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Paper No. 1158

THE NEW YORK TUNNEL EXTENSION OF THE PENNSYLVANIA RAILROAD. THE CROSS-TOWN TUNNELS.[A]

BY JAMES H. BRACE AND FRANCIS MASON, MEMBERS, AM. SOC. C. E.

In this paper, it is proposed to describe the construction of the tunnels extending eastward from the easterly extension of the Terminal Station to the permanent shafts east of First Avenue.

They were located under 32d and 33d Streets from the station to Second Avenue, and thence, curving to the left, passed under private property and First Avenue to the shafts, as described in a preceding paper. Typical cross-sections of the tunnels are shown on Plate XII.[B]

On May 29th, 1905, a contract was entered into with the United Engineering and Contracting Company for the performance of this work. This contract provided that work on each pair of tunnels should be carried on from two shafts. The first, here referred to as the First Avenue Shafts, were located just east of that avenue and directly over the line of the tunnels; the other two, called the Intermediate Shafts, were located on private property to the north of each pair of tunnels in the blocks between Fourth and Madison Avenues. It was originally intended to do all the work of construction from these four shafts. Workings were started both east and west from the Intermediate Shafts, and those to the west were [Page 392] to be continued to the Terminal Station. After the change of plans, described in a previous paper, it was decided to sink a third shaft on each line. These were known as the West Shafts, and were located between Sixth and Seventh Avenues. Finally, it was found necessary to build a portion of the tunnels on each line west of Sixth Avenue in open cut. The locations of the shafts are shown on Plate XIV.[C]

The First Avenue shafts were built by S. Pearson and Son, Inc., for the joint use of the two contractors, as described in the paper on the tunnels under the East River. While the shafts were being sunk, the full-sized tunnels were excavated westward by the contractor for the river tunnels for a distance of 50 ft., and top headings for 50 ft. farther. By this means, injury to the caissons and to the contractor's plant in the shafts by the subsequent work in the Cross-Town Tunnels was avoided. The west half of the shaft was for the exclusive use of the contractor for the Cross-Town Tunnels.

CONTRACTOR'S PLANT

The method of handling the work adopted by the contractor was, broadly speaking, as follows: Excavation was usually carried on by modifications of the top-heading and bench method, the bench being carried as close to the face as possible in order to allow the muck from the heading to be blasted over the bench into the full section. The spoil was loaded into 3-yd. buckets (designed by the contractor and hereinafter described), by steam shovels operated by compressed air, and hauled to the shafts by electric locomotives. Electrically-operated telphers, suspended from a timber trestle, hoisted the buckets, and, traveling on a mono-rail track, deposited them on wagons for transportation to the dock. Arriving at the dock, the buckets were lifted by electrically-operated stiff-leg derricks and their contents deposited on scows for final disposal. The spoil was thus transported from the heading to the scow without breaking bulk.

When concreting was in progress, the spoil buckets were returned to the shafts loaded with sand and stone. The concrete materials were deposited in storage bins placed in the shafts, from which they were fed to the mixers located at the foot of the shaft about on a level with the crown of the tunnels. The concrete was transported to the forms in side-dump, steel, concrete cars, hauled by the electric locomotives.

Electrical power was adopted largely on account of the restricted area at the shaft sites, where a steam plant would have occupied considerable space of great value for other purposes. The installation of a steam plant at the Intermediate Shafts, which were located in a high-class residential district, would have been highly objectionable to the neighboring property owners, on account of the attendant noise, smoke, and dirt, and, in addition, the cost of the transportation of fuel would have been a serious burden. Except for the forges and, toward the last, the steam locomotives, not a pound of coal was burned on the work. The use of the bucket and telpher also eliminated most of the objectionable noise incident to the transfer of spoil from tunnel cars to ordinary wagons at the shaft sites. Power plants were installed at the North Shaft near First Avenue and at the rear of the 33d Street Intermediate Shaft. [Page 393]

First Avenue Plant.—Fig. 1, Plate LVIII, is a general view of the First Avenue plant. The power-house at the corner of 34th Street and First Avenue supplied compressed air for operating drills, shovels, pumps, and hoists in the tunnels driven from the river shafts, and in it three Laidlaw-Dunn-Gordon compressors were installed. The largest was a 32 by 20 by 30-in., two-stage, cross-compound, direct-connected to a Fort Wayne 480 h.p., 230-volt, direct-current, constant-speed motor run at 100 rev. per min. This compressor was rated at 2,870 cu. ft. of free air per minute at a pressure of 100 lb. It was governed by throttling the suction, the governor being controlled by the pressure in the air receiver and the motor running continuously at a constant speed. The two others were of similar type, one was 22-1/2 by 14 by 18-in., rated at 1,250 cu. ft. of free air at a pressure of 100 lb., the other was 16 by 10 by 18-in., rated at 630 cu. ft. They were fitted with 9-ft. fly-wheels, and were driven at 150 rev. per min. by 105-h.p., General Electric, 220-volt, compound-wound, direct-current motors running at 655 rev. per min. The larger of these two compressors was driven by two of the motors belted in tandem, and the smaller was belt-connected to a third motor. The compressors were water-jacketed and had small inter-coolers, the water supply for which was itself cooled in a Wheeler Condenser and Engineering Company's water-cooling tower. The pump and the blower operating it were electrically driven.

The telphers, used for hoisting muck from the tunnels and for lowering supplies, were each hung from single rails on a timber trestle, about 40 ft. [Page 394] high, spanning and connecting the two shafts. One machine was provided for each shaft, and where their tracks crossed 33d Street they were separated sufficiently to permit the machines to pass each other. At this point, and covering the street, a large platform was provided, on which the trucks were loaded and unloaded (Fig. 2, Plate LVIII), and from which they descended by an incline on First Avenue leading south to 32d Street. The platform also covered practically all the yard at the South Shaft and materially increased the available working area. The telphers were built by the Dodge Cold Storage Company, and were operated by a 75-h.p. General Electric motor for hoisting and a 15-h.p. Northern Electric Company motor for propulsion. Their rated lifting capacity was 10,000 lb. at a speed of 200 ft. per min.

The carpenter shop and machine-shop, both of which served the entire work, were conveniently located in small buildings on the loading platform. In the former the saws were each run independently by small electric motors suspended under the platform. The heavy forms and form carriages used in lining the tunnels with concrete were fabricated and stored on the platform outside. The machine-shop lathes, etc., were all belted to one shaft driven by an 8-h.p. General Electric motor. Above the machine-shop was a locker-room and below it on the street level was the main blacksmith shop for the work. Subsidiary blacksmith shops were located at each of the other shafts. The storeroom and additional locker-rooms were located above the power-plant in the North Shaft yard, and isolated from the other structures was a small oil-house. Additional storage space was provided by the contractor on 32d Street just west of First Avenue by renting three old buildings and the yards in the rear of them and of the Railroad Company's cement warehouse adjacent. Here electric conduits, pipe, castings, and other heavy and bulky supplies were stored.

During excavation the headings were supplied with forced ventilation through 12-in. and 14-in. No. 16, spiral-riveted, asphalted pressure pipes, canvas extensions being used beyond the ends of the pipes. A No. 4 American Blower, located at the top of each shaft and driven by a 15-h.p. General Electric motor, supplied the air.

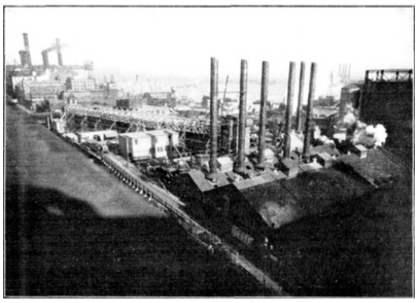

Plate LVIII, Fig. 1.—View of First Avenue Plant.

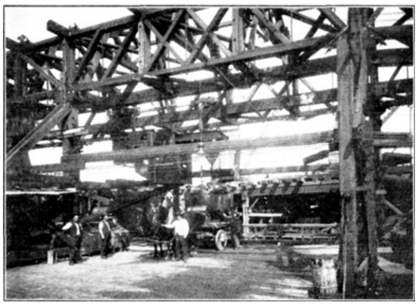

Plate LVIII, Fig. 2.—Telpher Structure and Loading Platform, First Avenue Shaft.

Plate LVIII, Fig. 3.—Headworks at 33D Street: Intermediate Shaft.

Plate LVIII, Fig. 4.—Loading Spoil on Barges, 35th Street Pier.

A concrete-mixing plant was placed in each shaft, the mixer being located high enough to discharge into cars at about the level of the springing line of the arch. Above the mixers were the measuring hoppers set in the floor of a platform which was large enough to carry half a day's supply of cement. At the South Shaft the cement was delivered to this floor from the loading platform through a spiral steel chute; at the North Shaft it was lowered in buckets by the telpher. The sand and stone were drawn into the hoppers through short chutes from the base of the storage bins which occupied the remaining height of the shaft—about 50 ft. At the South Shaft the bins were of concrete and steel, about 6 by 12 ft. in section, and attached to the central wall of the caisson. Sand and stone were delivered into them from dump-wagons on the loading platform. At the North Shaft steel-plate bins were used, and were supplied with material by the buckets handled by the telpher. The mixers were No. 5 Smith, belt-connected to 25-h.p. motors, and about 0.8 cu. yd. of concrete was mixed at a batch. The concrete cars were steel side-dumpers of the Wiener or Koppel type.

In order to be able to continue concreting during the winter, when neither sand nor stone could be obtained by water, practically all the space under the loading platforms in the South Shaft yards not occupied by the blacksmith shop was filled with these materials, which were placed in storage in the late fall.

Intermediate-Shaft Plant.—The air-compressing plant was located at the rear of the 33d Street Intermediate Shaft, and supplied air for driving the tunnels east and west from the Intermediate Shafts on both 32d and 33d Streets. Two compressors, the same as the large Laidlaw-Dunn-Gordon machine at First Avenue, were installed here, with a similar water-cooling tower.

Both shafts were on private property, owned by the Railroad Company, on the north side of the streets, and each was equipped with two telphers supported on timber trestles, similar to those at First Avenue. Here, however, the buckets were placed on wagons standing at the curb, as shown by Fig. 3, Plate LVIII.

Blowers for ventilation were installed at each shaft, as at First Avenue, and, after the excavation had proceeded some distance, small blacksmith shops, for sharpening drill steel and making minor repairs, were located in the tunnels near the shafts.

The concrete plant in each shaft was similar in arrangement to those at First Avenue, but the storage bins had wooden walls made of 2 by 4-in. and 2 by 6-in. scantling nailed flat on each other.

The contractor's office on 33d Street backed up against the 32d Street shaft site, and the basement was used as a storeroom for supplies for both [Page 396] shafts.

After the decision to do part of the work between Sixth and Seventh Avenues in open cut, an 8-in. air main was laid in 33d Street to the West Shafts, and air was supplied from the Intermediate Shaft for work on both streets in that neighborhood.

West-Shaft Plant.—West of Sixth Avenue, between 32d and 33d Streets and adjacent to the open-cut sections, the Railroad Company obtained from the Hudson and Manhattan Railroad Company the use of a large area from which the buildings had recently been removed, and gave the use of it to the contractor. This was of great value in prosecuting the west end of the work. The two West Shafts were located in the streets and were supplied with short timber trestles similar to those at the Intermediate Shafts. One telpher was taken from each of the Intermediate Shafts to operate at each of the West Shafts. In addition, a number of stiff-leg derricks were set up along the open-cut section, and were operated by Lidgerwood or Lambert air hoisting engines, or by electric motors, as circumstances dictated. A 15-ton Bay City locomotive crane was also used along part of the open-cut work on 32d Street.

Several concrete plants were installed at points along the open-cut section, and were moved from place to place, the same general arrangement being adopted as at the plants already described. No. 3 and No. 4 Ransome mixers were used, and were generally set up at about the level of the top of the arch. The sand and stone storage bins were made of scantlings spiked together, and were necessarily rather shallow on account of the proximity of the tunnels to the street surface.

Thirty-fifth Street Pier.—For the receipt and disposal of materials at the 35th Street pier, four stiff-leg derricks, operated by electric hoisting engines, were installed. Two were used in lifting the muck buckets from the wagons and dumping their contents on the scows for final disposal (Fig. 4, Plate LVIII); and the other two were fitted with clam-shell buckets for unloading sand and broken stone from barges and depositing the materials in large hoppers, from which they were drawn into wagons for transportation to the various concrete plants. A large part of the cement (all of which was supplied by the Railroad Company) was also unloaded at the 35th Street pier and hauled directly to the work, the surplus being [Page 397] stored temporarily in the Company's cement warehouses on 32d, 33d and 35th Streets, near First Avenue, from which it was drawn as required. On the dock was located the main powder magazine, a small concrete structure. Considerable use was also made of neighboring piers for unloading electric conduits, lumber, steel, etc.

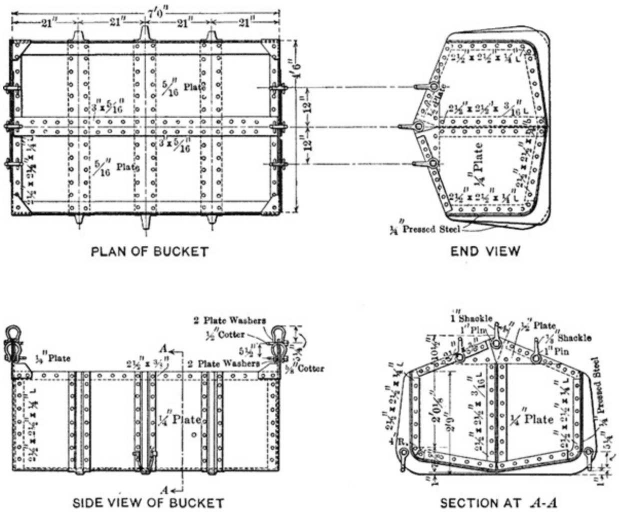

Fig. 1. SPECIAL STEEL BUCKET

Tunnel Plant.—The spoil buckets, designed by D. L. Hough and George Perrine, Members, Am. Soc. C. E., were a novel feature of the work. These buckets are shown in detail in Fig. 1 and various photographs. They were of 3 cu. yd. capacity and were split longitudinally, the two halves being pinned at the apices of the ends. For lifting, they were suspended from eyes at that point, and, when dumping, trip ropes were hooked into eyes at the bottom of each side; lifting the trip ropes or lowering the hoisting rope split the bucket, as shown in Fig. 4, Plate LVIII, and dumped the contents. They were transported in the tunnel on flat cars, and in the street on wagons, both cars and wagons being provided with cradles shaped [Page 398] to receive the bottom of the bucket.

In the tunnels the loading was done with air-operated steam shovels, four (Model 20) Marion shovels being used at various points of the work. In Fig. 1, Plate LIX, one of these is shown loading the bucket. The cars were hauled by General Electric, standard, 10-ton, mine locomotives, the current for which was taken at 220 volts from a pair of No. 00 copper trolley wires suspended from the roof of the tunnel. The collector was a small four-wheeled buggy riding on the wires and connected to the locomotive by several hundred feet of cable wound on a reel for use beyond the end of the trolley wire. Two 8-1/2-ton, Davenport, steam locomotives were also used in 32d Street, toward the end of the work, after the headings had been holed through and the tunnels would quickly clear themselves of gas and smoke. The steam shovels were supplemented by two Browning, 15-ton, locomotive cranes, which handled the spoil in places where timbering interfered with the operation of the shovels. All tracks were of 3-ft. gauge throughout and laid with 40-lb. rails.

Practically all the heavy drilling was done with Ingersoll drills (Model E 52), the trimming being largely done with jap and baby drills. A large number of pumps were used at various points on the work, and practically all were of Cameron make, the largest ones at the shaft being 10 by 5 by 13-in. The grout machines were of the vertical-cylinder, air-stirring type.

Shaft Sinking.

The sinking of the Intermediate Shafts was the first work undertaken by the contractor.

The 33d Street Shaft was 34.5 ft. long, 21 ft. wide, and 83 ft. deep. The rock surface averaged 5 ft. below the ground surface. Sinking was started on July 10th, 1905, and was completed on October 3d, 1905, the rock being hard and dry. The average daily rate was 0.73 ft. and an average of 17.1 cu. yd. were excavated per day, with two shifts of 8 hr. each. The first shift started at 6 A. M. and the second at 2.30 P. M., ending at 11 P. M. These hours were adopted in order to avoid undue disturbance during the night.

Plate LIX, Fig. 1.—Air-Operated Steam Shovel Used in Tunnel.

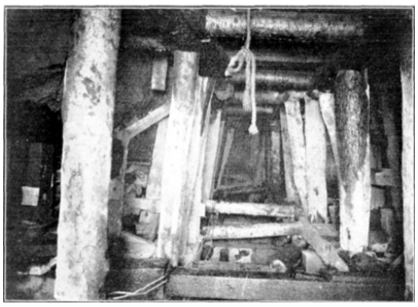

Plate LIX, Fig. 2.—Timbering in Top Headings Above I-Beams.

Plate LIX, Fig. 3.—First Section of Concrete Lining at Fifth Avenue.

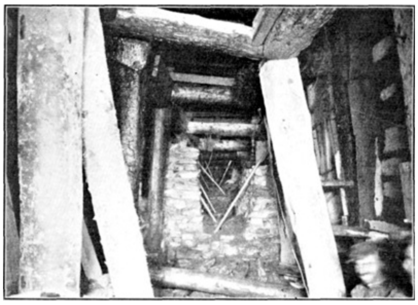

Plate LIX, Fig. 4.—Timbering and Rubble Masonry Over I-Beams.

Before blasting the first lift of rock, channel cuts 5 or 6 ft. deep were made along the sides of the shaft, in order to avoid damage to the walls of neighboring buildings. Timbering was required for a depth of only 10 ft. below the surface of the ground. [Page 399]

A drift, 30.6 ft. long, 17 ft. wide, and 27 ft. high, connected the south end of the shaft with the tunnels. The drift was excavated in three stages, a top heading and a bench in two lifts. While blasting the cut in the top heading, there was enough concussion to break glass in the neighboring buildings. The use of a radialax machine reduced the concussion somewhat, but it was very quickly abandoned on account of the length of time required for the drilling.

The construction of the 32d Street Shaft was quite similar to the one on 33d Street. It was 31.5 ft. long, 20.5 ft. wide, and 71 ft. deep. The depth of earth excavation averaged 19.5 ft. The rock in this shaft was seamy and not quite as hard or dry as that in 33d Street, and timbering was required for practically the full depth to the crown of the drift. Sinking was started on May 15th, 1905, and was completed on October 26th, 1905. The daily average rate was 0.30 ft. in earth and 0.52 ft. in rock. The drift was excavated in much the same manner as the one in 33d Street, but the rock being softer the radialax machine was not used.

Tunnel Excavation.

During the early part of the work, the contractor devoted his entire attention to the work of excavation. Nearly all the excavation east of Fifth Avenue was done before any of the lining was placed. At a number of points west of Fifth Avenue and at a few points to the east the nature of the rock was such that the two operations had to be done simultaneously.

Single-Tunnel Method.—For an average distance of 350 ft. west from the First Avenue Shafts there were four single tunnels. The rock was sound and comparatively dry. A top heading of the full size of the tunnel and about 8 ft. high was first driven. It was drilled by four drills mounted on two columns, and was blasted in the ordinary way. The bench was about 13 ft. high. Tripod drills, standing on the bench, drilled the usual holes, but, owing to the lack of head-room, steels long enough to reach the bottom of the bench could not be used. Tripod drills were set as low as possible at the foot of the bench and drilled lifting holes. These holes were inclined downward from 10° to 15° to the horizontal, and were spaced to converge at the location of the drainage ditches. The heading was usually driven from 10 to 20 ft. in advance of the bench. At this distance a large part of [Page 400]
the muck from the heading was shot backward over the bench. In the single tunnels the muck was loaded by hand.

Twin-Tunnel Methods.—From the end of the single-track tunnel westward to Fifth Avenue on 33d Street, and to Madison Avenue on 32d Street, with some exceptions, each pair of tunnels was excavated for the entire width at one operation. Three different methods of work were extensively used. They were the double-heading method, the center-heading method, and the full-sized-heading method, and these differed only in the manner of drilling and blasting. The bench was usually within 10 or 15 ft. of the face of the heading, and was drilled and fired in the same way as in the single tunnels. After the installation of the permanent plant, most of the muck was handled by steam shovels.

In the double-heading method, shown on Plate LVII, the top headings for each tunnel of the pair were driven separately, leaving a short rock core-wall between them. The headings were drilled from columns in the manner described for the single tunnels. The temporary rock dividing wall between the headings was drilled by a tripod drill on the bench of one of the headings, and was fired with the bench.

In the center-heading method, also shown on Plate LVII, only one heading was driven. It was rectangular in shape, about 8 ft. high and 14 ft. wide. It was located on the center line between the tunnels. In general, the face was from 6 to 12 ft., or the length of one or two rounds, in advance of the remainder of the face at the top. The center heading was drilled by four drills mounted on two columns. By turning these drills to the side, they were used for holes at right angles to the line of the tunnels, by which the remainder of the face of the heading was blasted. By turning the drills downward, the bench holes under the center heading were also drilled. The center heading explored the rock in advance of the full-width heading, and gave a good idea as to the care needed in firing.

For the full-width-heading method, Fig. 2, ten drills were mounted on five columns set abreast across the face. Holes were drilled to form a cut near the center line between the tunnels. The remainder of the holes were located so that they would draw into the cut. The bench was frequently drilled from the same set-up of columns by turning the drills downward. In sound rock this method proved to be the most rapid of any. [Page 401]

Practically all trimming was left until immediately before the concreting. It was then taken up as a separate operation, but proved to be costly and tedious, and a hindrance to the placing of the lining.

Materials Encountered.—All the rock encountered was the familiar Hudson schist, but it varied widely in its mineral constituents and in its physical characteristics. In many places where the rock surface was penetrated, a fine sand was found that was probably quicksand. The material above the rock in the open-cut sections was mostly sand.

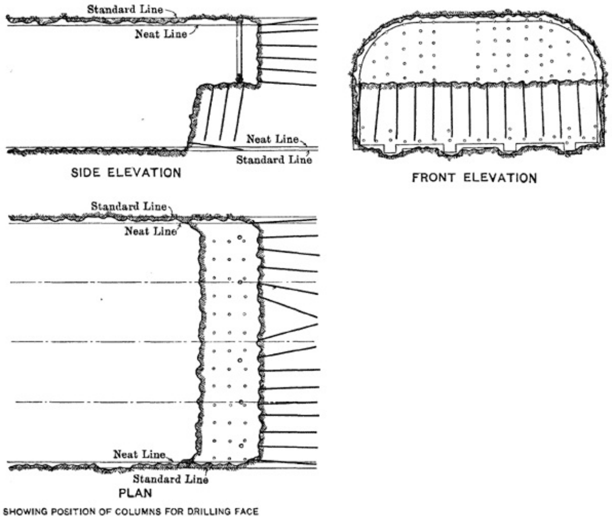

Fig. 2.—Method of Excavating with Full-Width Heading Cross-Town Tunnels, Manhattan.

The concurrence of the watercourse, shown on General Viele's map of Manhattan Island (Plate IX[D]), with the points where difficulties in the construction of the tunnels were encountered has been noted in a previous paper.

In all cases where the course of this ancient stream was crossed (except at its final intersection of 33d Street), the rock was found to be very soft and disintegrated, a large quantity of water was encountered, and heavy timbering was required. The construction at these localities will be taken up later. In addition, disintegrated rock, but of a less troublesome character, was invariably met under the depressions in the rock surface developed by the borings from the streets and test holes from the tunnels. Many of these places required timbering, and no timbering was elsewhere necessary except at the portals. These coincident conditions were especially marked in 32d Street, which for a long distance closely adjoins the course of the former creek. [Page 402]

Disposal of Spoil.—The materials excavated from the tunnels were dumped at the 35th Street pier on barges furnished by the Railroad Company under another contract, and were towed to points near the Bayonne peninsula where the spoil was used principally in the construction of the Greenville Freight Yards and the line across the Hackensack Meadows to the tunnels. Details of this work will be given in a subsequent paper. After December, 1907, when the excavation was about 85% completed, the contractor furnished the barges and effected the complete disposal of the spoil.

Difficulties of Excavation.—As stated in a previous paper, the excavation of the Twin Tunnel in 33d Street was continued westward to the west line of Fifth Avenue on the original grade. At that point the contractor started three drifts in the three-track section. The relation of the drifts to each other and to the cross-section are shown by Fig. 3. The center heading was driven a little in advance of those on the sides. At a distance of 65 ft. west of Fifth Avenue the rock surface was broken through in the top of the heading, and a very fine sand was encountered. For some distance east of this point the rock was badly disintegrated, and the heading required timbering. Through the soft material, tight lagging was placed on the sides and roof of the heading, and the face was protected by breast boards. There was a moderate flow of water through the cracks, and, in spite of every effort, some of the fine sand was constantly carried into the heading.

In one or two instances considerable ground was lost at the face. On the evening of December 14th, 1906, as a heavy coal wagon was passing along 33d Street above the heading, the rear wheels dropped through the asphalt pavement. An examination disclosed a cavity under the pavement about 14 ft. long, 12 ft. wide and 14 ft. deep. Evidently, the fine sand had gradually settled into the voids caused by the loss of material at the face, and the settlement broke the brick sewer over the heading. The sewer was temporarily repaired, and the hole in the street was filled before morning. A tight bulkhead was built across the heading, and work was abandoned at that point. The north drift was advanced to a point 108 ft. west of Fifth Avenue where sand was also encountered and a considerable run occurred. After that time all work on the three-track section was discontinued. [Page 403]

The Company then took up the consideration of changes in plan. To determine the difficulties of driving a Twin Tunnel at a lower elevation, an exploration drift, 8 ft. high and 12 ft. wide, was driven on the center line of the street as a top heading on the proposed new grade. Test holes were drilled above this heading and to the sides. The results indicated that there was sufficient rock cover of fair quality to enable the Twin Tunnel to be driven without great risk. The new plan (continuing the Twin Tunnel westward at a lower grade) was adopted in March, 1907, and work was immediately resumed at Fifth Avenue.

The relation between the cross-sections under the old and new plans at that point is shown by Fig. 3. Before the new section was excavated it was necessary to support the timber work in the old headings. The plan adopted is also shown by Fig. 3. The rock was excavated under the center heading, as shown in cross-section, for a length of about 3 ft. A girder composed of two 18-in. I-beams was then put in position over each line and supported on the sides by posts. The ends at the center lines between the tunnels were supported on short posts bearing on the rock bench. The support of the timbering in the headings was then transferred to the girders by additional posts. Blocking was also inserted between the tops of the beams and the rock walls between the headings. Fig. 2, Plate LIX, gives a good idea of the timber work in the top headings above the I-beams. When the roof had been made secure, the removal of the bench was begun. As the work advanced it was necessary to replace the short posts at the center of the tunnel by others of full height, and there was considerable settlement in the I-beams during this operation. When the bench had been removed to a point 61 ft. west of Fifth Avenue, settlement was detected in the street surface above. Bench excavation was suspended and a section of the permanent lining, 35 ft. long, was placed. The space between the lining and the beams and between the beams and the roof was filled with rubble masonry. Grout pipes were built into the masonry and later all voids were filled with grout. Fig. 3, Plate LIX, shows the first section of the concrete lining completed and part of the rubble in place; and Fig. 4, Plate LIX, shows details of the work above the tunnels. A second section of bench was next removed and more lining was placed. Work was continued in this way until all the roof at the old three-track headings had been secured. In this portion of the work the posts were embedded in the concrete. [Page 404]

Between Fifth and Sixth Avenues there were two more sections of bad rock where it was necessary to support the roof with steel beams. At these latter points there were no complications with the excavation for the Three-Track Tunnel, and the work was much simpler. To avoid leaving the center posts in the permanent work, two rows of temporary posts were placed, as shown by Fig. 1, Plate LX, the center wall and skewback were built, and the posts were removed, as shown by Fig. 2, Plate LX, before placing the remainder of the lining.

In 32d Street the normal progress of the excavation was frequently interrupted by encountering soft and unsound rock. In the excavation between the East River and the Intermediate Shafts it was possible to overcome these conditions by temporarily narrowing the excavation on one side and supporting the roof on 16 by 16-in. transverse timbers caught in niches in the rock at the sides, leaving sufficient room for the steam shovel to work through. In order to save time, the height of the excavation was not increased before placing these timbers, so that, previous to the concreting, they all required to be raised to clear the masonry lining and were then supported on posts on the center line between the tunnels. This permitted the remainder of the excavation to be made, and such additional timbering as was required was placed. At most of these sections a brick arch and water-proofing were used, on account of the presence of water. In certain places the center line posts were buried in the core-wall, and, in order to permit the placing of the water-proofing, were then cut off one by one flush with its top as the load was transferred to the completed masonry. In other cases the load was transferred to posts clear of the masonry and the center line posts were entirely removed. Under such conditions the normal concrete methods, to be described later, could not be used, and special forms were substituted. [Page 405]

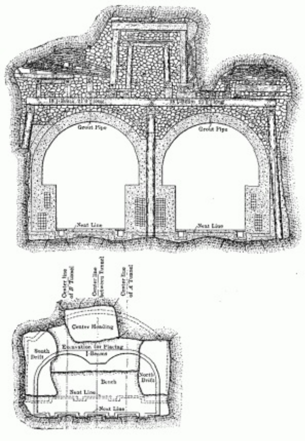

Fig. 3.—CONSTRUCTION OF TWIN TUNNELS, THROUGH EXCAVATION STARTED FOR THREE-TRACK TUNNEL IN 33D STREET NEAR 5TH AVENUE

In this section of the work the most serious difficulties were encountered near Fourth Avenue a short distance east of the Intermediate Shaft, and beneath the site of the old pond shown on General Viele's map. The rock cover was known from the boring to be very thin, and the presence of the subway overhead caused some anxiety. The excavation was at first taken out to practically full width and timbered, but the rock became so treacherous that the heading was narrowed to a width sufficient for one tunnel only. With this span the rock in the roof held without timbering. As the masonry lining approached, sufficient trimming was done to permit the placing of the core-wall and one arch. Above the completed core-wall and brick arch the voids were filled solid with rubble masonry to give an unyielding support to the roof. The excavation of the remaining width of tunnel was then undertaken. Near the west side of Fourth Avenue, the excavation broke out of rock at the top, and fine sand and gravel with a large quantity of water were encountered. The work of excavation was arduous, and proceeded very slowly, on account of the care with which it was executed. Only a small amount of sand entered the tunnel, but the lining was placed as soon as the excavation was completed. Rubble masonry packing and grout ejected through pipes built into the arch were used to fill the voids above the roof. As a further precaution against the settlement of the subway, 2-in. pipes were washed down from the street above the point where soft ground was exposed in the roof of the tunnel, and through them grout was forced into the ground at various depths. Careful levels show that no settlement of the subway has taken place. [Page 406]

West of the Intermediate Shaft the tunnel was excavated for full width until bad rock was encountered about 60 ft. west of Madison Avenue. (See General Viele's map, Plate IX.) Timbering was used for a short distance, and then the heading and bench were narrowed to 18 ft., and steam-shovel excavation was abandoned. As the heading advanced the rock grew steadily softer, the difficult conditions in this locality culminating when a slushy disintegrated feldspar was met, requiring poling and breasting. Thereafter the rock improved markedly, but near the east side of Fifth Avenue its thickness above the roof was found to be only 1-1/2 ft., and the advance was stopped, pending a decision as to a change of plan. [Page 407]

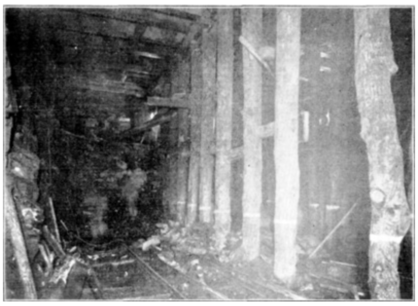

Plate LX, Fig. 1.—Double Row of Posts Under I-Beams, Supporting Roof in Bad Rock Section.

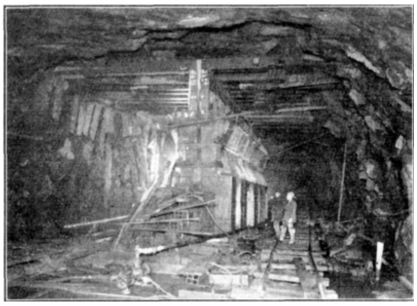

Plate LX, Fig. 2.—Center Wall and Skewback Under I-Beams, After Removal of Double Row of Posts.

Plate LX, Fig. 3.—Timbering in Full-Width Heading of Three-Track Tunnel.

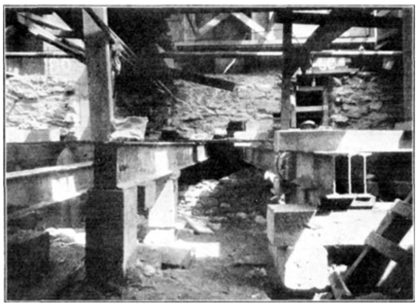

Plate LX, Fig. 4.—Underpinning Walls in Open-Cut Section.

After some delay, an exploration drift, similar to the one already described, was driven through to Sixth Avenue, and a change in plan was made, substantially the same as for the 33d Street tunnels. Enlargement to full size was at once started, but, for 400 ft. the rock was very soft and poor, and required extremely careful handling. The exploration drift was widened out to the full Twin-Tunnel width, and I-beams were placed and supported, in much the same manner as in 33d Street. The rock was so soft that it was frequently necessary to drive poling boards ahead as the face was mined out with picks and shovels. The load was very heavy, and the work the most difficult encountered in the tunnels.

After this stage of the enlargement was reached, the excavation of the bench and the placing of the lining proceeded alternately, with the I-beams temporarily supported on long posts while the concrete core-wall was being built. Considerable settlement took place while shifting the posts, and eventually showed on the street surface and in the adjacent sidewalk vaults, but no damage was done to the structural portions of the buildings.

While the above work had been going on westward from Fifth Avenue, the excavation of the Twin Tunnel eastward from the end of the open-cut section at Sixth Avenue had been proceeding rapidly, and, toward the end of the difficult Fifth Avenue work, it was being attacked from both directions.

Progress of Excavation.

Owing to the numerous sections of poor rock, interspersed throughout the work with stretches of sound rock, the progress of the excavation was very irregular, especially in 32d Street. The rate of excavation in good ground is shown in Table 1. In the sections of bad ground, the operations of excavation, timbering, and lining were often carried on alternately, and it is impracticable to include them in the table.

TABLE 1.—Progress and Methods of Excavation in Good Ground.

Thirty-Third Street.

Type of excavation.	Tunnels.	Worked from:	Dates.		Time elapsed, in days.	Length of tunnel excavated, in linear feet.	Average advance per day, in linear feet.	Methods and conditions.
			From	To				
Full-sized single tunnel	B	1st Ave. shaft.	Feb. 28, 1906.	May 12, 1906.	74	346	4.7	Top heading and bench. Muck loaded by hand.
Full-sized single tunnel	A	1st Ave. shaft.	Feb. 28, 1906.	Apr. 30, 1906.	62	255	4.1	" " " " " " " "
Full-sized twin tunnel	A and B	1st Ave. shaft.	Aug. 23, 1906.	Jan. 5, 1907.	136	789	5.8	Top full-width heading and bench. Muck loaded by steam shovel. Working exclusively on this heading.
Full-sized twin tunnel	A and B	Intermediate shaft. (West of shaft.)	Apr. 4, 1906.	Oct. 31, 1906.	210	730	3.5	Top center heading and bench. Muck loaded by steam shovel. Working alternately in headings east and west of the shaft.
Full-sized twin tunnel	A and B	Intermediate shaft. (East of shaft.)	Apr. 4, 1906.	Oct. 31, 1906.	210	783	3.7	Top center heading and bench. Muck loaded by steam shovel. Working alternately in headings east and west of the shaft.
Full-sized twin tunnel	A and B	Intermediate shaft. (East of shaft.)	Nov. 1, 1906.	Dec. 26, 1906.	56	311	5.5	Top full-width heading and bench. Muck loaded by steam shovel working exclusively on this heading.
Exploration drift	A and B	Intermediate shaft. (West of shaft.)	Mar. 1, 1907.	July 23, 1907.	145	947	6.5	Exploration drift about 9 ft. by 12 ft. Mucking by hand. Fourteen timber bents were placed in March, and seven in April, 1907.
Twin tunnel. Enlargement of exploration drift	A and B	West shaft. (East of shaft.)	Sept. 6, 1907.	Dec. 4, 1907.	89	603	6.8	Drift excavated to full width and bench. Muck loaded by steam shovel.

Thirty-Second Street.

Type of excavation.	Tunnels.	Worked from:	Dates.		Time elapsed, in days.	Length of tunnel excavated, in linear feet.	Average advance per day, in linear feet.	Methods and conditions.
			From	To				
Full-sized single tunnel	C	1st Ave. shaft.	Jan. 25, 1906.	Apr. 30, 1906.	95	367	3.9	Top heading and bench. Muck loaded by hand.
Full-sized single tunnel	D	1st Ave. shaft.	Jan. 27, 1906.	Apr. 30, 1906.	93	354	3.8	" " " " " " " "
Full-sized twin tunnel	C and D	1st Ave. shaft.	May 22, 1906. Aug. 11, 1906.	July 24, 1906.[E] Nov. 29, 1906.	173	810	4.7	Double heading and bench. Muck loaded by ste shovel. Stretches aggregating 200 ft. narrowed to about 25 ft. and later enlarged are included.
Narrowed twin tunnel	C	Intermediate shaft.	Mar. 19, 1906.	May 28, 1906.	70	58	0.8	Excavation about 30 ft. wide. Top full-width hea and bench. Muck loaded by hand. Steam shovel not installed.
Full-sized twin tunnel	C	Intermediate shaft. (East of shaft.)	May 29, 1906. July 18, 1906. Aug. 12, 1906. Jan. 15, 1907. Feb. 17, 1907.	July 3, 1906[E] July 31, 1906. Nov. 23, 1906. Feb. 5, 1907. Mar. 21, 1907.	208	1,206	5.8	Excavation about 30 to 35 ft. wide. Top full-wid heading and bench. Muck loaded by steam shov
Full-sized twin tunnel	C and D	Intermediate shaft. (West of shaft.)	Dec. 1, 1905.	May 10, 1906.	161	225	1.4	Double heading and bench. Part of the muck ha by hand and part by steam shovel.
Exploration drift	C and D	Intermediate shaft. (West of shaft.)	Feb. 1, 1907.	Sept. 13, 1907.	225	1,033	4.6	Exploration drift about 10 ft. by 13 in. Muck loa by hand. 14 ft. timbered.
Twin tunnel. Enlargement of exploration drift	C and D	Eastward from open cut.	Feb. 1, 1908.	Feb. 14, 1908.	14	65	4.6	At portal of twin tunnels. Drift excavated to full width and bench. Muck loaded by hand. 12 ft. timbered.
Twin tunnel. Enlargement of exploration drift	C and D	Eastward from open cut.	Feb. 15, 1908.	Apr. 14, 1908.	59	524	8.9	Drift excavated to full width and bench. Muck l by steam shovel. Full-width tunnel timbered for ft. independently of the main excavation.

[E] Time and distance omitted while working through timbered stretches.

Three-Track Tunnel Excavation.

When it became evident that the work through the Fifth Avenue section would be extremely slow, shafts were sunk in each street between Sixth and Seventh Avenues. The shafts, as shown on Plate XIV, were located in the streets, but in such a way as to block only half of the roadway. At the same time it was decided to construct in open cut about 200 ft. of the Three-Track Tunnel at the west end of the contract in 32d Street, where the rock surface was below the top of the tunnel. It was hoped that the remainder of the work could be built without opening the street, but further investigation showed that this was impracticable, and eventually all the Three-Track Tunnel in 32d Street, except 120 ft. east of the shaft, was built in open cut.

Thirty-second Street Work in Tunnel.—Following the sinking of the shaft, a drift was driven across the street at the crown of the tunnel, and a top heading on the south side was excavated in both directions. Frequent cross-drifts to the north side showed that the rock was nowhere very sound and that, except for a short distance east of the shaft, it was distinctly unfavorable for the wide Three-Track excavation. In this stretch the north ends of these cross-cuts were connected by a second heading, and wall-plates and sets of three-segment arch timbering were set up to support the roof of the drifts. The cross-cuttings were gradually widened and timbered until the entire excavation had been made down to the level of the wall-plates, as shown in Fig. 3, Plate LX. The bench was then excavated in two lifts, leaving the wall-plates supported on narrow longitudinal berms, which were removed in short sections to permit the placing of posts under the wall-plates.

Thirty-second Street Open-Cut Work.—Before actual open-cut excavation was started, all buildings facing it were underpinned to rock. For this purpose, a trench was dug along the face of the buildings and of the same depth as their cellars. Holes were cut in the front foundation walls through which long needle-beams (Fig. 4, Plate LX) were inserted and jacked up on blocking placed on the cellar floor and in the trench, until the weight of the building had been taken off its foundations. A close-sheeted trench was then sunk to rock under the front building walls, and a light rubble masonry retaining wall was built in it to support the building permanently. Frequently, the excavation for the underpinning wall, which was taken out in sections from 30 to 40 ft. long, and in places was carried to a depth of 40 ft., was very troublesome on account of the large quantity of water encountered and the fineness of the sand, which exhibited a tendency to flow when saturated.

The Elevated Railroad columns in Sixth Avenue, near the north and south lines of 32d Street, were underpinned in a manner similar to the [Page 411] building foundations, while those on the center line of the street were supported by girders riveted to them close under the track level. The girders in turn were supported on posts footed on the new underpinning of the adjacent columns. On the completion of the tunnels, concrete piers were built up from the roof of the tunnel to form a permanent foundation for the center-line columns. The area to be excavated under Sixth Avenue was enclosed by a rubble masonry retaining wall constructed in a trench.

Open-cut excavation was started by planking over the street on stringers resting on transverse 12 by 12-in. caps. The caps were gradually undermined and supported on temporary posts which were then replaced by short posts resting on 12 by 12-in. sills about 7 ft. below the cap. The operation was then repeated and the sill was supported on another set of short posts resting on a second sill. When the excavation had been carried down in this manner to the level of the top of the tunnel, diagonal 3 by 10-in. timbers were cut in between the posts and sills to form a species of double A-frame, the legs of which rested in niches cut in the rock and on posts carried up the face of the underpinning wall, and the whole was stiffened with vertical tie-rods. This construction is shown by Fig. 3, Plate LXII. The brick sewer was replaced temporarily by one of riveted steel pipe. This pipe and the water and gas pipes and electric conduits were suspended from the timbers as the pipes were uncovered.

Excavation in rock was made by sinking a pit to sub-grade for the full width of the tunnel and advancing the face of the pit in several lifts, the muck being blown over the slope and loaded into buckets at its foot.

The work was attacked at several places simultaneously, and the spoil was hoisted by derricks located at convenient points along the side of the cut.

Thirty-third Street Work in Tunnel and Open Cut.—The West 33d Street Shaft was similar to the one in 32d Street, and was sunk during February, March, and April, 1907, through 10 ft. of earth, 21 ft. of soft rock, and 29 ft. of fairly hard rock. It was necessary to timber heavily the upper 30 ft. of the shaft. The timber later showed evidences of severe strain, and had to be reinforced.

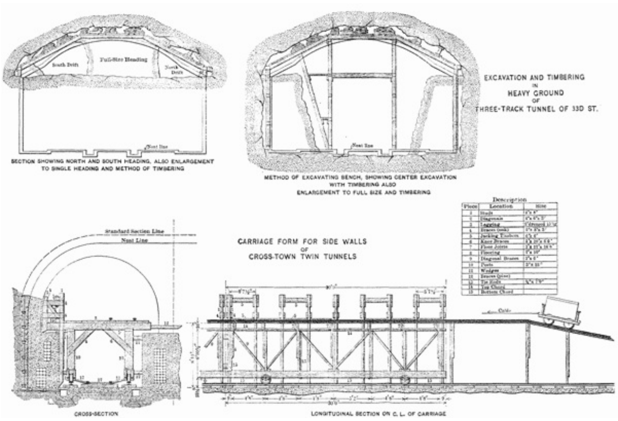

Plate LXI.—EXCAVATION AND TIMBERING IN HEAVY GROUND OF THREE-TRACK TUNNEL OF 33D ST.

As soon as the shaft excavation was deep enough, a drift was driven part way across the tunnels, and top headings were started both east and [Page 412] west to explore the rock. The heading to the west was divided into two drifts, as shown on Plate LXI. These two drifts were continued to the west end of the contract, and were then enlarged to a full-sized heading and timbered, as shown on Plate LXI and Fig. 3, Plate LX. The rock near the shaft contained many wet rusty seams, and settlement was detected in the segmental tunnel timbering soon after the widening of the heading was completed. Short props were placed under the timbers, and the street surface was opened with a view of stripping the earth down to the rock and thus lightening the load on the timbering. Street traffic was maintained on a timber structure with posts eventually carried down to the rock surface, and the walls of the buildings on the north side of the street were underpinned to rock. The settlement of the tunnel timbering was checked for a time, and the bench was excavated as shown on Plate LXI. In this work the cut in the center was first made, and the short props were replaced by struts, as shown; after this the berms were removed and the side posts were placed. While building the brick arches, holes were left in the masonry around the struts. After the masonry had hardened, piers were built on the arches to support the segmental timbers. The struts were then removed and the openings filled with masonry. The voids above the arch were packed with rock and afterward thoroughly grouted.

The timbers near the shaft continued to settle, and, although they had been placed from 9 to 12 in. above the level of the top of the masonry, by October 1st, they encroached 9 in. within the line of masonry. It was then decided to remove the rock for a distance of 48 ft. west of the shaft, and build this portion of the tunnel in open cut. The posts supporting the deck forming the street surface were replaced by an A-frame structure similar to that developed for the 32d Street open cut, without interruption of the street traffic.

After making the open cut to the westward of the shaft, there was a slip in the rock north of and adjoining the shaft. Fortunately, the timbers did not give way entirely, and no damage was done. The open cut was extended eastward for a distance of 46 ft., making the total length of tunnel built in open cut on this street 94 ft.

East of the shaft, for a distance of about 125 ft., the rock was broken and could not be excavated to full size without timbering the roof, but between this section of poor rock and those already mentioned in connection with the work at Fifth Avenue, there was a stretch of 600 ft. of good [Page 413] rock where all the spoil was handled with a steam shovel.

Twin-Tunnel Lining.

The masonry lining for the tunnels was not started until the late fall of 1906, after excavation had been in progress for a year and a half. At that time concreting was started in the single tunnels westward from the First Avenue Shafts, and by spring was in full swing in the Twin Tunnels.

The plans contemplated the use of a complete concrete lining except where large quantities of water were encountered; in which case the arches, beginning at a point 15° above the springing line, were to be built of vitrified paving brick. By reference to Plate XII it will be seen that the water-proofing, which in the concrete-roof tunnels extended the full height of the sides to the 15° line, was carried in the brick-roof tunnels completely around the extrados of the arch. The cross-sections also show the location of the electric conduits which were buried in the mass of the side and core-walls and which limited the height to which the concrete could be carried in one operation.

The same general scheme of operations was used wherever possible throughout the Twin-Tunnel work, but was subject to minor modifications as circumstances dictated. Concrete was first deposited in the bottom, to the grade of the flow line of the drains; after it had set, collapsible box forms, of 2-in. plank with 3-in. plank tops, were laid on it to form the ditch and the shoulders for the flagstone covers. The track, which had previously been blocked up on the rock between the ditches, was raised and supported on the ditch boxes above the finished floor level. At the same time, light forms were braced from the ditch boxes to the grade of the base of the low-tension and telephone-duct bank. After depositing the concrete to this level, the telephone ducts were laid.

The forms for the water-proofing or sand-wall up to the 15° line and for the main side-walls and core-walls were built in 30-ft. panels and were supported on carriages, which, traveling on a broad-gauge track above the ditches, moved along the tunnel, section by section, as the work advanced. The panels were hung loosely from joists carrying a platform on the top chord of the carriage trusses, and were adjusted transversely [Page 414] by bracing and wedging them out from the carriage. The small forms for the refuge niches, ladders, etc., were collapsible, and were spiked to the main panel forms just previous to the deposition of the concrete. The concrete was deposited from the platform on top of the carriage, to which the cars were elevated in various ways. Plate LXI shows the details of the carriages, and is self-explanatory.

The concrete for the sand-walls and the core-wall, to the level of the sidewalk, was deposited at the same time; two carriages in each tunnel, placed opposite each other, forming a 60-ft. length, were used at each setting. The floor section of the 4-in. tile drains had been laid with the floor concrete, and, as the sand-wall concrete was deposited, the drains were brought up simultaneously, broken stone being deposited between the tile and the rock to form a blind drain and afford access to the open joints of the tile for the water entering the tunnel through seams in the rock.

The drains were spaced at intervals not exceeding 25 ft., depending on the wetness of the rock, and were placed at similar intervals in the core-wall under the lowest projecting points of the rock on the center line between the tunnels. A small ditch lined with loose 6-in. vitrified half pipe was provided in the top of the sand-wall to collect the water from the extrados of the arch and lead it to the top of the drains. Great difficulty was experienced in maintaining these drains clear, and, on completion of the work, a large amount of labor was expended in removing obstructions from the floor sections, the only portion then accessible.

After water-proofing the sand-walls and laying the low-tension ducts, a second pair of carriages, with panels on one side only, for 60 ft. of side-wall and skewback to the 15° line, were set and braced against the core-wall. These forms are shown in connection with the carriage on Plate LXI. They were concreted to the base of the high-tension duct bank, and, after the concrete had hardened and the bank of ducts had been laid, the concreting was completed in a second operation.

In places where the roof was supported temporarily by posts and heavy timbering, such as at Fifth Avenue, the form carriages could not be used, and special methods were devised to suit the local conditions. Usually, the panels were stripped from the carriages and moved from section to section by hand, and, when in position, were braced to the timbering.

The arch centers were built up of two 5 by 3 by 3/8-in. steel angles, and, when set, were blocked up on the sidewalks opposite each other in the [Page 415] two tunnels. A temporary platform was laid on the bottom chord angles of the ribs, on which the concrete was dumped, the same as on the form carriages. The lagging used was 3 by 3-in. dressed pine or spruce 16 ft. long, and was placed as the concreting of the arch proceeded above the 15° line on the side-wall and above the sidewalk on the core-wall. After the arch had reached such a height that the concrete could not be passed over the lagging directly from the main platform, it was cast on a small platform on the upper horizontal bracing of the centers, shown in Fig. 3, Plate LIX, and was thence shoveled into the work. In the upper part of the arch the face of the concrete was kept on a radial plane, and, when only 3 ft. remained to be placed, it was keyed in from one end, the key lagging being set in about 5-ft. lengths. The arches were concreted usually in 60-ft. lengths.

Where brick arches were used, the core-wall skewback was concreted behind special forms set up on the sidewalks, or the arch ribs and lagging were used for forms, and the brick arch was not started until after the concrete had set. In laying the brick in the arch, the five courses of the ring were carried up as high as the void between the extrados and the rock would permit and still leave a working space in which to place the water-proofing. This was usually not more than 3 ft., except on the core-wall side. The felt and pitch water-proofing was then laid for that height, joined to the previous water-proofing on the side-walls, and was followed by the brick armor course over the water-proofing and by the rock packing, after which another lift of brick was laid and the operations were repeated. The large void (Fig. 1, Plate LXII) above the core-wall gave convenient access for working on top of the adjacent sides of the roof, and the keying of the arches and the water-proofing and rock packing above the core-wall were usually carried on from that point, the work progressing from one end.

The concrete for all work above the floor was dumped on the platform of the carriages, to which it was transported in the early part of the work in cars running on a high-level track laid on long ties, resting on the finished sidewalks. This arrangement, although requiring a large amount of timber for the track, permitted the muck to be carried out on the low-level track without interference. [Page 416] Later, when the advance of the heading had ceased and the heavy mucking was over, all concrete was transported on the floor level, and the cars were lifted to the carriage platforms by elevators and were hauled by hoisting engines up a movable incline. The latter method is shown by Fig. 3, Plate LIX.

Water-Proofing.—The water-proofing referred to above was in all cases felt and pitch laid with six thicknesses of felt and seven of pitch. The sub-contractor for the work was the Sicilian Asphalt Paving Company. All joints were lapped at least 1 ft., and, where work was suspended for a time and a bevel lap could not be made, the edges of the felt were left unpitched for 1 ft. and the newer work was interlaced with the old. This method was not always successful, however, on account of the softening of the unpitched felt on long-continued exposure to the water. The felt used was mainly "Tunaloid," together with some "Hydrex." It weighed about 12 lb. per 100 sq. ft. when saturated and coated on one side only, and contained about 25% of wool. The coal-tar pitch used had a melting point of 100° Fahr.

After the completion of the tunnel, the concrete arch showed some leakage and in places unsightly lime deposits. It was determined to attempt to stop these leaks by the application of a water-proof cement coating on the intrados of the arch. Extended experimental application of two varieties of materials used for this purpose—"Hydrolithic" cement and the U. S. Water-proofing Company's compound—have been made with apparent success up to the present time, and the results after the lapse of a considerable period are awaited with interest.

Duct Laying.—The position of the electric conduits, buried in the heart of the concrete walls, interfered greatly with the economical and speedy placing of the lining, and their laying proved to be one of the most troublesome features of the work. The power conduits were single-way, with the bank for high-tension cables separated in the side-walls from the low-tension bank, as shown on Plate XII. The conduits for telephone and telegraph service were four-way, and were located in the core-wall. All ducts had 3/4-in. walls and a minimum clear opening of 3-3/8 in. square, with corners rounded. They were laid with joints broken in all directions, and in about 1/4-in. beds of 1:2-1/2 mortar. Flat steel bond-irons, 2 by 1/8 in., with split and bent ends, were placed in the joints at intervals of 3 ft. and projected into the concrete 3 in. on each side, tying together the concrete on opposite sides of the ducts. The joints were wrapped with a 6-in. strip of 10-oz.duck saturated with neat-cement grout, and, in addition, the power conduits were completely covered with a 1/2-in. coat of mortar to prevent the intrusion of cement and sand from the fluid concrete. The four-way conduits were plastered only over the wraps. Splicing chambers were provided at intervals of 400 ft.

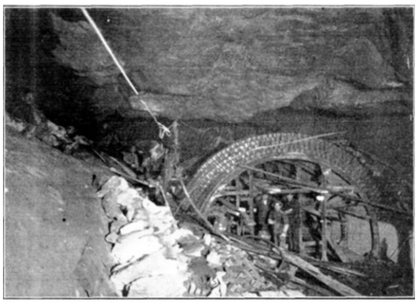

Plate LXII, Fig. 1.—Water-Proofing Over Brick Arches.

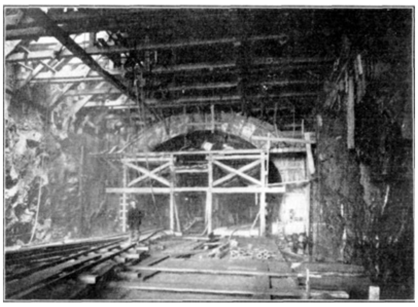

Plate LXII, Fig. 2.—Trestle Used in Concreting in Three-Track Tunnel.

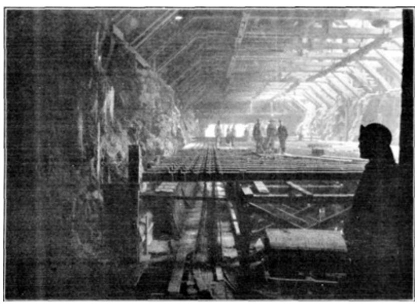

Plate LXII, Fig. 3.—Method of Street Support Over Open-Cut Excavation.

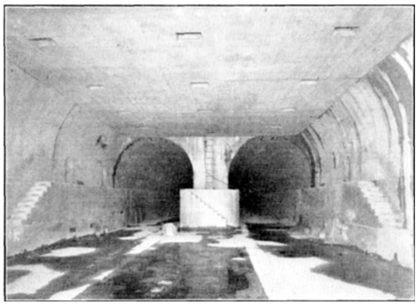

Plate LXII, Fig. 4.—Junction of Twin and Three-Track Tunnels.

Three-Track Tunnel Lining

In the Three-Track Tunnels, a heavy brick arch was used for those portions constructed in tunnel, while, in the open-cut sections, the roof was of concrete. Both were completely water-proofed on the roof and sides, and in the tunnel sections the space above the brick roof was filled with rock packing. On account of the unstable nature of the rock encountered throughout, the voids in the packing were afterward filled with grout.

By reference to the cross-sections, Plate XII, it will be seen that the haunches of the arch were tied together by steel I-beams anchored in the concrete, with the object of making the structure self-supporting in the event of the removal of the adjacent rock for deep cellar excavations. This construction materially influenced the contractor's method of placing the masonry lining.

After depositing the floor concrete, by the same method that was used in the Twin Tunnels, a timber trestle (Fig. 2, Plate LXII) was erected to the height of the underside of the I-beam ties, the posts being footed in holes, about 3 in. deep, left in the concrete floor to prevent slipping. In the open-cut sections the sand-wall forms were of undressed plank tacked to the studding and braced from the trestle; in the tunnel section they were spiked to the face of the posts supporting the timbering.

The side-wall forms were made up in panels about 3 by 10 ft., and were clamped to studs by U-shaped irons passing around the stud and bolted to the cleats on the back of the panels, the studs being braced from the trestle. The side-wall concrete was deposited in three sections. The first was brought up just above the sidewalk and formed the bench for the high-tension ducts; the second carried the wall up to the springing line. Before placing the third section the I-beam ties were set in position (Fig. 3, Plate LXII) on top of the trestle, and the reinforcing rods in the haunch of the arch were hung from them. The concrete was carried up to a skewback for the arch, as shown in the brick-roof cross-section (Plate XII) and embedded the ends of the ties.

The centers for the arches stood on the I-beam ties, and the tops of the hangers, for the permanent support of the ties near their center, were inserted through the lagging. The brick arch, water-proofing, and rock packing were laid up in lifts, in the same manner as in the Twin Tunnel, with grout pipes built in at intervals of about 8 ft. The concrete arch was placed in sections, from 25 to 50 ft. in length, with a rather wet mixture and a back form on the steep slope of the extrados.

The concrete for the sand-walls and lower part of side-walls was handled on tracks and platforms laid on cantilever beams at mid-height of the trestle, as shown by Fig. 3, Plate LXII. For the walls above the springing line, the tracks were laid on top of the I-beam ties, and some of the arch concrete, also, was delivered from the mixer at that level and hauled up an incline to the level of the top of the arch. By far the greater part, however, was turned out from mixers set on the completed arch, and was transported on tracks hung in part from the street timbering.

Completion.—Except in the heavily-timbered portions, such as at Fifth Avenue, where the load had to be transferred from posts to the completed masonry section by section, the lining of the tunnels presented no special difficulty. The large number of small forms to be set, and the mutual interference of the concreting and duct-laying operations proved to be the most troublesome features of the work.

The restoration of the streets, public utilities, etc., at the open-cut sections was a slow and tedious operation, but the tunnels themselves were completed in March, 1909, 3 years and 10 months after the inception of the work. The finished tunnels are shown by the photograph, Fig. 4, Plate LXII, taken at the junction of the twin and three-track types.

FOOTNOTES:

[A] Presented at the meeting of December 1st, 1909.

[B] Of the paper by Mr. Noble.

[C] Of the paper by Mr. Noble.

[D] Of the paper by Mr. Noble.