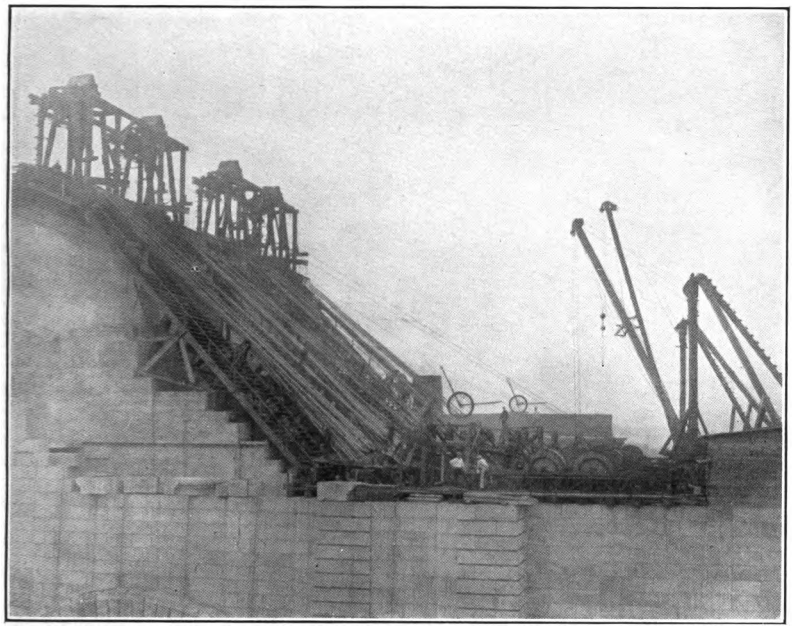

FIG. 1.—VIEW OF ANCHORAGE, SHOWING SYSTEM OF STRINGING CABLES.

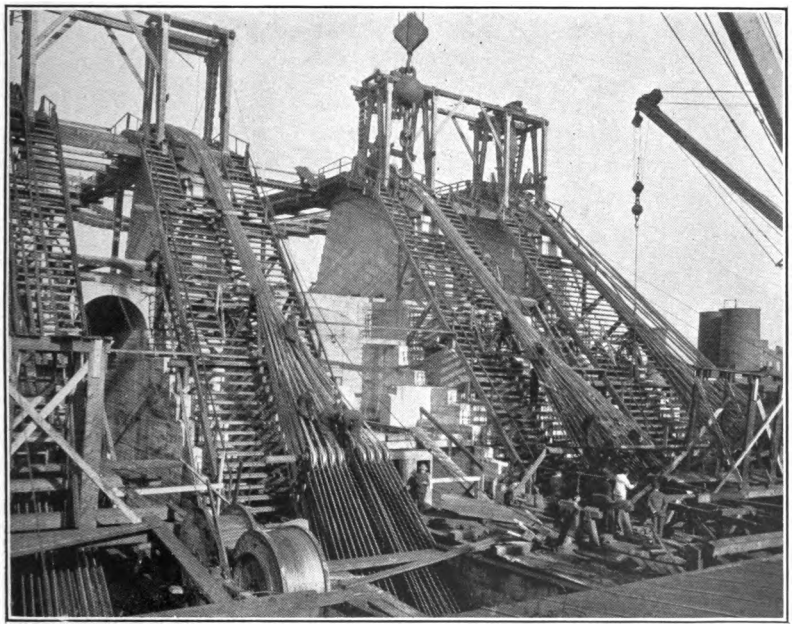

FIG. 2.—VIEW SHOWING CONNECTIONS OF CABLES TO EYE-BARS IN ANCHORAGE.

PLATE 16.
THE MUNICIPAL ENGINEERS
OF THE CITY OF NEW YORK.
JOHNSON ON THE MANHATTAN
BRIDGE.

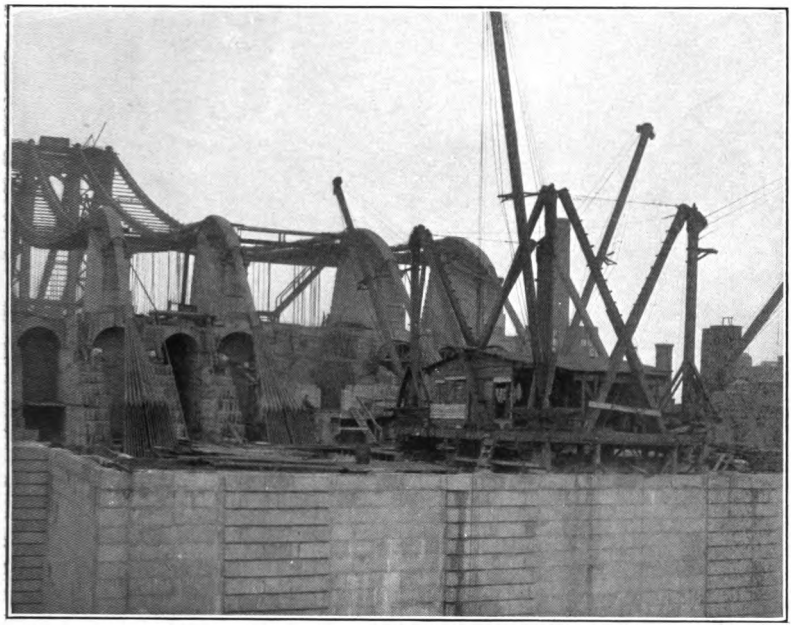

FIG. 1.—BROOKLYN ANCHORAGE, WITH CABLES COMPLETED.

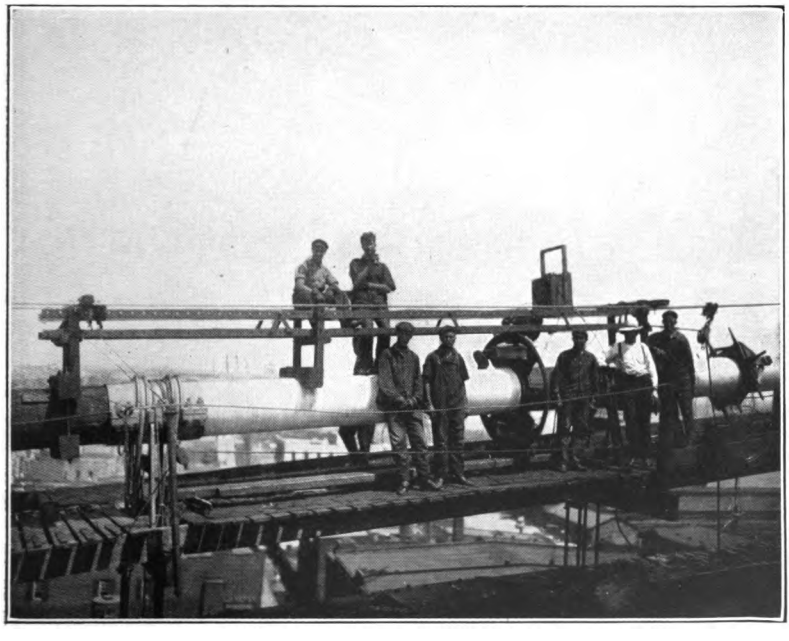

FIG. 2.—VIEW SHOWING SYSTEM OF WRAPPING WIRE ON FINISHED CABLES.

simultaneously with the work between the anchorages, under a separate contract. The steel approach on the Manhattan side is 1 293 ft. long from anchorage to the plaza abutment. It is divided into seven spans of through riveted Warren truss construction, five of 189 ft., one of 189.92 ft. and one of 158.08 ft. The varying lengths of span were necessary to prevent encroachment of the supporting piers on existing streets. The steel approach on the Brooklyn side is 1 211.84 ft. long from anchorage to plaza abutment. It also is divided into seven spans similar in construction to those on the Manhattan side, three of 189 ft., two of 189.92 ft., one of 139 ft. and one of 126 ft. The width of each approach is the same as that of the main bridge, 120 ft. The construction follows the same arrangement as obtains there. There are four trusses in each span and roadway, footwalks and tracks on lower and upper decks are placed as in the suspended spans.

The piers on which the steel is supported are built upon concrete footings founded on sand above water level. Above the street surface the piers are faced with granite. The backing is of concrete. Each of the piers is in effect made up of two piers, one on either side of the axis of the bridge and connected at the top by an arch of granite about 28 ft. in span. As at the anchorage, so in these piers, successful effort was made to bring about pleasing architectural result in connection with the more important requirements of utility.

The steel work for the approaches was erected on timber and steel falsework. The bottom chords and the main floor system were first erected. On this floor moved a rectangular tower traveller on which were four 20-ton derricks, one at each corner, by means of which the material was hoisted from trucks on the ground and assembled in the structure. After the floor had been erected the trusses and the upper deck were assembled and the riveting proceeded. The entire cost of the approaches amounted to $2 412 925.66.

In Manhattan, at Division Street, where the Second Avenue elevated railway structure crossed the line of the bridge, it was necessary to lower the street and the railway structure in order to provide sufficient head room for the railroad underneath the floor of the Manhattan Approach. A new railway structure was built and the old railway structure removed without accident to or

interference with the elevated railway traffic. This work was done by the Interborough Railway Company, under a contract with the City.

At the present time the work on the bridge consists of the laying of the lower deck railway tracks and the placing of the footwalk pavements. These lower deck tracks are being laid and equipped for operation by subway or elevated railway trains. The footwalk pavement consists of concrete slabs surfaced with rock asphalt.

On December 31st, 1909, the bridge had been so far completed as to permit its use for vehicle traffic, and the roadway was accordingly opened to the public. The volume of vehicle traffic over the bridge is steadily increasing and bids fair before the end of the current year to exceed that on the Brooklyn Bridge without diminising to any considerable extent traffic there.

The total cost of the bridge structure and the plaza structures when completed will be about $16 000 000. The land acquired for the purposes of the bridge will total in cost about $10 000 000.

PLATE 17.
THE MUNICIPAL ENGINEERS
OF THE CITY OF NEW YORK.
JOHNSON ON THE MANHATTAN
BRIDGE.

FIG. 1.—VIEW SHOWING CABLES AND SUSPENDERS.

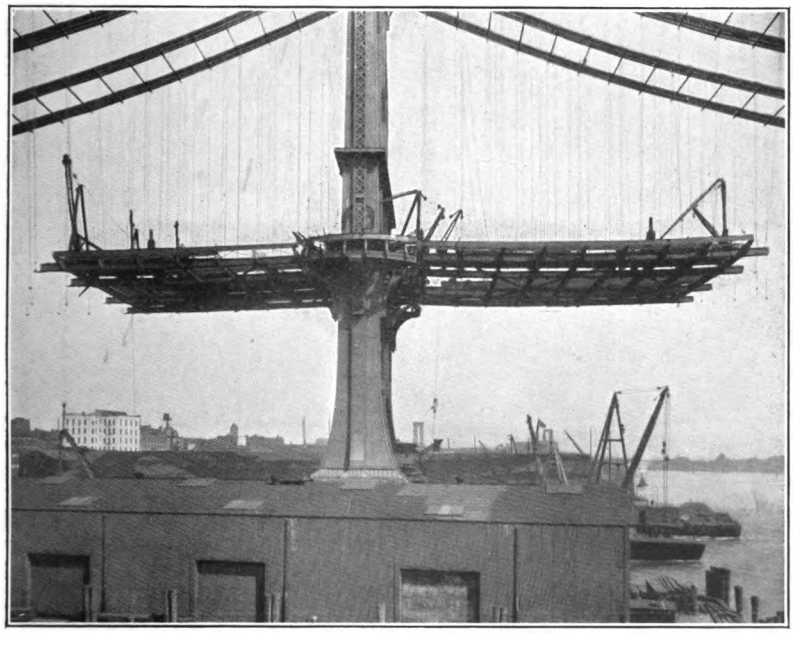

FIG. 2.—VIEW SHOWING ERECTION OF FLOOR SYSTEM ON SUSPENDED SPANS.

FIG. 1.—VIEW SHOWING STEELWORK SUSPENDED FROM CABLES.

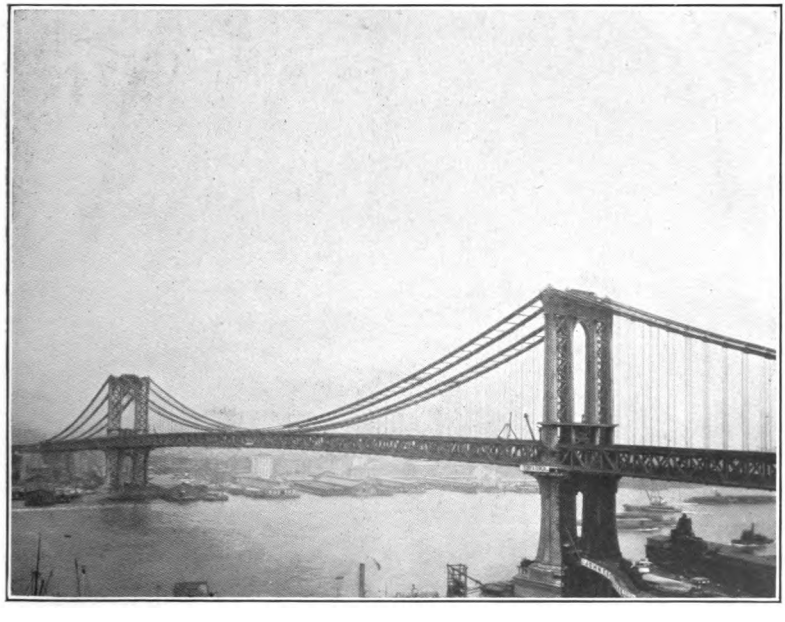

FIG. 2.—COMPLETED BRIDGE. CABLE FOOT-WALKS PARTLY REMOVED NEAR CENTER OF SPAN.

DISCUSSION.

ARTHUR S. TUTTLE, M. M. E. N. Y.—The subject of this paper introduces a large variety of engineering problems, all of which have been treated by the author as fully as the limits of a general discussion would permit. I have no doubt that there are many present who are desirous of further details concerning certain features of this great structure, and I know that the author will be glad to answer any questions.

A MEMBER.—Mr. Johnson said that the towers were fixed at the base and the saddles were rigidly fixed at the summit of the towers and that the towers moved. I do not quite understand where the motion is taken up due to the load and changes in temperature.

ALEXANDER JOHNSON, M. M. E. N. Y.—The motion is taken up by the bending of the tower. The entire tower will, under extreme variation of load and temperature, bend about 24 in. either way without inducing overstress, and thereby take up all the movement of the saddles, which, in the case of the Williamsburgh and Brooklyn Bridges is provided for by the movement of the saddles on rollers on the tops of the towers.

WILLIAM J. DUNCAN, M. M. E. N. Y.—I would like to ask what pressure was allowed on the soil under the tower piers?

ALEXANDER JOHNSON, M. M. E. N. Y.—The maximum pressure is a little over 8 tons to the square foot.

WILLIAM J. DUNCAN, M. M. E. N. Y.—Is there not some danger that when the tower is deflected one way for some time that there might be an unequal settlement in the soil which would throw the tower permanently out of plumb.

ALEXANDER JOHNSON, M. M. E. N. Y.—No; for the increase in pressure due to such eccentricity in the loading on the soil would not be sufficient to cause any settlement. Eight tons per square foot is a safe and conservative loading.

WILLIAM J. DUNCAN, M. M. E. N. Y.—Somewhat in excess of the building law requirements of the City.

ALEXANDER JOHNSON, M. M. E. N. Y.—The Building Code requirements of the City were intended to fix the regulations regarding foundations on the soil at ordinary building elevations. The building regulations are designed for the purpose of specifying the proper precautions in building structures which possibly may be affected by some deep foundation operation near at hand. The contention that the Building Code should be followed in designing deep foundations is a fallacy; ordinary sand at a depth of 60 or 70 ft. below mean high water level might carry safely 15 tons to the square foot, but you would not think of putting that load on sand at a higher level where that sand might be affected by movement due to an adjoining excavation.

A MEMBER.—I would like to ask why all the trusswork is suspended. On the Brooklyn Bridge a certain number of the panels are carried on struts resting on the cables.

ALEXANDER JOHNSON, M. M. E. N. Y.—The Brooklyn Bridge is suspended on the cables from anchorage to anchorage. The member by which the load is carried to the cable is a little different near the anchorages on the Brooklyn Bridge, of necessity, where the line of the cable is below the line of the floor of the bridge and there the load is transmitted from floor to cable through a short column. In the Manhattan Bridge the cable at no point intersects the line of the truss, and wire-rope suspenders may be used throughout.

ARTHUR S. TUTTLE, M. M. E. N. Y.—It has always seemed unfortunate that in the building of our bridges the City has not heretofore been able to make terms for the operation of the railroad facilities provided, until after the work was completed. As a result of this treatment the municipality has invariably been placed in such a position with reference to the limited competition that it must either accept the terms offered or lose some of the advantages which the improvement was intended to provide. I believe that the powers which have now been given to the Public Service Commission will make it hereafter possible to give ample consideration to the railroad use prior to construction.

ALEXANDER JOHNSON, M. M. E. N. Y.—As to planning the traffic lines, knowing just what lines will use a City bridge before you build the bridge, I doubt very much if that can ever be done. You can plan, of course, but you cannot be sure that your plans will ever be followed out. In the case of the Manhattan Bridge it was a well-conceived plan that the bridge would be built for the purpose of accommodating elevated railway traffic and surface railway traffic. The wide street in Brooklyn, known as the Flatbush Avenue Extension, was acquired by the City for the purpose of providing space on which to place an elevated railway structure that should approach the Manhattan Bridge. We know that now there is little likelihood of any elevated railway structure being put on the street which was acquired for that purpose. Lack of co-operation between public officials and lack of power on the part of these officials have contributed to bring about the situation stated by Mr. Tuttle. Both of these lacks seem in a fair way of being supplied in the near future.

GEORGE A. TABER, M. M. E. N. Y.—As the individual wires which form the strands of the cable were laid two at a time, I would like to ask the author just what method was employed in making those wires the proper length and securing in them the same tension as in the other wires of the cable?

ALEXANDER JOHNSON, M. M. E. N. Y.—The uniform tension in the wire, allowing that the point of support of each wire was approximately the same, would, of course, be indicated by the position of the wire. If the wires were all in approximately the same position or curve, it is proper to assume that they were all under approximately the same tension. In order to bring about that proper position, when each strand was started a guide wire was run across from anchorage to anchorage; that guide wire was very carefully suspended to the proper curve between towers and also between anchorage and tower; then all the wires that were run in that strand were set to that guide wire. As the strand increased in number of wires, the first wires became guide wires themselves and the succeeding wires were laid to them.

GARDNER L. VAN DUSEN, M. M. E. N. Y.—One question occurs to me in regard to the treatment of the cable. As I remember it, after the wires of the cable were laid in place, they were bound at short intervals and then treated with a petroleum preparation. Was this preparation poured on the cable in sufficient quantity to work through and fill all the space between the several wires that make up the cable, or was the cable immersed in a bath? In some bridges the cable covering is a canvas wrapper. In this instance, I understand, the covering is of Norway steel wound on tightly by machinery. What is the character of the final coating given to this Norway steel wrapper?

ALEXANDER JOHNSON, M. M. E. N. Y.—The wires were protected individually by galvanizing to start with. As the wire was spliced, and before being drawn on the shipping reels at the wire mill, it was run through a bath of petrolatum, a heavy neutral oil, which formed a protective coating in addition to the galvanizing. In the field after the construction of a strand it was coated with petrolatum, and in the following operations of making the core of the cable and compacting the outer strands about this core the entire cable was thoroughly slushed with the oil. In addition to all this the outer wrapping of soft steel wire which is coated with paint furnished additional protection to the cable and its wires.

MARTIN GAY, M. M. E. N. Y.—I remember very pleasantly the excursion which the Society made a while ago across the foot bridges used during cable construction. One of the things learned on that occasion, which has not been mentioned this evening, was the good quality, or the bad quality, depending on the point of view, at all events the lasting quality, of that preservative which had been applied to the cables.

As the cables were about shoulder high above the footways over most of their length, and as, at that height above the water, many of us liked to keep as close as possible to the most substantial thing

in sight, it was inevitable that we should occasionally in a friendly way, rub shoulders with a greased cable. In that way I was able to bring home enough of the preservative to form the basis of some experiments, and as a maintenance engineer, I was pleased to find it insoluble in hot water and soap, in alcohol and in gasoline. It was equally unaffected by whatever solvents were used by the cleaner to whom the coat was sent.

As these reagents were in a much more concentrated form than any which are found in the atmosphere, the strands of the cables, thus protected, will probably endure for centuries.

George R. Ferguson, M. M. E. N. Y.—There is one thing that might be added, and that is the utilization of the bridge, as to whether there should be a terminal, or whether the lines of surface cars should be continued across town.

The latter is all very well from the standpoint of the traveling public, but it is going to cut down the number of cars that can be run across the bridge. Take the Brooklyn Bridge at the present time; the cars come to the bridge in three distinct and separate lines, and after those three lines are united, the cars do not stop until after reaching the dividing point on the Manhattan side; in that way about 300 cars per hour can be run. If all the cars were continued across town instead of stopping at the loops, and stops made to let passengers on and off, the traffic would be cut down to about one-third of that of the present time. The fact that the cars on the bridge superstructure are kept at a distance of about 95 ft. apart, and run at a speed of from eight to ten miles per hour, might limit the number of cars more than will be the case on the Manhattan Bridge, where there will be no such limitation as to car spacing; still as the speed depends on the distance the cars are apart, it is doubtful if very many more cars can be run on a single pair of tracks than are run across the Brooklyn Bridge, and in any case the minute the cars stop on a single line, the capacity of the line is reduced to a very considerable extent. A double-track line will carry a large number of trains, provided there are no stops on that line. That is evidenced by the way the Pennsylvania Railroad is building its connection to the new terminal in Manhattan. It has only two tracks, but has stations of considerably more than two tracks. The subway itself is finding that same difficulty in running their express trains. They say, and truly, that if they could run express trains on either side of the platform, they could double the number of trains they are now running, and for that very reason, when it comes to running cars across the Manhattan Bridge, if, when they reach Manhattan, they divide into three lines, going uptown, downtown and across town, a great many cars can be run, but if they are concentrated on the single crosstown lines the

capacity of the bridge itself as a bridge will be cut to a small factor of what it ought to do.

ALEXANDER JOHNSON, M. M. E. N. Y.—I don't know, of course, what will eventually run over the Manhattan Bridge. If all the cars running over the bridge were to come from one direction, unquestionably there would be less operation of cars and trains over the bridge possible than if they come from say three directions. We assume, however, that in all likelihood trains will come—so far as subways are concerned, from three directions. They will come from uptown, they will come from across town, and from downtown through the bridge connecting loop. So far as surface cars are concerned, Brooklyn cars should operate into a loop station at the Manhattan terminal or into a subway. To operate them into the congested condition of street traffic on the Bowery and Canal Street is not desirable.