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THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD.

The east river Division.

By Alfred Noble, *past-President*, *am*. *Soc*. C. E.

A general outline of the work included in this Division has been given by General C. W. Raymond, M. Am. Soc. C. E., in the first paper of the series. The few pages following are intended only as a note to connect his paper with the more detailed descriptions of the execution of the work, which will be supplied by the Resident Engineers in immediate charge.

Soon after the Company's project was made public, in the latter part of 1901, borings were begun in the East River, and a few weeks later in Manhattan and Long Island City. A preliminary base line was measured on the Manhattan side, and temporary transit stations were established on buildings from which all borings in the river were located. The river borings were all wash-borings made from a pile-driver boat. After the results were plotted on the map, contour lines were drawn to indicate the rock surface, and profiles along the tunnel lines were plotted from the contours; as the borings were preliminary to the final location of the tunnels, and in many cases at some distance from the tunnel lines, considerable divergence from the actual rock surface was expected, and realized in a few places, yet on the whole the agreement was very good. The borings revealed two depressions or channels where the rock surface passed below the grade of the projected tunnels, these depressions being separated by a rock reef which extends down stream from Blackwell's Island. In 32d and 33d Streets in Manhattan, borings were made from the river to the station site at intervals of about 100 ft., wash-borings and core-borings alternating. In Long Island City, where the tunnel lines were to pass diagonally under the passenger station building and passenger yard of the Long Island Railroad and under streets and private property, the arrangement of borings was less regular, although the alternation of wash-borings and core-borings was carried out as far as practicable. After the final location of the work, additional borings were made, particularly on shaft sites and also along the approaches and in the Sunnyside Yard, Long Island City.

A triangulation was carried across the river with a measured base on each side. It was impossible to measure directly between the extremities of either base. The bases were measured with 100-ft. steel tapes, supported every 20 ft., stretched with a uniform pull, and frequently compared with standardized tapes. On account of the crowded condition of the streets during the hours of daylight and evening, most of the work was done between 10 P. M. and 5 A. M. Similar measurements were made in the streets along the tunnel lines. Angle readings were repeated many times, as is usual in such work. Fig. 1 shows the triangulation, the street measurements being omitted.

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Levels were first transmitted across the river by simultaneous observations of the river surface; then by several repetitions, across Blackwell's Island and the narrow channels on each side, where the longest sights were about 1100 ft.; and, finally, by several lines through the tunnel of the East River Gas Company at 71st Street.

The franchise granted by the City of New York provided for the sale to the Railroad Company of the portions of 32d Street between Seventh and Eighth Avenues, and between Eighth and Ninth Avenues. Later, the Company acquired by purchase the portion of 32d Street between Ninth and Tenth Avenues. The franchise granted sub-surface rights under streets around the station site to within 19 ft. of the street surface under Seventh, Eighth, and Ninth Avenues; to within 30 in. of the street surface under 31st and 33d Streets, except that, under the sidewalks opposite the station, that is to say, the south sidewalk in 31st Street and the north sidewalk in 33d Street, the construction must be at least 5 ft. below the street surface. In carrying out the work, full use of these rights was made under Eighth Avenue, but only under such portions of Seventh and Ninth Avenues as were indispensable for access by trains to the station area. It was not practicable to make full use of the rights granted under 31st and 33d Streets without incurring great expense for supporting adjacent buildings or for injuries to them, and, after careful consideration, the arrangement shown in the plans was decided on, making about 45% of the sub-surface area under these streets available at track level.

[Illustration: *Fig*. 1.—Triangulation System East River Tunnel]

The work of the East River Division at this site embraced the excavation to the depth necessary for railroad tracks, and the building of a retaining wall extending in 31st Street from the east side of Ninth Avenue to the west side of Seventh Avenue, thence northward along Seventh Avenue for a distance of 155.5 ft.; also a retaining wall in 33d Street from the west side of Seventh Avenue to the east side of Ninth Avenue, and thence southward along Ninth Avenue for a distance of 136.3 ft. This work was placed under contract June 21st, 1904, with the New York Contracting and Trucking Company, and later assigned by that company to the New York Contracting Company-Pennsylvania Terminal, and was carried out under the direction of George C. Clarke, M. Am. Soc. C. E., as Resident Engineer, by whom it will be described in detail.

[Illustration: *Plate* IX.—Map of Portion of Manhattan Island from 23d to 40th Streets, Showing Former Topography From Map Made by Gen. Egbert L. Viele in 1865]

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The station tracks leading eastward from the station will converge under Seventh Avenue and for some distance farther east, and pass into two three-track tunnels, one under 32d Street and the other under 33d Street, at the respective distances of 192 and 402 ft. from Seventh Avenue. A typical cross-section of the three-track tunnel is shown on Plate XII. The converging sections were considered as easterly extensions of the station, and were not included in the East River Division. Within a few hundred feet (Plate XIV), the tracks are reduced to two, each passing into a single tube, the two tunnels under each street being formed in one excavation, the distance between center lines of tunnels being 20 ft. 4 in. This construction has been termed a twin tunnel, and a typical cross-section is shown on Plate XII. The tunnels continue on tangents under the streets to Second Avenue where they curve to the left by 1 deg. 30' curves, passing under private property, gradually diverging and passing through shafts just east of First Avenue. About 350 ft. west of the shaft, the divergence of the two lines from each street becomes sufficient to leave a rock dividing wall between them, and thence eastward each tunnel is formed in a separate excavation. A typical cross-section of the two separated tunnels is shown on Plate XII.

It thus appears that eastward from the station the lines constitute a four-track railroad, each track being in a separate tunnel; for convenience of the work these lines were designated *A*, *B*, *C*, and *D*, from north to south.

[Illustration: *Plate* X.—Manhattan Shaft, Lines *A* and *B*]

At an early date, when the organization of the engineering staff was taken up, Charles L. Harrison, M. Am. Soc. C. E., was appointed Principal Assistant Engineer. He was directly in charge of all parts of the work, and all Resident Engineers reported to him. George Leighton, M. Am. Soc. C. E., was placed in charge as Resident Engineer of the 33d Street lines from the west end of the three-track tunnel to the shaft and also eastward from the shaft under East River. As he was not then able to endure the effects of compressed air, the work under the river was transferred to James H. Brace, M. Am. Soc. C. E., as Resident Engineer. Before the completion of the land tunnels under 33d Street, Mr. Leighton accepted more responsible employment elsewhere, and Mr. Brace assumed charge of them also. Francis Mason, M. Am. Soc. C. E., was in charge as Resident Engineer of the 32d Street lines during their entire construction, and also of the tunnels extending these lines eastward from the First Avenue shaft under the river.

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The work just described as the 32d and 33d Street lines, terminating at the easterly end at the First Avenue shafts, was placed under contract on May 29th, 1905, with the United Engineering and Contracting Company. The plans then provided for three-track tunnels from the west end of the work under the contract eastward 1,628 ft. in 32d Street and 1,418 ft. in 33d Street to the west line of Fifth Avenue, with a descending grade of 0.4%; this was to constitute, in a degree, an extension of the station, where trains could stand without brakes while awaiting signals to proceed to or from the station. From Fifth Avenue eastward to the lowest point under the river, the grade was to be 1.5% on all lines. Later, during construction, when excavating westward under 33d Street from Fifth Avenue, the surface of the rock was broken through, disclosing quicksand; within the next few days trial drill holes through the tunnel roof at 32d Street and Fifth Avenue showed a thin cover with quicksand above it. The conditions had been indicated in a general way by borings made before construction was begun, but they proved to be rather worse than anticipated. On the topographical map of Manhattan Island, made by General Egbert L. Viele in 1865, is shown a watercourse which had its source near what is now Broadway and 44th Street, flowing thence along the west side and south end of Murray Hill, passing under the present site of the Waldorf-Astoria Hotel, crossing 33d Street at the point where the rock surface was broken through in the tunnel excavation, as above stated, crossing 32d Street at its intersection with Fifth Avenue, where trial drilling showed thin rock cover over the tunnel excavation, passing thence eastward a short distance south of 32d Street, which it recrossed near Third Avenue, and finally discharging into the East River near 34th Street, and a little west of the present First Avenue. The ancient creek apparently followed the course of a valley in the rock, the valley having become filled to a considerable depth with very fine quicksand. This concurrence of depressions in the rock surface with the watercourse shown on Viele's map was noted in so many places and the difficulties of construction were so serious at these places, that a section of the map showing the old topography along and adjacent to the station and tunnel lines is reproduced in Plate IX.

[Illustration: *Plate* XI.—Long Island Shaft. Lines *A* and *B*]

The unfavorable conditions developed at Fifth Avenue affected both the construction of the tunnels and the maintenance of adjacent buildings. It would be necessary to construct the tunnels in open cut for a large part of the way westward, causing serious inconvenience to the public; the buildings were mostly of the older class, founded in earth, but there were several modern high buildings with foundations in the same material; some of these had been built since the tunnels were planned. In view of these added

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risks and the increased cost of construction, the value of the three-track construction was reconsidered, and two important changes were made in the plans. The first of these was to continue the twin tunnel westward to Sixth Avenue in 32d Street, and to a point 180 ft. west of Sixth Avenue in 33d Street; the twin tunnel being 9-1/2 ft. less in height than the three-track tunnel and 9 ft. narrower, the change reduced the difficulties considerably. Where the three-track tunnel was thus eliminated, there was no longer objection to a steeper grade, so that, going eastward from the station, a grade of 0.8% in 33d Street and 0.9% in 32d Street was substituted for the original 0.4% grade. From the west line of Fifth Avenue eastward short sections with descending grades of 0.3% connect with the original 1.5% grade near Madison Avenue. The effect of these two changes—type of tunnel and grade—was to lower the roof of the tunnels at Fifth Avenue about 15 ft., which made it practicable to avoid open cutting east of Sixth Avenue.

A full account of the construction of the cross-town tunnels will be given by the Resident Engineers.

Permanent shafts were made on both sides of the East River, those in Manhattan being located a few feet east of First Avenue, and those in Long Island City being located, one in the so-called Annex Slip, the other in the pier just south of it. The two railroad lines coming from 32d Street in Manhattan, and curving to the left at Second Avenue, are about 34 ft. apart between centers at First Avenue, and it was convenient to make the shaft large enough to cover both lines. Borings had shown that the excavation for the tunnels would break out of the rock about 200 ft. east of First Avenue. It was desirable to carry the tunnel excavation eastward from the shaft in normal air far enough to permit of building at least 50 ft. of tunnel and installing air-locks, so that compressed air might be available when the rock surface was broken through. The location adopted, and shown on Plate XIII, had the further advantages that the rock surface was several feet above the level of the top of the tunnels, and access to the river for receiving and discharging materials could be had without crossing any street. Similar reasons governed the location of the north shaft for the lines from 33d Street. On the Long Island side of the river there were only two feasible locations meeting these conditions, particularly in respect to a safe thickness of rock above the tunnels, one near the pierhead line, the other just outside the bulkhead line, and for many minor reasons the latter was preferable. The center lines of each pair of tunnels were 37 ft. apart, and each shaft, therefore, was made to cross both lines of a pair, the same as on Manhattan side of the river. It was not expected, however, that the Long Island shafts could be built conveniently or the tunnels begun from them in normal air.

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The decision to make the shafts of permanent construction was based not only on the desirability of having access to and egress from the tunnels near the banks of the river for convenience of the workmen or exit for passengers in case of accident, but to facilitate ventilation; these locations divide the entire lengths of tunnels east of the station into three parts, two of which were approximately 4,000 ft. each, and the other about 5,500 ft. The accident risk was believed to be very small, while much weight was given to the feature of facilitating ventilation. Further studies have enhanced the importance attached to ventilation, and it is now intended to provide appliances for mechanical ventilation at all shafts. The plans of the shafts are shown on Plates X and XI. The caissons for the shafts are of structural steel, with double walls, filled between with concrete, including a cross-wall between and parallel to the tunnels. All these structures were fitted for sinking with compressed air, if that should prove necessary.

Although borings had shown that rock would be found at all the shaft sites several feet above the tunnel level, it could not be determined in advance of excavation whether the caissons would have to be sunk to full depth; if sound, unfissured rock were found, the sinking could be stopped above the tunnel level; but, if not, the caissons, in any case, would have to be sunk far enough to permit placing a water-tight floor below the tunnels, and the tunnels themselves begun through openings in the side-walls of the caisson; such openings, therefore, closed by removable bulkheads, were provided in all caissons.

[Illustration: *Plate* XII.—Typical Tunnel Sections]

As already stated, the grade of 1.5% from Fifth Avenue eastward was fixed with reference to the lowest point of the river bed in order to give the requisite cover over the tunnels at the deepest point of the channel on the west side of the reef, where the river bottom was about 60 ft. below mean high tide for a short distance. On the other hand, as the use of compressed air in building the tunnels was anticipated, an excessive depth below the water surface was to be avoided as far as possible; it was necessary, however, to continue the descending grade some further distance until the tunnels were mostly in rock, so that drainage sumps under the tunnels could be made readily. Eastward from the sumps the tunnels had a rising grade of 0.7% to the established bulkhead line on the Long Island side, giving a cover at the points where the tunnels enter rock, a short distance westward, of about 10 ft. (if the dredging plane should be fixed at some future time at 40 ft. below mean low tide, as may be reasonably anticipated). Eastward from the bulkhead line, Tunnels *A*, *B*, and *D* have ascending grades of about 1.25%, while Tunnel *C* rises at the rate of 1.9% in order to effect a crossing over Tunnel *B* west of the portals. This feature was introduced in order to place the two west-bound tracks together through the Sunnyside Yard, and the heavier grade, being downward with the traffic, was not objectionable.

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The arrangement of grades and tracks in the approaches and in Sunnyside Yard would require the introduction of too much detail to be taken up here, but will be dealt with in the paper on the Sunnyside Yard.

It was recognized from the inception of the project that the tunnels under the East River would be the most difficult and expensive section of the East River Division. The borings had shown a great variety of materials to be passed through, embracing quicksand, coarse sand, gravel, boulders, and bed-rock, as well as some clayey materials. (See Plate XIII.) The rock was usually covered by a few feet of sand, gravel, and boulders intermixed, but, in some places, where the rock surface was at some distance below the tunnel grade, the material met in tunneling was all quicksand; the nearest parallels in work previously done were some of the tunnels under the Thames, particularly the Blackwall tunnel, where open gravel was passed through. Before the plans for the East River tunnels were completed, work had been resumed, after many years' interruption, in the old Hudson River tunnels between 15th Street, Jersey City, and Morton Street, Manhattan, and sand materials were passed through for a short distance. These experiences satisfied nearly all the engineers in any way connected with the work that the shield method was the most suitable for the East River tunnels, and the plans for the work were based on its adoption. (See Plate XII for cross-sections, *etc*.) Other methods, as stated by General Raymond in the introductory paper, were advocated, particularly caisson constructions and the freezing process, the latter being urged very strongly, and, when proposals were invited, in October, 1903, bidders were informed that alternative methods would be taken into consideration.

Bids were received and opened on December 15th, 1903. Only one bidder proposed to carry out the work on the basis of unit prices, but the prices were so low that the acceptance of the proposal was deemed inadmissible; no bid based on caisson methods was received; several offers were made to perform the work by the shield method, in accordance with the plans, for a percentage of its cost, and one was submitted, on a similar basis, covering the use of the freezing method. The firm of S. Pearson and Son, Limited, of London, England, submitted a proposal for building the tunnels by the shield method, on a modification of the percentage basis, and as this firm had built the Blackwall tunnel within the estimates of cost and was the only bidder having such an experience and record in work in any way similar to the East River tunnels, negotiations were continued between that firm and the railroad company.

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The original plans and specifications contemplated that all tunnels between the First Avenue shafts in Manhattan and East Avenue in Long Island City would be shield-driven, and that work would proceed simultaneously eastward from the First Avenue shafts and both eastward and westward from the Long Island City shafts located west of Front Street at the river, requiring twelve shields. When making their proposal, S. Pearson and Son, Limited, suggested that shields might be started from the east end of the work and arrive at the Front Street shafts as soon as these shafts could be completed, and proposed sinking a temporary shaft transversely across all four lines near the east end of the work just west of East Avenue, from which, within a short time, to drive toward Front Street by the use of shields. The railroad company accepted the suggestion for the additional shaft, although the greater part of the tunnels east of Front Street was built without shields. After several months of negotiation, a contract was entered into on July 7th, 1904, with S. Pearson and Son, Incorporated, a corporation of the State of New York organized by the English firm for the purpose of entering into and carrying out this contract. The main features had been agreed upon, and work had begun about two months before. The contract embraced the permanent shafts in Manhattan and Long Island City, the tunnels between these shafts, and their extension eastward in Long Island City to East Avenue, including in all about 23,600 ft. of single-track tunnels. The contract had novel features, and seemed to be peculiarly suitable for the unknown risks and the unusual magnitude of the work. A fixed amount was named as contractor's profit. If the actual cost of the work when completed, including this sum named as contractor's profit, should be less than a certain estimated amount named in the contract, the contractor should have one-half of the saving. If, on the other hand, the actual cost of the completed work, including the fixed sum for contractor's profit, should exceed the estimated cost named in the contract, the contractor should pay one-half the excess and the railroad company the other half; the contractor's liability was limited, however, to the amount named for profit plus $1,000,000; or, in other words, his maximum money loss would be $1,000,000. Any further excess of cost was to be borne wholly by the railroad company. The management of the work, with some unimportant restrictions, was placed with the contractor; the relations of the engineer, as to plans, inspection, *etc*., were the same as in ordinary work, and the interest of the contractor to reduce cost was the same in kind as in ordinary work.

[Illustration: PLATE XIII.—Plan and Profile. East River Tunnels]

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On account of the extent of the work embraced in this contract, and the dangerous exposure to compressed air required in most of it, it was divided into three residencies; two of these, including also the cross-town tunnels, have been described; the third, with S. H. Woodard, M. Am. Soc. C. E., as Resident Engineer, embraced all tunnels from the easterly end of the work near East Avenue in Long Island City to the meeting points under the river and also the permanent shafts in Long Island City. A few months after the execution of the principal contract, the work to be done was extended eastward 107.5 ft., across East Avenue. The extensions of the tunnels were built without cast-iron linings and with an interior cross-section of the same height as the tube tunnels, but somewhat narrower. The work was also extended westward from the First Avenue shafts to include the excavation of top headings in each tunnel for a distance of 100 ft. and an enlargement to full size for 50 ft. The borings having shown that soft earth existed below the grade of the tops of the tunnel under the passenger station building of the Long Island Railroad on the east side of Front Street, and that earth of varying character would be met in places beyond the station building under the railroad tracks in the passenger yard and the street car tracks in Borden Avenue, it had been decided, before proposals were invited, to extend the metal lining eastward to East Avenue, at the east end of the work embraced in the original contract, where the rising tunnel grades approached the surface of the ground so closely that their further extension would be in open cut. In places where the tunnels were wholly in rock, the weight of the cast-iron tunnel lining was reduced 43%; where the surface of the rock was below the top of the tunnel, but above the axis, the reduction of weight was somewhat less, about 25%; notwithstanding these savings, the cost of the tunnels was probably increased by the use of the cast-iron lining; on the other hand, when passing through bad ground, a section of tunnel could be made absolutely safe more quickly by erecting the lining as soon as a length of a few feet of tunnel was ready; under a crowded passenger yard, this feature had great value.

The execution of the work under this contract will be described fully by the Resident Engineers.

The plant assembled by the contractors is believed to be the most extensive ever placed on a single piece of work, and will be described in detail by their Managing Engineer, Henry Japp, M. Am. Soc. C. E.

For convenience in receiving materials to be used in construction, and to facilitate the disposal of excavated materials, one pier was leased on the east side of the Hudson River, two on the west side of the East River and three on the east side. Excavated materials from the station, the cross-town tunnels, and the river tunnels, were placed on barges furnished by Mr. Henry Steers under several contracts embracing

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also the disposal of the materials. In the earlier part of the work, they were used as fill in the freight terminal of the Pennsylvania Railroad at Greenville on the west side of the Upper Bay; when the fill at this place was completed, the materials were sent to the tunnel company's yard on the Passaic, at Harrison, N. J., and a small part to the embankment in the Meadows Division. On account of the occasional closing of the Passaic by ice, this involved the possibility of, and to some extent resulted in, interruptions to the work of excavation. The contract for the cross-town tunnels carried an option in favor of the company to require the contractor for those tunnels to dispose of materials at a stated price, and in the latter part of 1907, when the excavation in these tunnels was being pushed rapidly, the railroad company, unwilling to incur the responsibility for delays during the winter, availed itself of this option. The disposal of materials was an important part of the work, and will be dealt with more fully by the Resident Engineers.

[Illustration: PLATE XIV.—Map and Profile, Cross-Town Tunnels]

At the time the contract was made with S. Pearson and Son, Incorporated, it had not been determined whether mechanical ventilation would be provided for the tunnels, and therefore the contract with that firm did not include the final concrete lining at the shafts, above the inverts of the tunnels. After the adoption of plans for mechanical ventilation, in the latter part of 1908, the plans for lining the shafts with concrete, including flues for conducting air to the tunnels, and stairways for ingress and egress, were completed, and the work was placed under contract; it will be described in detail by F. M. Green, Assoc. M. Am. Soc. C. E.

At the east end of the work under the Pearson contract, the rising grade of the tunnels brought them so near the surface of the ground that their extension eastward could be carried out more readily in open cut than by tunneling. The locations of the portals could be varied somewhat, and they were built on rock which was found in rather narrow ridges at convenient places. Tunnels *B* and *D* have a common portal; Tunnels *A* and *C* have separate ones, the portal for Tunnel *C* being located about 800 ft, west of the others as a result of its crossing over Tunnel *B*, as already explained. Eastward from the portals, the track system expands, in order to provide connections with the tracks of the Long Island Railroad to and from Long Island City, with the New York Connecting Railroad and New England lines, and with the storage and cleaning yard known as the Sunnyside Yard extending to the west side of Woodside Avenue, 2-3/4 miles east of the East River. (Plate XV.) The yard and approaches are designed to avoid grade crossings by opposing trains. The various general features of the yard and tunnel approaches, bridge crossings, and street closings, have been described in sufficient detail by General Raymond in the introductory paper.

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[Illustration: PLATE XV.—Plan and Profile of Lines *A* and *B*, and Sunnyside Yards]

For convenience in placing the work under contract, a line was drawn 10 ft. west of Thomson Avenue, dividing the work east of that embraced in the Pearson contract into two parts. The work west of the line was placed under the immediate direction of George C. Clarke, M. Am. Soc. C. E., as Resident Engineer, with Naughton Company and Arthur McMullen, Contractors; Mr. Louis H. Barker was Resident Engineer of the part east of the dividing line, with the Degnon Realty and Terminal Improvement Company as the principal contractors. The substructures of the several bridges in or across the yard were included in these contracts, but the superstructures were carried out by various bridge companies, and other minor features were executed by other contractors. More complete descriptions of the plans and of the execution of the work will be given by the Resident Engineers.