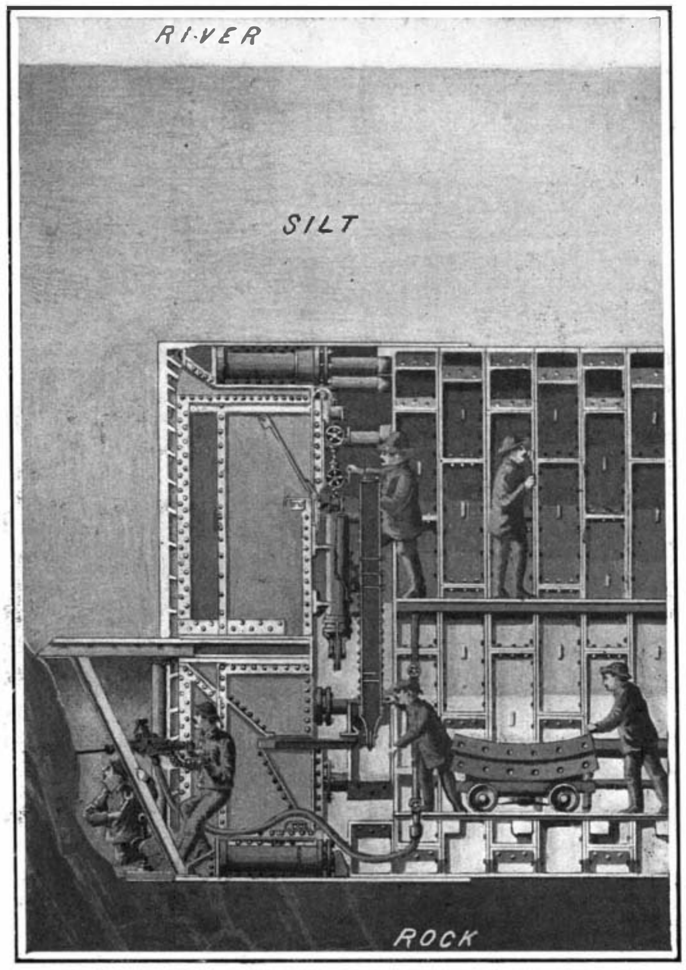
TUNNELS AND SUBWAYS

The fact that the most important section of New York city is located on a long and narrow island, flanked by broad and deep rivers and waterways, is largely responsible for the present activity in the construction of subways and tunnels. In the earlier days of the history of the city, passenger traffic was taken care of by lines of surface cars and ferries. These were supplemented, about thirty years ago, by the construction of four lines of elevated railways running the entire length of Manhattan Island. The Brooklyn Bridge, opened some five years later, afforded a greatly needed relief to the rapidly growing travel between New York and Brooklyn. The next step in the development of facilities was the electrification of the surface roads, which was followed in its turn by a change from steam to electric traction on the elevated system. Concurrently with these last developments, the construction of three additional bridges of unusually large capacity was commenced across the East River. One of these, the Williamsburg Bridge, was opened some four or five years ago; the Blackwell's Island Bridge will be opened as soon as the necessary changes to render it usable have been made; and the Manhattan Bridge should be thrown open to the public within the next two years.

In spite of the greatly increased accommodations provided by these enterprises, it became evident, even before they were completed, that the rapid growth of the city, and the even more rapid growth of travel, would necessitate the provision of additional means of transportation; and that any future roads which might be built must be placed below street level. It was realized, moreover, that the construction of bridges across the Hudson River was too difficult and costly for the city to depend upon any relief in this direction. After a protracted discussion of its feasibility, the question of constructing a subway system was submitted to the public vote, and a decision was given in its favor. A Rapid Transit Commission, consisting of leading men of affairs in the city, was formed and under their very able direction a comprehensive scheme of subways was laid out, and the portion of it which is now in operation constructed. The first section to be completed extends from the City Hall, New York, to Kingsbridge beyond the Harlem River, with a branch running from Ninety-sixth Street northeasterly to the Bronx. From City Hall Park to Ninety-sixth Street there are four tracks, the two outer tracks for local service, and the two inner tracks for express trains. North of Ninety-sixth Street, on the westerly branch of the road, the Subway contains, first three tracks and then two; the easterly branch from Ninety-sixth Street contains two tracks. Subsequently, a two-track Subway was constructed from City Hall Park to Flatbush Avenue, Brooklyn, the route lying below Broadway to the Battery and then under the East River in two tube tunnels. The section of the road from City Hall northward was opened in 1904, and the section from City Hall to Flatbush Avenue in Brooklyn, in 1907. The contract for the first section was let for $35,000,000; the equipment, power station, purchase of the real estate, etc., cost an additional $12,000,000, bringing the total cost up to $47,000,000. From the very first the Subway has proved an unqualified success. The express trains on certain sections of the line reach a speed of 45 miles an hour between stations, and run at an average speed, including stops, of between 25 and 30 miles an hour, the average depending upon the delay at stations. Express trains are made up of eight cars, of which five are motor cars. Local trains, which have a speed of about 16 miles an hour, including stops, are made up of six cars, four of which are motors. Before the opening of the line, it was hoped by the most optimistic that the system would develop a maximum capacity of from 375,000 to 400,000 passengers a day. As a matter of fact, on holidays and other special occasions, over 600,000 have been carried. The opening of the Brooklyn tunnel afforded greatly needed relief to the Brooklyn Bridge. It became immediately popular, and the city, as soon as funds are available, will build a branch line through southern Brooklyn to Coney Island. At present, there is under construction a loop-line which will connect the Manhattan terminals of the Williamsburg and Brooklyn bridges. In the first section to be completed the tunnels were built chiefly by the cut-and-cover method, and, except where they pass through rock, they are built of steel I-beams and structural shapes imbedded in concrete. For the later construction reinforced concrete was used. In view of the speed and rapidity of the service and the enormous volume of traffic handled, the New York Subway must be regarded as the most successful, as it is the largest and most important underground railway in the world. It is operated on the third-rail system.

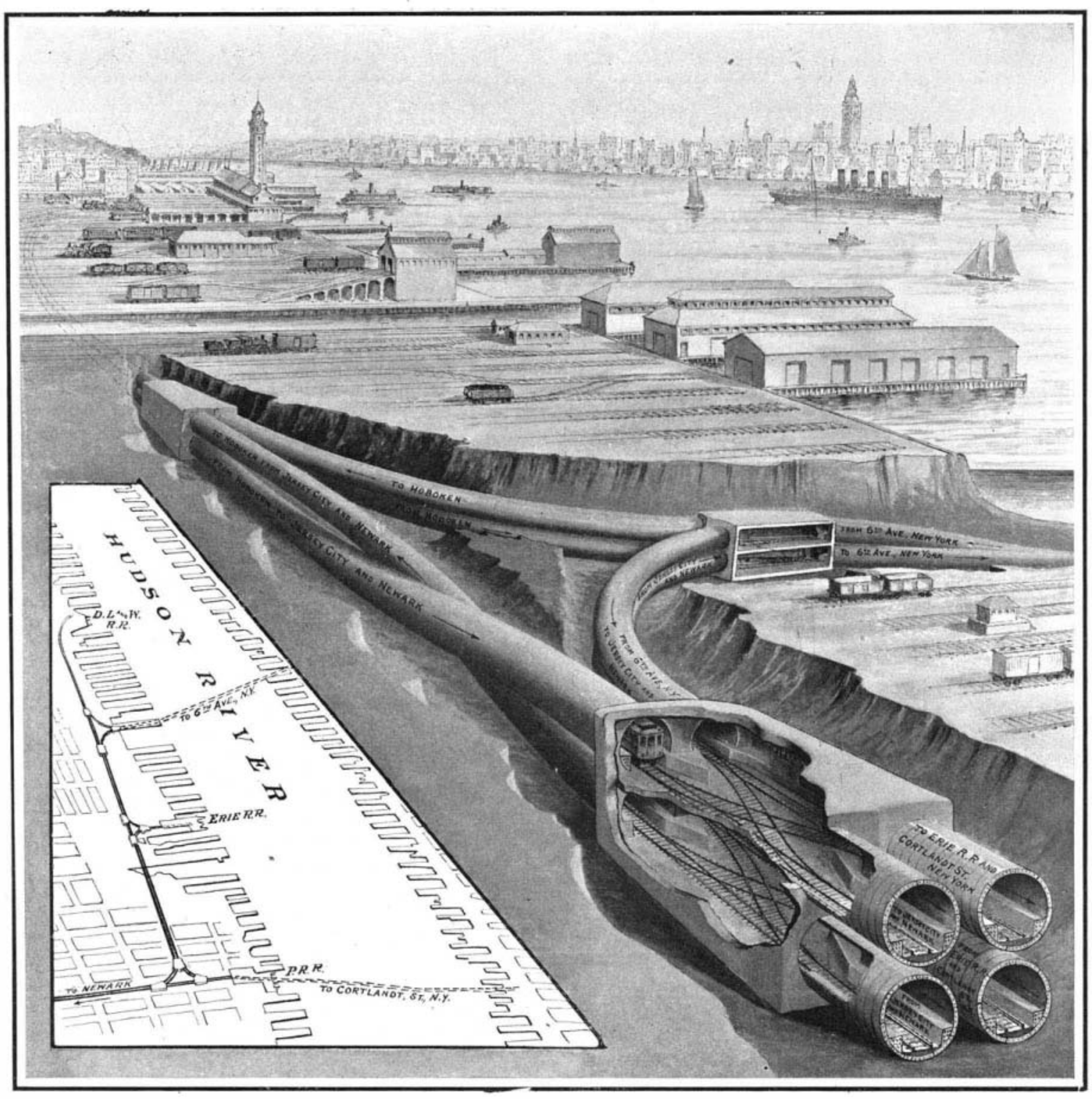
To provide the necessary power for operating the Subway, which, as we have noted, has carried over 600,000 passengers in a single day, has called for the construction of what is to-day the largest power station of its kind in the world. The plant, which is located at Fifty-ninth Street, is housed in a building 200 feet in width by 690 feet in length, which is divided centrally by a wall separating the engine room from the boiler room and coal bins. These coal bins, which are located immediately below the roof and above the boiler room, have the enormous capacity of 25,000 tons of coal. The coal is fed by gravity to the hoppers of the mechanical stokers, from which it is automatically fed to the furnaces.

One who has never visited a plant of this character can have no idea of the imposing appearance presented by the long line of engines and generators in the engine room. In the present case the equipment consists of nine reciprocating engines, the largest of their type ever built, and three steam turbines. The reciprocating engines are of the well-known type developed by the Allis-Chalmers Company of Milwaukee, Wis., and they are superb specimens of the engine builder's art. Because of the advent of the steam turbine with its peculiar fitness as a drive for large generator units, it is probable that these engines will stand as the "last word" in the history of the development of the reciprocating engine. When standing in the gallery at the power station and looking down the long perspective of the engine room, one cannot but feel that, whatever advantages of an economical kind the steam turbine has introduced, it has robbed the engine room of much of its spectacular features. New York city was already familiar with the Allis-Chalmers engines of this type because of their installation in that other great power plant, at Seventy-fourth Street and the East River, which provides power for the operation of the elevated roads. The Fifty-ninth Street engines are generally similar to these; but they include certain improvements in valve gear and in some minor details. The engines are rated at 8,000 horse-power, with a maximum overload of 12,000. Each consists of two compound condensing engines, one at each end of the crankshaft, with the alternator carried at the center of the shaft between the engines. The 44-inch high-pressure cylinder is placed horizontally, and the 88-inch low-pressure cylinder vertically, with the two connecting rods of each engine taking hold of a common crankpin. The stroke is 60 inches. The two cranks are set at an angle of 135 degrees to each other, an arrangement which gives eight impulses to the shaft at equal intervals in each revolution. The crankshaft has a diameter of 37 inches at the center and 34 inches at the bearings. The crankpins measure 18 inches by 18 inches, and the crosshead pins are 12 x 12 inches. The weight of



Showing projecting roof for protecting workmen while blasting out a projecting reef of rocks.

SECTIONAL VIEW OF HUDSON RIVER SHIELD.



These caissons, 45 feet wide, 45 feet deep, and 106½ feet long, the largest ever constructed, are built of reinforced concrete. They provide a double-deck system which eliminates dangerous crossovers between trains running in opposite directions.

HUGE DOUBLE-DECK CAISSONS AT JUNCTIONS OF HUDSON RIVER TUBES WITH THOSE ALONG THE JERSEY SHORE.

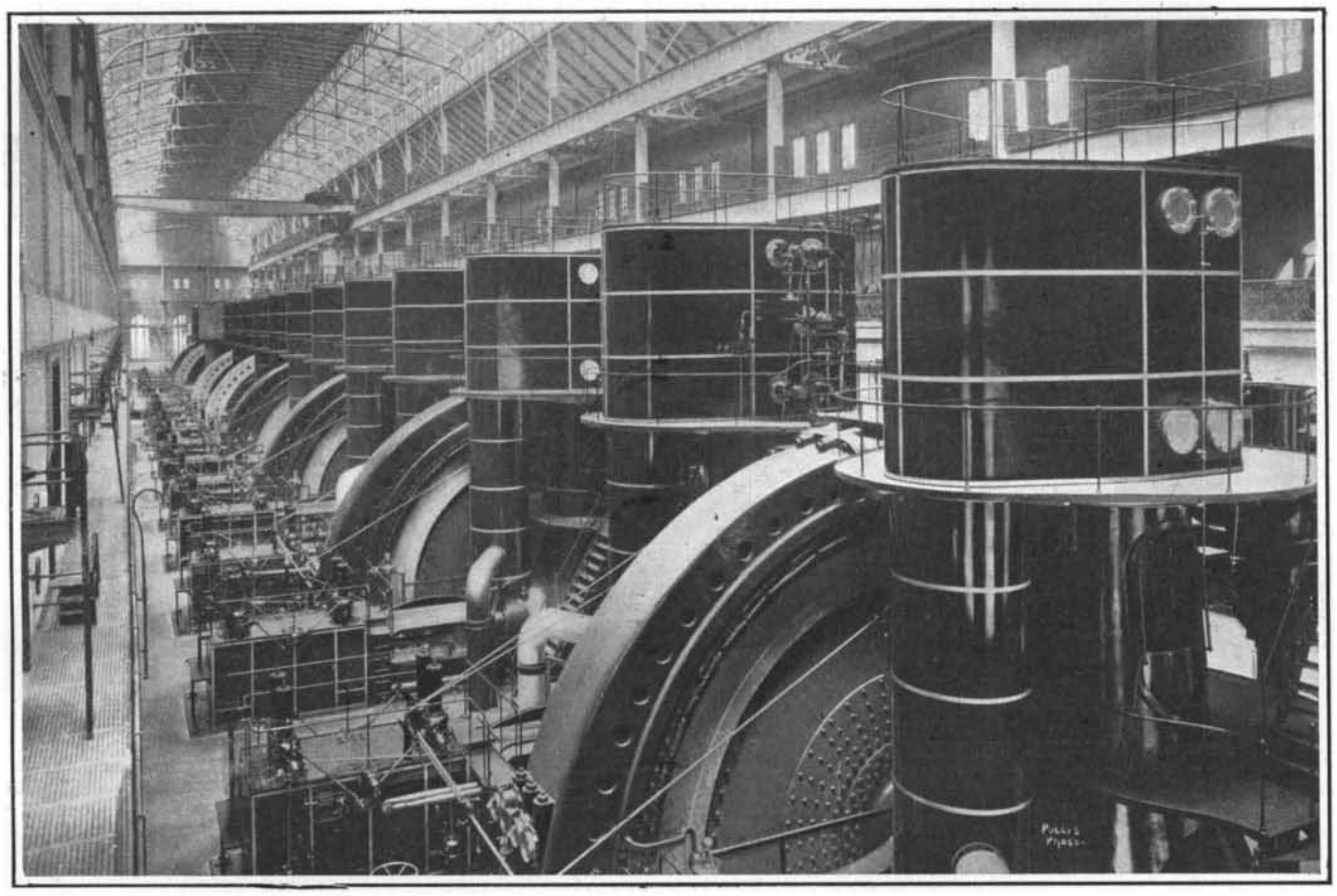
each pair of engines is 720 tons. The steam pressure is 175 pounds, and the steam consumption at the rating of 8,000 horse-power is about 13 pounds per horse-power per hour. At the far end of the station are three Westinghouse turbines of 1,250 kilowatts rating. The maximum horse-power of this station, under overload, is about 130,000 horse-power.

Next in importance to the Rapid Transit Subway, which, it should be mentioned, is owned by the city, is an elaborate system of subways and tunnels, constructed by an independent concern known as the Hudson Companies, to afford direct rail communication between Jersey City and New York. For the beginnings of this enterprise we have to go back twenty-five years, to the time when Mr. De Witt Clinton Haskin, one of the active spirits in the building of the Union Pacific Railway, commenced the construction of a tunnel for the use of steam trains. The scheme met with many difficulties and disasters. It was abandoned in 1882; started again in 1890 by an English company; and ultimately was taken in hand by a corporation known as the New York and New Jersey Railroad Company; which, ultimately, under the successive names of the Hudson Companies and the Hudson and Manhattan Railway Company, succeeded in pushing the great scheme through to completion. The credit for this enterprise is chiefly due to President McAdoo. The great value of the road lies in the fact that it intersects the trunk roads which have their termini in New Jersey, and enables passengers to transfer, under cover, to trains which carry them direct to the shopping, hotel, and financial districts on Manhattan Island.

The system consists in Jersey City of a two-track road, placed in two separate 15-foot tubes, which extends from the Delaware, Lackawanna & Western Railroad terminal south to the terminal station of the Pennsylvania Railroad. Ultimately, it will be carried down to connect with the terminal of the Central Railroad of New Jersey. At Fifteenth Street it is intersected by twin tunnels which pass beneath the Hudson, and are carried up Sixth Avenue to Twenty-third Street, and ultimately will be extended to Thirty-third, where they will be in touch with the Pennsylvania Railroad terminal. A branch line will be constructed at Ninth Street to connect with the Rapid Transit Subway. Below the Pennsylvania station, at a depth of 80 feet, there has been constructed a large station, access to which will be had by elevators from the Pennsylvania terminal. From this station twin tubes extend below the Hudson River and Manhattan Island to a large terminal station between Cortlandt and Fulton streets, above which has been constructed the large terminal office building to which reference is made elsewhere in this issue.

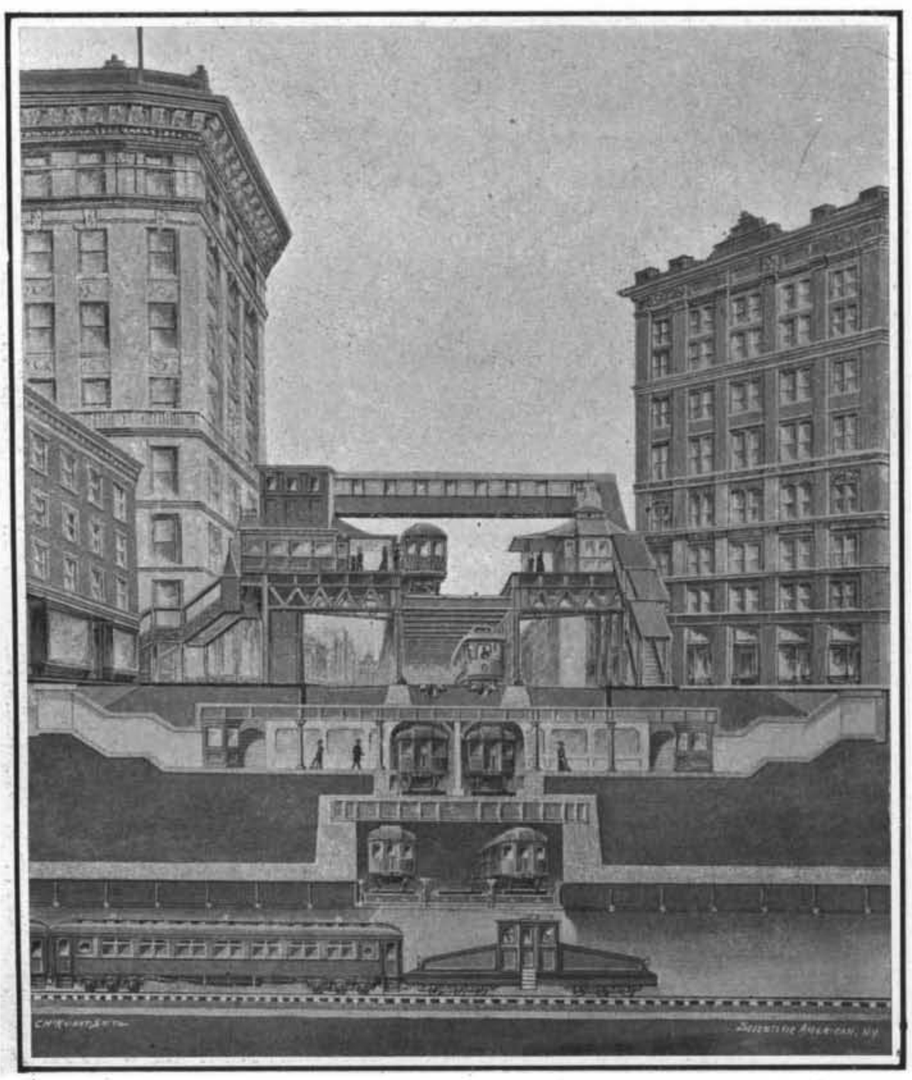
Because of the difficulties encountered in passing beneath the Hudson River, and the novel methods which were adopted to meet them, the engineering features of this system are particularly interesting. All four tunnels were driven by the shield method, which is too well known to call for any description at the present time. The tunnels are 15 feet in diameter internally, and it was originally intended to line them entirely with concrete. After they had been driven, however, it was found that they presented such absolute stability as to render the use of concrete unnecessary. Instrumental observations have failed to show any signs of settlement; and, as far as their stability is concerned, the tubes may be pronounced a decided success. Records for rapidity in driving were broken during the prosecution of the work, the rapid advance being due to the adoption of a method altogether novel and bold. In previous work with

(*Continued on page 414.*)



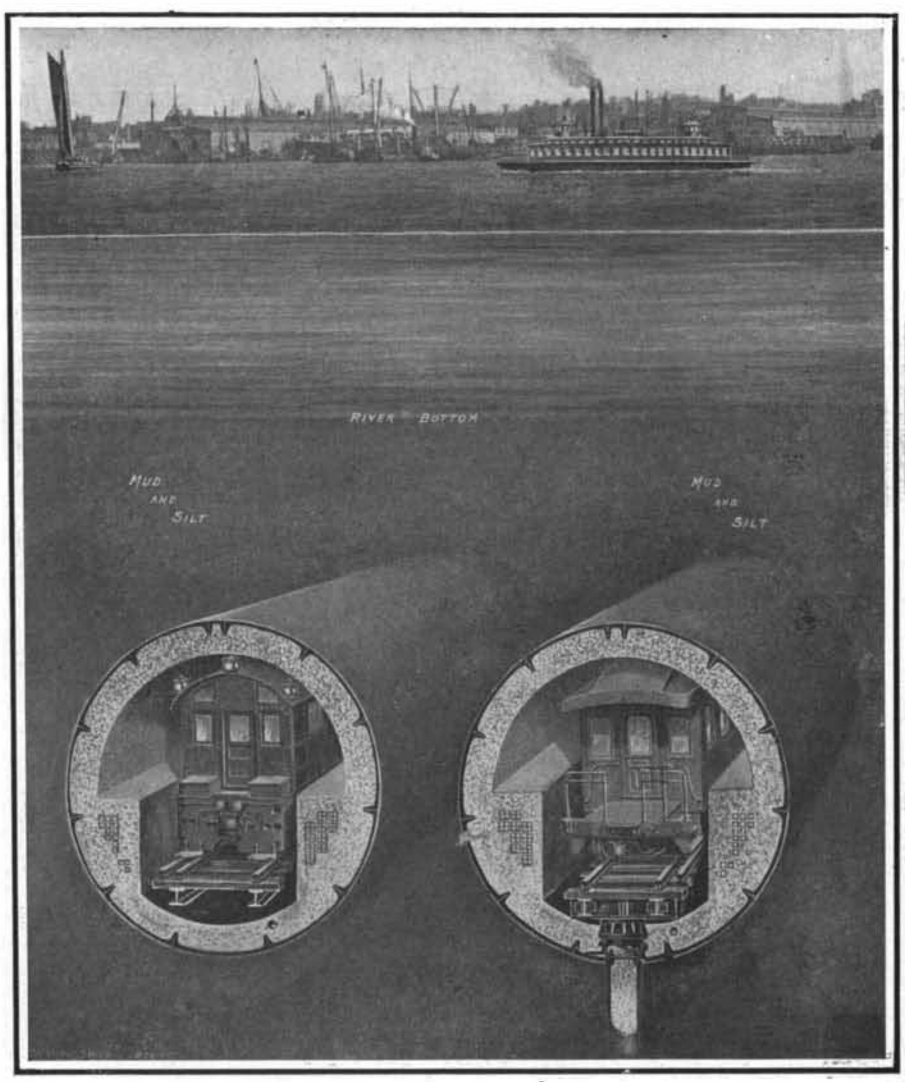
This power station, the largest for traction purposes in the world, is 200 feet wide by 790 feet long It contains nine reciprocating Allis-Chalmers engines of 12,000 overload horse-power and three steam turbines of 1,800 horse-power.

THE NEW YORK RAPID TRANSIT SUBWAY POWER STATION AT FIFTY-NINTH STREET.



If we include the footwalk across the elevated tracks, there are six separate levels for travel shown in the above view of conditions as they will ultimately exist at 33d Street.

SECTIONAL VIEW SHOWING HOW NEW YORK USES BOTH ELEVATED, SURFACE, AND TUNNEL ROADS IN PROVIDING FOR ITS EVER-GROWING TRAFFIC.



External diameter, 23 feet; internal diameter, 19 feet. Driven by the shield method. Maximum rate of advance through mud and silt, 37½ feet per day.

THE PENNSYLVANIA RAILROAD TUNNEL TUBES BELOW THE HUDSON RIVER.

THE CATSKILL WATER SUPPLY.

(Continued from page 396.)

in height and 17½ feet wide, which will be built partly by the cut-and-cover method and partly in tunnel. It will extend to the westerly bank of the Hudson River, which will be reached at a point between Cornwall and West Point. Originally it was the intention to carry the aqueduct below the Hudson River at New Hamburg; but the preliminary borings at this and other sites proved that it would be difficult to find a rock sufficiently clean from fissures and other imperfections. An examination of various sites by geologists led to the ultimate selection of the crossing near Cornwall, where it was believed that a thoroughly sound and suitable rock would be found at a depth not too prohibitive. The aqueduct passes through the mountains and reaches the westerly shore of the Hudson River at an elevation of 400 feet above tide level. Here a vertical shaft will be sunk to a depth of probably not less than 700 feet below the river surface, or 1,100 feet below the level of the aqueduct. In the bottom of the shaft a tunnel will be driven horizontally beneath the river to connect with another vertical shaft of practically equal depth on the easterly bank of the river. From this point it will be constructed through the mountains until it reaches the new Croton reservoir. Here connections will be made to enable the water to be drawn directly from the Ashokan reservoir into the Croton reservoir, with a view to augmenting the Croton supply until such time as the aqueduct from Ashokan to New York city shall have been completed.

From the Croton reservoir the aqueduct will be continued south to Kensico reservoir, which will be enlarged to include Rye Pond and will form an auxiliary storage reservoir at an elevation of 355 feet above mean tide, capable of containing 25 billion gallons, or sufficient to supply the city at the rate of 500 million gallons per day for a period of fifty days. About four miles south of Kensico, at Scarsdale, there will be built a large filtering plant, and at Hillview, six miles to the south of this, will be another storage reservoir. With these two auxiliaries or emergency reservoirs provided, the city will be secured against any sudden interruption of its supply through failure of the 69 miles of aqueduct lying to the north of them. By the construction of a tunnel of 200 million gallons daily capacity below the East River, Brooklyn and Staten Island will be provided with a supply of 100 million gallons daily, and this aqueduct will terminate in a large reservoir to be constructed in Forest Park. From the point where this tunnel reaches the shores of Long Island, a line of 20 million gallons capacity will be built through Brooklyn and below the Narrows for the supply of Staten Island.

TUNNELS AND SUBWAYS.

(Continued from page 405.)

the shield it was customary to allow the silt, etc., to pass into the interior of the tunnel as the shield was advanced, and take it away in cars. The Hudson Companies' engineers decided, however, to try the plan of pushing the shield ahead by displacement; that is to say, they closed the doors in the front face of the shield, and tried the experiment of pushing the shield bodily through the silt, causing the latter to flow over and around the tube by displacement. The plan succeeded beyond expectations, and the later work was all done by this method.

One of our illustrations shows the way in which the engineers overcame a serious obstacle, in the shape of a ledge of rock, which projected from the river bottom and covered the lower half of the path through which the tunnel was to be driven. To meet the emergency, a heavy iron working roof was built in front of the shield, and under this the workmen were enabled to set up their drills and blast out the obstruction. At the point of connection of the tunnel tubes with the Subway tubes running along the Jersey shore, it became necessary to work out the difficult problem of operating the trains to their various destinations without incurring dangerous crossovers on tracks running in opposite directions. The difficulty was solved by running the pairs of tunnels at such junction one above the other, and arranging the crossovers within huge double-deck caissons of the type shown in the illustration of this work. These caissons, which are truly mammoth affairs, 45 feet wide, 45 feet deep, and 106½ feet long, bigger than anything of the kind heretofore constructed, are built of reinforced concrete. The walls were first sunk to the desired depth, the necessary openings being left for connection with the tunnel tubes. Then the floor, the intermediate deck, and the roof were built, leaving the huge box-like structure ready for connection with the tubes and the laying of the tracks. The construction is clearly shown in our sectional view of the same.

The plans of the Pennsylvania Railroad Company for establishing a large terminal station for their system in the center of Manhattan Island, and connecting it with their trunk line to the West and the extensive system of roads of the Long Island Railroad Company to the East, has involved the construction of subaqueous tunnels of even greater importance than those of the Hudson Companies above referred to. Access to Manhattan Island is obtained by two single-track tubes, and to Long Island by four such tubes. As compared with the Hudson Companies' tunnels, those of the Pennsylvania Company are much larger, heavier, and more expensive to build. It was considered at the very outset that special strength and solidity would be necessary to safely carry the heavy transcontinental trains of Pullman cars. Accordingly, the tubes were made of an external diameter of 23 feet; and the segments were cast with an unusually heavy shell and deep flanges amply provided with bracing. The interior of the tube is lined with no less than two feet of concrete; and, in addition to this, the concrete is carried up parallel with the sides of the cars to the height of the window sills, where a broad shelf, wide enough to permit the passengers to walk in case of a breakdown, is provided. This shelf is formed integrally with the concrete lining of the tunnel. In the preliminary investigation of the problem, it was considered possible that the impact of the heavy trains upon the floor of the tunnel would tend to cause some settlement of the tubes in the silt in which they had been driven; and, as a provision against this, the original plans provided for sinking hollow cast-iron piles through the floor of the tunnel to bedrock, and laying the tracks upon a system of longitudinal girders within the tunnel, which would serve to transfer the trainloads directly to the piles, and so relieve the tubes themselves from all stresses due to live loads. These piles were to be 27 inches in outside diameter, with a shell 1½ inches in thickness. After the tubes had been driven, the satisfactory behavior of the Hudson Companies' tubes, which were built without any pile supports and have failed to show any settlement after many months of operation, convinced the engineers that the Pennsylvania tubes would be sufficiently stable without the supporting piles; and, consequently, this feature has been omitted. The tubes were driven by the shield method, and the work was pushed through without developing any problems of a serious or unusual character. The same may be said of the building of the tunnels across Manhattan Island, where the work consisted for the most part of straight rock excavation. With a view to accommodating the heavy future increase in suburban traffic to Long Island, the company determined to build four separate tubes beneath the East River. Because of the difficult character of the material encountered, the work on these tunnels has been somewhat protracted, many blowouts having developed, necessitating the construction of a false bottom to the river above the heading of the tubes by dumping in many thousand cubic yards of material from scows. All obstacles, however, have been overcome, and the whole of this vast tunnel system will have been completed before another twelvemonth has gone by. The total length of the run in tunnel from the portal in Jersey City to the portal on Long Island is 5.3 miles. The total length of single-track tube tunnels under the two rivers is 6.8 miles, and the total length of single-track tunnel under the land is also 6.8 miles. The total length of track in tunnels exclusive of the yard tracks and the station will be 16½ miles.

Contemporaneously with the execution of the above work, the financial interests which are responsible for the operation of New York city's subways were engaged in constructing a twin-tube tunnel below Forty-second Street and the East River from the Grand Central Station, Manhattan, to Long Island City. The tubes are similar in dimensions and general construction to those which form the connecting link at the Battery between the Manhattan and Brooklyn Subway systems. The tunnel was built under an old franchise granted many years ago, and it has been offered for purchase by the city at a price of $7,000,000.

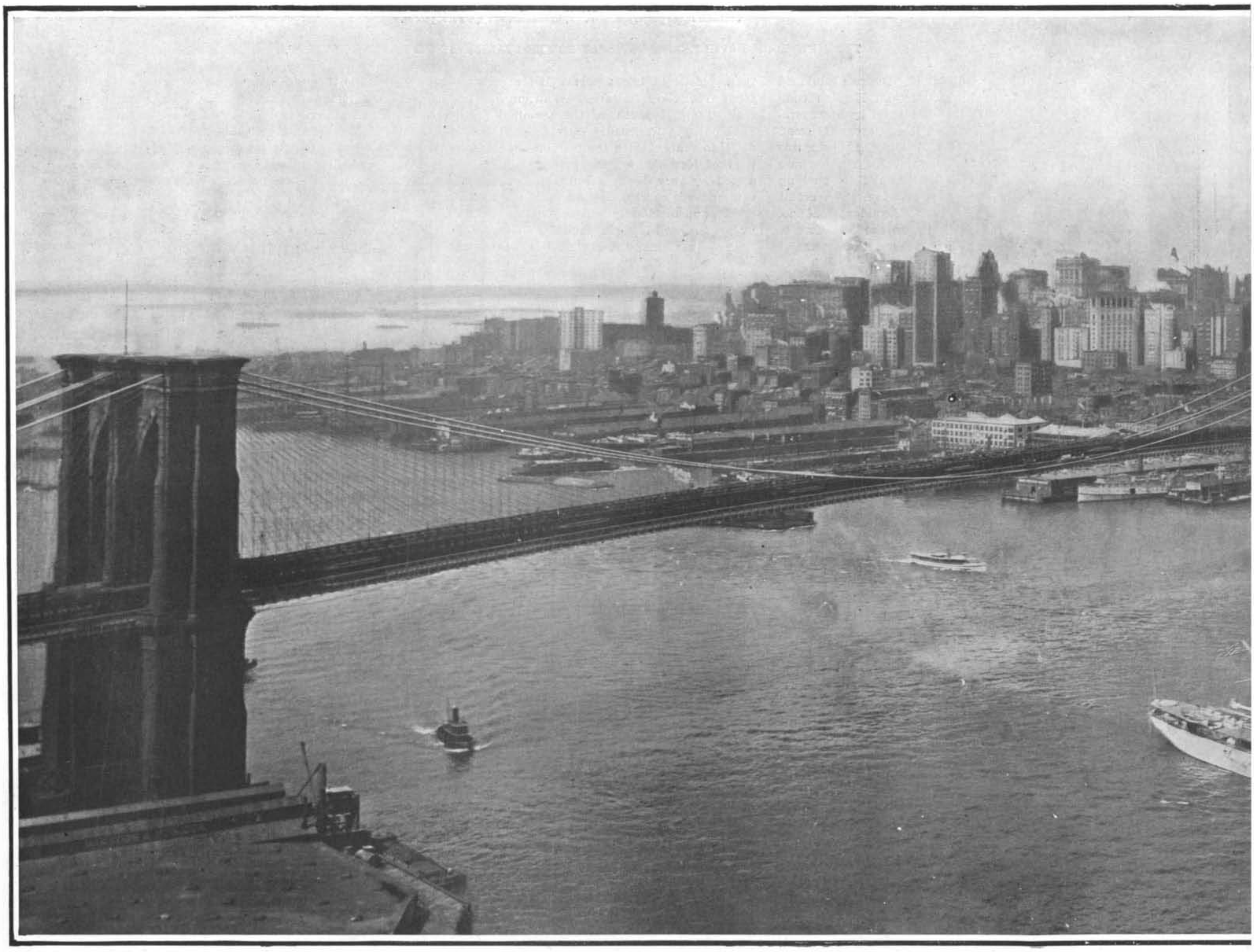
NEW GRAND CENTRAL TERMINAL STATION.

(*Continued from page 412.*)

trolley system consists, for each track, of two steel messenger wires below which is carried, by means of triangles of steel tubing, the ⅝-inch copper trolley wire. In the early days of the operation of the system, difficulties developed, due to the hammering of the collector shoes as they passed the points of suspension of the wire at the apex of the triangles. This was cleverly overcome by suspending a second wire below the first by means of clips attached to the upper wire midway between its points of suspension from the triangle. The arrangement has provided a system which combines great stiffness with uniform flexibility of the trolley wires; and the troubles of sparking, wear, and breakage have been practically eliminated. The electric locomotives, which because of their short wheel base were found to sway heavily at high speed, have later been provided with end trucks of ingenious design, which have completely eliminated the trouble, and rendered these locomotives as steady in their running as a Pullman car. The whole of this work was done by the

From a photograph owned by the Otis Elevator Co.

LOWER NEW YORK AS IT APPEARED IN 1875. REPRODUCED FROM A PHOTOGRAPH TAKEN FROM



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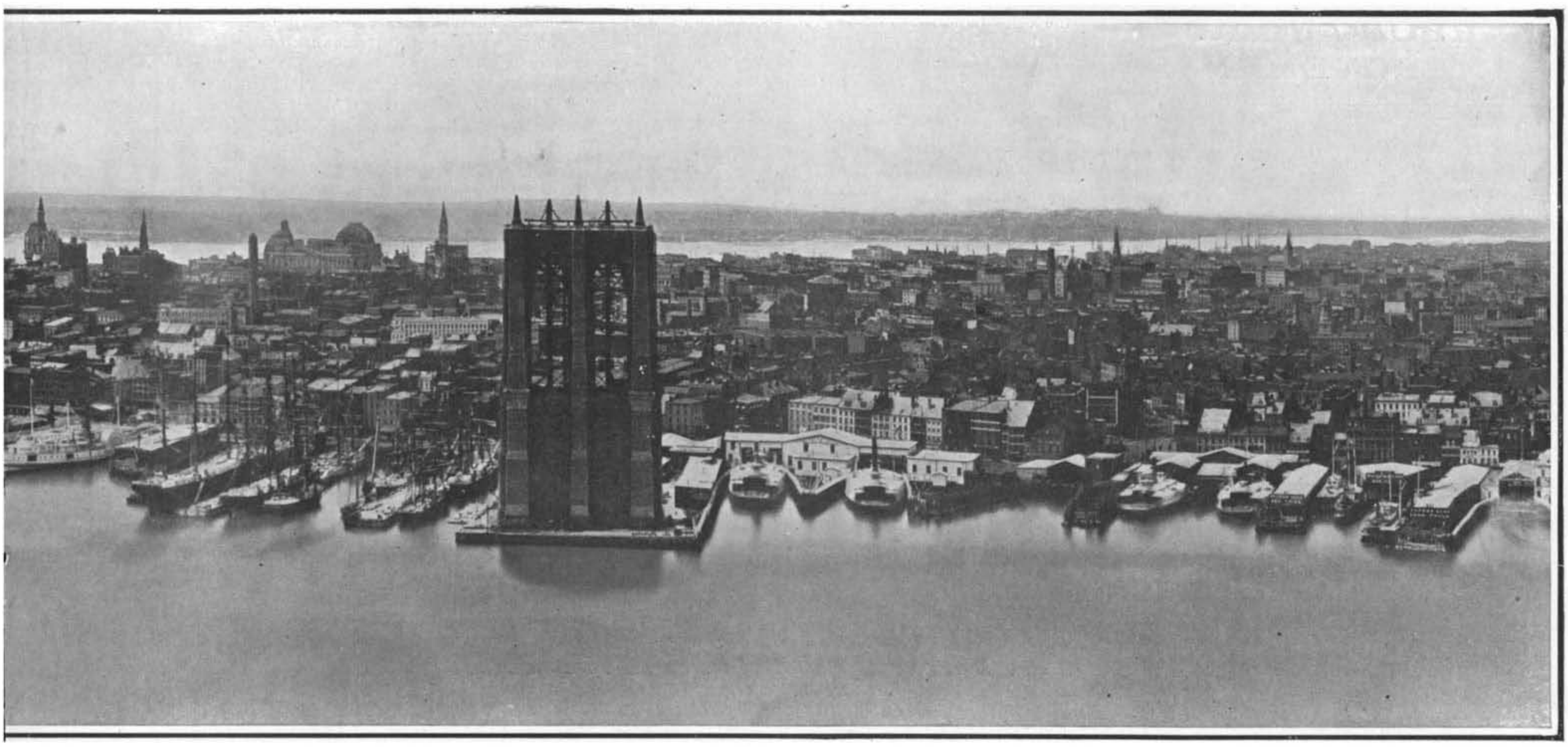
SKYLINE OF LOWER NEW YORK AS IT APPEARS TO-DAY WHEN VIEWED FROM



THE TOP OF THE BROOKLYN TOWER DURING THE CONSTRUCTION OF THE BROOKLYN BRIDGE.

THE TOP OF THE BROOKLYN TOWER OF THE NEW MANHATTAN BRIDGE.