Parsons, W.B.

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PARSONS

ON THE

NEW YORK RAPID-TRANSIT SUBWAY.

THE NEW YORK RAPID-TRANSIT SUBWAY.

BY

WILLIAM BARCLAY PARSONS, M. Inst. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

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in the Chair.

(*Paper No. 3739.*)

"The New York Rapid-Transit Subway."

By William Barclay Parsons, M. Inst. C.E.

The recent report of the Royal Commission on London Traffic made certain recommendations in regard to underground railways close to the surface of the street, to which the general term of "Subway" has come to be applied, as distinguished from the familiar London "Tube."

In this connection it may be of interest to The Institution to have placed before it a description of the New York Subway, especially as that subway is distinguished by certain peculiar features, such as extreme shallowness of cover, radical variation in the type of structure according to local requirements, a double service of high and low speeds, very heavy traffic, and control by a public commission.

The City of New York is divided politically into five boroughs whose populations and areas are:—

Table I.

	Population.	Area.
Manhattan	2,174,335	21·93 square miles.
Bronx	290,097	40·65 " "
Brooklyn	1,404,569	77·62 " "
Queens	209,686	129·50 " "
Richmond	74,173	57·19 " "
Total	4,152,860	326·89 " "

Before the consolidation of New York, Brooklyn, and the outlying districts into one city, in 1897, New York consisted of what is now the first two boroughs named, of which Manhattan Island formed the major portion, so far as inhabitants were concerned. This borough (or island, for they are conterminous) is the most congested of all the divisions of the City, and is the great commercial territory. At the southern extremity is the financial district, and next come, proceeding northwards, the wholesale district, the retail shopping district, the theatres and amusement-resorts, the chief park, and the fashionable residential districts; while on the outer edges of the island, but back from the water-front, are the tenement-house districts; and along the river-fronts on both sides are the wharves and piers. Manhattan borough, therefore, includes what is found in London from Kensington and Mayfair to the City, with the congested East End and the great docks.

Manhattan Island has a length of about 14 miles and an average width of about $1\frac{1}{2}$ mile. Taking into account its population, its concentration of commercial districts and places of amusement, and its peculiar shape, it is but natural that there should result a large volume of street-traffic along certain fixed lines within a narrow belt. Such conditions are the most favourable for the development of urban railways.

The local tramway-system had its beginning as early as 1832, when the population of the island was but a small fraction of what it now is. At that time, and for many years afterwards, by far the larger part of the population of the City and its suburbs resided on Manhattan Island.

On the successful termination of the civil war in 1865, the City of New York grew rapidly, so that in 1870, in order to furnish a required means of travel faster and of greater capacity than horse-tramways or omnibuses, the first overhead or "elevated" railway was begun. The initial line was not located along a route of traffic-congestion, the authorities having refused the use of such a street for an experiment; but nevertheless it was sufficiently successful to warrant extension of the structure.

Accordingly, in 1875 the State Legislature created the Rapid Transit Commission to lay out routes for additional elevated railways and to organize a company or companies to construct them. This commission caused to be built the nucleus of the present elevated-railway system, the prototype of other similar railways both in America and in Europe.

The additional facilities thus afforded, though increased by extensions and additions of third tracks and reinforced by the conversion of the horse-tramways into lines operated mechanically, either by cable or by electricity, did not suffice for two decades of the city's growth, so that in 1894 the Legislature created another Rapid Transit Commission, to which the Author was made Chief Engineer.

As a somewhat similar body has been suggested for London, it will not be amiss to describe the functions of the New York Board. The Act as passed by the Legislature decreed a Board of Commissioners, eight in number, five of whom were named in the Act, the others being *ex-officio* the Mayor and the Comptroller (the chief financial officer of the city), and the President of the Chamber of Commerce. It was provided that vacancies in the five non-official positions were to be filled by the remaining members, so that, as the life of the Commission was not fixed, it was, unless altered by the Legislature, a permanent self-perpetuating body, an anomaly in American practice. This arrangement continued until 1906, when the Act was amended, empowering the Mayor to fill vacancies as they occur. In 1907 the powers of the Board were further extended by giving it jurisdiction over all railways, including tramways and lighting-companies, and the power of appointment was vested in the Governor of the State.

The law required the Commission to let a contract for the construction of a railway, the city to advance all the money required for its construction, except for equipment. The contractor was to take a contract not only for construction but also for operation, for a period of 50 years, with one renewal of 25 years: the lessee was to pay, as rental, the interest on the bonds issued for the work and a sinking-fund of 1 per cent.

Although routes were promptly laid out and plans were prepared, it was not until 1900 that a contract was let. The constitution of the State of New York forbids any municipality to incur debt in excess of 10 per cent. of the assessed value of the real estate within the corporate boundaries; and as the City of New York had already nearly reached the borrowing-limit, the authorities felt that certain other things were more pressing than the need of railways, and therefore postponed the letting of a contract until the year mentioned. The contract was confined to Manhattan Island and a portion of the city lying north of the Harlem River, and it is officially designated as Contract No. 1.

As soon as Contract No. 1 had been let, plans were begun for an extension under the East River to Brooklyn, and a contract was executed on the 11th September, 1902, with the same syndicate that had Contract No. 1.

As the two contracts were carried out as one and the operating-leases of both were assigned to the same company, there is really no practical difference between them, and in this Paper it will be convenient to treat them as one, together with additions and extensions made during their construction.

Topography and Geology.

The portions of the City of New York whose topography and geology have a direct bearing upon the construction of the subways described in this Paper are chiefly the central part of Manhattan Island, adhering closely to the divide of the watersheds of the Hudson and East Rivers; the Harlem River, at a point midway in its length, a distance of about 1 mile on the north bank; the bottom of the East River, opposite the southern part of Manhattan Island; and a line 1½ mile long traversing a part of the Borough of Brooklyn. The upper portion of New York is composed of gneiss rock which, during the glacial period, was greatly affected by ice erosion. This rock, found everywhere as a surface outcrop north of 14th Street, disappears entirely from view south of this point, the rock surface being inclined downward, and reaching a measured depth of 170 feet from the surface of the ground, or at least 140 feet below mean high-tide level, thus forming the low point of the geological valley just south of Canal Street. The rock surface then rises on the south side of this valley and approaches the surface at the lower end of Manhattan Island; then, with a gradually descending slope, it attains a depth under the East River, on the line of the subway, of 70 feet and upwards below tide-level, except for a sharply-defined ridge of rock in the middle of the river, whose top is only 32 feet below the water-surface at low tide.

Generally, the strike of the rock is substantially parallel with the streets running northward, which are usually spoken of as running north and south, although their true bearing is about N. 29° E. The dip of the rock from the east towards the west varies from perpendicular to a slope of about 30° from the horizontal. The quality of the rock not only varies greatly but is subject to frequent changes, as the mica, the biotite, and the felspars occur in greatly varying proportions. As regards hardness, about one-half of the rock was fit to be broken for concrete and was thus largely used on the work; the balance was so soft as to crumble into dust, on account of the presence of mica in small flakes.

Leading Principles of the Design.

In constructing the "Subway," as it is popularly called, there were two ends to be served. One was to add to New York's transportation-facilities and the other was to give a high-speed service. As such a service is not possible on a line with frequent stations, and as a line with stations far apart would not be profitable, it was decided to construct four tracks in the district of maximum traffic, on which there could be run simultaneously a high-speed service with long intervals between stopping-stations, and a local service with short intervals between stations, and with convenient means of transfer from train to train at each express stop. Beyond the four-track zone there are either two-track or three-track lines, the latter to carry an express service in the direction of traffic movement, that is, towards the business district in the morning and from it in the evening. The interval between "express" stations varies between 1 and $1\frac{3}{4}$ mile. There are three or four local stations to the mile.

The route, as adopted and built, is shown on the accompanying map and profile (Figs. 1 and 2, Plate 5). It commences in Brooklyn at Flatbush and Atlantic Avenues, a terminus of some of the suburban lines of the Long Island Railroad; runs thence to the East River and under it to Manhattan Island, where it proceeds under Broadway, Elm Street, and Fourth Avenue to the Grand Central Station, the terminus of the New York Central and New York, New Haven and Hartford systems; thence westward to Broadway, and again northward under that thoroughfare to 103rd Street, where the route divides, one branch continuing northward to and across the Harlem River at Kingsbridge, the other branch extending in a general north-easterly direction to the Zoological Gardens in Bronx Park. The total length of the route is 25·7 miles, and it is under or over streets, or under parks and rivers, except in six places, where private property had to be secured to ease curves or to pass from one street to another.

The express-service section is on Manhattan Island. Another four- and five-track section has been built in Brooklyn for a distance of 0·9 mile, to provide for the bringing in of other routes to be built hereafter, without interfering with the line in operation. There are, however, several variations from the normal two- and four-track arrangements. For example, a single track terminating the local tracks at the end of the four-track section, a third track for express service on two-track sections, and sidings for disabled trains on the four-track section; while under Broadway between 137th and 145th

Streets, where the street is 102 feet wide between curbs, eight tracks have been built to form a yard.

The route mileage of the various track-arrangements is shown in Table II.

TABLE II.

	Contract No. 1.	Contract No. 2.	Totals.
One-track	0·1	0·0	0·1
Two-track	7·6	2·6	10·2
Three-track	7·6	0·0	7·6
Four-track	6·0	0·4	6·4
Five-track	0·7	0·5	1·2
Eight-track	0·2	0·0	0·2
Total route	22·2	3·5	25·7

When the general type of railway to be constructed was under consideration, the Board was urged by many people to adopt a tube as the basic idea, the first example of that system having just been successfully completed in the City and South London Railway. After a tour of inspection of the underground railways in Europe, the Author decided that a railway built as close to the surface of the street as possible, avoiding the use of lifts, and giving staircases of such height as could be readily ascended by passengers, would be, for the large crowds that such a railway would carry in New York, of greater benefit than any tube type; that, although such construction necessarily involved a readjustment of all pipes, sewers, and other sub-surface structures encountered along the route, the total cost would be no greater than it would be in tube tunnelling; and that, although serious temporary inconvenience might be inflicted on street-traffic, the final result would be preferable. This view was approved by the Board, and the plans were consequently prepared.

The form and details of the structure were indissolubly connected with the number of tracks, all of which were to be, so far as local conditions allowed, on the same level. As it had been decided to bring the whole structure close to the street-surface, any attempt at forming an arched roof spanning four tracks would have resulted in serious depression of the rail-level, even if the street-widths would have sufficed for the accommodation of the abutments of an arch of such dimensions. Except, therefore, where topographical variations introduced sufficient head-room for an arch, a flat roof was adopted as the standard design. In the matter of dimensions very serious consideration was naturally given to the question whether the subway should be large enough to accommodate standard steam-railway passenger-coaches. That this question should be answered in the affirmative was strongly urged by many who had doubts as to the successful outcome of the enterprise, and who argued that, should the subway fail to pay as a local-transportation system, it could be utilized by the trunk lines now terminating at the Grand Central Station as an extension for their suburban service to the commercial district, or that, by making the subway large, it could become a goods-line, especially on the express tracks during the night; as these persons were quite positive that the express service would fall far short of being remunerative, and that at least these tracks would be free for other service.

The Author felt confident that there was such an urgent demand for increased local-transit facilities in New York, that the whole capacity of the subway would be taxed to the utmost in performing its legitimate local service, and that there would be no accommodation in it for the standard-size suburban cars of the trunk lines, nor for local goods-service at night.

A high-speed service at short intervals can be maintained only when the units are of similar weight and similar power. It is obvious that this condition would not be fulfilled if there were permitted in the subway at the same time cars of the heavy weights of the trunk lines, drawn by a single electric locomotive, and cars of the lighter weights suitable for local service, propelled by a series of motors disposed throughout the train. The accelerating and retarding of the former class would be so much slower than in the case of the latter, that the speed of all trains would necessarily be that of the inferior. The Author therefore advised that the subway should be given dimensions only sufficient to accommodate a car of suitable capacity for local service and should be made so small that it would be impossible, at any time, to introduce standard trunk-line equipment. Should it be desirable to run through trains over the rails of the subway and the trunk lines to near-by suburban points, the subway-trains could be better run over the trunk-line system than the trunk-line cars could be introduced into the subway. The making of the subway of small dimensions, as compared with American steam-railway standards, therefore, would not preclude through suburban service.

For a size of car that would be satisfactory for an intra-urban service, the Author took the standard car of the Manhattan Elevated Railroad, a type also in use on some of the suburban lines of the

New York Central and the New Haven Railroads. By omitting certain ventilators on the roofs and making other slight alterations in design, which would not affect the serviceability, it was possible to run such a car in a subway whose clear height from the base of the rail to the under side of a flat roof was 13 feet. The internal diameter of a tube of corresponding capacity would be 15 feet 6 inches. Figs. 21, Plate 6, show the car to be of more generous proportions than similar cars on the London tubes, except those on the Great Northern and City Railway, which are substantially similar. Allowing 9 feet 6 inches as the overall width of the cars, and providing a generous clearance and space for inspectors to stand if caught between passing trains, a width of 12 feet 6 inches between the track-centres on the straight was adopted. For four tracks there was thus a clear width of 50 feet between the walls. The depth was controlled by the conduit-yokes of the surface tramways, which are 30 inches high. This distance fixed the minimum cover, which actually averaged about 6 feet. The shallowest distance from street-surface to rail-level was 17 feet.

Methods of Construction.

Various studies were made as to the best form of roof-construction, and full plans were prepared for spanning the whole width with girders without intermediate supports, and with such supports in the form of either one row of columns between the centre tracks or a row of columns between each pair of tracks. Further studies were made as to the columns themselves, to determine whether they should be placed beneath every girder; whether they should support a continuous girder and therefore be at intervals longer than the cross-girder intervals; or whether this continuous girder should be cut into sections, to be supported on two columns set back from the ends, the ends of the longitudinal girders being cantilevers. The long girders spanning all the tracks without columns, while providing a subway attractive to the eye, had the disadvantage of being the most expensive form of construction. They depressed the rail-level on account of the greater depth of girder required, and involved the handling of large and heavy girders under busy streets.

If intermediate columns were to be used, a continuous longitudinal girder carried by columns at economical intervals presented two objections. First, the longitudinal girder was subject—at least during construction—to variations in temperature, which would bring about difficulties in making closures; secondly, these longitudinal girders would vary with the gradient and would all be special members tending to delay erection; and thirdly, columns at long intervals introduced a possible source of danger, in that a derailed train might strike one of the columns and wreck not only the train but also the structure, and possibly the street. Separate longitudinal girders, each supported on two columns, removed the objection to longitudinal girders on the score of special members and variations in temperature, but not the danger resulting from collision. In fact, this danger was rather increased, as the knocking away of a single column would be certain to result in the wrecking of the roof. The placing of the columns between each pair of tracks and at the same interval as the roof-girders, without any longitudinal girders, seemed to be the best solution. It involved the minimum amount of steel, the smallest cost, the lightest individual members, the possibility of cutting the cross beams in lengths spanning either one, two, three, or four tracks, as might be most desirable, the bringing of the columns so close together that a derailed train would not have distance in which to get so far from the track as to strike one of them a direct blow, and the introduction of frequent supports for trackmen to take hold of when passed by trains. For these reasons frequent columns were adopted.

In order to make the walls thin and of uniform width, so as to leave as much space outside the subway-structure for sewers and house-vaults, I beams were built in the walls to carry the roof and withstand lateral thrust. The columns and wall-beams were usually each of uniform section. This enabled a great reduction to be made in the number of different kinds of members required, and introduced the principle of interchangeable members.

Although the New York Subway is regarded as an extreme type of shallow construction, and such was, as explained above, the basic principle of its design, as a matter of fact, shallow construction covers less than one-half of the route. The actual form used at any point was governed by the local topography and conditions. Although a standard design was adopted as preferable to others, there was no hesitation in departing from it if necessity required, or compensating advantages were to be gained. In some places the line was placed so deep that tunnelling by various methods was resorted to, while in other places where the depth to rail-level was not quite enough for tunnelling, the structure was made with an arched roof wherever the number of tracks did not exceed three. At the upper end of the island, for the sake of economy, a still more radical departure was made from the adopted type, and an elevated structure instead of a subway was constructed; and on the West Side line, crossing the Manhattan Valley, in order to avoid excessive depths in the subway on the north and south sides of the valley, the rails emerged at 122nd Street on the south and again entered the subway on the north at 135th Street. The railway, as constructed, includes all types of urban construction—by cut-and-cover, by tunnelling in rock, in soft ground, in subaqueous material under compressed-air, and by shield; and by open cut, embankment and metal viaduct. The total mileage of construction is divided among these several types as follows:—

TABLE III.—MILES OF VARIOUS TYPES OF CONSTRUCTION.

	Contract No. 1.	Contract No. 2.	Total.
	Miles.	Miles.	Miles.
Cut-and-cover	12·1	2·1	14·2
Tunnel	3·8	0·1	3·9
Iron lined tubes, single track	0·0	2·6	2·6
,, ,, ,, double track.	0·1	0·0	0·1
Open cut	0·2	0·0	0·2
Embankment between masonry walls . .	0·2	0·0	0·2
Steel viaduct	6·2	0·0	6·2
Total	22·6	4·8	27·4

It will be noted that the above totals exceed the miles of route previously given. This is due to the fact that the line beneath Murray Hill is divided into two tunnels of two tracks each, and that the line under a portion of Battery Park, East River, and Jerolemon Street in Brooklyn consists of two single-track tubes. Of the 14·2 miles of cut-and-cover, 13 miles have a flat roof, and 1·2 mile has an arched roof.

In making the detailed design, certain assumptions had to be made in regard to loading. The live loads that may be imposed upon the roof of a subway are of three kinds: rolling loads of heavy vehicles such as traction-engines or tramcars; the shock of falling walls, as the result of fires; and piles of building-, paving-, or other material. The depth of cover, even at the minimum, was enough to distribute the concentrated loads of heavy vehicles over a sufficiently wide area to make the effect upon the roof-beams of less intensity than could reasonably be assumed for the effect produced by either of the other classes of loading. It was also evident that the amount of loading would vary considerably according to the district traversed, being heavier in the commercial districts where there might be a great concentration of material piled in front of warehouses, and lighter in streets traversing the residential sections where the only loading likely to occur would be that produced at long intervals of time by piles of building materials. It is obvious that there will be a greater loading at the sides of streets than at the centre, which would have to be kept open for traffic. The following assumptions for live loads were therefore made:—

TABLE IV.

	Centre of Street. Lbs. per Square Foot.	Side of Street. Lbs. per Square Foot.
Heavy business district	1,000	1,135
Medium ,, ,, ...	690	950
Residential ,, ...	500	500

The maximum loading on the roof consisted of these live loads added to the weight of the cover, assumed arbitrarily at 100 lbs. per cubic foot. As the maximum live loading would consist of piles of material and be therefore quiescent, or practically dead, and inasmuch as the roof-beams were to be sustained laterally by the jack-arches of the roof for their whole length, the permissible unit-stresses were assumed to be:—

Beams and girders . . 20,000 lbs. per square inch.

Columns . . . . . $16{,}000 \text{ lbs.} - 60 \dfrac{\text{length}}{\text{radius of gyration}}$.

In order to diminish the number of sizes of beams required, the possible loadings were divided into four groups with the proper section of beam adopted for each, so that only four sizes of beams had to be kept in stock. For the first three, beams 15 inches deep and weighing 42 lbs., 50 lbs., or 60 lbs. respectively per foot, sufficed, and for the maximum loading a beam 18 inches deep, and weighing 55 lbs. per foot was required. The beams were spaced 5 feet apart between centres. To take the thrust of the walls a 12-inch 40-lb. beam was usually sufficiently strong. For the supporting column it was necessary to adopt a section which would be compact, strong against shock, and of a simple character. Taking a suggestion made by Mr. Theodore Cooper, M. Inst. C.E., the Author developed a column consisting of four bulb-angles with an intermediate plate; all the members being, therefore, merchantable shapes and easily manufactured. The thickness of the angles was $\frac{3}{8}$ inch and $\frac{1}{2}$ inch, according to loading. The intermediate plate varied from 6 inches by $\frac{1}{4}$ inch to $6\frac{1}{4}$ inches by $\frac{1}{2}$ inch. The over-all dimensions of the columns were $6\frac{1}{4}$ inches by $8\frac{1}{4}$ inches to $6\frac{1}{2}$ inches by $8\frac{1}{2}$ inches (Fig. 3, Plate 5).

As the subway for the greater part of New York rested on a foundation of rock or sand, it was not necessary to use an invert other than a flat concrete floor. There were places, however, where the bottom of the subway was beneath standing water sufficient to produce a decided upward hydrostatic pressure. To resist this upward pressure, beams were embedded in the floor, extending transversely from wall to wall. It will be seen, therefore, that in the steel framed structure all stresses, both vertically downward from the overhead loading, vertically upward from hydrostatic pressure, or laterally from the thrust of the earth at the sides, were taken by steel beams and columns. The floor, walls, and roof were always made of concrete, rather than brick, as being both better and cheaper. To have filled in all the spaces with brick and to have ensured a complete embedding of the beams, would have been a difficult matter in the contracted space for working. By using the fluid concrete it was made certain that the beams were completely embedded and that all work was tight. Concrete was found to be more economical than brick, as it could be put in place by less skilled, and consequently less expensive, labour; and further, as both stone and sand were encountered in the construction, much of the material used for concrete was taken from the excavation.

It was found in practice not to be necessary to place foundation-stones beneath the columns either in the walls or in intermediate rows. A foundation of concrete was brought up to the approximate level of the base of the columns, and the steel framework was erected and riveted, and then wedged up to the true gradient. Afterwards the space between the foot-plates and the concrete foundation was filled with cement.

The details of a two-track structure are shown in Fig. 4, Plate 5, and the general arrangement of a four-track structure is indicated by Fig. 5.

Wherever the topography of the ground gave sufficient cover, and the number of tracks did not exceed three, the subway was given an arched roof. The arch varied from the ordinary semi-circular arch with a minimum span of about 13 feet for a single track, to a three-centred arch with a clear width of 38 feet for three tracks. The thickness of the walls, of the invert, and of the roof varied according to local conditions and possible pressures. The three-track arch, with a rise above the springing of 14 feet 4 inches, was given a thickness of 2 feet 3 inches at the crown, with about 20 feet cover. The largest arch constructed in cut-and-cover was that of the Mott Avenue station, with a clear span of 50 feet and a maximum width, between the outer faces of the side walls, of

60 feet 3 inches, with a total length of 300 feet (Fig. 6, Plate 5). This arch is semi-circular in form, with a radius of 25 feet and a height from rail-level to key of 25 feet. The minimum thickness of the walls is 6 feet $7\frac{1}{2}$ inches, the roof being 2 feet 6 inches thick at the crown, but reinforced with 1-inch square rods running transversely and 12 inches apart, and a double row of $\frac{1}{2}$-inch longitudinal rods 20 inches apart between centres. With but few exceptions, all arches and side walls were constructed of concrete.

Use of Reinforced Concrete (Fig. 7, Plate 5).

Although the original contracts contemplated the use of steel beams for all portions of the subway where a flat roof is employed, the successful use of concrete during construction led to the adoption of reïnforced-concrete in lieu of beams. A two-track portion was first adopted for such construction where the cover varied between about 5 and 10 feet and the base of the rail averaged about 5 feet below the level of ground-water or high tide. The standard form of bulb-angle column was retained for the row of central columns, except that their tops were not designed to be riveted to cross girders. They were set as usual at the normal distance of 5 feet. In the walls opposite each column, at 5-foot intervals, were placed two angles, 3 inches by 3 inches and 14 feet 2 inches long, riveted together with their legs set parallel to the face of the wall and 2 inches back from it. The tops of these pairs of angles were cross connected, by two $1\frac{1}{8}$-inch diameter rods 12 feet 9 inches long, with the sides of the central row of columns. The feet of the angles were embedded in the floor concrete. Between these angles and running from wall to wall were six $1\frac{1}{4}$-inch rods in each 5-foot panel where the cover was 6 feet or less, and seven where the cover ranged from 7 to 10 feet. Similar rods 12 inches apart were set vertically in the side walls between the vertical angles. These vertical and cross rods were not connected at either top or bottom, but were simply left embedded in the concrete and set $2\frac{1}{2}$ inches back from the face of the wall. In order to form a vertical truss along, and on top of, the row of central columns, four $\frac{5}{8}$-inch diameter rods were run from column to column at a mean distance of about 18 inches below the lower surface of the roof concrete, and on the sides of the columns were riveted two small bars $2\frac{1}{2}$ inches by $1\frac{1}{2}$ inch by $\frac{5}{16}$ inch, and to the web of the columns were riveted two angles 6 inches by 4 inches by $\frac{1}{2}$ inch, the horizontal legs of these angles being 2 feet below the surface of the roof. The roof concrete was then moulded downward at the sides on a curve with a radius of

2 feet, so as to rest on the horizontal legs of the angles just mentioned and to surround the longitudinal rods completely. In the wall, and connecting the vertical angles, there were two $\frac{3}{4}$-inch horizontal rods bolted to the angles, the rods being set 4 inches apart, with the lower one 18 inches below the under surface of the roof. The roof concrete was again moulded to a cornice with a curve to the sides as in the centre, so that the $\frac{3}{4}$-inch horizontal rods just described formed the tension-member of a longitudinal truss on the top of the walls. In order to ensure distribution of reaction at the tops of the central columns, or, what is the same thing, to take up the reverse stress over the tops of the columns, $1\frac{1}{4}$-inch rods 6 feet long were placed laterally $8\frac{1}{2}$ inches between centres, with centres $2\frac{1}{2}$ inches below the top of the finished concrete. These short rods served as a tension-member in the roof, considered to be acting as a continuous beam over the columns. The thickness of the concrete in wall and roof varied with the loading to which it was to be subjected. For cover 6 feet or less in depth the walls were made 14 inches thick; for cover 6 to 10 feet deep the walls were made 16 inches thick. The roof concrete was given the following thicknesses:—

For 5 feet of cover	$18\frac{1}{2}$ inches
,, 6 to 7 feet of cover	$19\frac{1}{2}$,,
,, 8 to 9 ,, ,, ...	$20\frac{1}{2}$,,
,, 10 feet of cover	$21\frac{1}{2}$,,

In designing, 500 lbs. per square inch was allowed in compression on the concrete and 12,000 lbs. per square inch in tension on the steel.

Wherever the base of the rail was beneath water and there was upward hydrostatic pressure, the floor concrete was given a minimum thickness of 15 inches to the upper surface of the waterproofing, instead of 8 inches under normal conditions. The upper surface of the floor concrete was then reinforced with $1\frac{1}{4}$-inch rods, 12 inches apart, with the centres 3 inches below the top surface of the concrete. Two $1\frac{1}{4}$-inch rods were set longitudinally beneath the central row of columns and other $1\frac{1}{4}$-inch rods, 6 feet long, were placed laterally beneath the central columns, to distribute the stress set up during erection.

The first trial was found to give such excellent results that the same principle, with details varying to suit local conditions, was adopted for other sections where the work had not been begun.

The advantages of reinforced concrete construction are: economy in cost; rapidity of erection; use of non-skilled labour; employment of small members readily handled in a city street; complete embedding of the steel in concrete, thus avoiding all maintenance-charge for painting; and the ease with which the design may be modified at any point to give greater strength to withstand a specially heavy concentrated load, such as the thrust from the foundation of adjoining buildings or the weight of a monument overhead. Reinforced concrete was also employed in many of the details of the subway with equal success; for instance, in the over-hanging portions of station-platforms, stairways, the strengthening of arches, vault-lights and station-roofs—in fact, in any detail where concrete members are subjected to tension.

In the particular case under discussion exposed steel was used for the columns. This was necessary on account of the desire to economize space. In other work subsequently carried out by the Author, reinforced-concrete columns have been employed and consequently any exposure of the steel has been obviated. The experience thus gained during construction, and study of the constructed sections during operation lead the Author to prefer this type of design, unless special local reasons prohibit it. The method is not so suitable where there is necessity to block up and support any overhead structure during erection before the concrete has had time to set, such as the conduit structure of a surface tramway: for this purpose the steel frames or beams offer special facilities.

Table V illustrates the comparative economy of the two methods of construction by giving the quantities of the principal items for the same amount of cover :—

TABLE V.

Item.		Beam Construction.			Reinforced Concrete.		
		2 Tracks.	3 Tracks.	4 Tracks.	2 Tracks.	3 Tracks.	4 Tracks.
Excavation	Cubic yards	22·2	32·0	41·7	22·8	32·5	42·3
Concrete	" "	5·7	7·7	9·6	6·3	8·3	10·2
Steel	Tons (2,000 lbs.)	0·38	0·56	0·74	0·31	0·46	0·62
Waterproofing	Square yards	9·7	12·5	15·2	9·8	12·6	15·4

The reinforced concrete calls for a trifle more concrete but less metal, and the metal used costs less per pound. With equal depths, the arched cut-and-cover work is the most economical of all, other factors being disregarded, as all steel is omitted, except for minor reinforcements, while the quantities of excavation and concrete remain about the same.

Waterproofing.

As much of the subway was below tide-level, or where above tide-level was in wet ground, it was a matter of great concern that it should be dry at all times and in all places. It was therefore stated to be the "very essence of the specifications to secure a railway structure which should be entirely free from the percolation of ground-water." In order to secure this, it was decided to build in the floor, walls, and roof, a waterproof course consisting of asphalt and asphalted felt. The latter was the ordinary roofing-felt paper, dipped in asphalt and weighing 15 lbs. per hundred square feet. The asphalt was specified to contain in the refined state not less than 95 per cent. of natural bitumen, soluble in rectified carbon bisulphide or in chloroform. Not less than two-thirds of the total bitumen was soluble in petroleum naphtha at 70° Baumè, or in acetone. The asphalt, in order to be accepted, had to lose not more than 4 per cent. of its weight when exposed for 10 hours at a temperature of 300° F. Such asphalt, which is very much purer than the ordinary asphalt of commerce, becomes at a low temperature hard and brittle, and in order to maintain fluidity a flux of petroleum residuum was added. At high temperatures there was found to be the reverse difficulty of too great fluidity, to prevent which powdered limestone and sand were added up to 66 per cent. of the total, in the same way as sand is mixed with cement. Such additions were not only not injurious, but permitted work to be carried on which otherwise would not have been possible.

In order to put the waterproofing in place after the excavation was made, a bed of concrete, usually about 6 to 8 inches thick, was laid. After that bed had been made smooth, a bed of hot asphalt was spread, on which, while it was still hot, the felt was rolled. Then more asphalt was poured on the felt, another layer of felt was laid, and again asphalt and felt alternating, until the required number of layers of felt had been laid—usually three or four, although as many as six were used in wet ground. On the top of the waterproofing-course was laid the upper part of the subway floor. To waterproof the walls the same waterproofing-course was carried upward. Where possible, this was done by placing alternate layers of asphalt and felt against the side walls of the subway outside the beams; but in only a few cases was this possible, since as a rule the excavation was not wide enough to permit work on the back of the walls. The contractor usually built against the sheeting a wall of brick or coarse concrete, on which the waterproofing course was spread and connected with the waterproofing course at the bottom. The most satisfactory material for this outer or guard wall was found to be square hollow tile, about 4 inches thick and about 10 inches on the side. The hollow spaces were set vertically so as to act as vertical drains. This wall, with the waterproofing, was set to clear the back of the flanges of the wall-beams by about 2 inches, which space was completely filled by the fluid concrete of the walls.

The roof was finished in the same manner. After the roof-beams had been erected, and the arches between them were finished, so as to cover the tops of the flanges and give a slight drainage-slope from the centre to the sides, the alternate layers of felt and asphalt were spread. It will thus be seen that there was a complete envelope of waterproofing material surrounding the whole structure. In order to protect the concrete on the roof from damage by subsequent street-excavation a layer of coarse concrete about 3 inches in thickness was spread over it.

This method of keeping the subway dry was found to be entirely satisfactory against moderate hydrostatic pressure. Where a high hydrostatic pressure was to be encountered, say 20 to 40 feet, layers of brick dipped in asphalt were used instead of the felt. For this purpose porous bricks were adopted, which, after being warmed to remove moisture, were dipped in liquid asphalt of the quality described above, and were then laid, usually in two layers, flatways, in both floor and roof; but in the side walls, in a vertical wall either one or one-half brick in thickness. After the bricks were in place, hot liquid asphalt was poured over them so as to ensure the complete filling of all spaces. The concrete structure was then placed on top of this waterproof course.

Tunnelling.

Table III (p. 12) shows that there were 2·6 miles of single-track tunnels, and 3·9 miles of two-track tunnels. The word "tunnel" is used here to denote a subway constructed wholly by underground excavation, and not by cut-and-cover work. The single-track tunnels consisted chiefly of iron-lined tubes, built by means of a shield, and in a manner very similar to that employed in the construction of the London tubes, except that, being beneath the East River and the approaches thereto, and in water-bearing material, the tunnelling had to be carried on in compressed air under a pressure ranging from 20 to 40 lbs. per square inch. The cross section of these iron-lined tubes is shown in Fig. 8, Plate 5. It will be seen that the tubes had an internal diameter of 15 feet 6 inches, and an external diameter of 16 feet 9 inches. The cast-iron shell varied in weight, according to the nature of the ground, between 3,990 lbs. and 5,130 lbs. per lineal foot. The heaviest lining had a thickness of shell of $1\frac{1}{8}$ inch, a depth of flange from front to back of $7\frac{1}{2}$ inches, and a width of ring of 22 inches.

The other tunnels, chiefly for two tracks, were in rock, the longest being the Fort George tunnel, with a length of about 2 miles between portals. This and the other similar tunnels, had a width in the clear of 25 feet, the arch being semicircular in form. The Murray Hill tunnel, which is on the four-track section, consists of two twin tunnels of two tracks each. The roof was built as a three-centred arch instead of a full semicircle, in order to avoid endangering the foundation of the surface-car tunnels above. All these tunnels were in rock, which was generally of good character and required no timbering. There were places where the ground became locally heavy, and where very heavy timbering of the crown-bar type had to be resorted to in order to maintain the ground overhead. The lining of all these tunnels was of concrete. Where the ground was heavy, the walls and roof were thickened proportionately, and were further stiffened by reinforcing rods laterally and longitudinally embedded in the concrete. Fig. 9, Plate 5, shows a reinforced section of the Fort George tunnel in very heavy ground.

As it was not possible to waterproof the back of the lining, and as a considerable quantity of ground-water was encountered at several places, the tunnels were made dry by grouting. Two-inch pipes were embedded in the roof during construction, at intervals of about 50 feet. After the lining had been finished, force-pumps were connected to these pipes and grout was pumped behind the arched lining, until all the voids in the concrete and all the spaces between the concrete and rock were completely filled.

The largest tunnels were for two stations on the Fort George section, which had an extreme width of 53 feet from back to back of the walls, and a width in the clear of 48 feet. The roof-arch was struck from three centres, with a rise of 15 feet above the springing, and a rise of 26 feet above the base of the rails. In order to produce the desired architectural effect, these arches were made of brick instead of concrete, and were given a thickness of 2 feet 6 inches at the crown. The cross section of these tunnels is similar to that of the Mott Avenue Station described already, and illustrated in Fig. 6, Plate 5.

The north end of Manhattan Island is separated from the mainland by the Harlem River, a tidal connection between the Hudson River on the west and the so-called East River on the east. This waterway has a depth at low water, as fixed by the United

States Government, of 20 feet, and a width of 400 feet between retaining-walls on each side. It is crossed beneath by the East Side line (Fig. 1, Plate 5).

As the amount of natural cover was too small to tunnel beneath, the contractor decided, instead of making an artificial bed of the river with clay, which would afterwards have to be removed, to construct a roofed coffer-dam and to build the tunnel in sections beneath this coffer-dam, taking first one half of the stream and then the other, the Government permitting such temporary obstruction to the channel. For this purpose a structure was designed as shown in Fig. 10, Plate 5, consisting of two sectors of circles with a common vertical chord, all of cast iron and surrounded by concrete. The cast-iron lining had a shell 1 inch in thickness and ribs 6 inches deep. As the lining was to be put in place under a roof, it was not necessary to use a small key as ordinarily adopted in tubular linings. The plates were, therefore, made as large as could be conveniently handled, with a length of about 6 feet longitudinally and a transverse length of about 5 feet 11 inches each.

The contractor's plan for the first half of the river consisted of two rows of sheet-piling of 12-inch by 12-inch timbers, each timber being grooved, and the grooves being filled with 3-inch by 4-inch pine keys. This heavy sheet-piling was necessary to withstand the head of about 45 feet. The rows of piling were set far enough apart to clear the side walls of the structure. To the tops of the sheet-piles was bolted a heavy timber roof, through which there was an ordinary air-lock. When this structure was in place, the water was pumped out, air-pressure was applied, and the permanent tunnel was constructed in the caisson-chamber thus formed.

On the second half of the river the contractor decided to dispense with the temporary roof by ingeniously using instead the permanent roof of the tunnel. Rows of exterior sheet-piles were driven as already described, with interior transverse rows of piles at 8-foot intervals. On the interior piles were laid caps so arranged that their tops and the top of the sheeting would be at the plane of the centre of the tunnel when finally in place. The upper half of the iron lining was then erected in the open and covered with concrete, according to the plans, but was reinforced with rods to take up any unequal stress in the moving. To the lower part of the plates external lugs had been cast, projecting 2 feet beyond the exterior surface. This roof was then floated into place and sunk on top of the sheeting and transverse caps, the exterior lugs resting on the former. When the roof had been bolted down, the water was pumped out and air was admitted, the excavation was completed, and the lower half of the structure was put in (Fig. 11, Plate 5). In both cases the side sheeting was not drawn, but was left in place.

The Elevated Sections.

The elevated portions of the railway are for the most part a three-track structure, and consist of two rows of columns connected at the top by cross plate-girders carrying the longitudinal track-girders. Generally the elevated portions are built along streets with wide roadways; so wide, in fact, that to have placed the columns on the footwalks would have involved such deep and heavy cross girders as to be both expensive and awkward. Except in some special localities, the columns were therefore placed in the roadway 29 feet apart between centres, affording space for a double-track tramway along the street and beneath the structure, and a space for other vehicles between the columns and curbs. Longitudinally their location was governed by cross streets and other local conditions, but usually they were set about 50 feet apart. The general features of this design are shown in Figs. 12 and 13, Plate 6, and call for no special notice other than a few words as to the cross section of the columns, the connection between the columns and the cross girders, and the expansion-joints of the longitudinal girders.

The columns are similar in design to, but of larger detail than, the small subway columns (Fig. 3, Plate 5), consisting of four bulb-angles with a single connecting plate. This design of column rendered possible a special connection between the top of the column and the cross girders. The usual plan is either to rest the cross girder on the top of the column and use a stiffening bracket in the corner between the two, or to rivet the end angles of the cross girder directly to the side of the column, throwing the vertical load in shear on the rivets. The single plate between the four angles was omitted for several feet at the top, and the outer pair of angles was extended beyond the normal length of the column by the depth of the web of the cross girders. The angles of the bottom chord of the cross girder were cut off by a length equal to the width of the column. The web of the cross girder was in three sections, the central section being the required depth of the girder, but the two end sections being deeper than the girder at the ends by several (usually 5 or 6) feet. In erection, after the column had been set up, the projecting webs of the cross girders were slipped in between the vertical angles of the column, which were then all riveted together. It will thus be seen that the same plate acted as the column-web and girder-web, and that the vertical angles of the column became the vertical end stiffeners of the cross girder. The projecting webs of the girders were sheared to a curve and stiffened on the edges by angles. This formed a cross structure as near a unit as it is possible to make of riveted members, and consequently gave the maximum stiffness.

This design of column not only has the merit of maximum stiffness for the erected structure, but it is economical in construction, requiring but two rows of rivets; has all its parts exposed for inspection and painting; and, being smooth on the sides and without lattice bars, prevents mischievous boys from climbing from the street to the structure above.

The expansion-joints in such a structure are usually sources of trouble, especially if they consist of any kind of pocket or shelf in which dirt may find lodgment. The joint employed in the elevated structures of the railway consisted of a vertical bracket riveted to the web of the transverse girder, on which was placed a half pin 4 inches in diameter, on which rested a projecting bracket riveted to the web of the longitudinal girder. The ends of the pins were then covered with lug angles to prevent lateral movement of the pins or accumulation of dirt. These joints were introduced at every third or fourth panel. The details are shown in Figs. 12, Plate 6. The symmetry of the structure was preserved by placing brackets at the end of the movable girder with slotted holes in their top angles to correspond with the stiffening-brackets riveted to the cross girders and the longitudinal girders at bents other than those with expansion-joints.

The only structure of special magnitude on the elevated portion is an arch with a span of 168·5 feet, carrying the railway and a station, at a height of 50 feet, over the diagonal crossing of two very wide streets occupied in the centre by a complicated crossing at the junction of two double-track tramways, which prohibited the use of any vertical supports. The street followed by the railway is on a decided gradient, so that the arch has a difference of 5 feet in elevation at the springings. A parabolic two-hinged arch was adopted, with three ribs spaced 24 feet 3 inches apart. The foundations of the arch are concrete piers carried to rock, and of sufficient length to contain within the foundations the resultant line of thrust of the arch and the vertical load transmitted by the first row of columns. The skewbacks are composed of granite blocks. The general design of the arch and details of the end bearing are shown in Figs. 14 and 15, Plate 6.

All the elevated portions were designed to carry a train of motor-cars, each of which had an extreme length of 46 feet, with a total weight of 100,000 lbs. on four axles, giving a load of 12,500 lbs. per wheel, with unit stresses in the longitudinal girder-flanges of 10,000 lbs. per square inch. The permissible stresses in the flanges of the cross girders varied with the number of tracks, being 10,000 lbs. when one track was carried, 12,000 lbs. for two, and 13,000 lbs. for three.

STATIONS.

The stations are of three distinct types:—

A. "Local" stations on four-track sections with the platforms outside the outer tracks, at which only local trains stop.

B. "Express" stations on the four-track section at which both express and local trains stop, with island platforms between each pair of local and express tracks and sometimes additional platforms on the outside of the local tracks, permitting the passengers on the local trains to embark from and disembark to platforms on both sides.

C. Stations on the two- and three-track sections at which both local and express trains can stop. The stations of this third type have platforms exterior to the outer tracks, except two on the two-track sections which have each a single island platform.

The number of stations of the several types are:—

Type A	17
,, B	4
,, C	37

The basis of the design for all stations was to have all the platforms as close to the surface of the street as possible, so as to give the minimum height of staircase from platform to side-walk and avoid the use of mechanical means of ascent and descent. The minimum distance from the rail-level to the surface of the street being 17 feet, and the platform-level being arranged to be 4 feet above the base of the rails, the minimum distance from platform to street-surface was about 13 feet, which has been approximately realized at nearly all the underground stations. Stations of type B were necessarily depressed in order that access might be had to the island platforms, as will be explained later.

What may be called a standard station of type A is in plan like the letter T with arms elongated parallel to the track, while the stem is under the street transverse to the main route. Beneath the cross street is located the station with the ticket-offices, lavatories, etc., and about 30 feet by 45 feet in area. In front of this space and symmetrical with the axis of the station, the platforms extend 100 feet each way. Where possible, the platforms for the central portion and for a length of 100 feet are 20 feet wide, and for the remaining 50 feet at each end they are narrowed to a width of 10 feet. A plan of a standard local station is shown in Figs. 16, Plate 6. To the central space, and on each side, lead four stairways, two for ingress and two for egress. There being two platforms, there are thus eight stairways in all to each standard local station. The entrance-stairs lead directly by the booking-office, so that incoming passengers continue in a direct course always forward from the moment of entrance until they board the train. The other staircases for exit are closed, except on the arrival of trains, by sliding iron gates operated by the attendant at the ticket-box. These stairways open on the platform facing towards the train, and thus form a direct passage from the train to the street for outgoing passengers. The incoming and outgoing passengers are therefore entirely separated, except immediately along the edge of the platform where they enter or leave the train. As a general rule, the stairways lead to and from the street foot-pavements, which in New York are usually 15 feet wide. The stairways are thus limited to about 5 feet in the clear, but as there are two for exit and two for entrance, all of them short, no serious congestion occurs. The stair-openings are covered by kiosks, the main portions of which are of cast iron with plates of wire-glass with copper flashings and copper leaders throughout. As the lavatories are usually situated below the staircases, one of the columns of the kiosk is used as a ventilating chimney.

In some instances the owners of abutting property have obtained the privilege of constructing entrances from the stations to their buildings, which can be easily effected, as the platforms and basements are nearly on the same level. Shopkeepers have also built show-windows facing the platforms.

The stations of type B, which are arranged for the stoppage of both express and local trains, have one main feature in common, in that they have two island platforms situated between each pair of tracks, using the word " pair " to designate the two northbound and the two southbound tracks. There are five stations of this type, namely: Brooklyn Bridge, 14th Street, Grand Central, 72nd Street, and 96th Street. In addition to the island platforms, side platforms exterior to the local tracks are added to the stations at Brooklyn Bridge, 14th Street, and 96th Street. These island platforms have a uniform length of 350 feet, the width varying as follows:—

Brooklyn Bridge	20 feet	6 inches
14th Street	30 ,,	
Grand Central Station	20 ,,	
72nd Street	15 ,,	6 inches
96th Street	18 ,,	

The same general method of reaching island platforms has been used at Brooklyn Bridge, 14th Street, and Grand Central stations. The rail-level is placed low enough to permit of the construction of a passage-way beneath the surface of the street over the trains. The minimum height inside passage-ways of this description has been taken at 7 feet 6 inches, so that the minimum depth of rail-level to accommodate the passage-way and its street-floor is about 25 feet, which is substantially the distance at the three stations. Figs. 17, Plate 6, showing the Grand Central station are also illustrative of the others, and show the methods of approach to the overhead passages and of descent from the passages to the platforms.

These Figures also show one of two extraordinary pieces of construction. In order to make a curve that would be feasible in working, it was necessary to acquire an easement under private property at the corner of Park Avenue and 42nd Street. This property was far too valuable to be left unimproved even for that part over the railway. A hotel with twenty-two stories was projected on the site, and plans were drawn for the railway to occupy a part of the basement. In order to prevent vibration from being felt in the hotel above, the steel columns carrying the latter pass through the railway roof to their own foundations, being set in line with, but quite independent of, the subway-columns. The other piece of similar construction, at Times Square, was even more extreme. In this case the subway passes directly through the building, which was not only built above the railway but also beneath it. The basement below has a height of 22 feet, sufficient for two stories, though occupied as one by the press-room of the *New York Times*. As with the hotel, the building and the railway are separate structures. Either can be removed without affecting the other. The railway easement secures a certain height, beginning at an established distance beneath the street, and terminating at a second distance, all rights above and below being retained by the property.

At 72nd Street advantage was taken of a parkway in the street, from which staircases run directly, from a station-building on the surface, to the two platforms, so that the express station at this point has its platform only 14 feet below the surface of the street, or substantially the standard local-station distance.

At 96th Street a special local difficulty confronted the designing of the station. Immediately to the north is the junction between the East Side and West Side lines, and from the station the tracks ascend in both directions at gradients as steep as are desirable, even if the station were placed at the normal minimum depth. To lower the station so as to permit the construction of an overhead bridge would have increased the gradients to an extent that would have restricted freedom in train-running. Again, 96th Street being at the bottom of a drainage-valley, there existed a large trunk sewer 6 feet 6 inches in diameter. With the station as designed, this sewer was lowered 2 feet 3 inches. To have lowered it 7 to 8 feet more would have greatly increased the magnitude of the work. It was therefore decided to reverse the procedure at this station, and, instead of building a bridge over the tracks, to construct a passage beneath them. By doing this the station was kept close to the surface of the street, similar to the 72nd Street station, connection between the two island platforms, and between the island platforms and the street, being made by underground passage.

Although nearly all the stations are covered generally by the plans already described, there are a few stations which are peculiar, owing to special topographical features.

The two stations at 167th Street and 181st Street are of the same general design and are both constructed in a deep tunnel. The station at Mott Avenue, although constructed in open cut, is similar to these two stations in general dimensions, methods of working, and access. The plans for the station at Mott Avenue are therefore shown in Fig. 6, Plate 5, as illustrative of the three. The other two stations have a width of 53 feet between the lines of excavation, and 48 feet between the surfaces of the finished walls. The roof is an arch, the springing of which is just above the station-platform. The two platforms are each 13 feet wide, and are reached by a shaft at one side containing two elevators and a stairway. The elevators are arranged to stop at two levels, either at the platform next adjacent to them or at about 10 feet higher, which is the level of a bridge spanning the two tracks and reaching to the farther platform. The shafts have the following depths to platform-levels:—

Mott Avenue	46 feet
168th Street	97 „
181st „	122 „

In the construction of stations the same general principles were adopted as in the subway proper—namely, a combination of steel beams with concrete walls, the ribs being placed, as in the subway, 5 feet between centres. In order to carry the roof over the platforms it was necessary to place columns on them. They were located at intervals equal to three bay spaces, or 15 feet. As a general rule, these platform-columns are of cast iron, which gives a better architectural effect and, being round, they occupy less space.

Wherever possible, the platforms are made to project 20 inches beyond the faces of the supporting walls, so as to give space for a person falling from the platform in front of an approaching train to find security, or to permit of inspection of the wheels or running-gear in case a train should be stopped at a station for that purpose.

In working out the architectural treatment of the interiors of the stations, the Author received valuable assistance from Messrs. Heins and La Farge, architects.

A large number of materials for use upon the walls and ceilings were considered, examined, and tested. At the outset the use of enamelled bricks was contemplated; and the first station to be constructed, that at Columbus Circle, had the jack-arches finished with this material. The cost of enamelled bricks, especially in view of the large areas of the walls and ceilings to be covered, prohibited the general use of this material which, in spite of many desirable qualities, was deficient in that the enamel was subject to "craze" and discoloration, and had the drawback that in the event of an individual brick becoming broken, much labour would be involved in replacing it. It was finally decided to make use of glass tiles, which possessed all the advantages of enamelled bricks without the disadvantages mentioned above, and, in addition, they could be had in a greater variety of colours and at very much less cost. These tiles, while strong enough for the ordinary wall, were not considered sufficiently so to withstand the hard usage to which the walls are subjected close to the surface of the platform; and to meet this requirement a wainscoting was built, about 2 feet 6 inches in height, made of light-coloured but very hard bricks, the shape being that known to the trade as Roman, 12 inches long and $1\frac{1}{2}$ inch thick. The top of the wainscoting was finished with a marble cap, above which came the glass tiles. In order to relieve the monotony that a plain-tiled surface would present, the architects divided the wall-space into panels, the division-lines of these panels being made either by coloured tiles or mosaic, or by a combination of the two. The tops of the walls are finished with a cornice of terra cotta or faience. Each station has a distinct design of wall treatment, and the extent of the decoration varies with the relative importance of the stations. At the Borough Hall Station, Brooklyn, the brick wainscot is replaced with marble. In stations of this character advertisements on the walls are prohibited.

The finished surface of the walls was separated from the main walls by an air-space, for two reasons. Although the exterior wall was waterproofed with great care, the possibility of water leaking through the wall—owing to faults in the original construction, or by the development of a crack through subsequent accidents—was kept in mind. To prevent such a leak from showing on the surface was one purpose of this air-space, as any water passing the exterior wall would find its way down to drains at the bottom. The second purpose was to permit the exposed surface to take the temperature of the air, and not that of the outlying soil, so as to reduce the possibility of condensation. In building the walls, the wainscoting courses were run up to the proper height and set off from the main wall with a clear space of about 1 inch. On the top of the Roman brick a wall of ordinary brick was run up to the height of the cornice, with occasional headers run back, resting against the main wall, to stiffen the interior wall. On the surface of this common brick wall were placed the tiles and mosaic. In building the walls scrupulous care was taken to avoid angles. Intersections between main wall-surfaces were made with curves of large radius, and even the junction between the walls and the platforms was made with curves. This was done in order to facilitate the cleaning of stations, to prevent the chipping of the exposed edges of bricks or tiles, and, in the case of the main wall vertical intersections, to facilitate the passing of passengers.

The proper treatment of the ceilings was a matter of much concern. It was finally decided to use white plaster. Within the station-limits the jack-arches over the tracks were plastered with white cement, the plaster being applied directly to the concrete. Over the platforms and in the station-space, except where vault-lights were used, the exposed ceiling was set off from the concrete by an air-space, as in the case of the side walls, the plaster being applied to wire lath. In some cases the jack-arch construction was followed, and in others the ceiling was made flat. The station-lights were placed in recesses in the ceiling-panels. As already explained, the cast-iron columns supporting the roof of the station were set at intervals of 15 feet each. This same interval was accentuated in the roof-design by plaster moulding.

The nearness of the platforms to the street-surface, and their situation beneath the foot-pavement, rendered feasible the lighting of the stations in large part by natural light, by making the overhead pavement of glass, known as "vault-lights."

After experimenting with two kinds of vault-lights, it was decided to use glass set in reinforced concrete. The main beams of the station-roofs were set at 5-foot intervals; at right angles to them were placed secondary beams of either small steel I section or reinforced concrete, with a 1-inch twisted steel rod on the tension side. These smaller beams were set at intervals of about 5 feet, and between them was laid a sheet of reinforced concrete 2 inches in depth, with circular glass lights $2\frac{3}{4}$ inches in diameter, set at about 4 inches between centres. The reinforcement consisted of $\frac{3}{16}$-inch twisted steel rods placed transversely, one between each row of vault-lights. In the event of any light being broken it is quite feasible to cut out the light and re-set it without damage to the frame.

The floors of the stations are of concrete with a granolithic surface, consisting of 1 part Portland cement and 2 parts sand, trowelled smooth.

The stairways were first planned to be built in the ordinary manner with metal carriages and supports. Before construction was begun, however, the application of reinforced concrete had been adopted, and practically all the staircases have been built in this material. The steps are supported at intermediate points on columns 6 inches by 8 inches in exterior section and reinforced with $\frac{3}{8}$-inch square bars tied together with $\frac{1}{4}$-inch loops at 12-inch intervals. The steps have a minimum thickness of 5 inches measured at the intersection of the rise and the tread, and these are also reinforced with 3-inch bars set 6 inches apart. The open sides of the stairs are protected by a plain wrought-iron grill, the main vertical bars of which are $1\frac{1}{4}$-inch pipe, with intermediate members $\frac{1}{2}$ inch round, set about 5 inches between centres.

As the ordinary sewer is about 13 feet below the surface of the street, and as the floors of the stations were usually below the sewers, it was impossible, except in a few cases, to get natural drainage to the sewers. Where natural drainage could not be secured, the stations were equipped with Shone ejectors, by which the water from the lavatories and platform-washing was lifted into the sewers outside.

Junctions.

There are three important junctions on the railway. The first is at Bowling Green where the line from Brooklyn joins the line on Manhattan Island, the terminus of the latter being one station removed, at South Ferry, where the trains run around a loop and so reverse their direction. At Bowling Green the two tracks to Brooklyn dip rapidly on a gradient of 1 in 33 passing under the line to South Ferry.

The second junction is at the Brooklyn Bridge station, which is the south terminus of the four-track service, and from which point a two-track line extends southward to the lower part of Broadway and to Brooklyn. Track-arrangements had to be made at this point to permit either express or local trains to be reversed in direction at the Brooklyn Bridge station, or to proceed to Brooklyn. Reversal on the express service is effected by means of a centre track, on to which a south-bound express can pass and then be returned to the north-bound express track, or can wait on such track in the event of the north-bound track being occupied, and yet stand clear of the south-bound express track. Ordinary confluent junctions were made between the express tracks and local tracks in both directions. In order to turn the local trains without a level crossing of the other systems of tracks, a curved line was run westward on a continually descending spiral curve, passing beneath the main tracks under Park Row and then rising to a connection with the north-bound local track at the southern end of the Brooklyn Bridge station. The City Hall station is situated on this curve. Thus at the Brooklyn Bridge station, either express or local trains can be continued southward to the two-track line to Brooklyn, or can be reversed in direction without a level crossing.

The third junction was the northern terminal of the four-track lines just previous to the branching-off of the East Side line from the West Side line under Broadway at 103rd Street. At the north end of 96th Street station each pair of express and local tracks is cross-connected by interlocked double cross-overs, so that the operator can place a train, whether on local or express service, in either direction, to continue northward by either the East or the West line, or southward by either the express or the local track. Immediately north of the double cross-overs the two inside tracks are depressed and the outside tracks rise. As soon as the inner tracks are sufficiently depressed to permit of their being passed under the outer tracks, the inner tracks turn sharply to the east, and become the East Side line. By this arrangement, trains coming from the south are made to take either the West or the East Side line, and trains south-bound from either branch are passed either to the local or to express service according to the character of the train.

Although every arrangement is made to facilitate this interchange, and there is no crossing of trains on the same level in opposite directions, this junction is found in practice to be the limiting condition of the whole railway, and plans are now being prepared to add additional standing-tracks, so that in the event of two trains approaching simultaneously, one train may be allowed to proceed and the other passed to a standing-track so as to clear the main track for a closely-following train.

Permanent Way.

The specifications contemplated two types of track: in one the rail was to be laid on a continuous bearing of wooden blocks in the concrete floor, the grain of the wood to be transverse to the length of the rail, and the blocks to be held by a shoulder of concrete on the outside and by a removable steel angle on the inside; the other was the standard American type of track consisting of wooden sleepers on stone ballast. The latter was adopted by the operating company.

The sleepers are of yellow pine, not creosoted or otherwise chemically protected, and are 8 feet long, 8 inches wide, and 5 inches thick. Beneath the rail are steel tie-plates pressed into place by hydraulic pressure before being laid.

The rail is of the Vignoles type, American Society of Civil Engineers section, weighing 100 lbs. per yard. This rail has a height and a width of base of $5\frac{3}{4}$ inches. Physical tests were imposed in the specifications and the following chemical composition was required—

Carbon	Not less than 0·55 per cent.
„	„ more „ 0·65 „ „
Phosphorus	„ „ „ 0·085 „ „
Sulphur	„ „ „ 0·07 „ „
Silicon	„ less „ 0·1 „ „

At the request of the company rails were laid in which the carbon ranged from 0·4 per cent. to 0·58 per cent., when the phosphorus exceeded 0·07 per cent. When the phosphorus was less than 0·07 per cent. the carbon was to range from 0·45 per cent. to 0·6 per cent. This mixture in practice was found to be too soft, and the higher percentage of carbon is being used. The rails are 33 feet long. Figs. 18 and 18*a*, Plate 6, show not only a cross section of the permanent way, but also the third rail carrying the current, its support on porcelain insulators, and its protective cover of wood.

The maximum gradient is 1 in 33, or, facing stations where acceleration will be required, 1 in 60.

With the alignment of the curves great care was taken. With one exception, referred to later, every curve having a radius less than 1,910 feet was laid out as a transition-curve by Crandall's formula, which is based on the theory that the curvature increases directly as the distance from the point of transition, from zero at the tangent to the curvature of the circular curve where it connects therewith. Although there are several methods of laying out spiral curves, this one was preferred for the following reasons:—

The curvature increases directly as the distance.

The calculations are simple.

The method may be used for a long easy transition-curve or a short sharp one; or between two parts of a compound curve, to provide a gradual change from one to the other.

It may be laid off by off-sets or by deflection.

It lends itself to field-work, as the instruments may be set up on an intermediate point and work continued.

The sharpest curve on the subway is the one at the City Hall loop, which has a radius of 147·5 feet. There is a station on the outside of this curve, and all trains approaching it have to move very slowly, regardless of the curve. The sharpest curve where trains are likely to proceed rapidly is one at the south end of the Grand Central station, where there is a deflection of 90°. In order to reduce the taking of very expensive property this curve was laid out with a short radius. It begins at the end of the platforms with a radius on the centre-line of 250 feet. After proceeding for a short distance with this curvature, the transition-curve begins with a constantly increasing radius to the point of tangency in Park Avenue. The sharpest curve between stations on the express lines is that passing from 42nd Street into Broadway, the radius of which is 458 feet. This curve necessitates the slowing-down of trains to a speed not exceeding 25 miles per hour.

Superelevation was adapted separately to each curve on the line, according to the speed that the trains would be scheduled to make on such curves, taking into account, if necessary, the reduction of speed due to the curvature. Superelevation was computed by the following formula:—

$$\text{Elevation in inches} = \frac{3\cdot 77\ (\text{Velocity in miles per hour})^2}{\text{Radius in feet}}.$$

Wherever possible, the superelevation is divided between the two rails, the inside rail being lowered and the outside rail raised, each by one-half of the elevation to be attained. The maximum elevation permitted is 6½ inches, corresponding with a speed of about 30 miles per hour on a curve whose radius is 525 feet. On sharper curves the speed is reduced to correspond with this elevation. The standard minimum clearance from the side of the car to the side of the column, or the side-wall column is 1 foot 3 inches. Wherever a curve would bring the sides or end of a car nearer to a wall or column than that distance the track-span was widened correspondingly.

Methods of Dealing with Sub-surface Structures.

The greatest difficulty to be overcome in building a shallow subway is the disposal of the sub-surface structures. In this respect New York does not differ materially from London or any other large city, except that there are found, in addition to other structures occurring elsewhere, elevated-railway piers and a very complex surface tramway-system.

House-vaults were held not to be property, but only a revocable license from the city. The owners therefore received as compensation only the price paid originally to the city for the right of use. A few instances dated back to colonial and early times, when the original price was stated in bushels of wheat. The city repaid not in kind but in the market value of the grain on the date of settlement.

The elevated structures where encountered were carried by temporary supports, and the foundations were then removed. In making a permanent connection between the column and the roof of the subway two different methods were used, either reinforced concrete or the standard beam construction. In reinforced concrete there were built in the side walls two 12-inch 40-lb. beams, spaced 5 feet between centres and symmetrical with the centre-line of the column to be carried. Resting on these girders and carried to the first row of bulb-angle columns were two 24-inch 90-lb. I beams with four 12-inch $31\frac{1}{2}$-lb. I beams set between them, resting on the lower flanges and covering a total span about 5 feet square, $\frac{3}{4}$-inch rods for construction purposes passing through the webs of the main I beams to hold them together (Fig. 19, Plate 6). The large and small I beams were then encased in concrete, an ordinary layer of waterproofing being placed on top, carrying a concrete pyramid 6 feet or 7 feet square at the bottom, to distribute the load of the elevated column above. The small I beams were probably not necessary, being introduced in Brooklyn at the request of the officers of the Elevated Company. The mass of concrete suffices to distribute the load over the main I beams without bringing any stress on the small beams. In beam construction the supporting structure was built in the ordinary manner, except that the roof-beams that came beneath the elevated columns were made of heavier section.

The electric conduits of the surface tramways, like the elevated columns, could not be removed, but had to be carried in place during construction and left after construction in the same place that they originally occupied. The yokes are of cast iron, or in the more recent forms of steel members, set as a rule 5 feet apart, and encased in concrete. As it was necessary that these yokes should be given a firm support, and as the earth which was filled on the roof on top of the subway could not be counted on to give such support during the time required for its completion, it was decided to place the yokes on a masonry foundation consisting of small piers built beneath the yokes down to the roof of the subway.

The problem of handling the water-mains and gas-pipes was practically similar, and they may therefore be treated as one. These pipes differed from the elevated foundations and the trolley-conduits in that they could be removed during construction, could be given a different position after construction, and, if necessary, could be changed in form. In the laying of pipes in New York it is unfortunate that no systematic arrangement has been followed. In fact, in the older parts of the city even the records are incomplete, and it became necessary for the engineers of the commission to make an investigation along the route in order to determine as nearly as possible what might be expected beneath the surface. In main thoroughfares the water- and gas-pipes, varying in size up to 48 inches in diameter, lie in a perfect tangle. A pipe which is on top at one point may be below other pipes at another, and pipes frequently cross to the other side of the street in order to secure a location or avoid previously-constructed obstructions. The result is that the mass of pipes and other conduits, exclusive of sewers, occupies a depth of about 6 feet. The earlier work indicated that the most serious limit to rapidity of construction would be the time required to readjust the sub-surface structures. At points badly congested by sub-surface structures the difficulty at times was avoided by depressing the subway-roof so as to clear the structures above. In other cases this was not possible, as the lowering of the structure would have caused a more serious interference with drainage problems. A typical case was that shown at 23rd Street and Fourth Avenue, where, in addition to the sewers, there were found in Fourth Avenue north of 23rd Street, on the east side seventeen different lines, and on the west side eighteen, with all the necessary manholes and valve-boxes, and, in addition, the crossing and a junction at the street intersection of two double-track surface tramways. Some of these mains ran through; others turned from one street to the other: all were in service and all had to be maintained.

In order to get the subway over a transverse sewer at 22nd Street, the roof of the subway at this point had to be brought to within 30 inches of the surface, the extreme minimum as governed by the depths of the tramway-yokes. It was finally arranged to take up all the sub-surface structures and to relay them according to a systematic arrangement, the north and south mains keeping one plane and the cross mains another. As it was not possible to construct all the junctions directly at the crossing itself, some of the lines of 23rd Street were carried either north or south of that street for a distance of about 100 feet, then crossed over beneath the north and south lines and returned on the other side of the street to a continuation in 23rd Street, depressions in the roof-girders being made for some of the cross connections. The work of readjusting these pipes was carried out at a point where there was not only a large vehicular traffic, but also, during the busy hours of morning and evening, no less than 800 cars per hour crossing the point of intersection. A temporary roof of timber was built to carry the traffic.

The principle of separating the longitudinal and cross lines into separate planes formed the general basis for plans at other places. If pipes were small they were left on top of the subway, there being usually sufficient space to accommodate them thus. If they were large they had to be moved to a new position at one side.

The details of beam construction for the roof of the subway afforded easy means of carrying pipes across, as it was determined at the outset that no pipes for either gas or water should be carried beneath the subway. The roof of the subway being close to the surface of the street, there was not, except in special cases, sufficient room between the top of the subway-roof and the bottom of the trolley-conduits to pass between them large mains. By constructing troughs between adjacent cross beams of the subway-roof it was possible to gain about 15 inches of extra depth. These troughs were formed either by placing 3-inch beams on the beam-flanges of the roof-girders, or by placing plates with the ends resting on the flanges of the girders and then covering them with a layer of concrete and waterproofing. Mains up to 15 to 20 inches could then be dealt with, even in extremely shallow places. At places, however, mains of larger diameter were encountered, which had to be carried across the subway; and where it was not possible to lower the roof, the large pipes were divided into a series of smaller ones of equal total capacity. As an example of this form of construction may be mentioned the work of dividing two gas-mains, one 36 inches and one 30 inches in diameter, at 65th Street and Broadway, where, by constructing a series of shallow troughs, there was room for 24-inch pipes above the roof. The 36-inch main was divided into three lines of 24 inches each, and the 30-inch main into two lines, one of 24 inches and the other of 20 inches. This arrangement is shown in Fig. 20, Plate 6. A similar arrangement was used for the subdivisions of water-mains and through gas-mains at other points. In respect of changing section, however, gas-mains were more easily handled than water-mains. At Lenox Avenue and 112th Street there was room for a main only 1 foot 6 inches high, and it was necessary to carry a 30-inch gas-main across the subway. Instead of subdividing the main into a series of pipes whose exterior diameter would not exceed 1 foot 6 inches, it was decided to construct a rectangular box 3 feet 6 inches by 1 foot 6 inches in area, with a section at the ends changing from the rectangular to the circular.

The officials of the Department of Water Supply and the officers of the gas-companies co-operated; and while insisting, as was proper, that the consumers along the route should receive their full and continuous supply, nevertheless did permit temporary reductions in pipes so as to allow such alterations as those described, which were necessary for the completion of the subway. The officers of the gas-company, however, prohibited the maintaining of live gas-mains under a temporary street-cover, fearing that in the event of any leakage of gas an explosive mixture of gas and air would result, which might be fired either by lamps or by a spark from the trolley-conduit. As it was necessary to construct the subway under such a roof on Lower Broadway, the companies allowed two mains to be put out of service temporarily, and the two remaining mains, which were necessary to maintain pressure, to be placed on wooden trestles above the surface of the street.

The mail- and telegraph-tubes and the electric conduits were easily dealt with. The electric conduits were usually moved bodily, the cables being cut and re-spliced. Steam-pipes were frequently encountered carrying live steam at a pressure of 90 lbs. per square inch: they were exceedingly dangerous to readjust, as a bad leak would have filled the trench with steam and caused a serious loss of life.

The sub-surface structure most difficult to handle was the sewer. The standard depth to sewer-invert in New York is 13 feet, and as the subway-excavation went to a depth of at least 19 feet, it was obvious that the City sewers would be met the whole length of the route. As a matter of basic principle it was determined, first, that the longitudinal sewers encountered along the line should be reconstructed in duplicate, one on each side of the subway and substantially at the same level as the original sewer; secondly, that the longitudinal sewers should be kept as small as possible by diverting the flow at every opportunity into adjacent cross streets leading to the rivers on either side; thirdly, that where the line of the subway deviated from the summit of the drainage-ridge, the drainage from the area thus cut off should be disposed of either by cutting a low-level sewer through the ridge and thus making a new artificial drainage-ridge at the line of the subway, or else by building at some convenient point a new outfall-sewer beneath the subway and taking into it through intercepting sewers the subsidiary drains from the district cut off. The following Table gives a list of the various sizes of new sewers built, together with the lengths of each:—

	Feet.
Pipe sewers, 6 inches to 4 feet 6 inches	45,682·7
Egg-shaped sewers	24,901·9
Circular sewers, 3 feet 9 inches to 15 feet . . .	15,094·0
Irregular shapes	2,057·0
Special chambers	238·7
Total	87,974·3

From the foregoing it will be seen that in building 14·2 miles of cut-and-cover railway, not less than 17 miles of sewers of various kinds had to be built anew. Portions of the cut-and-cover work, where passing parks and public places, required no sewers on either side, and at other points, for local reasons, sewers were needed on one side only, while the deep-tunnel and elevated sections obviously called for no sewer-reconstruction at all.

The building of these sewers did not differ materially in main features from standard sewer-construction elsewhere, except that, especially where sewers had to be curved, it was found advantageous to build them of concrete moulded in place.

Where drainage had to be passed across the line of the subway the points of crossing were made as few as possible by building intercepting-sewers on the upper side of the subway and conducting the drainage to a few chosen points. At these points large drop manholes were constructed, leading to chambers connected with iron pipes embedded in concrete and passing beneath the floor of the subway. The size of these pipes was regulated not only by the amount of flow, but also by the available height beneath the floor of the subway and the allowable gradient for the sewer. Where this height was not sufficient to permit the flow to be carried in a single pipe, the up-stream chamber was arranged in the shape of a bell-mouth and was connected with two or more pipes of a suitable size to aggregate the proper area.

In all instances but one it was found possible to pass sewers under the subway without siphoning, by carrying the sewer on the down-stream side at a lower level, and with a continuous but less fall, until the new gradient met the old. In the case in question the subway-bottom was beneath tide-level and cut off a large drainage-area. The circular sewer had a diameter of 6 feet. On the upper side of the subway a large chamber 10 feet across was constructed. At the upper end of this chamber there was a sludge-well 6 feet by 10 feet in plan, divided longitudinally by a brick wall, with grooves at the upper end so arranged that by means of stop-planks either part of the sludge-well could be cut off. Across the lower end of this chamber there was a dam, in front of which was a 14-inch cast-iron pipe whose capacity was sufficient to take the entire dry-weather flow of the sewer. When the sewage-flow exceeded the capacity of the 14-inch pipe, it flowed over the dam into the second part of the chamber, from which there led two 42-inch cast-iron pipes. These two pipes, together with the 14-inch pipe, were embedded in a mass of concrete and carried beneath the subway to a second chamber on the down-stream side into which the pipes discharge, but through separate passages. The 14-inch pipe was always left open at the down-stream end for continuous flow. At the discharge-mouths of the large pipes grooves were again made for stop-planks. Normally both the 42-inch pipes are dry, and by introducing stop-planks at the lower end they can be examined at any time and cleaned of any deposit. The continuous flow through the small pipe keeps that clear. The arrangement of this siphon has been found by experience to work well.

Materials.

The two materials used in greatest quantity in the subway were iron, either as steel or cast iron, and cement. For the inspection of these materials a fully-equipped inspection-bureau was established, and all the material, cement as well as metal, was inspected at the mills and not upon the ground after delivery.

The steel was required to show a tensile strength of not less than 58,000 lbs., and not more than 68,000 lbs., per square inch, with an elastic limit of 35,000 lbs. per square inch, an elongation of 20 per cent. in 8 inches and reduction of area at the point of fracture by 44 per cent.; in addition the steel was subjected to certain physical tests such as bending and drifting; annealing for testing was forbidden. Cast iron was required to withstand a tensile stress of at least 21,000 lbs., and a transverse stress of 750 lbs., per square inch.

In order to ensure a proper quality of cement, the specifications provided that it should be subjected not only to the usual short-time tests of 1 and 7 days, but also to a test of 28 days; and, as cement was being used at the rate of 2,000 barrels per day, special provisions had to be made by the manufacturer to furnish the necessary facilities for this inspection. This was done by erecting, at the mill, bins holding 1,500 barrels each, from which samples were taken and tests made until the cement was accepted, when it was shipped to the work in bags fastened by a metal seal. In addition to the usual requirements in respect of fineness and checks for soundness by boiling and the making of thin pats on glass, the specifications required that this cement, when tested neat, should exceed in strength 150 lbs. per square inch at the end of 1 day, 400 lbs. at the end of 7 days, 6 days being in water, and 500 lbs. at the end of 28 days, 27 days being in water. Briquettes composed of 2 parts of cement and 1 part of sharp coarse sand were to have a strength of not less than 200 lbs. per square inch at the end of 7 days, and 300 lbs. at the end of 28 days. To ensure a continual increase in strength, it was also required that neat briquettes must show a minimum increase in strength of 15 per cent., and sand briquettes of 25 per cent. between the tests at the end of 7 days and 28 days. An average of tests on upwards of 1,000,000 barrels of Portland cement showed for neat Portland cement a strength of 300 lbs. at the end of 1 day, 700 lbs. at the end of 7 days, and 800 lbs. at the end of 28 days; and for the same cement with sand in the ratio of 2 to 1, 400 lbs. at the end of 7 days, and upwards of 500 lbs. at the end of 28 days.

As explained already, the greater part of the cement was used in concrete, which was of varying proportions according to its position in the work. For the concrete in the thin walls and roof, where a very tight and compact mixture was necessary, it was composed of 1 part cement, 2 parts coarse sand, and 4 parts broken stone or gravel, the last being limited in size to what would pass through a 2-inch ring. In the less important parts of the work mixtures of 1:3:4, 1:3:5, and 1:3:6, were employed. In all cases the concrete was laid exceedingly wet, so that the usual ramming with rammers was avoided, the concrete being cut with spades in order to ensure a compact mixture.

In addition to the tests of cement in briquette form, further tests were made on concrete in larger masses, and on the effect and value of reinforcement. As the greater part of the subway structure consisted of steel beams with intervening arches of concrete, it was deemed of special interest to ascertain the effect of these arches on the strength of the beams, though in the computations all the load was supposed to be carried eventually by the beams, and their section was proportioned correspondingly. Four 7-inch deck-beams 7 feet long were spaced 2 feet apart and embedded in concrete 8 inches deep. Two blocks of oak were set at the middle transverse to the central pair of beams, on which rested a double grillage of 15-inch beams carrying a load of pig-iron. Thus the central beams carried the whole load, the small amount transmitted vertically to the outer beams being negligible.

Three sets of beams were prepared for tests. In one set the concrete was in the proportion of 1 cement, 2 sand, and 4 gravel, and in another 1 cement, 3 sand, and 5 gravel, and to get a fair average three sets of each kind were made and tested. The third set of beams was without concrete, the central pair being stiffened laterally by blocks. The steel was tested and found to have an ultimate strength of 62,000 lbs. per square inch.

When loaded to destruction the average of the results was as follows, reducing the stress to that per square inch in the beams:

	Maximum Load. Lbs.	Stress per Square Inch. Lbs.
Beams without concrete	44,000	50,500
„ with concrete 1.3.5	73,000	83,800
„ „ „ 1.2.4	77,000	88,400

The plain beams failed at about the stress under which they would be expected to buckle, namely, about midway between the ultimate resistance as determined by small test-pieces and the elastic limit of the metal; while the concreted beams carried a load equivalent to more than double the elastic limit and one-third more than the ultimate resistance: clearly indicating that even in such a form of construction the embedded beams and the surrounding concrete act together as a composite girder. At the time the tests were made the concrete was 1 month old.

In the designing of the reinforced concrete the question arose whether or not it would be better to protect the rods by painting them. The general practice is not to paint, but there were no available data as to what the effect of paint was on the adhesion between concrete and the embedded steel members.

Concrete blocks 8 inches square and 12 inches long were made, with steel rods $\frac{3}{4}$ inch and $\frac{7}{8}$ inch square embedded in the blocks to a depth of 9 inches. At the age of 1 month one set of rods was pulled, and at the age of 3 months another set. In each set the rods were in the following different conditions: rusted, cleaned by removing the rust, or painted with red-lead, linseed-oil and graphite. The tests gave the following interesting figures, demonstrating the very injurious effect of any preservative coating if adhesion between the metal and the concrete is intended to be relied on, as is the case in reinforced concrete. For convenience the total load has been reduced to the corresponding adhesion per square inch of surface of rod in contact with the concrete.

TABLE VI.

Size and Condition of Rod.	1 Month Old.		3 Months Old.	
	Total Load.	Adhesion per Sq. In.	Total Load.	Adhesion per Sq. In.
	Lbs.	Lbs.	Lbs.	Lbs.
$\frac{3}{4}$-inch, rusted	11,800	437	17,350	642
$\frac{7}{8}$-inch, clean	9,260	294	13,590	431
$\frac{3}{4}$-inch, red lead	1,700	63	3,460	128
$\frac{3}{4}$-inch, linseed oil	900	33	1,700	63
$\frac{3}{4}$-inch, graphite	460	17		

The injurious effect of a hard-coated paint, and still more of a slippery surface of oil or graphite, is very apparent. As the result of these tests and other experience, the Author inclines strongly to the belief that the best method of preserving steel when embedded in concrete, even when no reliance is to be placed on the combined strength of the steel and concrete, is to omit any paint or other coating. The union of the metal and the cement is so complete that the former is not capable of rusting. To ensure, however, a complete covering of the metal with cement, the concrete should be quite fluid.

The rods referred to in Table VI were plain and square in section. In order to determine the effect of section and the value of a mechanical bond between the concrete and the rod in addition to surface adhesion, tests were made on $\frac{3}{4}$-inch twisted rods and $\frac{7}{8}$-inch rods rolled with enlargements in section alternating at right angles. At the age of 1 month the adhesion per square inch of the twisted rods averaged 509 lbs., and of the enlarged rods 637 lbs., but in all cases the concrete block was split, indicating a wedge-like action of the enlargements and the twists. If a mechanical bond is desired in addition to adhesion it can be better obtained by a square shoulder, such as a nut on the end of the rod, than by any shape that tends to split the enveloping mass.

A series of tests was made on reinforced-concrete beams using various methods of reinforcement. The beams were 8 inches by 8 inches in section and 5 feet long, but so set up for testing as to have an effective length of 4 feet 10 inches between bearings. The concrete was made with fine gravel in the proportions 1 of cement, 2 of sand, and 4 of gravel, and when tested in 6-inch cubes had an ultimate resistance to crushing of about 1,800 lbs. per square inch at the end of 1 month, and 2,300 lbs. at the end of 3 months. The steel used in reinforcement had various qualities, as shown in Table VII.

TABLE VII.

Kind of Rod.	Ultimate Strength per Square Inch.	Elastic Limit per Square Inch.
	Lbs.	Lbs.
Plain rods, square	62,000	42,600
Expanded rods, soft	58,000	34,000
„ „ medium	66,500	40,000
„ „ hard	70,000	45,000
Twisted „	80,700	55,000
Corrugated „	93,700	62,000
Hennebique „ square	66,100	45,000

The load was applied at the centre of the beams by a powerful slow-moving testing-machine, the load being released at the time of the first crack in order to measure the permanent set and the total central deflection, and then reapplied until the beam finally yielded.

For computing the distribution of load between the concrete and the steel reinforcement the usual formulas, based on the respective moduli of elasticity were used, the modulus for concrete being assumed at 1,500,000 lbs. and that for steel at 30,000,000 lbs. per square inch. Table VIII records the tests, the general results, and the reduction of the load to stresses per square inch on both concrete and steel.

Inspection of this Table shows good uniformity in result, especially as regards the ultimate load. The irregularity in the load producing the first crack is to be expected, for in many instances such a crack

TABLE VIII.

Age.	No.	Kind of Reinforcement.	Area of Steel.	At First Crack.					Ultimate Load.
				Load.	Centre Deflection.	Permanent Set.	Stress per Square Inch of Concrete.	Stress per Square Inch of Steel.	
			Sq. In.	Lbs.	Ins.	Ins.	Lbs.	Lbs.	Lbs.
1 month	1	Three ⅜-inch plain rods	0·422	7,950	0·089	..	1,750	47,000	10,800
	2	Six ¼-inch Hennebique rods (water) . . .	0·295	6,000	0·088	0·017	1,460	49,000	9,100
	3	,, ¼-inch ,, ,, (air)	0·295	6,000	0·069	0·017	1,460	49,000	10,330
	4	Three ½-inch expanded rods (soft) . . .	0·574	8,500	4·086	..	1,700	37,800	10,380
	5	,, ,, ,, ,, (medium) . .	0·574	6,100	0·067	..	1,220	27,100	11,340
	6	,, ,, ,, ,, (hard) . . .	0·574	8,200	0·095	0·021	1,640	36,400	11,350
	7	,, ⅜-inch twisted rods	0·422	7,500	0·092	0·020	1,650	44,500	11,230
	8	,, ,, ,, ,, with stirrups .	0·422	6,800	0·078	0·017	1,500	40,000	12,440
	9	,, ½-inch corrugated rods	0·590	10,500	0·105	0·020	2,100	45,800	14,920
3 months	10	,, ⅜-inch plain rods	0·422	5,500	0·054	0·016	1,210	32,600	11,050
	11	Six ¼-inch Hennebique (water)	0·295	7,000	0·066	0·019	1,700	57,000	11,920
	12	,, ,, ,, (air)	0·295	5,500	0·054	0·020	1,340	45,000	11,120
	13	Three ½-inch expanded rods (soft) . . .	0·574	5,500	0·054	0·016	1,100	24,500	10,690
	14	,, ,, ,, ,, (medium) . .	0·574	7,000	0·065	0·018	1,400	31,000	12,740
	15	,, ,, ,, ,, (hard) . . .	0·574	6,400	0·063	0·019	1,280	28,400	12,430
	16	,, ⅜-inch twisted rods	0·422	7,500	0·083	0·027	1,650	44,300	15,650
	17	,, ,, ,, ,, with stirrups .	0·422	7,100	0·070	0·018	1,560	42,000	16,570
	18	,, ½-inch corrugated rods	0·590	7,000	0·072	0·020	1,400	30,500	15,780

did not indicate rupture, as is shown in every case by the very much higher ultimate load required to break down the beam. Thus in the test of plain rods at the age of 3 months, the first crack appeared at 5,500 lbs. as against 7,950 in another similar beam at the age of 1 month. Yet the former beam carried an ultimate load of 11,050 lbs. as against 10,800 lbs. for its fellow. The two were equally strong. Allowing beam No. 10 to give as high unit-stresses as beam No. 1, it will be noted that the beams with smooth rods of plain sections, Nos. 1, 2, 3, 10, 11 and 12, gave the highest steel-stresses, and higher stresses at the time of the first crack than the elastic limit of the steel reinforcement, as shown in Table VII. The rods in the Hennebique reinforcement were the only rods that broke when the beams finally failed, indicating that adhesion between concrete and steel exceeded the strength of the latter, as should be the case. In the tests under examination this was due, not to the method of reinforcement, but to the small cross section of the rods, which had a larger surface in proportion to area than the rods in any other test.

The manner of failure further indicated the lack of virtue in the variable sections. In all cases the beams with plain rods, including the Hennebique tests, broke squarely across in the middle. The beams with twisted, expanded and corrugated rods not only broke in the middle, but also split along the rods, indicating the wedge-like action of the expansion, as had been also noted in the adhesion tests. The only exceptions were the tests with twisted rods supplemented with stirrups. The latter, by giving vertical reinforcement, prevented the beams from splitting along a horizontal plane.

Specifications always prohibit the use of any cement that has taken an initial set, though experiments have shown that cement can be retempered without injurious result. As concrete formed such a very important part of the subway, and as careful inspection could not be absolutely relied on to ensure every batch of mortar being free from set, it was decided to repeat experimental tests on the effect of retempering.

Cubes of 6-inch edge were made of concrete in the proportion of 1 cement, 2 sand, and 4 gravel. One set was allowed to stand for 1 month after being made from freshly-mixed mortar. The second set was broken at the end of 24 hours, retempered and remoulded, and allowed to stand 1 month. The third was retempered at the end of 48 hours and then allowed to stand 1 month. On testing, the following results were obtained, showing that concrete broken and retempered at the end of as long a period as 24 hours was not injured.

Table IX.

Kind.	1st Crack.		Ultimate.	
	Load.	Compression.	Load.	Per Square Inch.
		Inch.		
Untouched . . .	65,000	0·049	69,320	1,925
Retempered 24 hours	62,000	0·041	70,800	1,970
,, 48 ,,	32,000	0·041	33,020	914

As has been shown, the underground portions of the railway were built partly by tunnelling and partly by open excavation. Wherever streets were wide and traffic light, great latitude was given the contractor in the way of opening and obstructing streets. Where, however, the streets were narrow, important, or congested with surface traffic that could not be diverted, the work of excavation and construction was carried on under a temporary timbered surface. The most extensive work of this character was done in lower Broadway. The first step after removing the paving at night was to lay in each of three longitudinal trenches a pair of 20-inch 80-lb. beams. Transverse to the street, and resting on these beams and at the sides on either the vault-walls or a 10-inch by 10-inch timber cap, were laid 8-inch beams at every 10 feet. On top of these beams was the wearing surface of 6-inch yellow-pine planks. Under this cover excavation proceeded, the main beams being supported at 15-foot intervals by three pairs of 12-inch by 12-inch pine posts. Suspended from the 20-inch beams were cross timbers 10 inches by 12 inches in section, one beneath each tramway-yoke, i.e., 5 feet apart, to carry the yokes and tramway. The vault-walls along the curbs acted as convenient retaining-walls, but where such walls were not present the earth was held by vertical sheeting and cross braces.

Cost.

The total cost of building the subway, with its 25·7 miles of route and 76·5 miles of main track, was about $50,000,000, exclusive of equipment, which, for the power-plant, rolling stock, signals and all other appurtenances, cost about $25,000,000 more, and exclusive of interest during construction and of easements. It must be remembered that the cost of construction covers a considerable mileage of elevated railway, which is much cheaper than underground construction. The cost of constructing the subway portions ranged from about $1,000,000 to $1,250,000 per mile of each track. The main contracts were taken by the Rapid Transit Subway Construction

Company on a lump-sum basis, and sub-contracted on a unit basis. In these sub-contracts the cost of excavation varied greatly, according to the locality and the facilities for doing the work. In the least populated districts, where the streets were wide and work could be carried on without interruption, the cost per cubic yard for excavation in sand ranged from 70 cents to $3.50, and in rock from $2 to $6.25. The cost rose to $6 per cubic yard for the earth in lower Broadway, with a very heavy and congested traffic above, which had to be borne by a timber roof. The cost of tunnelling in rock ranged from $4.50 per cubic yard to $10 per cubic yard.

Concrete in place, including the necessary forms, varied from $8 to $12 per cubic yard, and the steel cost from $80 to $90 per ton (2,000 lbs.) in place.

The total quantities of the major items handled were:—

Structural steel	Tons (2,000 lbs.)	97,500
Rail-steel	Tons (2,240 lbs.)	12,600
Cast iron	Tons (2,000 lbs.)	38,000
Excavation: Rock	Cubic yards	925,000
,, Earth	,, ,,	2,700,000
Tunnelling	,, ,,	515,000
Waterproofing	Square yds.	1,100,000
Cement	Barrels	1,320,000
Concrete	Cubic yards	725,000

Accidents.

Besides minor accidents, which are inseparable from a work of this magnitude, there were but two of serious character. One was an explosion of dynamite, caused by the carelessness of a workman, and the other was a slip in one of the Murray Hill tunnels. At the point where the latter occurred, borings indicated hard rock. The tunnel-heading had been driven some distance beyond the point and had been widened to the full width of the tunnel, and the bench was in process of excavation. The rock was hard, firm, and required vigorous blasting for its removal. All indications pointed to perfect safety. Unfortunately there was a fault in the rock not determinable from the interior of the tunnel. This fault left but a thin shell of rock on the side nearest the houses, the plane of the faces of which was but 10 feet away, measured horizontally, from the side of the tunnel, the bottom of the tunnel being about 60 feet beneath the surface of the street. This thin shell of rock slipped inward along a seam, the dirt behind it fell into the tunnel, disturbed the foundations of three houses at the side, and brought down their front walls. Fortunately no personal injury occurred. For a distance of nearly

100 feet the tunnel was filled with a mass of debris consisting of rock, earth, street-pavement, and brick and stone from the fallen house-fronts. In order to avoid digging out this mass and still further endangering the street, the tunnel below was tightly closed with two bulkheads, one on each side of the break, and grout was pumped in at the top into the mass of debris, which became completely solidified. After the cement had been given about 10 days to set, the bulkheads were removed and tunnelling operations through the mass thus solidified were resumed with entire success.

Under the terms of the lease the equipment is to be furnished by the lessee company, and was designed by its engineers, subject to approval by the Commission. It is not therefore for the Author to describe the equipment beyond giving salient facts necessary for a complete description of the railway.

Power-House, Rolling Stock, etc.

The power is furnished from a single house 950 feet by 200 feet, containing sixty water-tube boilers of a nominal capacity of 600 HP. each. The generating-units are nine in number with a rating of 5,000 kilowatts each, and are capable of being overloaded 50 per cent. In addition there are separate units for lighting- and signal-currents. The main current is generated and sent out at 11,000 volts, and transformed and reduced in ten sub-stations to continuous current at 600 volts, at which pressure it is fed to the line. The current-cables are carried in terra-cotta ducts built in the walls of the subway, as can be seen in the cross sections (e.g., Fig. 4, Plate 5). In order to give access to these ducts, manholes are built in the walls, with covered openings in the street. Through these manholes cables are drawn in or removed. There are 841 cars. Each car is 51 feet 2 inches long over all, and 9 feet ½ inch in maximum width, with seating arrangements for fifty-two persons. Figs. 21, Plate 6, show the general design of the cars. The first cars made had a steel underframe with wooden sides and roof, sheathed with copper. Later, an all-steel car was adopted, the only combustible material being wooden window-sashes and cane seats. All recent cars are of this type. Such car-bodies weigh 34,000 lbs., or with the trucks and motors, 77,000 lbs., the composite cars weighing 72,000 lbs. The seating-capacity of the steel cars is likewise fifty-two passengers.

The longest express trains consist of eight cars, and local trains of five cars. Of the former five are motor-cars and three trailers, and of the latter three are motors. The motor-cars are equipped with two 200-HP. motors on one truck, and are interchangeable in the express and local service. When running in trains they are all under a single control. Their power is sufficient to accelerate in practice at the rate of $1\frac{1}{4}$ mile per hour (1·83 foot per second) per second.

Signalling.

The express tracks, on which the aim is to give a service at 30 miles per hour, including stops, at train-intervals of $2\frac{1}{2}$ minutes, are divided into short blocks controlled by automatic signals on the overlap block principle, that is, the home signal indicates a train on the second block ahead, giving one intermediate block clear. In addition to the home signal there is a track-stop working with the signal. If the latter is at danger, the stop is up. Should a motor-man overrun the signal the stop cuts off his current and automatically applies the brakes. The local tracks are not blocked like the express tracks, as trains are running slower and under control. There are signals, however, immediately approaching stations and curves, equipped with the automatic stops. All signals are electro-pneumatic.

On every station-platform, and at intervals between stations, there are special switches, at which the electric current can be cut off from any or all tracks, in the event of an accident. The lighting-system, both at stations and through the subway, receives its current from a circuit quite independent of the power-lines, so that any interruption of the latter will not plunge the railway into darkness.

Results.

The results of operation have been financially successful. During the year ending 30th June, 1907, 166,363,611 paying passengers were carried, an increase of 28,443,979 over the previous year. During these years the line to Brooklyn had not been in operation, so that four stations on the list contributed nothing. In succeeding years these stations will make heavy returns. There is a uniform fare of 5 cents ($2\frac{1}{2}d.$), regardless of distance. In fact a passenger can ride 17 miles for this sum, and can change from local to express, and vice versa, many passengers taking three trains—a local to the next express station, an express train to the express station nearest their destination, and a local to the latter. The transfer from one service to the other has been found not only to exceed estimates, but to occur to such an extent as to seriously delay express trains. By far the greater burden of traffic falls on the express trains, whose cars are often crowded to the utmost limit while the local trains contain empty seats. The station of heaviest traffic is that at Brooklyn Bridge, which during the past year received 21,326,672 fares, and discharged presumably an equal number of passengers. Next in importance was Grand Central, with 10,391,676, and then 14th Street, both being express stations, with 8,688,025. As indicating the importance of express stations, even in residential districts, the 96th Street station took in 3,421,044 passengers, while the stations immediately south and north had 1,201,300 and 2,582,514 respectively. The actual tributary population does not differ materially in the three localities. Trains are run continuously during the 24 hours.

The gross receipts from the last year's operation amounted to $8,687,952·60, including an income of $368,484·36 from miscellaneous sources; the total expenditure was $3,883,369·68, leaving $4,804,582·92 to pay the interest-rental to the City and a satisfactory dividend on the Company's stock issued for equipment and other expenditure. The cost of operation per passenger was 2⅓ cents. The distribution of the total cost is about as follows:—

	Per Cent.
Maintenance of way and structures	13
„ „ equipment and plant	21
Operation of power-plant	24
„ „ trains and stations	35
General and miscellaneous	7

Conclusion.

Experience in the construction and operation of the New York Subway points to the following conclusions:—

(1) The cost of an underground railway is at best high, and in order that it may not become prohibitive, constructors must be given as much assistance as possible in the way of facilities, and the enterprise must not be burdened by heavy extraneous expenditure through the acquisition of so-called vested rights.

(2) That while shallow construction involves the difficulty and expense of readjusting all sub-surface structures, the total cost does not exceed the cost of deep-tunnel construction, especially when the capitalized cost of maintaining a lift-service at the stations is considered.

(3) Shallow construction, with the more convenient and quicker access to stations, undoubtedly attracts traffic.

(4) To the express service much if not all of the financial success is due. A two-track railway would have cost much less, but

taking as evidence the preponderance of passengers in the express trains and the increase in traffic, without corresponding loss on other lines, it would seem as if the receipts were increased by the express service in a higher ratio than the increase in construction-cost.

(5) An intra-urban railway, to be successful, cannot be a compromise in operation with stations situated at such intervals as to be too far for short-distance travellers and not far enough to afford the attraction of a high-speed service for long-distance passengers. It should give one or the other service, or preferably a combination of the two.

(6) Reinforced concrete is the most convenient and economical form of construction under a temporary roof in a street.

The Paper is accompanied by a tracing and several sunprints, from which the Figures in Plates 5 and 6 have been selected for reproduction.

Discussion.

The President. The PRESIDENT observed that he was sure it would be the wish of the members that the best thanks of The Institution should be accorded to the Author for his extremely interesting and valuable Paper. The Author had been a Member of The Institution for 15 years, but the present was his first appearance at any of its meetings. The members were very pleased to welcome him that evening, and were the more gratified that his first appearance should be associated with so valuable a communication as that which he had laid before them.

Sir John Wolfe Barry. Sir JOHN WOLFE BARRY, K.C.B., Past-President, observed that it gave him great pleasure to be allowed to say a few words. The Author could scarcely be looked upon as anything but half an Englishman and half an American; at any rate, the members looked upon him as a brother in engineering. All of them could learn lessons from the monumental Paper which the Author had set before them, descriptive of what could, without exaggeration, be described as a monumental work. He took peculiar pleasure in being present, from the fact that he had been associated with the Author for a good many months as one of the Board of Advisory Engineers to the Royal Commission on the Traffic of London, the members of which had derived great advantage from the Author's experience in New York; and Londoners were grateful to him for the help he had given in trying to solve a problem which was still unsolved, and which had been neglected in a way that nobody could have anticipated. He presumed the Author would not deny that in designing the very interesting work described in his Paper he had received some benefit from the experience of London. He had been able to see a large amount of shallow-railway work which had been previously done in London, some of it dating back 40 or 50 years, and a good deal of it not dissimilar to some of the work undertaken in New York. In many respects the Author had wisely improved upon some of the work executed in London so long ago; nevertheless, in respect of the main features of the New York subway, the Author would agree that he had gained some assistance from the constructors of the Metropolitan, the Metropolitan District, the Thames Tunnel, and other lines of that kind. He congratulated the Author very sincerely on his decision to adopt a shallow form of construction. He himself had been convinced for the last 30 or 40 years that that was the proper mode of constructing town railways, and he had never lost an opportunity of urging that view. He considered that, to be convenient, urban railways should be as near to the street as they could possibly be made, and that it was a mistake to carry people down to depths of 80, 90, or 100 feet in lifts, with the idea of gaining advantages which he was bold enough to say had not been realized. The seductive argument which had caused engineers to adopt tube railways in London was founded upon the existence of the impermeable London clay. It had been thought that boring through London clay would be cheap and easy, and would have great advantages over a shallow subway: but what was the result? The cost of tube railways had risen to £700,000 per mile; and the lifts had been found extremely expensive to construct and also to work. A passenger who made a horizontal journey by railway found that he also had to make two vertical journeys by lift—neither a cheap nor an expeditious mode of transit. In his opinion the old system of easy access to the street by commodious staircases was infinitely superior to any system of lifts, however carefully designed. Again, it had been thought that no disturbance of buildings would be caused by burrowing in the London clay. That anticipation also had not been realized. There had been very considerable—he did not say dangerous—disturbances, involving the payment of large amounts in compensation, while at the same time some alarm had been caused. It had been thought that the cost of the lifts and iron subways would be counterbalanced to a large extent by the cost of diverting gas- and water-mains. Of course, expenditure on such work was saved, but as to what the amount of that saving was, he might state his own experience in completing the Inner Circle through the most crowded part of London. Through Cannon Street Eastcheap, the Minories and Whitechapel Road, gas-pipes and water-pipes were encountered in every direction, including the great trunk gas-mains which supplied London and very important water-mains. On 1½ mile of railway the whole of the work on the gas- and water-mains had cost £26,000: what was that when dealing with expenditure at the rate of £700,000 per mile? It was also held by some that the shallow system involved danger to buildings; but what was the experience in building the Inner Circle, a full-sized railway, made through the most crowded part of the City of London—the most crowded square mile of the whole world—with lofty buildings adjoining, and through comparatively narrow streets. Absolutely no damage to property had been caused. Of course the engineers had been liberal in carrying out precautionary underpinning, but, nevertheless, Sir John Wolfe Barry.

Sir John Wolfe Barry. the cost of the underpinning on that $1\frac{1}{2}$ mile of railway was only £34,000. The figures here quoted he had taken from the final certificates of the work. Those savings were a mere nothing compared with the cost of two or three lifts at every station, considering first cost alone; but when the capitalized cost of working the lifts was taken into consideration, the financial facts were enormously against any undertaking involving lifts. Nobody could deny that the delay due to the lifts was very considerable; it could not be otherwise. The passenger had to change from the street to the lift, from the lift to the passage, and from the passage to the platform; and that made a great difference in the time occupied and in the cost of working the railway. Taking a lift 85 or 90 feet deep at each end of a journey of $\frac{1}{2}$ mile, it would be found that a very large portion of the time occupied by the whole journey had been spent in getting from the street to the train and back to the street. He had estimated that in a $\frac{1}{2}$-mile journey about 8 to 10 per cent. of the distance was travelled in lifts and passages. Such facts had convinced him many years ago that the tube system of construction was wrong; and he believed that as time went on it would be admitted by all that the tubes in London, although highly ingenious, well constructed, and admirably worked, could never afford the accommodation which was given by a shallow subway such as existed in New York, Paris, and Budapest. The Metropolitan Railway in Paris, with its numerous stations approached from the pavement, short staircases, and frequent trains, gave an amount of convenient accommodation which he was certain could never be given by the tubes of London. As journeys on the surface became easier, owing to the widening of streets and the development of quicker modes of surface transit, he believed the tube railways would suffer severely from that competition. Another point on which he thought the Author must be highly congratulated was that he had grasped the necessities of an express service as well as a local service. Unfortunately that had not been realized in the past in London, and he supposed it never would be now, unless some day a railway were built beneath the Metropolitan or the District Railway, and even that could not compare for a moment with the arrangements for the express service which was given by the New York Rapid-Transit Subway. The requirement of a person travelling from the suburbs to his business was that he should be carried quickly, and not be made to stop wearisomely at the innumerable stations which were necessary for local traffic. In the system of an express service interchanging conveniently with the slower trains, he thought New York possessed a means of urban communication which would be

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pre-eminently useful—a service such as all engineers would greatly desire to see in London, if only it were attainable. When he turned to the details of the work, he found so many things that might be discussed that he hesitated even to begin to refer to them. But the Paper would remain as a record of a highly successful and well-thought-out work, and all the members—at least those of them who ever saw any more London railway-work—would turn to it for information and guidance hereafter. One point which struck him peculiarly was the way in which the Author had restricted the width of the subway, by the use of steel. Owing to the difficulty of constructing shallow railways and subways in streets, a great advantage was gained when the outside width of the structure could be reduced, because the engineer was then able to leave, outside the walls, spaces for the accommodation of sewers and gas- and water-pipes, and for fortifying-works for adjoining structures. Therefore, the Author's success in making efficient side walls of a width of 2 feet or 2 feet 6 inches instead of 5 feet, as in London, meant that he had saved a 5-foot strip all along the railway, which was an immense advantage. He could speak from practical knowledge of the far greater ease there must be in building a subway of that width, as compared with a subway of the width adopted in London. When the side walls of the Metropolitan and Metropolitan District railways were designed, there was not so much experience of the use of steel for such structural purposes to guide the engineers, and in that respect the Author had much improved upon older practice. The height of the subway did not differ more than about 6 inches from the height of the Metropolitan and Metropolitan District lines, so that in that feature they were not dissimilar, and the London lines accommodated the ordinary rolling stock of the country. He thought he was right in saying that the stress the Author had put upon the steel was certainly higher than was put upon similar work in England, or than engineers would be allowed by the Board of Trade to put upon it. He believed it worked out to about 9 tons per square inch, which was considerably more than English engineers would be prepared to adopt. The results of the traffic had been very encouraging, and he thought the Author was right in saying that the great success of the New York system of subways was due largely to the introduction of the express service. From the financial point of view he was quite certain it must have a very important effect; and if on the Metropolitan line in London the same service could be given to the suburban passengers as was given in New York, the receipts would be much larger than they were at present. People were

Sir John Wolfe Barry. driven off the London railways by the wearisome delays due to stopping at (to them) unnecessary stations. The Author was also very fortunate in having 5 cents as a uniform fare as compared with 2*d.*; and he supposed that must be put to the credit of the decimal coinage. Happily for those who had made the subway in New York 5 cents was, he supposed, the equivalent for the English 2*d.*, but people did not seem to recollect that ½*d.* added to 2*d.* was a very large addition; and if those who were interested in London railways could by a stroke of the pen add ½*d.* on to the fare of every passenger they carried, their balance-sheets would look very different. He supposed the London railways would have to start at 3*d.*, as they could scarcely adopt 2½*d.*, and if that were done the shareholders would be still better off, if they could secure the same number of passengers, which, however, he did not think they would. It was lucky for the New York Company that in America 5 cents was apparently almost a negligible quantity; but the extra ½*d.* made a great difference in the finances of the undertaking. He had been much struck, also, with the admirable section of column shown in Fig. 3, Plate 5, which must be very cheap. As far as he could form an opinion, the section was well designed and simple, and its parts were easy to roll. The work under the river almost required a Paper and a discussion of its own, and he had not had time to study the drawings in the way he would have liked; but he was certain they would be very useful to those who had to look into such matters hereafter. On the whole, The Institution had received a very interesting Paper, and the members had every reason to be grateful to the Author for coming among them, giving them the results of his experience, and pointing out improvements to which English engineers ought certainly to give careful consideration. He might express his personal regret that he had never seen the subway in actual operation; but in his mind's eye, and with his knowledge of London traffic, he thought he could very nearly judge the ease with which the traffic was carried on, and New York was to be highly congratulated on having taken the matter in hand so thoroughly. As far as he could judge, the great improvements in New York which had been described in the Paper were due to the establishment of the Rapid-Transit Board. That Board was not only a consultative body but had also power to act, and it had acted in a very judicious way in the laying-out of the lines and the appointment of the Author. A body of that kind was what all engineers sighed for in London. It was the main thing recommended for adoption by the Royal Commission on the Traffic of London; yet it had been utterly neglected by both Governments, and London was now in the same position as it was before the Royal Commission sat. There

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was no Transit Board and no general body to take into consideration the local wants and the larger wants of London. Until a body of that kind was constituted, with whatever powers it might please Parliament to endow it, he felt sure they would go muddling on in London in the way they had done for so many years, finding obstacles erected against improvements which should never have been erected, the widening of streets and through routes neglected, and the whole matter continuing without any intelligence or foresight and in that happy-go-lucky way which seemed to be the pride of Englishmen, but was certainly not admired by any other nation in the world.

Sir William White.

Sir William White, K.C.B., Past-President, remarked that his excuse for taking part in the discussion was to be found in the fact that when The Institution visited New York in the autumn of 1904, during his Presidency, those members who had the pleasure of joining in the visit had the opportunity, thanks to the courtesy of the Author, of visiting the Rapid-Transit Subway at a very interesting stage of its construction. He saw present several of the members who composed the party, many of whom were much more competent than he was to speak of the engineering details of the work; but on their behalf, and on behalf of The Institution, he desired publicly to thank the Author, and those who joined with him in acting as the hosts of the members while they were in New York, for the great kindness shown to them throughout the visit, which they would never forget. They had had the opportunity of seeing not merely a large section of the completed work, which was being prepared for practical use within a very few weeks of their visit, but also of going into portions of the work still in process of construction, and there seeing the difficulties which had to be met, and the boldness and resource with which they were being overcome. Those of the party who went down Broadway one Saturday morning would, he thought, never forget what they saw. In that great thoroughfare, crowded with surface traffic, the works were proceeding only a few feet below the street-level. It was a fearsome sight—gas-pipes, water-pipes, and other things hung up, as it were, to a temporary structure, over which tramcars, heavy wagons, and multitudes of people, were passing freely. He well remembered many engineers of experience in tunnelling work who were of the party being deeply impressed with the nature of the work that was being undertaken, and the rapidity with which it was being pushed forward. They emerged finally into Broadway through a man-hole in the sidewalk, much to the surprise of the passers-by, because the party was a numerous one. Passing

Sir William White. from that section, which was the approach to the decline that led down to the tunnel under the East River to Brooklyn, they had the opportunity of going right out to the north end of Manhattan, and there seeing the other extreme of the work, where the rapid-transit line, called a subway, developed into a succession of viaducts, and passed through some interesting and striking scenery. Throughout the work he thought the general impression made on the minds of the party was that although they were told there was a standard method of construction—and for certain lengths that was true—yet there was almost infinite variety in the methods by which local conditions were met. Another thing which was remarked to him on many occasions by railway-engineers of the party was the freedom with which the engineers of the subway could work—a freedom vastly greater than would be possible under existing conditions in England: he referred to some of the arrangements in the stations and not in the subway proper. In the positions chosen for supporting-pillars in relation to the edges of the platforms, and in many other ways, regulations which were regarded as absolute in this country were certainly not conformed to in New York; and, so far as he had been able to learn, the departure from what were considered essential conditions here had not been accompanied there by any particular injury to life or limb. But that was not all; that was only on the engineering side. The conditions of construction in New York, as compared with the conditions in England, had differed in other ways, which were important as influencing the cost. There was a very interesting statement on p. 34, where the Author said: "House-vaults were held not to be property, but only a revocable licence from the city. The owners therefore received as compensation only the price paid originally to the city for the right of use. A few instances dated back to colonial and early times, when the original price was stated in bushels of wheat. The city repaid not in kind but in market value of the grain on the date of settlement." He wondered what would be said in England if a proposal of that kind were made. He remembered many years ago a proposal, which Sir John Wolfe Barry would recollect, to make a sub-surface line down Oxford Street, very closely resembling what had been carried out on a much larger scale in New York. He remembered the drawings quite well, and also the correspondence that took place in the newspapers, when the shopkeepers in Oxford Street rose in revolt, and said this thing should never be, because customers would be driven away while such a work was in the course of construction. The project would have been an

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anticipation of the Central London tube for a great part of its length, but it never got farther than the House of Commons. In New York the gneiss rock was blasted out in the public streets in the freest possible way. Probably the Author would say he might have chosen the night to do it in, which could scarcely have helped the slumbers of those who lived in the neighbourhood! Sir John Wolfe Barry had spoken of the Traffic Board, but in New York the engineers had behind them the power that created the Traffic Board, namely, the local authority, and he believed the Author had been practically a despot during the construction of the line. If those conditions could obtain in England, even for only a short time, English engineers would probably be able to do many things which they were not able to accomplish at the present time. With regard to the electrical equipment, the party saw enough on their short visit to realize the great ingenuity which had been bestowed upon that section of the work; in fact, they had experimental proof of the remarkable ingenuity of some of the electrical arrangements. He mentioned the fact in public with fear and trembling, remembering what might happen to him afterwards; but the party had had explained to them, before descending into the subway, the arrangements that had been made whereby if a driver were seized with illness, or died suddenly at his post, the train would stop automatically and the passengers would be safe. The party started out on the voyage to the north of Manhattan, and he could not say how many proofs they had *en route* of the capability of stopping. They stopped in the most unexpected places in the most sudden manner, and he was afraid the Author used very forcible expressions in regard to this demonstration. It was only fair to say that these things happened before the line was in complete working order. When he went back to New York about a month afterwards, the Author insisted upon his going over the line again. He did so with very great pleasure, so far as having another chance of going on the Subway with Mr. Barclay Parsons was concerned, but at considerable inconvenience to himself, because he was leaving for England almost at once. On that occasion the automatic electrical appliances were in perfect working order, and there was not a hitch from first to last. He understood that the subsequent working of the electrical appliances had given great satisfaction. There was one question he desired to ask the Author. After looking through the Paper, he could see no allusion to the question of ventilation in any detail. He remembered seeing in the newspapers, after the party came back from America, and the line was opened, complaints that the ventilation was not all that could be desired. He knew the difficulty had been

Sir William White. surmounted, but it would be interesting if the Author would state whether it had been serious or exaggerated, and also how the ventilation was dealt with. To anyone visiting the line it seemed almost certain that the motion of the trains and the free access to the outer air would make the problem of ventilation a simple one, but he would be much obliged if the Author would state what the facts were. He thought Sir John Wolfe Barry had sufficiently expressed the importance attaching to the Paper and its wealth of detail, but he was sure that those who read it in the Proceedings would agree with the members present in saying that the Author had conferred upon them the greatest possible kindness in coming himself to England while the Paper was being read, and in placing at the disposal of The Institution such a mass of valuable information.

Mr. Ross. Mr. A. Ross, having been one of those who had the great pleasure and benefit of joining the party which was so well received all over the States, especially in New York, desired to say that the attention paid to them on their visit to the works of the Subway, then coming to a conclusion as regarded its inner lengths, was extremely courteous and profitable. The Author spared no pains or trouble in giving details and information which would be likely to interest the party. As regarded the Paper itself, the conditions regulating the means of transport in New York and the conditions in London were entirely different. London was a huge area enclosed by an outline resembling a complete circle, the radius of which was about 5 miles. All the traffic to and from London converged at some point within that circle, generally speaking on a base-line which extended from the City to Victoria Station. As in all large towns, the traffic consisted of a vast influx of people in the mornings, and a similar exodus in the evenings, with a general flow up and down throughout the day. New York, on the other hand, was enclosed in what might be called a great parallelogram about 14 miles in length and only 1½ mile in width. There the traffic in the morning was from north to south, practically all of it going to the business quarter at the extreme south, while in the afternoon and evening the traffic was all the other way. In both cases there must be a more or less even traffic either way during the day. The conditions for laying out a railway in those cases must be entirely different. With regard to the question of subsoil, in London there was a great depth of London clay underlying the surface, whereas in New York there was the hardest material imaginable—gneiss rock. There could be no doubt that the fact that London clay was an easily-penetrated material had led up to the construction of the tube railways. The shield had been found very useful on many other occasions, but primarily it had been designed for penetrating the London clay. Bearing in mind the respective conditions, it was obvious that a deep tunnel was not a suitable thing for New York, but it was supposed to be the easiest thing to construct in London, inasmuch as it was not necessary to interfere with the surface, nor with sewers, pipes, and mains. Whether it was the wisest thing he was not prepared to say. He agreed with Sir John Wolfe Barry that there was a great deal to be said on the other side, and there could be no doubt that a railway nearer the surface was better for the general travelling public. Still there was a certain amount of reason why London had been led into making tubes. The shallow subway in New York was admirable in every way. The engineers of the visiting party had been highly interested in the way in which everything was done—in which, as Sir William White had said, every difficulty that arose was immediately tackled and solved. The nearest approach to the New York subway was the Metropolitan and Metropolitan District railways, which preceded the New York line, and the next, and he thought probably the most like it in every way, was the Paris Metropolitan railway. Coming to the question of the construction, there was a mass of detail in the Paper which was invaluable to the engineer, and almost every sentence of which might lead to a long discussion. The results of the testing of all the materials, in view of the extreme care with which the work had been carried out, were very valuable. Particularly valuable to him was the simple way in which the reinforcement of the concrete had been made. It was obvious from the mere inspection of the drawings that no more and no less had been done than was absolutely necessary. The advantage of the express tracks was a great feature in the laying out of the line. That was quite possible and almost necessary in a straight line 25 miles in length; but in the London lines—for instance, the Central London tube, which was $6\frac{1}{2}$ miles in length—there was scarcely the same necessity for express lines, because the time gained would not be so much as on a long run. It was obvious, however, that in New York the express service gave great facilities for rapid transit. He was sure everyone was very glad to hear that it had been possible to make a return on the capital expended. Sir John Wolfe Barry had taken up a point Mr. Ross had intended to make himself, namely, that if an extra $\frac{1}{2}d.$ per passenger which 5 cents gave could be given to the "Twopenny Tube" it would make a great difference in the financial results. With regard to the six conclusions arrived at by the Author, he thought all engineers would admit that they were correct and indisputable. Mr. Ross.

Col. Yorke. Colonel H. A. YORKE wished to follow the previous speakers in expressing his high appreciation of the cordiality and courtesy with which the Author and his assistants had received him on the occasion of his visits to New York in 1902 and 1905, and to thank them for the trouble which they took to show him all that they were doing in the construction of their great undertaking. It was always a pleasure to Americans to welcome Englishmen, and among no class was that more marked than among American engineers and railway men. Attention had already been directed to certain general features of the work, and more particularly to the boldness and originality shown in designing and carrying it out, as well as to the ingenuity with which difficulties had been met and overcome; and he proposed to say a few words on one or two details which were of special interest to himself. Sir John Wolfe Barry had observed that the stresses in the roof girders were high, amounting to as much as 9 tons per square inch. In another part of the Paper Colonel Yorke noticed that the girders which carried the elevated portion of the railway, and which would have to bear the rolling loads of the trains passing over it, were not stressed so much. On p. 24 it would be seen that in the longitudinal girders the stress was limited to about $4\frac{1}{2}$ tons, and in the cross girders to $4\frac{1}{2}$ to 5·8 tons, per square inch. The Author explained the high stresses in the roof-girders of the subway by saying that a very liberal estimate had been made of the loads that might be brought upon the girders; and probably the Author had also in his mind the point that those loads would only come on the girders at rare intervals: that was to say, the maximum loads for which he had provided were the piling-up of materials for building purposes in the streets, or the fall of a building into the street in case of fire, or other special loads of that description. That being so, perhaps it was legitimate to take rather a higher limit of stress for the roof-girders than was usually taken in England. The stresses of the girders of the elevated structure, which might be regarded as regular working-stresses, accorded with English practice. The stations seemed to him to be laid out in an admirably convenient manner, and he was particularly glad that the Author had laid great stress on the necessity of having the entrances and exits from a platform situated as nearly as possible in the middle of the length of the platform. That point had come to his own notice on more than one occasion in connection with the plans of the more recently-constructed tube railways in London, in which every effort had been made to keep the exits and entrances as nearly as possible in the middle of the platform. Unfortunately it

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was not always possible to do that, as, owing to the difficulties on the surface in connection with sites and the width of streets, it was not possible in all cases so to arrange the street-approaches to the stations and to construct the lift-shafts and stairways in the necessary positions. In those cases the exit had to be placed at the end of the platform, which undoubtedly was not a desirable arrangement. Sir William White had drawn attention to the fact that columns were placed along the edges of the platforms, and he gathered that Sir William thought that the arrangement of those columns was a point that would probably appeal to him. Of course, in England the regulation was that columns or works of any description should not be nearer to the edges of platforms than 6 feet. The reasons for that rule were fairly obvious: steam-trains with side doors opening outwards, accumulations of luggage on platforms, and the wheeling of large barrows of luggage along them, and the well-known fact that passengers would put their heads out of the windows to say good-bye to their friends, were some of them. Such conditions did not exist in America, nor did they exist on tube railways or underground railways where the rolling stock was of the type in use at the present time, with sliding doors and with windows which could not be opened for people to put their heads out. The luggage question did not arise on tubes and underground railways, and therefore from that point of view the placing of columns as little as 15 inches from the edge of the platform would not be objectionable. But there was one reason why columns should be kept back from the edges of platforms even on tube railways, and that was in the interests of the train-men. The motor-man had to put his head out of the window to receive from the guard the signal to start the train. The gate-men and conductors in charge of the various cars had to be on the platform until the train had commenced to move, and then they had to do their best to get into the various cars; and if they had to run along the platform at all the presence of columns alongside the train would be highly dangerous to them. Therefore he was glad to see that, on the tubes and underground railways in England columns had not been placed near the edges. He ventured to think that the placing of these columns so close to the edge of the platform was a defect in the otherwise excellent arrangement of the stations of the New York subway. With regard to the permanent way, he noticed that the sleepers were much lighter in section than was common in England, and he concluded that they were placed closer together than they were here, which was the usual American practice; in that event the section was probably amply sufficient. The Author said nothing

Col. Yorke. on the subject of corrugated rails, and Colonel Yorke did not propose to enter on that much-debated question. There were many theories on the subject, but as far as he knew, not one of them held the field at the present time. An ounce of fact was worth a good deal of theory, and he ventured to ask the Author, when he replied to the discussion, to say whether there had been any trouble in the New York subway due to the corrugation of rails. It was interesting to note in that connection that on the more recently constructed tubes—the Baker Street and Waterloo, the Great Northern, Piccadilly and Brompton, and the Charing Cross, Euston and Hampstead lines—the trouble of corrugation had not arisen. That was somewhat remarkable, inasmuch as the wheels, the trucks, and the motors, and he believed the whole sub-structure of the cars on those tubes, were precisely the same as on the Metropolitan District Railway, where the corrugations had been exceedingly troublesome. The method of guarding the third rail seemed to him to be an excellent way of protecting those men who, more than any other men on a railway, needed protection, namely the permanent-way men. Those men had enough troubles to guard against in watching the trains running on the rails on each side of them, and he had always sympathized very strongly with those who now had also to pick their way among highly-charged electrical conductors. When the question of electric traction was first discussed in England, he hoped very much that some method of guarding the third rail by means of a horizontal plank, such as that shown in Fig. 18, Plate 6, would be adopted. It was similar to what was used on the Metropolitan Railway of Paris, where he first saw it. For some reason or other it had not been received with readiness by English railway-companies; difficulties seemed to be anticipated with regard to it, and the present mode of guarding the third rail was by means of a plank placed vertically on one side or on both sides of the third rail and projecting a couple of inches or so above the level of the top of that rail. He believed that one of the difficulties anticipated with the horizontal-plank method was that, in the event of the collecting shoe not being kept always in accurate adjustment in relation to the permanent way and the third rail, it would strike the plank placed above the third rail, and would rip it up and do general mischief, and might possibly give rise to dangerous short-circuiting or other troubles. On that point also it would be very interesting to hear from the Author whether any difficulty had been experienced in New York. The arrangements for signalling were distinctly interesting and novel, or novel so far as the absence of signalling upon the local or stopping tracks was concerned. On the express track the signalling was of the usual automatic description combined with automatic train-stops, such as had been in use in America for some years past. He did not know where it was first introduced, but it was used many years ago on the Boston railways, both elevated and underground, and it had been adopted in England on the Metropolitan District line and on the three more recently constructed tubes, already mentioned, and he believed it had yielded admirable results. The novelty about the New York subway was that on the local tracks, upon which trains stopped at every station, no signals at all were provided. In that case the driver of one train had nothing to guide him except the tail-light of the train in front of him. He was asked not long ago by a General Manager of one of the underground railways of London what he thought of the arrangement, and he hoped that he gave a sufficiently discreet answer. It seemed to him that, although it sounded very simple to say that the motor-man of one train was to be guided by the tail-light of the train in front of him, it was difficult for the man to realize whether that tail-light was moving away from him or whether it was stationary. Under normal conditions he would think it was moving away from him, and as a general rule, when the train in front stopped at stations, he was prepared for that stop. But supposing the train in front to be stopped at some unexpected point, owing to some failure of the electric current, or for any other reason, how was the motor-man of the train in the rear to realize at once the fact that the train in front had come to a stand? He would probably not realize it for some appreciable period of time, and possibly he might not realize it soon enough to prevent his running into the tail of the train that had come to a stand. It had struck Colonel Yorke that that might be got over to a certain extent by providing an additional tail-light, which would only be lighted as soon as the train stopped. There would be no difficulty, for instance, in having a light that the guard could turn on the moment the train came to a stand, and turn off the moment it moved away, such light to be in addition to the ordinary permanent light; or, better still, the second tail-light might be brought into use automatically by the stopping of the train. Whether that would be found a practical solution of the difficulty he was not prepared to say; it would of course require experiment. At any rate he threw it out as a suggestion for what it was worth. But even supposing it was possible to adopt some method of that sort for minimizing the risk accompanying the absence of signals, there was still another tribunal far more powerful than the Board of Trade to be consulted, Col. Yorke.

Col. Yorke. namely, the public. Would the British public consent to travel upon an underground electric line upon which they knew there were no signals? The final decision would rest upon that. If the public refused to travel by the railway which adopted such a system, the railway would be in an uncomfortable position. To those who had not been to America, and especially to the younger members of The Institution, he wished to give the advice to go there as soon as they conveniently could. There was a vast amount to be seen and learnt in that immense country, and he felt sure that they would find, as he had found, that a trip to America was one of the most enjoyable and instructive experiences of their lives.

Mr. Galbraith. Mr. Wm. R. Galbraith, Vice-President, wished to make a few remarks on the points raised by Sir John Wolfe Barry with regard to the light the New York subway threw upon the future underground railways of London—for no doubt, after a time, more tubes or underground railways would have to be constructed in the metropolis. He wished to contrast the cost of the two systems which were likely to come forward in London, based upon the experience of the cost of the subway in New York. He found that the shallow subway of New York cost, on an average £468,000 per mile of double track, dealing only with the shallow subways and not with the overground portions. The Author gave the total cost at $1,000,000 to $1,250,000 per mile, and he had taken the mean between the two, as a fair figure. Adding the equipment, which cost £136,000 per mile, the cost per mile of double-track line as laid out by the Author was £604,000. Mr. Galbraith had been connected with the Waterloo and City railway as Engineer, and it was the only one of which he could give the exact cost per mile. The length was a little over 1½ mile (1 mile 47 chains), and he had the figures for the whole cost, including construction, equipment, land, and everything up to the opening of the railway, even including engineering, which was not a very heavy amount, and interest on capital during construction. The cost of the Waterloo and City railway, for two lines of rails from Waterloo to the Mansion House, was £439,000 per mile, but as there were only the two terminal stations he had thought it fair to increase that figure by the estimated cost of an intermediate station. There would have been room for only one intermediate station, which probably would have been somewhere near Blackfriars. For that station he had added £70,000, which increased the cost per mile by £44,000, so that the total cost of the Waterloo and City railway per mile, for comparison with the Author's £604,000, would be £483,000, showing a saving of about £120,000 per mile in favour of the Waterloo and City line. On that line the tubes were a little larger than on the Central London; they were 12 feet in diameter on the straight and 12 feet 9 inches at the sharp curves, whereas the Central London tubes were 11 feet 6 inches. The cost per mile of the Waterloo and City line included the concrete lining of the tunnels, and he thought there was nothing of that kind on the running-tunnels of the Central London. Sir John Wolfe Barry had made rather an onslaught on tubes. He had given the cost of one tube, probably the Piccadilly line, as £740,000 per mile; he had objected to the disturbance of buildings and to the delay in the lifts; and had concluded by saying that the tube-railway system of London was totally wrong. With regard to those objections Mr. Galbraith would like to say a few words. There was no need to spend £700,000 per mile on a tube railway in London, and it seemed to him that some financial mystery must be responsible for that figure. He had already given the cost of one tube railway at £483,000, and he failed to see the ground for £700,000. With regard to damage to buildings inflicted by tubes, the figure he had given with regard to the Waterloo and City railway included all damage to buildings because the contractor's price covered that item. What damage was inflicted the contractor had to pay for himself. He did not know what had been spent on the Central London railway in compensation for damage to buildings, but on the Baker Street and Waterloo, which was 4½ miles long, and on the Charing Cross, Euston and Hampstead, about 8 miles long, double track, although these lines ran through very crowded parts of London, and, in places, through very narrow streets, the total cost of damage to property was only about £3,000 or £4,000 on the whole of the lines, from Charing Cross to Highgate and to Golders Green on the one line, and from the Elephant and Castle to the Great Central railway on the other. Of course if a railway was not properly constructed and maintained, the cost very soon mounted up, but if it was constructed properly, and the rings were grouted as the work went on, there was no need of any apprehension of great outlay in compensation for damage to property. On the Waterloo and City railway a little damage to property occurred in the neighbourhood of Walbrook, where there was a very treacherous bit of ground, consisting of an embankment deposited many years ago. At one end of the street certain failures occurred; the contractor did not admit liability, but compromised by repairing the buildings, and nothing had been heard about it since. With regard to the delay at the lifts, Mr. Galbraith freely admitted that a shallow subway with short stairs to the street was far better than a tube with lifts, causing a certain amount of delay. But the question was, were shallow subways in London practicable? He had very great doubt about that. He did Mr. Galbraith.

Mr. Galbraith. not think the people in London would consent to the construction of a double line up Regent Street, for instance, or in the City, or along the Strand, having regard to the disturbance caused by the rearrangement of pipes during construction. His belief was that, although in the outskirts shallow subways might be built, they could not be constructed in the principal thoroughfares of London. With tube railways the interference with the streets was reduced to a minimum. He believed that the people of London between Waterloo and the City hardly knew that a railway was being constructed. Scarcely an ounce of material or excavation was carried along the streets: the excavation was all taken out to a stage in the river and barged away, and the materials for construction were brought in by river. The point raised was that if it could be done in America, why could it not be done in London? He could only say that the ideas of property in America and in England seemed to be very different. In America nothing was paid for the subsoil of the street or even for removing a man's cellar. In New York, the contractors seemed to have had a very free and easy time; in fact, the Author said that "great latitude was given to the contractor in the way of obstructing streets." He did not propose to go any farther into that matter, as Mr. Fitzmaurice would probably be able to say something upon it. The greater portion of the railway in New York was in rock; blasting was done in the streets, and one of the blasts not only blew up the subway but let down three houses. One defect of the London tubes was the enormous cost of the stations. The cost of the work in connection with the tubes themselves was comparatively moderate, but he was almost afraid to think what the property and the station itself cost. In New York the stations were built under the streets, and that had been done in two cases in London, one being the Trafalgar Square station on the Baker Street and Waterloo railway, which had been a great success. At first it was intended to put a station, by permission of the Commissioners of Woods and Forests, in the middle of the road, near the statue of King Charles I., but it was found that the rearrangement of the pipes and the sinking of the shafts would involve so much delay and expense that an arrangement was gladly come to with the Commissioners to pay a certain sum of money to be allowed to put the station near the Trafalgar monument; and that station had been built without the slightest disturbance of anything in the neighbourhood. It was within 35 feet of the foundations of the Nelson column, and although that column had been very carefully watched, there was not a sign of any disturbance. There was one thing in which he was glad to agree with Sir John Wolfe Barry; he believed that no more tube railways could be made in London by small private companies. Further tubes must be the work of a powerful body able to give tube railways their proper chance of doing the work at a fair price and getting a fair dividend for the money expended. Over and over again he had noticed that, when a Bill was promoted by a small company, immediately it came before Parliament sheaves of petitions against it were lodged. In one instance within his knowledge there came, first the London County Council, then the borough councils, then the Thames Conservancy, the Gas Light and Coke Company—as a matter of fact, there was a general provision for pipes, but the Gas Light and Coke Company had a petition of its own—the water-companies, the telegraph- and telephone-companies, and the railway-companies. He believed that in some Bills there was a provision that the accesses to railway-stations must not be obstructed even by interference with the streets, and the large railway-companies victimized the small ones, who had no money to fight with and were therefore obliged to yield. Finally came the private owners, followed by the Crown in the shape of the Commissioners of Woods and Forests. In the presence of Mr. Fitzmaurice he wished to express his indebtedness to the Engineers of the London County Council in this matter. He had worked in the most amicable way with them, and felt nothing but gratitude towards Sir Alexander Binnie and Mr. Fitzmaurice for their treatment of the tubes. But they were not all-powerful; there were other officials. Besides petitions against the undertakings, the tubes had to face the demands of the County Council for the widening of streets, in connection with stations, in the entrances and exits of which that body had a voice. The Oxford Street station was very costly, and yet the County Council wanted a bigger one. Probably they did not know what it would cost. The railway went to arbitration with the Council, and he was glad to say the railway won. If more tube railways were to be built in London, the owners of the tubes must not be left at the mercy of such a host of petitioners. Immediately he received a notice, a man went to his solicitor and the result was a petition. He agreed that the shallow subways of New York, if they could be introduced into London, would be first rate things, but his deliberate conviction, based on his experience, was that they could not be introduced. The public would never sanction them—he believed there would be a sort of revolution if they were attempted. He noticed on the table some photographs of what the streets of New York were like when the work was going on, and he would be afraid to put his neck into the noose by attempting such work in London. With regard to the engineering work of the New

Mr. Galbraith.

Mr. Galbraith. York subway, he quite approved of the flat-roof construction. The width between the columns (12 feet) decided of course the width of the carriages, which was the same as on the Waterloo and City railway. No doubt the form of the cross section had a great advantage in the room it gave in the upper part of the carriage. He had intended to say something about columns at the edges of platforms, but Colonel Yorke had already disposed of that point. No doubt the carriages were not fitted with side doors, but there was still that source of trouble in England, as he noticed the Metropolitan railway continued to run the old carriages with side doors. Delay in the lifts had been much aggravated lately by the change in the fares. When there was only one fare the passenger dropped his ticket into a box and the matter was ended; now he had to show the ticket as he entered the lift on arrival, and again on entering the lift at his destination. That all caused delay. The logical deduction was to have only one fare; but that had been tried and found wanting, for the public would not pay 2*d.* to ride half a mile along the street when they could take a penny omnibus. With regard to reinforced concrete, he was glad to see the Author used a waterproof covering all round. Reinforced concrete was very good if water was kept away from it. At Southampton and Liverpool, where a good deal of reinforced concrete had been used, there had been failures, the water finding entrance to the rods and causing rusting and scaling. It was necessary to have the rods thoroughly surrounded with the best of concrete. He had had an idea that painting the rods would afford better protection against rusting, but he noticed that the Author's experiment of applying a coat of paint to the iron spoilt the adhesion of the concrete to the metal, and therefore he had given up that idea. The actual tunnelling was much the same as had been done in London. In conclusion, he complimented the Author on his very instructive and admirable Paper.

Mr. Mott. Mr. Basil Mott had read the Paper with the greatest interest and had learned a great deal from it. He had hoped that some of the designs might have assisted in dealing with the traffic-problem in London, but he was afraid that was not so. He thought that anyone who had studied the subject of London traffic would agree that if a shallow subway was possible there was no doubt that it was the proper thing to have, but the question was whether it was possible. Sir John Wolfe Barry had spoken very strongly against tubes, and he believed Sir John never had liked them, looking on them as a sort of glorified sewer, with not much glory left. There was something in that view. They were very much like sewers—especially the latest sewers constructed by Mr. Fitzmaurice—and they sometimes had a smell. It had been his privilege to be associated with the late Sir Benjamin Baker in making several tube railways in London. Sir Benjamin did not care for tubes and would have gladly substituted a subway, but on going into the designs and estimates the conclusion was come to that in London subways were impossible. In the case of the Central London railway the cost per mile was rather higher than Mr. Galbraith had given for the Waterloo and City—it was £631,000; but then the Central London had very expensive land to purchase, which was not the case with the Waterloo and City line. The estimate of cost for the cheapest kind of subway in London that Sir Benjamin Baker worked out was practically £1,000,000 per mile, which included the pipe-subway, and diversion of the various electric cables, sewers, etc. That was practically the cost of the latest shallow railway, the Whitechapel and Bow line; the actual cost of construction was, he thought, £780,000 per mile, to which had to be added the cost of equipment. From experience in constructing the station for the Central London railway at the Bank, he thought the cost of moving pipes was much greater than anticipated in making the estimates. The cost of diverting the pipes and wires for the Central London station at the Bank for a distance of about 300 yards was £25,000. Sir John Wolfe Barry had stated that he had constructed a line of 1½ mile and the total expense of diversion of pipes, etc., was only £26,000. Mr. Mott did not see how that could be reconciled with his own experience, because in congested areas the cost worked out in practice at very much more than that. Mr. Fitzmaurice had been asked by the Traffic Commission to make an estimate for a shallow subway, for their convenience, and his estimate worked out at £1,000,000 per mile through the congested area; but Mr. Mott was rather inclined to think that with the later experience Mr. Fitzmaurice had had in diverting pipes for the conduit system of tramways, which necessitated going only to a depth of 3 or 4 feet, he would probably increase his estimate. Another very serious difficulty in London in the way of constructing shallow tramways was that there were few remaining routes where such a subway could possibly be made, because there were so many existing impediments which could not be diverted, such as shallow railways and main sewers running at right angles to the routes. To have a shallow subway with gradients suitable for working was impossible, because the subway would have to dip so frequently to get under the railways and other things that it would ultimately come to tube construction with lifts. That, he thought, was inevitable, and was altogether apart from the question of cost. He thought the difficulty

Mr. Mott.

Mr. Mott. of dealing with the matter was also shown by the fact that, before the tubes came to the rescue in 1884, there were thirty-six schemes for shallow railways in London between 1855 and 1885, and none of the suggested schemes was ever carried out, on account of the cost, except, of course, the Metropolitan District and the Metropolitan railways. That position with regard to cost still existed. A shallow line could not be made for less than £1,000,000 per mile, and he thought the Advisory Engineers to the Traffic Commission had come to much the same conclusion. Dealing with short railways of high cost, they said[1]:

"The short lengths of railway, to which the cost of over one million a mile apply, were in many respects exceptional, but, however that may be, it will be seen, on the basis of the above figures, and of Mr. Fitzmaurice's estimates, that the extra cost of carrying out the works of a 'shallow' railway with large stations, under a street that has such heavy traffic as the Strand or Piccadilly, would be approximately £1,000,000 a mile, including generating stations and equipment, so that there is no escape from the conclusion that such lines cannot be made on a commercial basis as independent undertakings by private enterprise."

He thought that was fairly conclusive that shallow subways would not and could not be made in London under existing circumstances. If the present tubes were not everything that could be desired, what was to be substituted in their place? He quite agreed with Mr. Galbraith that unless some authority was appointed which could give greater facilities in the way of free easements and stations in the streets, there would be neither shallow subways nor more tube railways. Something should be done also for the relief of the rates and taxes. The Central London railway had to earn £60,000 per annum out of pennies and twopences to pay rates and taxes alone—a frightful burden, from which railways, in view of their great benefit to the public, might be relieved. With regard to the type of construction in New York, it appeared to him to be extremely light, and he doubted very much whether, if Sir John Wolfe Barry had to carry out another section of the Inner Circle, he would advise the adoption of such a light section. Again, were engineers really satisfied from their experience that steel buried in concrete was the right thing to adopt for permanent structures? No doubt for temporary structures, such as the buildings for the Franco-British Exhibition, it was admirable, but for permanent structures he doubted whether it was the right thing. He did not think there had been enough experience of it. In widening Blackfriars Bridge hoop-iron bonding had been found in

[1] "Report to the Royal Commission on London Traffic by the Advisory Board of Engineers," p. 108. London, 1905.

the abutment, and from the heart of the abutment, above water-level, some of that hoop-iron had been taken out, which he had laid on the table. It would be seen that it was absolutely destroyed, although it had been buried in a practically impervious mass—much less permeable than most concrete. The idea of the express line which the Author had constructed was undoubtedly admirable, and if the money could have been found, such a line would probably have been constructed on the Central London. Arrangements had always been made for sufficient space to be left for an express line underneath the Central London railway. The District railway actually had powers to build an express line from Hammersmith to the Mansion House, but for some reason—no doubt a good one—that scheme had been dropped, and a portion of the project had been carried out in the form of the Brompton and Piccadilly tube, which seemed to be a competing line with the District railway between Hammersmith and Kensington. Mr. Mott.

Sir George S. Gibb was afraid he could not contribute much to the discussion of an engineering Paper by a distinguished engineer in a company of distinguished engineers, as he had no engineering knowledge. The Paper was the record of a great engineering achievement, which, he was glad to see, was also a commercial success. He could quite imagine any engineer who had to do with it revelling in the job; he was surrounded by that atmosphere which seemed to be so congenial to the engineer and to bring out his best qualities—surrounded and supported by an ample supply of cash! But the field for the enterprise was unique. First of all, it was necessary to consider the origin of the enterprise, which was based upon an urgent and overwhelming need for better and more means of conveyance in New York. The traffic was there, the people were moving and wanted to move, and he could not imagine a more fruitful source for enterprise of that sort than existed in New York. The subway could not be referred to as a triumph for private enterprise. On the contrary, although the field was so fruitful and so rich, although the Americans were certainly never deficient in commercial courage, nor wanting in sanguine temperament, they had not come forward to make the subway. Indeed, it had been declared over and over again that there was no possibility of private people putting their money into the enterprise, and consequently it had had to be taken up by the Municipality; there was such a surging multitude of people requiring to be carried that the subway had had to be made. Of course, that pointed to very favourable conditions for such an enterprise. Naturally, one feature of the Paper to which attention was at once directed Sir G. Gibb.

Sir G. Gibb. was the cost of the enterprise. It was put at £600,000 per mile, the mile including four lines of way and a considerable percentage of cheaply-constructed elevated railways, so that £600,000 was a high figure. It might be difficult to make comparisons between the cost of a subway in New York and the cost of a tube or shallow subway in London, because the cost must depend on the work that had to be done; but this figure pointed to the fact that underground railways could be made only where there was an enormous traffic to support them commercially. He had noticed in the remarks of one or two of the speakers a desire to make a forecast with regard to future tubes in London. His own interest was more directed to seeing what could be made out of the existing tubes than to encouraging any forecast as to the work to be obtained in making more tubes. A leading feature in the operation of the subway in New York was the running of the express trains; it was a very interesting feature, and there was no doubt that the running of express trains was an advantage. The Author said that the express trains ran about $1\frac{3}{4}$ mile between the stops. Three stations, with one intermediate stop, would more than cover the average distance that passengers were carried on the District railway, and far more than cover the average distance they were carried on the tubes. Although the running of express trains was a great advantage, it was an advantage that could only be obtained where there was a huge traffic to be carried. The problem in London was not the problem of New York. There the problem was to carry the people; in London the problem was to get the people to carry! He had lately had to address shareholders about a line designed for express traffic. It was no secret, probably, that the estimates for the express line showed that there would be a heavy loss if the line were made. It was easier under those circumstances to understand why it was abandoned than why it was promoted. It was necessary to look for the source of the favourable features for a subway in New York, yielding the excellent commercial results which apparently had been achieved. There was the shape of Manhattan, with a length of 14 miles and a width of $1\frac{1}{2}$, and the movement of the people taking place within that narrow parallelogram. It was equivalent in London to the distance from Ealing to a little beyond Whitechapel, short of East Ham, and from the River Thames to King's Cross. The density of population in Manhattan was considerably greater than it was in the central area of London, and owing to the shape and to the density of population, and perhaps owing to the habits of the people—accustomed to ride more than to walk—there was more railway-traffic. In America they had no omnibuses, and he Sir G. Gibb. envied them! In London the problem was to deal with an old settled population. Diagrams of the movements of people in New York and London would show absolutely different conditions of affairs. The movement in London would appear like a kaleidoscope, whereas the movement in New York would be a series of black lines all running in one direction. No doubt that was due to the fact that London was settled long before railways were thought of. The trades, the professions, theatres, residences, etc., were absolutely and finally settled: the people travelled where they wished to go, and no speed of travel would induce them to go where they did not wish. Railways had to be made to serve the needs of the people, and there was no doubt that in New York the subway had been urgently needed and had fitted into the realized visible needs of the people. The Subway had at once come into possession of an enormous traffic. In the second year after its opening the Author mentioned the total passengers carried as being 166 millions. That worked out at 6½ millions per mile. On the District railway, excluding those branches over which few travelled, and dealing solely with the main line—on which upwards of 24 millions travelled last half-year out of a total of 25 millions odd, so that the movement on the District took place almost entirely on about 12 miles of railway, although the company owned 24—the traffic was 4 million passengers per mile per annum as compared with the 6½ millions on the subway. The figures for the last half-year on the three tubes, the Piccadilly, the "Bakerloo," and the Hampstead, worked out at 3 millions per mile per annum. As one would expect, in New York there was a density of population which justified the expenditure that had been incurred, and which made one wonder why private enterprise had not been found adequate to the task of providing the money. The Author gave the total bookings at one of the principal stations on the subway as 21 million passengers in a year. The maximum bookings in London on any of the lines with which he was connected were at Victoria station, where about 4½ million people were booked per annum as compared with 21 million at one station in New York. It was to the conclusions in the Paper he naturally looked, as being perhaps of chief interest to himself, and he noticed that the Author drew first the moral that constructors must be given as much assistance as possible in the way of facilities. That passage appealed to him. When he read it he had a high sense of approval, and, he was afraid, a vain feeling of regret. He sympathized very much with Mr. Galbraith in his reference to the number of petitions through which he had had to wade. The trouble

Sir G. Gibb. was that in London they were not accustomed to the easy grant of those facilities which really ought to be given to enterprises such as tubes, and he did not know how the facilities were to be obtained. The London County Council were leaders—he would not say they were the leading sinners—in those matters; they naturally took a prominent position in all the conflicts in Parliament, and the difficulty was to reach their hearts and soften them. He was afraid prayer would not be efficacious: it might not reach the quarter whence inspiration came. Still, it was a great pity that before tubes were commenced the County Council did not make for themselves a little tube to begin with, because probably after that experience they would have been less onerous in their demands. No doubt now, if any promoter was thinking of going into the river-steamboat business, he would find the demands were not so onerous as they were for the costly tubes. The next conclusion in the Paper had reference to the historically important question as between shallow subways and tubes. He would not venture to enter into that controversy, because it was a mere question of cost, as to which he was unable to offer an opinion. Sir John Wolfe Barry's views he had heard before. Sir John's argument had always seemed to him to have two fatal defects: it failed to convince two rather important interests, the people who granted powers and the people who found cash. Neither Parliament nor the promoters of railways had been convinced by the arguments that a shallow subway was better than a tube, and he confessed he was more inclined to be terrified by Mr. Mott's £1,000,000 per mile than to be coaxed by Sir John Wolfe Barry's estimate of a very much smaller figure. But it was quite clear that London people would not have tolerated on any terms whatever the construction of shallow subways. He was in New York when the Subway was being made and saw the condition of the streets, with their irregular wooden floors, and the pavements blocked, and the people subjected to the most intolerable inconveniences. The English people would not have tolerated those conditions—they were an obstinate and conservative people in every walk of life. He had found them so in dealing with them as passengers. He did not know that those qualities deserted them even when they got into the position of Government controllers of railways. His opinion was that it was impossible to imagine Oxford Street left for a few years in the condition in which he saw Broadway in New York. The passion aroused by that state of things would have been so great that he would really have been afraid for the safety of the Chief Engineers; every time they passed along the work there might have been opportunities for the professional advancement of some of the junior members of the profession! Of course, now the question had only a past interest. It was not likely that the arguments or the estimates would lead anybody to think of making a shallow subway. The one great argument against tubes was the necessity for using lifts. That, of course, was a great misfortune, and he thought everybody would agree that an underground railway should be made as near to the surface as possible. Whether it could be made close to the surface or must be made lower down was a practical question that had been decided for London, and, he thought, rightly decided. The lift question was serious, but the delay was not so great according to the clock as it was according to the temper. There was no doubt people were apt to exaggerate the time they waited for a lift; it was only a few seconds, but they always imagined, when they were standing there, that they were missing a train down below. With the very frequent service of trains, however, there was really not much delay. With reference to what Mr. Galbraith had said as to the effect of the differential-ticket system as compared with the uniform fare, it was not so great as people thought; in fact, he very much doubted whether there was any practical difference at all. A number of records had been taken of the bookings at a uniform fare on the Central London railway, and similar records with differential fares, and there was no difference in time worth speaking of between the two systems. But the lifts cost money; the lifts in the three more recent tubes had cost in the last half-year about £35,000 per annum. That, capitalized at 25 years' purchase, added to the cost of 22 miles of tube an item of £40,000 per mile. That was just the capital burden which was added by the operation and maintenance of the lifts, and it was for engineers to say whether the burden of making the railway close to the surface would be greater. Sir G. Gibb.

Sir George C. T. Bartley, K.C.B., remarked that he had been a member of the Traffic Commission with his friend Sir George Gibb, but unfortunately he was not, like Sir George, a practical railway man, nor was he an engineer, and therefore he knew little about the technical points of the great subject under discussion. He represented the man in the street, interested in the facilities for travelling about London. Sir George Gibb had given the real difference between London and New York when he mentioned the shape of the district. When in New York, it seemed to him that the long narrow parallelogram was a very much easier thing to manage than the large round centre of London. He did not agree with Sir George that the passengers were not in London; he believed there was an immense quantity of Sir G. Bartley.

Sir G. Bartley. traffic; but he thought an impossible task was being attempted in connection with the fares charged on the lines. If the lines were to be extended they must be made to pay. There was a spirit abroad which led people to expect to get everything for nothing; that was really the whole trouble. If anybody could make the tubes pay, he was sure it was Sir George Gibb. But whatever a tube cost, it was absolutely impossible to make it pay with the present system of fares. He thought it was a grievous thing for London to see the traffic-managers competing one with another in such a way as to prevent the extension of the various enterprises. He could not conceive of anybody embarking his money in further extensions of tube railways. Personally he preferred the shallow subway to the deep tube, and he thought everybody would prefer it were it not for the question of cost; but whether the lines were deep or whether they were shallow, the fact remained that the cost could not be covered with the fares as they were now. What with the competition of the omnibuses, and of the tramways at the public expense, it seemed to him that London was handicapped very largely by the attempt to carry the traffic on unremunerative systems. He remembered one of the leading lights on the Metropolitan line advocating strongly one uniform fare—he believed about 4*d.*—on the Underground railway from Ealing to Aldgate; of course that was an impossibility. People would not pay 4*d.* to go from Victoria to Westminster Bridge; they would simply take a penny omnibus. He did not quite agree with Sir George Gibb about New York with regard to omnibuses and tramways, because there were an immense number of tramways, in addition to the elevated railways. He believed that the more facilities were given for traffic, the more traffic was obtained. When in New York he was told that the tramway was made first, and when the elevated railway was projected the tramway opposed it. When the elevated railway was made it was found that the tramway did more business with the railway on the top of it than it had done before; and when the subway was proposed, the tramway petitioned for it, because it said it would increase the tramway-traffic. Therefore, if only the lines could be made at a remunerative rate, with the fares so adjusted as to give a proper return for the capital outlay, he did not see why the present systems should not be extended. But as long as there was competition between trams, omnibuses, trains, tubes, and subways, and everybody was trying to get everything for nothing, he thought there would be a retardation of one of the most important movements in London, namely, the provision of greater facilities for travel. In spite of all Sir George Gibb's efforts—and everybody was thankful to him for the work he had done—London had not yet got the means of communication it required, and it was being hindered from getting them because it was rendered impossible for private enterprise to furnish them on remunerative terms. Sir G. Bartley.

Mr. MAURICE FITZMAURICE had known New York since 1888. He went over specially in 1903, about 15 months before the historic visit of The Institution in 1904 under the leadership of Sir William White, to view the subways in New York and Boston. He spent 4 or 5 days in looking over the works and he was deeply indebted to the Author for the kind way in which he showed him everything at that time. He was much struck then with the amount of work done in the short time. He had followed very carefully the Annual Reports issued by the Author, recording the progress of the Subway, and he considered that those reports were of very high value—they were really text-books of that special class of engineering—and, together with those issued by Mr. Carson in connection with the Boston subway, were such as had never been issued before to his knowledge in connection with any engineering work. The Author's successor, Mr. Rice, had maintained this high standard in the reports he had issued during the last 2 years. The discussion so far had naturally dealt very much with comparison between shallow subways and tube railways, because the Author himself raised the question very pointedly in the Paper by stating that he had only advised the Rapid-Transit Board to adopt shallow subways after he had carefully examined, in 1894, everything that had been done in England and on the Continent. That was an interesting fact, because the year 1894 was practically the time when engineers in London deliberately chose to make tube railways. At that time the only underground lines existing in London were the City and South London (tube) railway and the Metropolitan and Metropolitan District railways. After seeing these and other railways, the Author deliberately chose shallow subways for New York, while in London engineers deliberately chose tube railways. Since that time the Author had gained further knowledge of the work, because, as was well known, he had been one of the Advisory Board of Engineers of the Royal Commission on London Traffic. There was nothing in the Paper to lead one to think that with the practical knowledge he had thus acquired he would in any way modify his views with regard to the making of shallow subways in New York. As had been pointed out, there were great differences between the two cities, and Mr. Fitzmaurice wished to mention some that had not been dealt with in the discussion. One point had been dealt with fully by Mr. Ross and Mr. Fitzmaurice.

Mr. Fitzmaurice. Sir George Gibb, namely, that the natural configuration of Manhattan Island rendered it a place where railways were bound to obtain traffic to almost any extent, whatever kind of locomotion was adopted. Manhattan was a long, narrow island 14 miles in length and 1½ mile broad, and consequently nine-tenths of the traffic was in a north and south direction. According to the Paper, the population of Manhattan Island was 2,200,000, spread over an area of 21 square miles, as compared with the population of London, nearly 5,000,000, spread over an area of 121 square miles. Manhattan thus had an enormous population per acre to draw upon for any kind of locomotion, quite apart from the large numbers of persons who entered it every day from outside areas. Out of curiosity he had attempted to discover the most densely populated 21 square miles in London, and the most he could get was 1,300,000 to compare with 2,200,000 in New York. One of the first points of difference to which he wished to draw attention was the width of streets in New York. He did not think it was quite realized what the width of streets meant to those who were making subways. Taking the New York streets under which the Subway was made, and beginning at the south end of the Subway, the width of Broadway at that point was 80 feet; further on, in Elm Street, there was also a width of 80 feet; in Lafayette Place there was a width of 100 feet; in Fourth Avenue there was 100 feet increasing to 150 feet; crossing over from Fourth Avenue into Broadway, through Forty-second Street, there was a minimum width of 90 feet; the upper part of Broadway began with a width of 100 feet and increased to 150 feet. Such streets were not to be found in London; it was possible to count on one's fingers the streets in London which were 80 feet wide, and as far as he knew there were only three streets in London 100 feet wide, Whitehall, Whitechapel Road, and Kingsway. It was interesting to consider for a moment the construction of subways in wide streets as compared with narrow streets. First, there was of course the great facility afforded for construction by enabling cranes, materials, etc., to be brought alongside the work. Then, room for stations could be found under the streets, doing away with the necessity of acquiring property; and there was ample room for access from the streets to the stations—a matter which those who have been engaged in making subways in London found extremely difficult and expensive to arrange for. There were also facilities for dealing with pipes and sewers. People hardly realized what difficulties there were in dealing with a number of pipes, unless they had to do it. He had had to carry out such work in narrow streets and had found that while it was quite easy to take the pipes out it was very difficult to find any place to put them in again. In taking up a long, narrow street in London a considerable number of pipes would be found, and if any width of the street was occupied with new works it was difficult, without widening the street at great expense, to replace them—an operation upon which the water-companies and gas-companies naturally insisted. In wide streets there was of course less interference with the traffic, and the people who lived in the houses fronting the street had a better chance during construction of being comfortable, in fact of living at all. The next point had reference to the traffic in New York and in London. The traffic in New York was quite different from that of London, the greater part of it being tramway-cars. In some of the Reports that had been issued there were particulars of the maximum traffic in certain streets. Probably Broadway carried the maximum traffic, and at certain hours of the day there were about 600 vehicles, including cars, per hour. In places like Piccadilly, Fleet Street, and the Strand, the traffic was very nearly double that amount, and was continuous throughout the day. Looking at the statistics put before the Royal Commission on London Traffic it was seen that the number of vehicles using Piccadilly from 10 a.m. to 6 or 7 p.m. exceeded 1,000 per hour. Again, New York had another great advantage over London in that there was always a parallel street within a short distance of the street in which construction was going on, thus enabling traffic to be diverted into that parallel street. That advantage was seldom found in London. If the whole of Regent Street were taken up, it would be found difficult to divert the traffic into any other route. The parallel streets also rendered it easier to deal with pipes, because where there were two large, wide streets running parallel, the pipes could very well be divided among them and they were not crowded into one line of traffic as in London. Then the ordinary sub-surface structures, according to his observations, were considerably fewer and less difficult to deal with in New York than in London, and that also was due to the parallel streets, and to the fact that the sewers had not been constructed under the same difficulties. In London all sewers had very flat gradients, while in New York the sewers discharged directly into either the East River or the Hudson River, and the gradients were not so flat as in London. It was an easy matter to deal with a sewer which had a steep gradient, whereas it was very difficult to deal with a sewer with a flat gradient: in the one case the gradient could be flattened, but in the other it could not. Probably one of the principal considerations that had determined the Author to build a shallow subway was the material through which the subway was made. Practically the whole of New York, from the

Mr. Fitzmaurice.

Mr. Fitz-maurice. Harlem River as far south as Fourteenth Street, was rock, and making a subway through rock was a very different matter from making it through such material as was found below the surface of the streets of London, a great deal of which was made ground and mud. The last point to which he wished to draw attention in regard to the differences between London and New York was that the Subway had been practically made by the Municipality and helped by the Municipality in every possible way. The Author stated that house-vaults were held not to be property but only revocable licences from the City, and the owners received as compensation only the price paid originally to the City for the right to use them. Even with the present conditions in London it would seem that Londoners were almost in a better position than the people of New York as regarded rights of property. At the end of the Paper the Author stated that the cost of an underground railway was at best high, and in order that it might not become prohibitive, the constructors must be given as much assistance as possible in the way of facilities, and the enterprise must not be burdened by heavy extraneous expenditure through the acquisition of so-called vested rights. In another part of the Paper the Author stated that in only six places had it been necessary to acquire any private property, over 25 miles of railway—private property of course not including cellars; and that showed at once what a considerable difference there was in this respect between New York and London. If anyone thought it possible to build 25 miles of railway, or even 3 miles, in London without acquiring a considerable amount of private property, he would find out his mistake before going very far. The great latitude given to the contractors had helped very considerably in carrying out the work. It was work, he thought, as carried out in Contract No. 1, that would not be tolerated in London. Later on, when the constructors came to Contract No. 2, which extended from City Hall down to the Battery, the Author came to the conclusion that it was better to carry the work deeper below the roadway, and instead of keeping the top of the roof of the subway 30 inches from the road, it was made 6 feet from the road—a very considerable difference. Probably the Author thought, as he himself realized when he saw the work, that, as carried out in Fourth Avenue and other streets under Contract No. 1, it was the kind of work that an engineer could do once in his life, and consider himself rather fortunate to be alive at the end of it. The Advisory Board of Engineers of the Royal Commission on London Traffic said in their report that in the case of the original Metropolitan railway the local authorities and the public put up with very great interference with traffic, an interference which would never be

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suffered again. He thought exactly the same remark might be made in connection with the New York subway. With regard to the methods of carrying out work, in either a tube railway or a shallow subway, the same Board, which had the advantage of the Author's experience at that time, stated very properly that the question was not one that could be dealt with off-hand in any given place; it was a matter of detailed estimate under the particular conditions, and no law could be laid down with regard to shallow subways or tubes. Everyone would agree that during construction it would be of great convenience, both for the general public and for frontagers, to have tube railways, but in actual working it would be to the great convenience of passengers to have shallow subways. He noticed that Sir John Wolfe Barry rather objected to tube railways in London, and he did not really know why Sir John should be so severe upon them. He thought it was largely sentiment, because he thought Sir John had never quite got over the excellent way in which the line from Cannon Street to Aldgate was made by him when a complete temporary roadway was made and the road-traffic was not interfered with. He believed the words "Cannon Street to Aldgate" were engraved on Sir John's heart in large letters, leaving no room for "tube railway," even in small letters. The question of cost was a very important matter. He had looked up two Papers read at The Institution some years ago, one by the late SirBenjamin Baker[1] and the other by Sir John Wolfe Barry[2], and he noticed that Sir Benjamin Baker gave the cost of maintaining a timber roadway over excavation as 5*s.* per superficial foot. For an ordinary width of subway that came to £40,000 per mile. Sir John Wolfe Barry gave the cost of underpinning as about £30,000. The cost of the timber temporary road, of the underpinning, and of the diversion of pipes, sewers, and things of that kind, when added together, came to a very considerable amount, which was avoided by constructing tube railways. He might say that in connection with the recent construction of a conduit tramway from Westminster Bridge to Wandsworth, a distance of 6 miles, the cost of the diversion of pipes to make room for the conduit was £76,000. But even when these expenses were incurred there was a little difficulty with the subway, because he found that Sir John Wolfe Barry said, in connection with the Cannon Street to Aldgate line: "It will be easily understood that the neces-

[1] "The Metropolitan and Metropolitan District Railways." Minutes of Proceedings Inst. C.E., vol. lxxxi, p. 1.

[2] "The City Lines and Extensions (Inner Circle completion) of the Metropolitan and District Railways," *Ibid.*, p. 34.

Mr. Fitzmaurice. sity for temporary accommodation of the sewers and house-drains during the construction of the works involved great loss of time and expense and much discomfort to all concerned." So that even where the work was done with the greatest possible care, and the public were guarded in every way, there was a large amount of discomfort, and he did not think anybody could possibly expect to make subways without causing that. An engineering journal, in giving a description of the New York subway, had stated that middle-aged citizens had been heard to doubt whether they would live long enough to get compensation for the inconvenience of the last few years; and he thought that was not at all an unfair statement with regard to the upper part of New York as he saw it. He had been deeply impressed, however, with the extraordinarily good work which was carried out there and the wonderful facilities for getting about which were afforded by the express line, and by the interchanging with the local line. Some time ago he went very carefully into the cost of making shallow subways, as compared with tube railways, between Devonshire House, Piccadilly, and Cannon Street. The authorities he was working for were very anxious to make shallow subways at that time, but the cost in nearly every case rendered them impossible. Without giving very great facilities to the public for using the streets he had made out the cost to be £1,000,000 per mile, and a very careful valuer had estimated the cost of acquiring cellars between Devonshire House and Cannon Street at £600,000. Sir John Wolfe Barry appeared to over-estimate altogether the cost of tube railways in London when he put it at £700,000 per mile. Tube railways without equipment could be made for about half that sum. The most expensive part of tube railways was the stations, which, it was not very far wrong to say, represented half the expenditure on any existing tube railway. In many cases the stations were much too close together and great unnecessary expense had thereby been incurred. The stations ought to be much farther apart on any new lines, thus enabling a better train-speed to be obtained and diminishing the cost of construction. Under such conditions tube railways in London could be built and equipped for about £450,000 per mile, or less. There were one or two questions he wished to ask with regard to construction. First, there was the crossing of the Harlem River, a work which he had seen in progress and had never quite understood. Perhaps the Author would say in his reply why that crossing could not have been made in an open coffer-dam. The foundations were, he understood, in good clay, and there was a head of water of 40 feet; but coffer-dams had been made in 40 feet of water, and the head was perhaps not quite so important as the range of tide. In 40 feet of water, with a range of tide of 20 feet, coffer-dams might be unsuitable ; but at the Harlem River the range was only 4 to 5 feet, so that if there were good ground at the bottom, he did not see why the work should not have been done in an ordinary coffer-dam. He also wished to pay tribute to the extreme care taken in passing Trinity Church in Lower Broadway. Anyone who knew the work done there could only express appreciation of the care taken to prevent subsidence or injury of any kind in that very fine building, with its spire 285 feet high. With regard to crossing the East River, he understood there had been very considerable difficulty there, owing to the shield getting out of line and to the distortion of the lining, and he believed that a great deal of the lining had had to be taken out and made good: perhaps the Author would say a little on that subject in his reply. Mr. Fitzmaurice would have liked to go into many other matters, such as the experiments with reinforced concrete, for which the thanks of The Institution were specially due to the Author, but for want of time he would confine himself to reference to one or two matters with regard to cost. The Author stated that the cost ranged from £200,000 to £250,000 per mile of track. Mr. Fitzmaurice would like to know how that cost had been arrived at, because the contract was rather a curious one. The Rapid-Transit Company had to build a subway and to work it for 50 years, and during working they had to pay 4 per cent. interest on the cost of construction, and 1 per cent. for a sinking-fund, so that they had it in their power either to put the money into the construction or to spend it on the working. The effect of that arrangement was particularly marked in the tenders for the second section, extending from the City Hall into Brooklyn. The estimate for that work was $8,000,000 to $10,000,000; the tender which the Rapid Transit Subway Construction Company sent in was $2,000,000, so that naturally in that particular case they expected to recoup themselves later on. As a matter of fact, they also sent in another tender, for $3,000,000, and they further said that if that were accepted they would be prepared to build a new line under Broadway, from Forty-second Street to Fourteenth Street, about 1½ mile in length, for $100,000—probably about 5 per cent. of the actual cost of construction. The Brooklyn Rapid-Transit Railroad Company sent in a bid of $7,000,000. As the estimated cost of the work for which tenders were invited was $8,000,000 to $10,000,000, it would be seen that all the bids were less than the actual cost, the bids of the Rapid-Transit Subway Construction Company being especially low. After consideration the Board decided to accept the bid of the latter Company for $2,000,000, the other bid being too irregular to be entertained.

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Mr. Fitzmaurice. Was the price of £200,000 to £250,000 per mile based on the actual figures of the Rapid-Transit Subway Construction Company or on the detailed figures which the Author gave in the Paper, and which were extremely interesting, as they were the figures of the sub-contractors? The Author might give some information on that also when replying to the discussion. Mr. Fitzmaurice would like to express his admiration for the rapidity with which the whole work had been carried out, and the way in which all difficulties had been quickly and satisfactorily dealt with. This could have been accomplished only by long and careful study of all details before the contract was let. Although the description of the work by the Author could not be improved on within the limits of a Paper, it was impossible without actually seeing the work to realize what a vast undertaking it was.

Mr. Macassey. Mr. LYNDEN MACASSEY apologized for intervening in an engineering discussion, but having had the honour and misfortune of being the Secretary to the much-maligned Royal Commission on London Traffic, and having in the course of his duties spent a considerable time in New York in investigating, and in writing about 200 to 300 pages of a Blue book on, the subject under discussion, he took considerable interest in it. Not being an engineer, he did not presume to criticize the engineering, nor did he propose to say anything with regard to the excellent traffic-results; but when the Royal Commission was sitting in London and abroad, many witnesses, from all parts of the world, proposed schemes for London, bringing forward figures based on experience in New York and elsewhere, and attempting to show that because in New York subways had been built at certain costs, and there were so many journeys *per capita* per annum on them, therefore subways could be constructed in London at the same cost, and that if they were so, the promoters would be sure to reap an exactly similar return. That form of argument was not unknown to expert witnesses in another place. It seemed to him, after an exhaustive inquiry, that there were conditions in New York which might be described as unique. For example, there was the extraordinary topography of Manhattan, which lent itself to minimum route-mileage, and probably to the maximum of traffic. If one examined all over the world the different ways in which cities grew, it would be found that there were three or four different types. One was what was commonly called the "island" or "delta" form, a city on the lines of old New York, Manhattan Island, or San Francisco, or a valley-shaped city something like Pittsburg or Philadelphia. In another type, of which London was perhaps the most marked example, the city grew out, gradually extending radially from a small nucleus. It might be a complete circle like London or Paris or, like Chicago, simply a semi-circle. The growth of a city seemed to depend entirely upon facilities for locomotion. In early days the City of London was small, with business and residential quarters combined. When facilities for locomotion were afforded, the business centre gradually separated from the residential centre, leaving the businesses in the middle, with the residences outside. In modern Manhattan the business district was at the extreme south, the shopping district was farther up the island, the higher-class residential district was as nearly as possible in the centre, and at the other end there were the suburban and middle-class residential portions. That made a vast difference in the mileage of railways which had to be constructed to afford adequate facilities for locomotion, and also in what might be called the riding-capacity of the inhabitants. In a long narrow island like Manhattan, where the main travelling was north and south—where the persons who lived at the north end were forced to travel in the morning perhaps 10 miles to the south of the island and back again in the evening—railways could be laid out to secure the maximum traffic per mile of route. In London the lines necessarily radiated from the centre and were widely separated at the periphery of the circle, a condition which made for maximum route-mileage and one likely to afford the least return to the promoters of the railways. So far as the cheapness of construction went, what obtained in New York was absolutely no criterion at all of cost in other places, and no deductions could be drawn from New York as to the returns in London on tube or subway railways. In the latter connection there was another condition rather difficult to explain. Taking elongated cities like San Francisco, the people inside the city appeared to travel about three hundred and fifty times per head per annum. In Philadelphia, a less elongated city, but with a larger population, and therefore normally with a greater riding-capacity, they travelled only about two hundred and seventy times per head per annum. In a circular-shaped city, even where there was a much larger population, the number of times people travelled per head per annum was very much less; in London it was only about one hundred and eighty-nine times. It was very difficult to discover why that curious tendency existed. Several German inquirers had attempted to give an explanation, and one of the explanations was the following:—A population, of say, 100,000, distributed uniformly over a given area, would use the means for locomotion a given number of times per head per annum. If that population was compressed into a smaller area, as was usually the case Mr. Macassey.

Mr. Macassey. in elongated cities, although one would be inclined to think that as distances were less people would travel less, it was entirely the other way: as the density of the population increased the number of times the people travelled increased also. There were illustrative figures, for which he was partly responsible, in the Report of the Royal Commission on London Traffic, where a good many instances were given showing the tendency on the part of a population whose density was high to travel more than the same population would travel if spread over a larger area. In Manhattan there was an extraordinarily dense population, and there was a greater tendency on the part of the New York population to travel. There were other traffic-conditions which differentiated New York from London. Even the multi-millionaire seemed to have no objection to travelling in the street-car with his less wealthy brethren, and there was generally among all classes a constitutional tendency to make much greater use of the local means of transport than was found in London. Therefore, when figures were put forward to show that because with population of a given amount in New York a certain number of journeys were made annually per head, those figures were absolutely no criterion at all as to what similar populations would do in other cities. There were, moreover, certain natural and legislative conditions in New York making for cheap construction. Perhaps the strongest tendency of modern reform in municipal matters was to secure as far as possible co-ordination of travelling facilities, and to restrain wasteful expenditure on them. In a city of the type of New York, Nature herself did that. On some of the main routes of Manhattan there were street-cars on the surface, "elevated" cars overhead, and the new subway immediately underneath; and each of those means of transit was performing an entirely different function. A number of tests had been made for the Royal Commission and published in their Report. There were three or four things that influenced people in choosing their means of transport—the time of the journey, the cost of the journey, and the "convenience," meaning the proximity of the means of locomotion, the frequency of the service, and so forth. Because there was a frequent service of street-cars and the means of transport was in immediate proximity to the side of the curb, people in Manhattan used the street-cars up to about 2 miles in preference to the overhead railway or the subway. For longer journeys they travelled by the elevated railway; they did not mind the inconvenience of walking to the station and climbing up the stairs for the purpose of getting a faster journey. For still longer journeys they did not mind walking to the corner of a block, perhaps 100 yards or 150 yards, to a subway-station, for the purpose of getting the express service which would carry them faster still. In New York no question of relative cost arose, as all the facilities for locomotion were working at a uniform fare of $2\frac{1}{2}d$. It would be seen, therefore, that in New York all the means of transport were fulfilling entirely different functions, and were not overlapping at all—a condition absent in London. There were a few matters affecting cost of construction in connection with the New York subway from which London might draw one or two useful lessons. From what he had seen, he quite agreed with Mr. Fitzmaurice that London would not tolerate for one moment the construction of an underground railway under such conditions as the Author had been fortunate enough to have for building the Manhattan-Bronx section of the subway. At the same time there was much to be learned. When underground railways were proposed first of all in New York, private enterprise was tried and failed absolutely. Then municipal ownership and working was suggested, and that was vetoed by the plebiscite of the citizens. Then New York adopted composite procedure, the city to construct and private enterprise to work. They profited by the experience of Boston, which was the first to adopt that system, and by Paris, which had copied the example of Boston. The city then secured the incorporation of the Rapid-Transit Board, a Board with administrative functions, with power to construct the railway at the expense of the city or to procure its construction by private enterprise, and in either of such cases to lease it to private enterprise to work. The Government, in conjunction with the city, gave every possible facility for the execution of that work. First of all, they allowed the streets to be used for the purposes of the stations. Nothing struck foreigners more forcibly than what they observed in London, namely, the stations of so many of the tube railways situated in inconvenient places, when they might very properly have been situated under the surface of the streets if the local authorities had seen fit to grant the streets for that purpose. In Paris, in Boston, and in New York, such facilities had been granted willingly. The New York local authorities had allowed their streets to be used for the purpose of building stations, and decided not to allow the construction of the underground railway to be thwarted by vested interests. It was rather a radical view to advocate, no doubt, but still a wise and proper attitude in the interests of the community. They altered the law providing for the acquisition of land, and said that, where the underground railway had to be constructed under private property, an owner should not be entitled to demand an extortionate price for that private property, but should Mr. Macassey.

Mr. Macassey. be compensated for the damage which the construction of the railway did him. That was very different indeed from the law in England. A similar course might quite properly have been adopted in London, because there was a precedent for it already in the case of sewer-construction, which he understood could be carried out by the London County Council without hindrance under private property, the Council paying only for the damage caused by the construction. It seemed to him it was impossible to differentiate, on principle, between a sewer and a tube railway; both were works of public utility. Therefore, if a tube railway injured property, the owner of property should be paid for damage done, but should not be paid a fictitious value in respect of subsoil beneath his house which was absolutely of no value to him. That was the attitude taken by the New York Municipality. They also said they would tempt private enterprise into working the railway by relieving the equipment of the contractor who undertook the work from oppressive taxation. The Company was relieved from taxation in New York, and that again on principle seemed a perfectly proper thing to do. The relief, of course, was in respect of the equipment only—rolling stock, plant, machinery, etc.—not the real-property part of the railway, on which taxes must be paid. They also indemnified the contractor in New York against all claims and demands on account of vibration and injurious affection of property. The municipality agreed, if any such claims arose, to settle them themselves. That also had been done in Paris. As Mr. Fitzmaurice had said, the subway was leased for a term of years, the municipality agreeing at the expiry of that term to buy the equipment of the contractor, not at the munificent terms on which tramway-companies' property was bought in England—scrap-iron value—but at fair value, allowing for wear and tear and depreciation. What was the result of giving those facilities for construction and working? When the second contract, that for the Brooklyn and Manhattan section of the railway, was put up for tender, the estimated cost was $8,000,000 to $10,000,000, and the tender for the construction of that section was $2,000,000, with $1,000,000 for terminals. The contractor expected to make his profit out of the profits of working. Although Mr. Macassey ventured to think it was absolutely fallacious to draw deductions from the cost of construction and results of operation of underground railways in New York, and apply them to underground railways in London, yet on the other hand, as he had endeavoured to indicate, there were some useful lessons to be learned as to how underground railways, and municipal and private enterprise in relation to underground railways, should be treated.

Mr. James C. Inglis, Vice-President, felt bound to say that he had never read a more suggestive Paper, as regarded both engineering and methods of transport, or heard a more suggestive discussion dealing with considerations eminently needing attention at the present time in England. Short-distance traffic in England had had a very severe blow. The public had put on to the shoulders of private companies many heavy burdens, as the last speaker had so ably pointed out, with the result that the financial conditions were exceedingly unsatisfactory. It was so with the larger railways. They had come to a point beyond which they could scarcely go. That very day he had been engaged at the Board of Trade in initiating discussions upon the subject, endeavouring to show that in this country the burdens put upon private companies were too much for them to bear. The situation was very serious. As a responsible agent of a large railway, he felt they were carrying a load it was not good they should carry—not good even in the public interest. They desired to see a more liberal treatment of transit questions, such as had been spoken of in New York. The annoyance and inconvenience which the citizens of New York had had to submit to were serious, but they only measured the value which the municipality of New York set upon having the best means of transit in the city. London could not copy New York, but New York was really an example to be approached as nearly as possible, and he was quite sure that the nearer it was approached the better it would be for the people. Dealing with the Paper from the engineering point of view, the work showed evidence of much resourcefulness, especially in the changing of design to meet altered conditions. He admired also the wholesale and bold use of reinforced-concrete, and would like to have seen the exhaustive and instructive experiments described in more detail in the Paper. For instance, the simple fact, which he himself had investigated, that a rusty bar made an enormous difference in the strength of the beam as compared with a painted bar, was not very apparent to many people. The experiments on the effect of the intervening concrete arches on the strength of the steel beams yielded valuable facts to have in the Proceedings of The Institution. Another interesting point to him was set out in the conclusions of the Paper, where the high commercial value of speed in regard to the whole undertaking was stated. The promoters of the scheme wished to move the largest number of people over all distances in the shortest possible time. It struck him that the conclusions arrived at were as applicable to long-distance traffic as to short-distance. The problems discussed by Mr. Macassey were the same as were being discussed Mr. Inglis.

Mr. Inglis. with regard to longer distances. The Author could not be thanked too much for the Paper. Though long, it was remarkably condensed and could easily have been extended. He only wished Mr. Macassey would give The Institution a Paper dealing with the business side of the question, because such a Paper, combined with that under discussion, would be a very useful contribution to the solution of the traffic-problem.

Sir Herbert Jekyll. Sir HERBERT JEKYLL, K.C.M.G., was glad that Mr. Macassey had dwelt upon the fact that although the differences between New York and London were so great, and the system that suited one place would not suit the other, there were still very useful lessons to be learned from the experience gained in dealing with travelling facilities for large numbers of people. One of the most striking features of the subway was the four lines of rail. In London it would scarcely be possible to have four lines under any of the existing streets, even apart from the difficulties of construction. Still there might be some sort of combination by which each class of traffic could do the work appropriate to itself, instead of entering into a futile competition damaging to itself and to others. Railways, tramways, omnibuses, and cabs, all had their respective fields of action, and if they could so co-operate as to get the greatest advantage from each, it was possible some system might be evolved which would produce the maximum benefit. The best hope for the future lay in co-operation rather than in rivalry. There were signs of improvement, and the establishment of the London Traffic Conference was of the happiest augury. The improvements which had taken place during the last 3 or 4 years had added enormously to traffic-facilities in London, and for the moment the supply seemed to have overtaken if it had not outrun the demand. He said "for the moment," for, without attempting to prophesy, it was fairly certain now that the demand would overtake the supply. The provision of new facilities invariably created additional traffic and fostered the travelling habit among the people, irrespective of the growth of population. In the year 1902 the number of journeys made per head of population was 137; in 1906 it had risen to 159, a very marked addition. Therefore he held it was a great mistake to suppose, as some people asserted, that the traffic-problem had been solved; the pressure had been relieved for a time, but at no distant date it would probably recur in an aggravated and acute form. The relative advantages of tubes and subways had been fully dealt with by Mr. Fitzmaurice. Probably everybody agreed that shallow subways with convenient access from the street were more convenient than having to go down lifts and wander along passages, although Sir George Gibb was of opinion that the time taken in lifts and passages was less than it seemed. It was tolerably apparent, however, and Sir George Gibb's remark reminded him of the interesting question—" Why do married men live longer than single men ? " to which the answer was, " They don't, but it seems longer." Although it might not be possible to construct shallow subways in the crowded streets of London owing to the enormous expense, there were parts of London where the conditions were not so prohibitive. The shallow subways in Paris had cost a little over £200,000 per mile and the equipment about £100,000 per mile. There were parts of London where the conditions approximated to those in Paris, and there was no apparent reason why a subway in London constructed under the same conditions should cost more than it did in Paris. When the traffic-problem became once more acute, it was to the members of The Institution that the public would look for the most efficient help. Everyone was much indebted to the Author for his admirable Paper and to The Institution for the interesting discussion to which it had given rise. Sir Herbert Jekyll.

Mr. F. Hudleston thought it might be useful to refer more in detail to the relative cost of subways and tube railways, as it would assist in arriving at some sort of decision with regard to London traffic. It seemed to him from what had been said in the discussion that there was too much tendency to lump together the whole cost of a London railway—the land, the equipment, and the subway itself. That led to considerable difficulty, because it ignored the proper relative values of the different conditions of the problem. There were many conditions that were common to all. In London the builders of a railway could not hope to have the same latitude that had been given in New York, and to have places found for stations. Mr. Fitzmaurice had shown that very clearly, and it was hardly necessary for later speakers to say that it ought to be done in London. There was no room in London to have the upper parts of stations, the booking-halls and so forth, underground; they must be on the surface. In the average London street the only thing that could be done in the most favourable conditions was to get the platform itself by the side of the railway without interfering with the cellars of the houses. Cellars in London were private property, and it was not much use girding at that fact. In order to have a booking-office on the surface it was necessary to buy land. With a tube it was obvious the station must be on the surface, and in a subway it was the same. On the Underground Railway the booking-hall and everything else was on private property on the surface, and the Mr. Hudleston.

Mr. Hudleston. same thing would obtain with either kind of construction. In the case which he knew best, the Central London (Tube) Railway, nothing could have been saved in the cost of land had that been made a subway. There were one or two places on the south side of the river where land might have been obtained fairly cheaply from the Government if they had been charitably inclined; but in busy places, to put a station, however small, partly on each side of a street, necessitated booking-halls and entrances, and would take quite as much land as a tube station. Again, the whole of the equipment was practically the same, whether the line was a tube or a subway. If all those things were added together and deducted from the actual cost, some rather extraordinary results were obtained. A subway in London, even if everything were in its favour and if there were no particular trouble with sewers and pipes, would be no cheaper than a tube railway, even taking the entire capitalized value of the lifts, which of course ought to be done. Taking out the whole expenditure on the Central London Railway, for land, equipment, rolling stock, permanent way, and signals, all of which was common to each class of construction, and the expenditure on the upper stations, which would cost quite as much, it was found that the cost of the carcass, so to speak, of the Central London Railway, that was, the station-tunnels, running-tunnels, sidings, platforms, and shafts, came out at only about £240,000 per mile of double track. To that had to be added the lifts, which averaged about £20,000 per mile. Therefore the whole cost of a tube railway laid under ordinary conditions in London, when nothing extra had to be paid for wayleave, was about a quarter of a million sterling per mile. With regard to a subway, turning to Fig. 4, Plate 5, which he thought had been in everybody's mind for the last 10 years, since electrical working came in, the cost depended on size. Along Oxford Street it would not be easy to get any structure of the dimensions of Fig. 4 if a platform had to be made on each side. Some years ago he took out an estimate for a subway more or less of that type, 10 feet wide and 10 feet above the rails, to carry rolling stock of the same size as the Central London, as against the American stock, 12 feet 6 inches wide and 12 feet 6 inches above the rails. The cost, even allowing for a temporary road-surface, would not be so very heavy; he made out that it would, with underground stations and passages, come to £200,000 per mile or a little more. The cost of a structure of the dimensions shown in Fig. 4, including the stations underground and the passages, would be about £260,000 or £275,000 a mile, but then came the question of the pipes and sewers. There were not many wide streets left in London now, but in a wide street like Oxford Street, with luck, it might be Mr. Hudleston possible to manage with very little disturbance of sewers. The main sewer along Oxford Street was the Middle Level sewer, which in most, but not all, cases was laid at a considerable depth. Assuming the sewers had only to be diverted at stations, it did not seem to involve very much work; but along the whole length of the route there were heavy pipes that would have to be shifted, and the universal practice in London was to insist that anything of that sort should be laid in new pipe subways. That was practically the wayleave that would have to be paid for carrying a subway along important streets, disregarding entirely the question of property in cellars if they were touched. Those things added together, meant at least another £100,000 per mile for sewers, pipes, and pipe-subways added to the mere cost of the carcass of the surface-subway railway. Under the most favourable conditions, therefore, it could hardly be expected that any subway could be made for less than the cost of making a tube, even when the capitalized value of the lifts was added. Sir George Gibb put that at £40,000 per mile, which he himself thought was a little low. The capitalized value of the Central London lifts would be nearer £60,000 per mile, because they cost about £15,000 a year altogether to work and maintain, which, at 25 years' purchase, was £60,000 per mile. Adding all that to the other sum, £320,000 per mile was obtained as the cost of the tube, which was practically the same as a subway. He thought there could be no expectation of saving anything in first cost, even under the most favourable circumstances, on a subway through London, where pipe-subways had to be built. In the open it was another matter. With regard to the possibilities of constructing subways, Mr. Mott had remarked that it was doubtful whether a subway were practicable. Considering the question in detail, Mr. Hudleston thought it was practically impossible. For example, a subway along the line of the Central London Railway could start at the surface at Shepherd's Bush, but immediately afterwards it would run into the West London line at a level crossing, which meant that it would have to drop into tunnel: the station would have to be in tunnel, and it would be very much like a tube railway. Having passed that, the subway could come close to the surface for a short distance, but presently it would reach the foot of High Street, Notting Hill Gate, where there was a gradient of about 1 in 30, and he did not think even the most sanguine advocate of subways would care to face such an incline. Even if he did, when he got to that point he would find the Inner Circle in his way and he would have to drop down again underneath. So that practically the whole of that length would be in tube or in

Mr. Hudleston. tunnel, and a tunnel was more costly than a tube. After that, care would be required to get round the Middle Level sewer, although it might be managed; but at Lancaster Gate the task would become hopeless. A large sewer crossed there just below the road-surface, the Middle Level sewer was immediately below, and the subway would then have to change into a tube or deep tunnel again. After that it would get on fairly well, and formerly it could have reached Chancery Lane without much trouble, because the County Council subway did not then exist. Then came Holborn Viaduct, which could not be passed except by tunnelling, and the remainder of the distance would have to be finished off practically in tunnel. Of all tubes the Central London was perhaps the one that had been constructed on a route which would strike an ordinary man as being an ideal one for subways, but looking at the matter closely, it was practically impossible to adopt that form of construction. He was of opinion that if anything more were done in London within the 4-mile radius it must be practically a tube. Outside the 4-mile radius subways could be constructed; and a little farther out it would be really cheaper in most cases to buy the land and make an ordinary open railway.

Mr. Boardman. Mr. W. H. Boardman observed that the losses and annoyance to the public in Fourth Avenue, Forty-second Street and Upper Broadway during the period of construction had been not at all exaggerated; nevertheless, that did not prove everything. In Upper Broadway at every cross street wide passages were made, so that the whole street was not obstructed. Amsterdam Avenue was near by, and there were other broad avenues leading to the north. It was in fact a case of the suffering of the few for the benefit of the many. The outrages on Fourth Avenue and Forty-second Street were inexcusable; the loss to property-owners, dealers, and others had been severe. The subsequent construction, from the City Hall to below Wall Street, which had been alluded to by one of the speakers, had been done without any annoyance whatever to the public. He would not describe the method except to say that a little of the cover was moved each night, and all that the man in the street saw was the substitution of thick plank paving for the ordinary paving. On the curb-line a longitudinal wooden trestle was placed, with exhaust-pipes to take the material away. Except for that, the pedestrian and vehicular traffic was unimpeded. Safety in operation had not been alluded to in the discussion. Where electricity was used for power purposes intense heat arose from short-circuiting, and two instances had occurred already. In one case only employees were concerned, and they took care of themselves; and in the other case a train-load of passengers came to the street in less than 1 minute, as reported. The whole train-load Mr. Boardman. thus got away from the fumes. "Fire-proof" construction was only partially fire-proof, and was not altogether protective against fire and fumes where there was a strong electric current. He did not wish to say anything further on that subject, except to ask the members to compare dangers of that kind in a subway and in deep-level tubes. Another thing to be considered was what might be termed the saleable value of the transportation offered by the tube and the subway. New York local-station platforms were about 16 feet below the street-level, and were reached by openings on the sidewalk, down a flight of straight steps to the centre of the platform. A person in a hurry would accomplish that in less than 10 seconds, and an ordinary person could take his ticket, drop it into the box, and reach the train in less than 30 seconds as an average. On a tube the average time of reaching the train from the street might well be put at 2 to 3 minutes, depending on whether the passenger had to wait for a lift. To reach the platform involved a considerable amount of physical exertion, probably enjoyed by healthy persons, but deterrent to passengers who were not healthy or who objected to walk the long passages, apart from the waste of time. In New York City, the subway was paralleled on the surface by fast electric cars. In London there were motor-omnibuses running parallel with the lines. In New York, owing to the saving of time and the ease in reaching the station, people preferred to travel by the Subway for distances of a mile or more. The Author's recommendation of a shallow subway for New York seemed to have been justified by the result. Its capacity during the busy hours had been long over-taxed, and it was now in contemplation to increase the train-service from thirty trains per hour on the express tracks to forty trains per hour, each of seven cars. From Mr. Rosenbusch, the lift-engineer of the the Underground Electric railways, Mr. Boardman had obtained calculations adapted to Brooklyn Bridge station where 21,000,000 tickets were issued in one year, a week-day average of 65,000, and it was estimated that 60 per cent. of the average daily booking occurred during the five busy hours, and on special days there was a large increase over the average. That meant a one-way movement of more than 8,000 passengers per hour. Mr. Rosenbusch assumed the working-capacity of the standard tube lift to be 1,000 persons per hour one way, and from that he estimated that eight lifts under ideal conditions, and twelve lifts under ordinary conditions—standby, breakdown, and so on—would have been necessary for the present traffic of Brooklyn Bridge station, if there had been a deep tube there. With an increase of 33 per cent. in the traffic it would be a heavy

Mr. Boardman. tax to work the lifts required. He would summarize his conclusions thus:—Under like conditions the subway should be safer than the tube: the subway attracted more passengers than the tube: serious obstruction to street-traffic was not inherent in subway construction: a tube would not have been justifiable in New York because of its lack of high capacity with reasonable working-cost.

Mr. Bury. Mr. OLIVER BURY agreed with the view that shallow subways were infinitely preferable to deep tubes, and he thought the future for shallow subways was far greater than anything that could be expected for deep tubes. The secret of the success of the Subway in New York was that four tracks had been made, and the fast traffic kept separate from the slow; and the wisdom of that plan was probably confirmed by the experience of many men who had to deal with the large volume of traffic in and out of London. It was obvious that London would not tolerate such a condition of things as had obtained in New York. Whilst he could not help admiring strongly the resourcefulness which had been shown throughout the engineering and structural part of the work, he wished to deal chiefly with the working of the subway and the commercial side of the undertaking. In regard to the stations, he was struck with the shortness of the platforms, which were only about 350 feet long. On the Great Northern Railway platforms so short would be in many cases of no value at all. The projection of the platform by 20 inches he considered a great advantage. The standard in England on some lines was only 12 inches, but even that was better than it had been formerly. A striking example of the benefit of the projection had been shown a short time ago at Finsbury Park, when, in a dense fog, an elderly lady fell off the edge of the platform just as a train was coming in. A young man jumped down and pulled her off the track under the ledge of the platform, and so saved her life; but both the lady and her rescuer would probably have preferred 20 inches to 12 inches, which was the standard. With regard to the permanent way, it would be interesting if the Author could say how the rails were wearing. At first the rails had been found to be too soft. He really thought that something would have to be done in the way of making rails harder. That was rather a bold thing to say in the presence of so many eminent permanent-way engineers, but his excuse must be that he had been a permanent-way engineer himself. It was well known that from some unexplained cause electric traction wore the rails a good deal faster than steam-traction, and it would be interesting to know what was the experience on the Rapid-Transit Subway. It would also be useful to know why the sleepers were not creosoted or treated in any way. It might be that it was on account of the possible risk of fire; but there were other means of treating sleepers in order to prolong their life, and in a subway where trains were running almost continuously it would appear highly desirable to use every possible means of prolonging the life of sleepers. As to the rolling stock, he noticed that the trains running on the slow lines had five cars, each car being 52 feet long and carrying 52 people, or 260 people in the whole train. If more than that could not be carried in a Great Northern train the Company would be doing very badly. The fast trains on the Subway, which were 408 feet long, carried 416 people. An ordinary Great Northern suburban train was composed of eleven four-wheeled coaches, particulars of the seating accommodation, etc., being given in the first line of the accompanying Table (p. 100). A short time ago the coaches were widened by sawing them down the middle and putting in an extra panel, thus adding about 20 per cent. to the seating-capacity. It was not possible to lengthen the trains; they worked into Moorgate over the Metropolitan line and were as long as the platforms there. When it was found that the trains running into and out of King's Cross were crowded, the length of the train was increased, in order to take full advantage of the long platforms on the Great Northern main line, and the second line of the Table gave particulars of such a train, which seated 816 people. The Great Northern Railway Company still desired to electrify their system if possible, and they had invited various firms to send in tenders for electrification. The third line of the Table gave particulars of a train proposed by an eminent firm for an electrified railway. The train was as long as that shown in the second line, but it would only carry 496 people seated; and there were 939 lbs. of dead weight per passenger, against 639 lbs. (including a 60-ton engine) in the train immediately above. The next line showed a proposal by another firm who sought to meet the case half-way, retaining the existing coaches and side doors; and the next line was of the same nature. The last line but two was a Great Eastern suburban train, not one of the longest, some of which carried about 1,000 passengers. The last line but one represented a Great Northern and City train very similar to the trains on the Rapid-Transit Subway, but with seven coaches, the fast trains on the Subway having eight. The last line showed a North London train such as those which ran into Broad Street. There was a considerable loss by having an empty guard's van at either end, and therefore the proportions were not quite so favourable as on the Great Northern and Great Eastern lines. When the Great Northern invited tenders

Mr. Bury.

Mr. Bury.

PARTICULARS OF SUBURBAN TRAINS.

	Number of Coaches.	Total Length of Train, including Engine or Motors.	Seating-Capacity for Passengers.				Number of Passengers for each 100 Feet Length of Train.	Dead Weight of Train including Engines and Motors.			Motive Power.
			First Class.	Second Class.	Third Class.	Total Passengers.		Total.		Per Passenger.	
		Feet.	No.	No.	No.	No.		Tons.	Cwt.	Lbs.	
Great Northern Railway (widened) suburban train	11	$373\frac{1}{4}$	80	336	240	656	176	194	$1\frac{3}{4}$	663	Steam
Great Northern Railway (widened) suburban train (lengthened) . .	14	$476\frac{1}{2}$	80	396	340	816	171	233	2	639	Steam
Great Northern Railway suburban train, as proposed by an electrical company	8	$478\frac{1}{4}$	147	349	..	496	104	208	..	939	Electricity
Great Northern Railway suburban train, as proposed by an electrical company	10	$373\frac{3}{8}$	64	300	256	620	166	199	14	721	Electricity
Great Northern Railway suburban train, as proposed by an electrical company	12	$369\frac{3}{4}$	80	336	312	728	196	179	$9\frac{1}{2}$	552	Electricity
Great Eastern Railway (widened) suburban train	15	$461\frac{3}{8}$	80	300	408	788	170	209	$5\frac{3}{4}$	595	Steam
Great Northern and City train (electric)	7	$356\frac{3}{8}$	(all	one	class)	394	110	140	..	796	Electricity
North London	12	374	96	200	150	446	121	157	8	790	Steam

from the best firms in England they were told by those who Mr. Bury. tendered that it was necessary to discard the idea of side doors. It was pointed out by the Company that end doors would not allow the people to get in and out as quickly, but that view was looked upon as old-fashioned. It was curious to find that in the United States they were coming back to side doors, and Mr. Ellis, the Manager of the Metropolitan railway, who had had 2 years' experience of electrified trains, had all but decided to go back to side doors. With regard to the interesting subject of steam versus electricity, the Great Northern Railway Company would like to adopt electrical working, and were fully aware of the advantages of an electric train: the train could be accelerated quickly, stopped quickly, time was saved by doing away with reversing at terminal stations, and more trains could be run per hour over a given pair of metals. It might therefore be asked: Why not electrify? The answer was, that there was no inducement commercially to do so. No more people—he said that without fear of contradiction—could be carried with electricity on a pair of rails than could be carried with steam; it was not done anywhere. People could not be carried at less cost—that also was not done anywhere. There was an enormous loss in scrapping everything, and capital had to be found for the electrification. There were several examples of steam railways converted into electric railways, and no one could say they were very encouraging in their results. There was a strong need in London for some large power-house which would do away with the necessity of each railway spending capital in building one. There was no possibility at present of taking electricity, as it were, on tap. It was, however, neither electricity nor the change from steam to electricity, that had caused the disappointing results. The whole of the London transport at the present day was being carried on at a loss. It was perhaps invidious to name companies, but what company was paying? The fares were much too low. The larger companies who had long-distance traffic and other traffic did not show in the half-yearly accounts the results of the suburban working, but men like Mr. Inglis and himself knew very well what they were. Some of the speakers seemed to think that twopence was the least fare charged, but that was a mistake. Millions of people were carried every year on the Great Northern for less than a 1*d.*, more millions still were carried for less than 2*d.*, and conversion from steam to electricity would not help that one bit. The experience of the Metropolitan railway showed that the cost was a little more per train-mile with electricity than with steam. On p. 50 the Author had given the cost of working. In view of the possibility of electrification, the Great Northern Company had been

Mr. Bury. very careful for 2 or 3 years to keep the suburban accounts separate from the main-line and long-distance accounts. It was somewhat curious to find that where the Author had for the maintenance of way and structures 13 per cent. of the expenses, the Great Northern had 10 per cent. The Author's 45 per cent. for maintenance and operation of equipment and plant was exactly the same as the figure for the corresponding steam-costs on the Great Northern, which was arrived at long before the Paper was issued. The working of trains and stations corresponded with what on the Great Northern were called the traffic-expenses, which were 35 per cent. in the Subway and 27½ per cent. on the Great Northern. The next item, however, showed a striking difference. On the Subway, general and miscellaneous expenses were 7 per cent.; on the Great Northern, rates and taxes and miscellaneous charges were 17½ per cent. He did not believe it was possible to carry a passenger first a vertical journey, then a horizontal journey through a mile of tube that had cost £600,000 or £700,000, and then a vertical journey again, for a penny. The railway might be filled day and night with such traffic without earning interest on the money. What were the lessons to be learned from the Paper? The Author said that the expresses were often crowded to the utmost extent, which meant that passengers were standing up as close to each other as possible—in fact, that the cars were crowded with "strap-hangers." The local trains frequently had empty places. It seemed to Mr. Bury that the first lesson to be derived from the Paper was that surface means of transport—trams, motor-omnibuses and horse-omnibuses—would continue to take the passengers for short distances, no matter whether there was a subway, tube, or anything else. The second lesson was that beyond all doubt the fares in London were much too low. The third, and he thought the most valuable, lesson was that railway-managers in looking for means of increasing their receipts, must run faster trains for the long-distance, or outer suburban passengers. If that were done passengers would move farther out. That was the class of traffic that paid, and no tramway could compete with a railway for distances beyond 5 or 6 miles out of London. The penny traffic should be left to the omnibuses and the trams, and some reasonable arrangement should be made with them to avoid the cut-throat competition. Lastly, there should be no attempt to mix fast suburban traffic with slow suburban traffic.

Mr. Cuningham. Mr. G. C. Cuningham, referring to the general system of constructing railways in such a city as London, could not agree with those who thought that the tube was not a suitable system. It seemed that the beautiful homogeneous clay of London had been designed by Nature for the very purpose of having tunnels pierced through it, and it would be a great pity to balk Nature in her design. The simplicity with which the tubes were constructed was wonderful, and the absolute non-disturbance of the streets through which the tubes passed was an incalculable point in their favour. For instance, while the tube was being constructed under Regent Street, of all the millions of people who passed along that street during the construction he did not suppose there were a hundred who knew what was going on down below. Picturing the scene if there had been an open cut, with all the water-pipes, gas-pipes and sewers removed, one could scarcely imagine the outcry of the people of London, and even of people throughout the world, at such an intolerable disturbance. But the construction of a tube went on with absolute simplicity and with the greatest ease. Mr. Hudleston had given some figures relating to the cost of construction, and Mr. Cuningham thought he was not far wrong in saying that the cost of a tube 11 feet 6 inches or 12 feet in diameter could be calculated at about £34 per lineal yard, which came to about £60,000 per single mile, or about £120,000 per double mile.[1] It would cost a great deal more than £120,000 per mile, in constructing an open cut along Oxford Street, to remove and relay all the gas-pipes, water-pipes, and sewers; and that was a very strong point in favour of tube construction. One thing that had been urged against tubes was that the air was not good. He had seen the Subway in New York, and the air was not good there; there had been a tremendous outcry among the people of New York about the condition of the atmosphere, and great difficulty had been found in improving it, because the various openings in the side of the subway prevented any pumping out. The heat of the subway became intolerable in the hot weather, and there were no means of cooling it. The ventilation of a tube was a simple matter. The proper place for such ventilation was, in his opinion, midway between the stations, and not at the stations themselves. A shaft could not be constructed in the street; but it was possible to have a horizontal shaft connected with the top of the tube, running back 200 feet or 300 feet to a convenient backyard, where a vertical shaft might be erected, and the atmosphere could be changed by means of a fan, which could work at all times while the trains were running. If that were done, a great deal of the objection to the atmosphere of the tubes would be overcome. As a matter of fact, on the Central

Mr. Cuningham.

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[1] That is, for the tube alone, lined complete, but without permanent way and not including the cost of any land.—G.C.C.

Mr. Cuningham. London railway the air was pumped out every night after the traffic ceased. The doors of the station-passages were closed, the large fan at Shepherd's Bush was started, and air was drawn from the Bank to Shepherd's Bush to the extent of about 20,000,000 cubic feet every night, a process which entirely renewed the air three times over. Bacterial and chemical observations showed that the air was as good and pure as the air outside when the fan ceased to work. There was, of course, the further question of the warmth of the tube, which was objectionable to many people. The clay had gradually become warmed to a steady temperature of about 68° F., and thus kept the atmosphere of the tube at that temperature. Still, that of itself could not be an objection. The lift service was also objected to, as being a source of heavy expense. The cost of the lifts was about 0·1*d.* per passenger, and amounted to about £16,000 per annum, a large sum, but just about one-half of what was paid in rates and taxes, for which there was no return. If relief was required, the relief might come very properly from the municipalities, who rated the railways so heavily that it became an exceedingly serious matter for a railway to continue financially sound. With regard to the wear of the rails, touched upon by Mr. Bury, on the Central London railway the wear of the rails had been chiefly on the curves, due almost entirely, Mr. Cuningham thought, to the fact that it was extremely difficult, with a considerable overhang of platform, to get a train sufficiently elastic in going round a curve; the close coupling made the train so stiff that the wheels ground against the rails and cut them away. The wear of the rails on the straight was hardly $\frac{1}{16}$ inch in the $7\frac{1}{2}$ years of running, in spite of the enormous car-mileage; but on the curves the wear was severe. As to side doors, on the Central London railway the average stop of trains with end doors was 10 to 15 seconds, and he did not think it was possible to do better than that with side doors. The difficulty about side doors was the impossibility of having a man to look after every door. People were apt to injure themselves in getting in and out whilst the train was moving, whereas by the system of end doors and platforms with men guarding them the passengers were perfectly controlled and their safety was absolutely secured. The Central London railway had now carried about 300 million passengers without injury to one, and that said a great deal for the end-door system.

Mr. Read. Mr. R. J. G. Read was one of those who had had the privilege of visiting the subway with Sir William White, in 1904. Several things struck him, especially the interminable lines of upright stanchions, such as were shown in the sections. The question occurred to him why they were put so close together, instead of Mr. Read. having longitudinal girders with the stanchions farther apart, and this the Author now explained in his Paper by saying that variations in temperature would have caused difficulties in making closures if longitudinal girders had been adopted. Some years ago Mr. Read was engaged on a railway-contract in which a very large area had to be covered with longitudinal girders, cross girders, and floor-plates. The bays of the cross girders into the longitudinal girders were all made, fitted at the works, and riveted up on the site, but the junction-bays between the longitudinal girders were left open, and were to be closed when the others had been riveted up. He had templates made of all the junction-bays, each bay being about 30 feet by 5 feet, and sent them to the works, where the plates were made and drilled to the templates. The templates were taken in September, when it was fine and warm, and the plates came on to the work about Christmas, in cold weather, and when they came to be put into the junction-bays they were all too short. They were all rejected by the inspector, and Mr. Read was ordered to send them back and obtain new ones. He delayed the matter for some months, until the principal of the works and the chief engineer came on the scene, and then insisted on having the plates tried again. It was a warm day in March; the plates fitted exactly, and the chief engineer turned his wrath upon the inspector who had kept them out all the time. Perhaps the Author had had some such experience as that in his mind when he considered the question of longitudinal girders. As to the Author's experiments to determine the relative strength of girders carrying loads when embedded in concrete and when free, Mr. Read had been accustomed, in designing floors in which concrete was used with steel joists, to reckon that the joists were 25 per cent. stronger when thoroughly embedded in concrete than when free, and that seemed to have been borne out by the Author's experiments. Another interesting matter was the beneficial effect of rust on iron bars in concrete. Professor Bach of Stuttgart had also found by experiment that the adhesion of dirty bars was greater than that of cleaned bars in about the same ratio as given by the Author, although the actual figures were not so high. Professor Talbot had made some researches in America with reinforced-concrete beams and columns, and had found that the "bond"—meaning the adhesion, no doubt—was about 376 lbs. per square inch for the rough rods, against 147 lbs. per square inch for the clean rolled rods. That was about the same ratio as was given by the Author, who was of opinion that the union of the metal with the cement was so complete that the former was not capable of

Mr. Read. rusting. Some years ago Mr. Read was carrying out the foundations for the Seamen's Hospital at the Albert Docks in reinforced concrete, and the question arose whether the rods should be cleaned or coated. After the work was done, he had a block made with some of the rustiest bars procurable embedded in it. He had quite forgotten the block, which had been lying in his garden, half in the ground and half out, since 1903. When the Paper was read, a fortnight ago, he unearthed the block, which was then in the snow, and broke it open; and he had laid it on the table. He found that the rusty bars were perfectly clean. He had held for some time the opinion that steel rods which had been thoroughly embedded in concrete would not rust if taken out and exposed. He left the clean bars taken out of the concrete exposed to the atmosphere, the snow, and the rain, in order to see what the effect on the bars would be. He had also placed with them on the table some steel test-bars, and it would be seen that, as the result of the fortnight's exposure, the steel test-bars had rusted considerably more than the bar which had been taken out of the concrete. He had been very much interested in the account of the construction of the tunnel under the Harlem River. A few months ago he had an opportunity of seeing the construction of the Metropolitan railway in Paris, where they were sinking into the river in much the same way as had been done in New York. Alongside of the river, in water-logged ground, they were sinking a whole station from the street. The steel skeleton of the station was built above-ground, the street was excavated, and the framework was let down and concreted. Then air-locks were placed in it and it was sunk deeper. When he saw it the top was about level with the surface of the street, and the air-locks were in.

Mr. Haigh. Mr. Arthur H. Haigh remarked that the question of cost of construction had loomed large in the discussion, and he would like to compare the cost of a shallow subway with that of a deep tube. He had recently had the privilege of going through the New York Subway, and had examined the tunnel just being completed near the Brooklyn Bridge; and he had been especially struck with the reinforced-concrete work for the ordinary length of the subway, a matter he would like to refer to later on. With regard to cost, the information given in the Paper was meagre, and it was not very clear what was implied. It had to be remembered, in comparing the work, that the line had not been made on one system; it was really a combination of a shallow subway with an elevated railway. The small amount of tunnelling was only such as would be requisite under any system to meet the topography of the district. As a matter of fact, only about one-half of the length was shallow subway, and Mr. Haigh. one-quarter was elevated railroad, a much cheaper form of construction. He could not quite reconcile the figures in the Paper. The minimum cost quoted for the shallow subway construction was given as about £200,000 per mile of single road, which meant over £400,000 for double line. The first contract was he believed £1,000,000 for the portion of the work represented on the long sections in Figs. 2, Plate 5—that was, without the section under the East River represented in tunnel. The latter was let for a very small sum; the tender was £400,000 for the construction, irrespective of the terminals, and the work could not possibly have been done for that amount. Another tender put forward at the same time was £1,400,000 and the work could not have cost much less. Therefore it was necessary to know whether the £10,000,000 for the construction of the whole system included the contract for the 3 miles comprising the East River tunnel at £400,000, an amount which must certainly have been tendered in order to keep the whole system in the same hands. Tubes could not be made in London for anything like the figure mentioned by Mr. Cuningham, namely, £120,000 per mile. Some figures which had been brought forward in the discussion were not very different from his own. Taking a general average of the tubes in London already made, he found the cost to be about £550,000 per double mile, including construction, stations, cost of promotion, land, equipment, and power. Deducting land, power, and equipment, the cost was about £300,000 per mile of double line of 12-foot tunnel, and that was the figure which he proposed to compare with the New York Subway, in showing what might have been the approximate cost if the subway had been made on the tube system. Those familiar with London tunnelling and dealing with mains and sewers would know that what had been done in New York could not possibly be done in London; and although it was possible that some shallow subways might have been made in those districts in which tube tunnels had been made, the same method could not have been applied. Even if it could, economy would not have been effected, because in those places the expense of diversions and other matters was such that the cost would not have differed much from the £300,000 per mile he had alluded to. The shallow Metropolitan railway between Paddington and Aldersgate Street, which was made in the sixties, cost for construction £186,000 per mile; but in those days the prices of labour and of materials were less than half what they were now, and therefore the figures were not comparable. With regard to comparison of the cost of the tunnels of New York and what might

Mr. Haigh. have been the cost of a tube system, he had put together a synthetical Table to make up the $10\frac{1}{4}$ millions sterling given as the total cost of the construction of the Subway. The rates he had put were, of course, quite imaginary, but, being proportionate, they might serve the purpose of comparison. He had first put down the Table given on p. 12, which showed 27·4 miles of different classes of work, of which 13 miles was in flat cover and 1·2 mile in arch; then he had put down the amount of single-track and double-track line from p. 8, which gave 25·7 miles of railway. He had separated those into a few items according to the differences of construction, and had obtained the following particulars:—0·1 mile of single-track route at £250,000 per mile, £25,000; 3·9 miles of two-track at £450,000 per mile, £1,755,000; 1·3 mile of two-track at £600,000, £780,000; 5 miles of two-track at £315,000, £1,575,000; 7·6 miles of three-track at £160,000, amounting to £1,216,000; 6·4 miles of four-track at £630,000, £4,032,000; 1·4 mile of five-track at £720,000, £1,008,000; the whole amounting to £10,391,000. That was slightly in excess of the 50 million dollars stated on p. 46, but for apportioned figures, it was fairly near as a matter of comparison; whereas, the £200,000 given as the cost per single-line mile of the flat-covered subway portion, which could not be reconciled with the total quoted, was half as much again as the average cost of the whole route. As a matter of fact, the cheaper construction only extended to one-fourth of the route, and there was much more expensive work in the tunnels. From these figures, and considering that for shallow subways the minimum cost given was £410,000 per double mile, he obtained the following comparison: 38 miles of double line would equal 76 miles of line made on the New York Subway, and at £300,000 per mile the cost worked out at £11,400,000. But in order to make a fair comparison it was necessary to take, not 12-foot tubes but 16-foot tubes, and for that extra diameter had to be added £5,700,000, the total thus coming out at £17,100,000. The Paper gave the total cost of construction at $10\frac{1}{4}$ millions, but adopting the rate of £410,000 per mile, the cost worked out at £13,000,000, so that on that basis the deep tube would have cost 4 millions more than the subway on the whole cost of the work. There were many other points which he would not occupy time by referring to. For instance, there was the addition to the cost of construction owing to the expense of working lifts. He did not quite agree with capitalizing that. He thought it should be considered simply as an increase of working-expenses. He did not see how it could be fairly put to capital in any way, because no capital was expended,

and the expense which was incurred from time to time in working Mr. Haigh.
depended on the number of passengers. One curious feature was that although 166,000,000 passengers per annum were carried on the Subway, after an expenditure of £15,000,000, and there was a gross revenue of 10 per cent. and a net revenue of 6 per cent., yet no private enterprise was to be found to carry the undertaking through; whereas in London, where the tubes did not pay at present, the work had been done by private enterprise. It simply showed that the results could not be foreseen even by the most acute financial minds. It was difficult to discern from the discussion whether the financial mouth or eyes did water most in considering the 166,000,000 passengers on the Subway. There were other methods of transit on Manhattan Island, and in some places the tramways and the elevated railroads passed along the same street. The tramways, he believed, carried three times the amount of traffic the Subway carried. Strange to say, the out-of-date horse-tramway was still in use. He would suggest as a subject for consideration, from the points of view of hygiene and of costs in street-cleaning and indirect ways, that horse-omnibuses in London should be suppressed gradually. A remarkable feature about the construction of the Subway was its extreme simplicity, whereby easy adaptation to local requirements was secured. The forest of stanchions spoken of by Mr. Read had not a very good appearance, but the posts were simple and strong, and they afforded an exceedingly facile means of making necessary changes in the width of the subway. The variation from single line to double line, and from double line to four lines, was simply made by leaving out posts, or re-spacing them and changing the length of the girders, as the case might be; and the subway being rectangular, the cant of the rails on sharp curves was easily allowed for by re-spacing the standards a few inches. The extreme adaptability of the standards was certainly an admirable feature, and the cost of using them was correspondingly small. With regard to the type of station in vogue on the London tubes, the enlarging of the tube from running-tunnels to station-tunnels was the most expensive, troublesome, and dangerous feature in the whole of the tube system, but if special attention were given to the study of economical and expeditious tunnelling a suitable form of station could be devised which would not involve that defect. Not only would this avoid the delays occurring in breaking up for the large stations, but it would produce a cheaper structure and a more suitable one in many respects. The loads that had been allowed for on the Subway seemed to be very slight, especially in the residential districts, where only 500 lbs. per square foot was taken for the superimposed load. It seemed a wrong

Mr. Haigh. principle in a permanent structure to allow the tensional side of the concrete to fracture. The subways being designed, as stated in the Paper, with an allowance of 12,000 lbs. per square inch on the steel, long before that stress was reached tensional cracks would occur in the concrete, oxidation of the steel might commence, and when the load came the rods might not be in a condition to bear it. They could be designed to bear the load with the depths adopted in the Subway and yet have the bottom concrete limited to a tensional stress which was under the normal breaking-stress. It was not necessary to allow a safe tensional stress, because reliance was not placed on the concrete but on the steel bars. The ratio of the moduli of elasticity was about 20 to 1 before the concrete fractured. Although there were records now available of numerous tests of concrete beams, and the use of that type of construction was rapidly extending on the basis of such tests, it was well to recognize that the element of permanency of reinforced concrete had not yet received the proof it needed. In the meantime an absolutely safe procedure for important engineering structures involving the use of reinforced-concrete beams could be adopted by limiting the compressive stress on the concrete to a safe limit, and reinforcing with steel the lower tensional portion to such a degree that fracturing strain might be presumed not to occur before the required maximum loading was passed. Up to a limit very near to the tensile fracture-strain of concrete, its modulus of elasticity altered very slightly. In order to examine what such a procedure meant in comparison with the flat reinforced-concrete cover adopted for New York, he would take the Author's limiting compressive stress on the concrete, (500 lbs. per square inch) and ratio (20 to 1) between the moduli of elasticity, and, in addition, he would use a limiting tensile stress of 300 lbs. per square inch:—

Let M be the bending moment of maximum external loading on 12 inches breadth of beam;
c „ the maximum compressive stress of the upper surface of the beam;
t „ the maximum tensile stress of the concrete at the under-surface of the beam;
d „ the depth of beam;
A „ the cross-sectional area of steel reinforcement;

the units being inches and pounds. Then, equating forces and moments in the usual way for the middle of the beam, and assuming the metal to be buried 2 inches—

Mr. Haigh.

$$M = 2 . t . d \left[d + 20 \frac{A}{d} \left(\frac{d}{3} - 1 \right) \right]$$

$$\frac{A}{d} = \frac{3}{10} . \frac{c - t}{t} .$$

Using the numerical limits for c and t simultaneously, the equations became

$$M = 200\, d\, (7d - 12)$$

$$\text{and } A = \frac{d}{5}$$

The area of steel required for each foot of breadth was one-fifth of the depth of the beam, in square and lineal inches respectively. The reinforcing steel being near the point of maximum tensile strain in the concrete, its stress had been taken as 300 multiplied by the ratio of the moduli. The flat cover under consideration had a cross section of reinforcing metal about half of that shown by the calculated formula: but the stress was double. The increase of metal required in accordance with the suggested calculations would bring the whole amount to about the same as the metal in the girder construction for which the reinforced concrete of the subway was substituted. With regard to decoration of stations, the Borough Hall station at Brooklyn presented an appearance greatly superior to that of the ordinary station. Its polished marble wainscot was a feature certainly requiring, from an æsthetic standpoint, the protection that had been afforded by the prohibition of advertisements. This prohibition might be extended with general advantage. In tube stations it seemed worthy of further consideration by the architects whether the beauty of a vista of wide-sweeping cylinder did not transcend chequered tile-work, and whether distraction of the eye in its search for station-names and direction-notices might not be mitigated by more single-toned treatment. Further details from the Author would be acceptable with regard to the methods of construction beneath the Harlem River, including the lengths of timber caisson used, the adjustment into position of the tunnel-sections, and the jointing for connection of the lengths separately placed; and an explanation of the traffic over the three-track portions of the railway, where there would appear to result a rapid accumulation of the express-traffic cars at one end. would be interesting.

Mr. Copperthwaite.

Mr. W. C. Copperthwaite thought the main lesson to be drawn from the Paper was that such an excellent piece of work as the subway in New York was quite impossible of imitation in London. He had had to do with both tube railways and surface railways, and he could not imagine anything of the kind being built, at any rate

Mr. Copperthwaite. in the central part of London. Even if the physical difficulties could be overcome, the cost of work of that description would be such as to render it quite prohibitive. Mr. Hudleston, who was experienced in the matter, had given some figures for the cost of tube railways, and had found that under the most favourable circumstances the shallow subway might compare on even terms with a tube railway; but in order to arrive at those figures Mr. Hudleston had omitted two points which might be referred to briefly. In the first place, Mr. Hudleston had assumed that the cost of the land was to be the same for a tube as a subway. In the London streets it was quite clear that a station of the type of Fig. 16, Plate 6, could not be built without land being acquired on each side of the roadway. The land on the Central London railway cost upwards of £100,000 per mile; and if, instead of having a station on one side of the road, the station had been divided, part being placed on each side of the road, the cost, it was true, would not have been doubled, but it would certainly have been very much more. Land alone would probably have added £50,000 per mile to the cost of constructing shallow subways in London. Another point which Mr. Hudleston had disregarded in making his comparative estimate was the economy in working effected by the arrangement of gradients to suit the direction of the trains, a matter easily managed in a tube railway without extra expense, but impossible, save at great expense, in a surface subway. Although it was quite impossible to work by cut and cover in the present condition of London traffic, there was one way that had been tried in Paris and Boston whereby shallow subways could be built at a very fair rate of progress—what was called the "roof-shield" method of tunnelling. It was not as good as the ordinary shield method, because it required two operations, but it was comparatively simple, and it was possible to apply it without serious disturbance of large water-mains and gas-pipes. In Tremont Street, Boston, 24-inch, 12-inch, 10-inch, and 8-inch gas-mains and 18-inch water-mains had been tunnelled under for a distance of 550 yards, without difficulty. Two side headings were driven first, in which were built the side walls of an ordinary two-track tunnel. When the side walls had been driven, the semicircular roof-shield was started on the top of the two walls, running on shoes. The earth was taken out of the crown, the concrete roof was put in, and the invert was built afterwards. Progress was made at the rate of about 9 or 10 feet per day—not at all bad progress for a double line of track; and the process had the great merit of not interfering in any way with the traffic overhead. When the same thing was tried in Paris an attempt was made to drive a tunnel as close to the surface as the shallow subway under discussion, the top of the shield being about 1 metre below the roadway-paving. The method was not quite so successful there, because it was found that the effect of driving the huge shield forward with a pressure of about 300 tons was to cause a small wave in front, where the earth was forced up to a height of about 2 feet and impeded the traffic. However, there was a great difference between closing the whole street, and closing one small area about 20 yards in length. In Paris the shield had been driven along the quays from the Pont d'Austerlitz down to the Quai d'Orsay without any trouble at all, except for the momentary interruption of the particular piece of street where the shield was to run. That he thought was the only conceivable method of doing anything of the kind in London, and even of that he was rather doubtful. Mr. Copperthwaite.

Mr. R. C. H. Davison thought the Author might usefully supply a small Appendix showing the different steps that had to be taken to obtain powers to construct the shallow subway, and also the laws under which the works had been carried out. Mr. Macassey had mentioned some of them, but it would be a good thing to have them all set out on paper, so as to see exactly the difference between such projects in the United States and in England. Sir William White had mentioned having seen pipes suspended from the under side of the decking of Lower Broadway, but he had not alluded to those carried along the street-gutters, nor to those bracketed to the faces of houses. It would be interesting to know under what powers the gas-pipes were thus bracketed. In England it was a matter of the greatest difficulty to get a clause in a tramway Bill allowing the bracketing of a wire to a house; while in the great cities of the Continent they preferred to bracket things on to houses and even to suspend the electric lamps from such brackets on wires. In London the preference appeared to be for as many obstructions in the streets as possible. Quite recently a row of lamp-posts had been put down the centre of Oxford Street, dividing that thoroughfare into two narrow lanes. There was a cab-rank in Victoria Street, Westminster, that rendered it as quick to get along that thoroughfare by omnibus as by cab. The thing that struck him most was the great assistance given to the New York subway by the local authorities. The only assistance afforded in that way in England had been given by the City of London, which helped the Metropolitan Railway in its infancy, and assisted the Central London Railway in constructing the fine station at the Mansion House. If that assistance had been given to the tube railways of London he ventured to think that lifts would have been Mr. Davison

Mr. Davison. in the middle of streets, and the passengers would have been taken down direct on to island platforms, instead of through long lengths of underground passage, which no doubt deterred people from travelling on the tubes for short distances. Another heavy tax upon railway-companies was the price of land. The promotion of a Bill raised the price of land at once, and the promoter was raising the price without any assistance on the landlord's part. The principle of betterment should apply. Mr. Davison lived in hopes of seeing the price of land purchased under compulsory powers fixed at the rateable value plus 10 per cent.; that would be good for the rates and just to the traction-companies. With regard to local authorities, it would never be known who was to blame, because in Greater London there were no less than 106 highway-authorities. He had been the resident engineer for the late Sir John Hawkshaw and Sir John Wolfe Barry on a portion of the City lines, and on those lines he did not think the traffic was obstructed for a single hour. A sufficient length of roadway was opened each night, and balks were put across the street, with longitudinal planks on top and then cross planking. This was finished during the night, and street-traffic was resumed next morning. The only difficulty occurred when tramways had to be carried. In reinstating the lines of tramway in the Whitechapel Road raised platforms had to be placed at the sides of the footpaths. These certainly were a great obstruction to traffic, and considerable hardship was suffered by frontagers during the reconstruction of the road-surface. The ideal underground railway was mentioned in the Report of the Advisory Board to the Royal Commission on London Traffic, where it was suggested that the station should be as near the surface as possible and should be connected by tubes—giving a kind of switchback section. With regard to costs, the only comparable costs that could be taken were those given as paid to sub-contractors. It had to be remembered that the New York tenders were bids not for construction alone, but for working for so many years, and a low tender was worth risking, as the money would be returned on the working. Mr. Macassey had given some interesting facts about the shape of cities and the number of journeys *per capita*. There was no doubt that the habit of travel increased with the facilities for travel. The shape certainly had something to do with it, but the *per capita* journeys of London, which had not changed its shape, had increased enormously, even since the sitting of the Royal Commission on Traffic. In that Report it was shown that the urban railways carried 70 per cent. of the passengers the omnibuses 15 per cent., and the tramways

15 per cent. In London the tramways were greatly neglected. In New York there was 1 mile of tramway to 5,800 inhabitants; in London in 1904 there was 1 mile to 33,000 inhabitants, but since then the ratio had advanced to 1 mile to 20,000. He hoped that the County Council would carry out the policy suggested by the Advisory Board and extend the tramways, as he believed the habit of travel would grow. A very gloomy view had been taken of tube railways, but it should be remembered that upwards of 24 miles of new line had been opened within a short time, and also that at the hours of greatest pressure the Central London railway carried about its maximum. The traffic totals for London railways as a whole were constantly increasing, and he ventured to think that it would not be long before the tube railways were working to their full capacity. The London traffic-problem was not yet solved. Mr. Davison.

Sir John Wolfe Barry.

Sir John Wolfe Barry, K.C.B., Past-President, remarked that there were two matters to which, in speaking on the spur of the moment at the commencement of the discussion, he had not alluded. One was the subject of accommodating the traffic while surface subways were being made. What had been done lately in London was very different from the course adopted in New York, and also very different from what was done when the first Metropolitan railway was made under Euston Road, when the road was cut up from end to end, and the inhabitants suffered the greatest inconvenience, being almost as badly treated as they had been in New York. Since the date of the first Metropolitan railway, about 1863, the method of constructing subways had altered; and in the construction of the City lines and the Whitechapel extension the traffic in the streets was not only not blocked for a single hour during the daytime, but the whole street was left open for roadway and footpath, the only part occupied by the works being certain specified places in the road railed off to accommodate the width of one cart and the length of two carts, together with a crane—a space not larger than was frequently used for constructing a sewer. There had been absolutely no obstruction of traffic along the crowded thoroughfares of Cannon Street, Tower Street, Eastcheap, and the Minories, under which the railway was made, and the only exception was what Mr. Davison had alluded to in regard to the tramways in the Whitechapel Road. In that statement he included underpinning of houses and the diversion of all the pipes and sewers. With regard to the cost of these precautions the first contract had in it the following clause:—

"In constructing the works, the contractor's attention is drawn to the circumstance that the roadway and footpath traffic is not to be interrupted,

Sir John Wolfe Barry.

The contractor will be required, in constructing the railway along or across streets, and at such other places as the engineers will direct, to provide over the whole site of the covered way a temporary platform, or coverings which will consist of balks of whole timber not less than 12 inches square, laid at distances of not less than 4 feet centre to centre, and covered by two layers of planking, the lower layer not less than 4 inches thick, and the upper layer not less than 3 inches thick. This platform will have to be effectually supported by timber, and effectually maintained, and beneath it the works will have to be carried on."

That was done, and there was consequently no obstruction of traffic. The lump sum put into the contract to cover that clause was £7,500 for the whole of the work from the Mansion House to Aldgate, so far as it passed under public streets, which was a very large portion of the way. The Whitechapel contract contained the same clause. He did not wish it to be understood that this was the price per mile, because there were portions under private property where there was no planking. The same remark applied to the Whitechapel extension, the cost of those precautions on the Whitechapel line being £9,000. Therefore the matter was a comparatively small affair when it had to be dealt with. Exactly the same process was carried out in the underground railway through the heart of Glasgow, passing down Argyle Street and other main thoroughfares for 2 or 2½ miles—and he believed the traffic along a considerable portion of Argyle Street was comparable with the traffic of the Strand—and again, in a great city like Glasgow, there was no obstruction of traffic on account of either sewers or gas-pipes. Another matter he had omitted to mention was the cost of the shallow subways in London and Glasgow, in regard to which he was able to give some figures. It would be understood that he was giving only the cost of the works, and not the price of the land. The railway from the Mansion House to Aldgate cost £440,000 per mile without stations, and £532,000 per mile with stations, the stations on that line being extraordinarily difficult and very numerous. From Aldgate to Whitechapel the cost of the line without stations was £270,000 per mile, and £301,000 per mile with stations. The Whitechapel and Bow Railway, 2¼ miles long, cost £350,000 per mile without stations, and £430,000 with stations. The 3 miles of the Glasgow Central Railway cost £200,000 per mile without stations, and £308,000 with stations, the stations in Glasgow being also very heavy and difficult. All those lines were double lines of ordinary railway, large enough to accommodate all the rolling stock of the suburban lines, and the stations were designed on the most liberal scale, with very long and wide platforms. In the foregoing figures the cost of diversion of sewers, and of traffic precautions and underpinning, was included.

The Author. The AUTHOR desired to thank the two Past-Presidents who had spoken for the very flattering remarks they had made with regard to him. He appreciated the compliment in Sir John Wolfe Barry's claim that he was half an Englishman; but Sir John had not stated whether it was the better or the poorer half he claimed for England! It was a source of regret to him that Sir William White had not mentioned, when paying his second visit to the subway, that he was sailing next morning, because had he done so he would have found just as much difficulty in getting through it as on his first visit.

Replying to the discussion, he gladly acknowledged, in response to a suggestion by Sir John Wolfe Barry, the benefits derived in the preliminary study of the various underground railways in London, and especially of the very instructive work executed by Sir John himself. The point raised by that speaker in regard to the unit-stresses permitted in the roof- and wall-beams had been answered by Colonel Yorke, regardless of the additional strength of the concrete arching, which, as the experiments described on p. 41 showed, amounted to an increase in resistance of one-third. The reinforcement of the side walls, thus admitting of thinner construction, not only economized space so as to permit work in a narrow street otherwise impossible, as Sir John Wolfe Barry had pointed out, but was also a cheaper form of construction. Sir William White and other speakers had referred to the Transit Board. Without such a board and the concentration of power, the subway would have been impossible of accomplishment. The growth of a modern city, and the comfort and welfare of its inhabitants, depended largely on facilities for internal transportation. Unfortunately, there existed a feeling on the part of some people that the granting of any special privileges benefited only a private corporation, and that no privileges should be granted, but taxes and other burdens should be imposed. The public was more vitally interested in the building of interurban railways than were investors. For the sake of the public, therefore, all possible aid should be given to reduce the cost, burdensome at best, in order to induce construction, perhaps even going to the extent, as Mr. Macassey had pointed out, of not permitting vested rights to impose a veto. Mr. Davison had inquired as to the laws and the necessary steps to acquire powers under which the subway had been built. There was but one law, that creating the Rapid Transit Commission and conferring upon it all authority necessary to lay out and construct the railway with the City's money. After the location had been approved by the city authorities, the Board had power, by mandamus proceedings if necessary, to compel the finance department to pay the cost; and it

The Author. had also power to take up, alter, or relay all surface or sub-surface structures, subject only to the reasonable requirement of the companies owning the same, or of the Public Works Department in case of city ownership. The authority of the Transit Board was therefore complete. As to obtaining "powers" to construct, there was nothing analogous to British procedure. The enterprise being municipally owned, the Board, having fixed the route and adopted plans, simply let a contract, after advertising, for construction and operation. In such matters special charters were avoided in American legislative practice. Usually there was a general Corporation Act under which any company proceeded, having complied with its provisions, and, in the case of railways in some States, having secured in addition the consent of the State Railway Commission. The Author had referred Colonel Yorke's inquiries about rail-wear to Mr. George H. Pegram, Chief Engineer to the Interborough Company in charge of Maintenance of Way, who stated that the original rails were still in service on straight portions of the line, but their life was estimated at 6 years. On curves the wear was much more rapid. *Fig. 22* showed the wear of the outside rail on the City Hall curve, after being laid only 3 months, from August 18th to November 18th, 1907, while *Figs. 23* showed the wear on both rails of the southbound express track at Great Central Station during 4 months. The tonnage given was the approximate tonnage passing over the track, not over each rail. An analysis of these rails showed :—

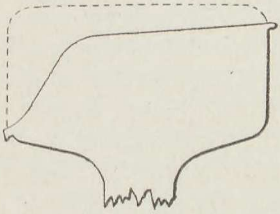
	Per Cent.
Carbon	0·60
Phosphorus	0·086
Sulphur	0·053
Silicon	0·066
Manganese	1·06

Some experimental rails had been laid having the following composition :—

	Per Cent.
Carbon	0·62 to 0·72
Phosphorus	0·075
Sulphur	0·075
Silicon	0·2
Manganese	0·9 to 1·1

which seemed to give better service. With corrugation there had been some but not serious trouble. It had been general on curves, but rare on the straight. On the latter the cause had not been apparent, chemical analysis not showing any irregularity in composition in the rails where it appeared. On the inside of the outer rails on curves there was laid originally a guard- or check-rail of special section, which in service was found to be flexible, concentrating pressure on its bolts. If they held, the check-rail would bend between the joints, causing lateral motion and corrugated wear on the track-rails. These flexible guard-rails had been replaced by 100-lb. rails of the normal section, which had overcome most of the troubles of this character. In fact, on the City Hall curve the life of the rails had been increased from 3 months to 4 by the stiffer guard- The Author.

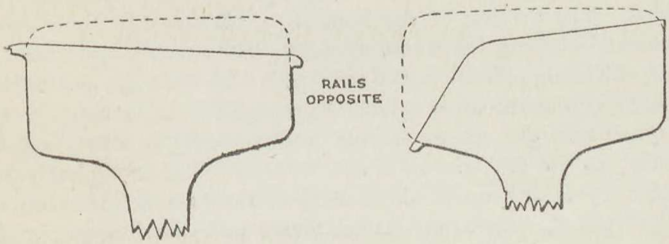
Fig. 22.



WEAR OF A RAIL AT CITY HALL LOOP.

(Life of rail, 3 months. Radius of Curve, 147 feet. Gradient 1 in 77 down. Traffic, 7 million tons. Average speed 11·14 miles per hour.)

Figs. 23.



WEAR OF RAILS AT GREAT CENTRAL STATION.

(Life of rail, 4 months. Radius of curve, 220 feet. Gradient 1 in 87 down. Traffic, 13 million tons. Average speed 18·2 miles per hour.)

rails. Corrugation at present appeared to be due to braking and accelerating on curves. Where these took place corrugations were found, ranging in length from 12 to 36 inches, and of various depths up to $\frac{3}{32}$ inch. Sometimes the corrugations on the inner and outer rails differed, those on the former being longer but not so deep. On curves where there was no braking or accelerating, corrugation if present was quite irregular, sometimes but a single rail being affected. In reply to the several questions by Mr. Fitzmaurice, the

The Author. Author would state that nothing in his own experience, or in his subsequent study of the experience gained in other cities, had led him to regret his decision in 1894 that for New York shallow subways were to be preferred to deep tubes; but, contrary to Mr. Fitzmaurice's opinion, the existence of rock was not a factor tending to such corroboration. This material, requiring drilling and blasting, was not attractive for open excavation with pipes being supported overhead. The determining reasons had been the greater public convenience, lower working-expense, and consequent greater net return, of the shallow subway. Obstruction to other traffic during construction and annoyance to frontagers could be reduced, but at increased cost, by roofing over the excavation, as had been done in Lower Broadway, where there was no parallel street to which traffic could be diverted, or as was being done in Boston by Mr. Carson, where the streets were quite as narrow and irregular as those in London. It was only a question of money. The Harlem River crossing could have been made in open coffer-dams. The sub-contractor who had the contract for a lump sum chose the method described, as being cheaper. Less timber was needed, the cost of compressed air probably did not exceed the cost of pumping, and all risks attending an open coffer-dam against a hydrostatic head of about 55 feet, with a bottom that was not of the best, were avoided. The driving of the East River tunnels had been a very serious undertaking, the material varying from rock to quicksand, at times both being present in the same face. To blast the one without causing a run of the other called for great skill. In driving through the quicksand, the sub-contractor unfortunately so disturbed the material as to get the tube out of level. The irregularity was rectified by taking up in short sections the bottom plates on the "high" places, excavating the material, and then replacing the plates to a new gradient-line level with the low places. Special castings were provided for making up at the sides and closing at the ends. The maximum depression thus resulting was 18 inches. The tube where altered was not circular, but as it contained at the sides concrete benches carrying the ducts (Fig. 8, Plate 5) it was so strongly stiffened internally against distortion that the small variation from circular section was of no importance. The stiffening effect of the benches was increased by running them up vertically to support the roof-plates. When driving a shield through a flowing material such as quicksand and under high air-pressure, there was a decided tendency to keep the particles of sand at the sides in suspension, so that the iron ring had at the sides only hydrostatic pressure for support. Unless the ring was restrained laterally during construction, or until such time as the particles of sand had again come to rest and exerted a pressure, the iron ring would settle vertically and deform, cracking the plates along the top. This flattening could be resisted by chains and turn-buckles, applied at every other ring and as close to the shield as possible. The estimates of cost given in the Paper, which had confused Mr. Fitzmaurice and other speakers, were based not upon the prices paid by the City—which, as Mr. Fitzmaurice has pointed out, did not, in the case of the Brooklyn extension, represent the true cost—but upon the actual payments by the company to the sub-contractors. Mr. Galbraith had given some interesting figures of cost of the Waterloo and City tube, which was over $1\frac{1}{2}$ mile long, with only the terminal stations. In order to compare the cost per mile of this railway with the average cost of the New York Subway, it was necessary to add the cost of five intermediate stations, and not merely one, as Mr. Galbraith had done, because on the Subway they occurred at $\frac{1}{4}$-mile intervals. When this arbitrary allowance was made, Mr. Galbraith's figures also confirmed the experience of Sir John Wolfe Barry and the Author, that deep tubular construction was more expensive than a shallow subway. In this particular comparison the difference in size was wholly in favour of the New York Subway, the Waterloo and City tube being but 12 feet in diameter, as against the 15 feet 6 inches which would be necessary for tubes to carry the Subway rolling stock. Sir George Gibb, in dealing with the traffic aspect and financial return, had stated that in America there were no omnibuses, but as Sir George Bartley had remarked, there was a much more dangerous competitor for traffic in the tram-cars. In New York, to the surprise of many, the subway had not only created new traffic, but had drawn heavily from the tram-lines overhead. This was due to the higher speed, the freedom from traffic-delays, and, as compared with London, to much less loss of time in going between pavement and station-platform. In reply to Mr. Bury, the sleepers were not creosoted in order to keep out of the subway the very objectionable odour of that material. Under the conditions existing, with no sun and no moisture, there was little tendency for wood to decay, and therefore no need to preserve it. Wear was the destructive agent, and that was guarded against by "tie-plates." Mr. Bury, in comparing the carrying-capacity of a five-car subway train with one of the Great Northern trains, overlooked the fact that his trains took their full load at King's Cross or other terminal, and this load gradually diminished as the train proceeded. In the Subway there was no terminus, but a continual emptying and loading, so that every seat was occupied by several successive passengers on the same journey. The difference

The Author.

The Author. in the portion of the working-cost chargeable to general expenses in the Subway and in the Great Northern was due to the fact that rates and taxes were not included in the former percentage. The Author referred Mr. Haigh to the answers to Mr. Fitzmaurice for an explanation of the estimates of cost: in the total cost was included much overhead line that was much less expensive than subway, as were also the rock tunnels which were lined with concrete instead of with iron, like tubes. This explained the difference between the stated average cost of subways and the total average cost of the whole line. The length of open coffer-dam in the approaches to the Harlem River tunnel was 976 feet, of which 250 feet was held by 12-inch sheet piling; and the lengths of the two air-caissons were 218 and 306 feet. The junction between the iron and concrete sections had been made by extending the concrete arching a distance of 15 feet over the cast iron, while the junction between the two iron sections had been effected by building the second caisson to enclose the open end of the completed half of the tunnel. Traffic over the three-track section was worked by returning the central-track trains over the opposite outer track. Thus, when trains were running south-bound on two tracks they were all returned on the other or north-bound line. This was possible because at such hours, the traffic being less in the other direction, the station-stops were shorter and more trains could be accommodated. Many of the speakers had referred to the reinforced concrete and to buried steel beams and their preservation. A dozen years or more ago the late Sir Benjamin Baker stated to the Author that he seriously questioned the necessity, or even the propriety, of painting steel members which were to be encased in cement mortar. The Author's subsequent observations and experiments had convinced him of the soundness of Sir Benjamin's observation. When the whole surface was protected by a strong covering which incipient rust could not break away or dislodge, rusting was practically impossible. The Author had seen pieces of metal removed from Chinese masonry several hundred years old and still in perfect condition. But there must be immediate contact, which could not be obtained by using concrete mixed dry, with unfilled voids, and rammed into place. The mortar must be in excess of the voids in the stone, and the cement in excess of the voids in the sand, and the whole must be so fluid as to flow into place without ramming, aided only, if aid was necessary, by cutting the fluid concrete with shovels. Water carrying the fine mortar must not be allowed to leak through the forms. Concrete so proportioned and mixed became a compact monolith, and could be depended on to encase thoroughly the embedded steel, which, to secure the best bond, should not be painted. The members asking for information in regard to the conditions of the air in the Subway were referred to a communication by Dr. George A. Soper (*below*), who had been specially retained by the Transit Commission to report on such matters. It should be remembered that not only were there many more trains in the New York subway than in any similar railway, but these trains generated more power, namely, 2,000 HP. on each express and 1,200 HP. on each local train. Nearly all this energy was dissipated as heat. In conclusion, the Author desired to express his appreciation of the reception of the Paper by the members of The Institution, and of their references to the work it described. Naturally much had been said in the discussion in comparison with tubes, and as to the possibility of shallow construction in London, on which opinion seemed to be divided. He had presented the Paper in order to record a work executed under conditions differing in many respects from those existing in London. The difficulties peculiar to London were many and great. Whether they could be overcome, and, if overcome, whether a shallow subway would be profitable, as had been accomplished on a large scale in New York, Boston, Berlin and Paris, was not for the Author to discuss within the limits of the Paper. The Author.

Correspondence.

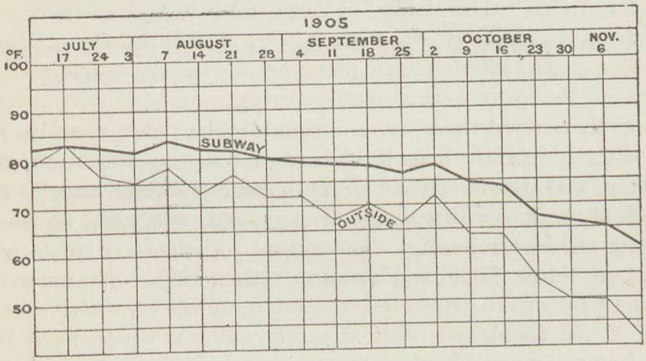
Dr. GEORGE A. SOPER, of New York, communicated the following observations upon the ventilation of the subway:—Shortly after the subway was opened, reports appeared in the Press to the effect that the ventilation was defective. These reports were made by volunteer investigators who claimed to have analysed the air and found it to be alarmingly impure. Upon inquiry, these investigators turned out to be unreliable persons and their results untrustworthy. But harm had been done, and a considerable number of people had come to regard the air with suspicion. In the hope of establishing the truth about the air, Professor Charles F. Chandler, of Columbia University, made a number of accurate analyses. He pronounced the air good. This allayed suspicion for a time, but soon the heat, which became noticeable about 5 months after the line was put in service, revived the belief that the air was vitiated. At this point Dr. Soper was Dr. Soper.

Dr. Soper. invited by the Board of Rapid Transit Railroad Commissioners to make a careful study of the whole question in order to discover whether any injurious conditions existed, and if so, how to get rid of them. The investigation extended over about 18 months and was divided into two periods. The first, which might be called the analytical part, extended over the 6 months from June, 1905 to January, 1906. In this period about 50,000 determinations of temperature and humidity were made, and finally a system of automatic thermometric records was established. About 2,000 samples of air were collected and analysed for carbon dioxide and oxygen. About 3,000 bacteriological examinations were made. Microscopic examinations were made of the dust which settled from the air, and, by a special device, the weight of dust in a given volume of air was determined. Careful studies were made of the force and direction of the air-currents set up by the moving trains. The utility of large fans was studied at several points in the subway where fans were installed for experimental purposes. The effects of the processes of cleaning employed by the operating company were also critically examined. Numerous special experiments were made, as, for example, the determination of the efficiency of certain chemical disinfectants, the effects of oil on bacteria and the longevity of pathogenic bacteria under subway conditions. Two condensed official reports were made on this first part of the investigation.[1] The second period of the investigation began in March, 1906, and ended in March, 1907. The object of the second part was to determine, by examining the physiological condition of the people who worked in the subway, whether any injury was being done to health. The time during which the subway had been in service was too short for any evil effects to be plainly visible, but it was thought desirable to undertake the inquiry at this early date in order to discover impending dangers, if any existed. The work involved a minute study of the physiological condition of one hundred subway employees, all of whom had been engaged in subway work for at least a year. The bodies of employees who happened to be killed during the course of the investigation were autopsied. In order to determine the physiological condition of average men of similar social condition to the subway employees, but engaged in other occupations, 200 men from various walks of life were examined. After the completion of the second part of the investigation, Dr. Soper was requested by the Interborough Rapid

[1] See the Annual Reports of the Rapid Transit Commission, 1905, pp. 142–147 and 1906, pp. 210–232.

Transit Company to make a study of the sanitary condition of the air and ventilation of subways in Europe, a task which occupied about 3 months in the summer of 1907. During this final investigation, practically all the large subways in Europe were visited. The principal results of the inquiry were the following. The air of the New York subway did not differ much from the air of most subways, as far as he was aware, except as to temperature and dust. The temperature was high because of the extraordinarily large amount of heat generated by the consumption of electrical energy; the heat from the bodies of the passengers had practically nothing to do with it. The most objectionable feature of the heat was less the actual elevation of temperature than the fact that the subway remained warm continually while the city streets became Dr. Soper.

Fig. 24.

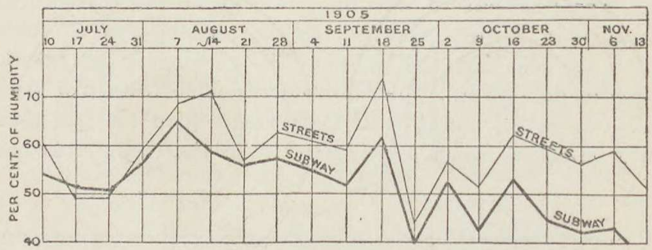


Weekly Average Temperatures in the Subway and Streets, 10 July–13 November, 1905. (*From 47,476 Observations.*)

relatively cool during the nights and mornings of summer. It was at such times that the greatest inconvenience was experienced from the heat. In winter the heat given off by the trains was advantageous, since, if low temperatures occurred they would, with the strong draughts, render the air uncomfortable. The hottest week during the period of the writer's investigation was that of the 4th–10th August, 1905. The average daily temperature in the subway during that week was 83·4° F.; in the streets 78·2°; difference 5·2°. Averages for 18 weeks were given in *Fig. 24*. The relative humidity was slight. The actual weight, or tension, of aqueous vapour was practically the same in the New York subway as in the air of the streets under which the subway ran. Since the temperature was higher in the subway, the humidity there was less noticeable. This

Dr. Soper. dryness was excellent testimony of the thoroughness with which the work of waterproofing had been carried out. Had the subway been wet it would have been excessively uncomfortable in summer. The relative humidity of the subway and streets for about 4 months was given in *Fig. 25*. The chemical analyses showed that the general

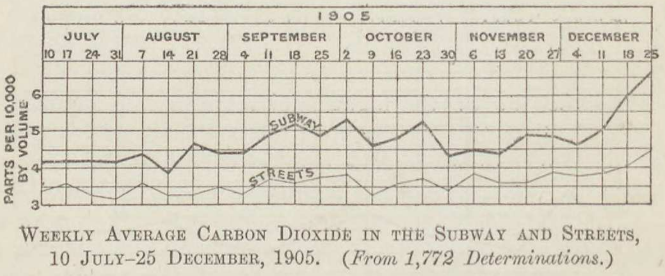
Fig. 25.



WEEKLY AVERAGE RELATIVE HUMIDITY IN THE SUBWAY AND STREETS, 10 JULY–13 NOVEMBER, 1905. (*From 47,456 Observations.*)

air of the subway was by no means deficient in oxygen nor was the carbon dioxide from the lungs of passengers present to an objectionable extent. The highest amount of carbon dioxide found was 8·89 parts per 10,000, the average being 4·81, and the average for the street-air 3·67. The amount of carbon dioxide varied with the place, hour, and season. The method of analysis was

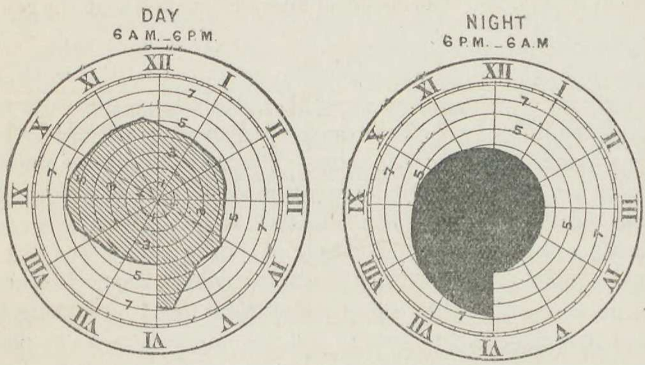
Fig. 26.



WEEKLY AVERAGE CARBON DIOXIDE IN THE SUBWAY AND STREETS, 10 JULY–25 DECEMBER, 1905. (*From 1,772 Determinations.*)

accurate to within 0·03 part in 10,000. The CO_2 found in the subway and streets over about 6 months was given in *Fig. 26*. Hourly variations due to differences in the number of passengers carried were shown by *Figs. 27*. The bacterial analyses showed that there were about half as many bacteria in the air of the subway as in street-air, the average being 3,200 bacteria per cubic metre of air in the subway as compared with 6,500 bacteria per cubic metre of air in the street. Some results of bacterial analyses by the familiar plate method were given in *Fig. 28*. The impurity which was most Dr. Soper.

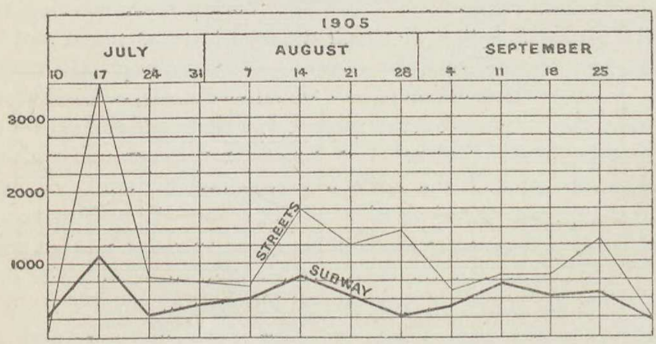
Figs. 27.



Hourly Variations in the Amount of Carbon Dioxide in the Air of the Subway. (*Average of 1,244 Analyses.*)

suggestive of danger to health was iron-dust. This dust was produced by the wear and tear of metallic surfaces, especially brake-shoes. The consumption of brake-shoes alone amounted to about

Fig. 28.

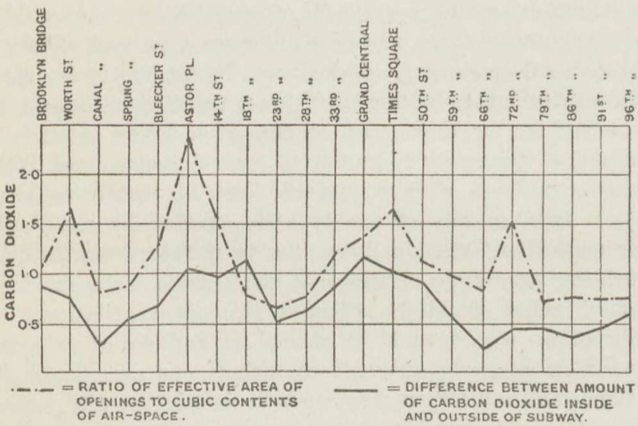


Average Numbers of Bacteria which Subsided from the Air per Square Foot per Minute in the Subway and Streets. 10 July–2 October, 1905. (*Samples Represented, 2,742.*)

1 ton for each mile of road per month. There was no difficulty in finding the metallic particles in the air or in the dust of the subway. He had found metallic dust of similar character in all the subways

Dr. Soper. which he had visited. The amount produced in the New York subway appeared to be but little in excess of the amount produced in the congested parts of the Metropolitan Railway of Paris. By the use of fibre brake-shoes the quantity of metallic dust had been reduced on the Underground Electric Railways, according to Mr. James R. Chapman, Chief Engineer, by about 80 per cent. The examinations of employees did not show that such dust, or any property of subway air, was producing injury to health; but Dr. Soper was strongly of opinion that these physiological investigations should be repeated, in order to determine whether effects might be visible after a longer period of exposure. The examinations of employees revealed an unexpectedly large amount of dry pleurisy. About 53 per cent. of the train-men exhibited this condition to an unmistakeable extent. The explanation of this pleurisy was the most difficult question involved in the whole investigation. It seemed to have no connection with subway conditions; and he at length concluded that the condition of the men was due to attacks of pleurisy, sometimes mild and unnoticed at the time, which the men had experienced previous to entering upon their subway work. It was taken to be a significant fact that practically all of the men examined had served as drivers or firemen for many years on outside steam-railways. In that work they had been much exposed to pleurisy through over-heating and chill. Much had been said about the odour of the New York subway. It was not to be denied that the subway had an unpleasant odour, as had all subways with which he had any acquaintance. The odour of the New York subway was due largely to the trap-rock ballast of which the road-bed was made, and to oil which had dripped from the machinery of the cars upon the road-bed. The peculiar odour characteristic of all electrically-worked cars was present also. Other odours existed, but those mentioned were the most prominent. Unlike most European underground railways—particularly some of the London tubes—peculiar musty odours due to excessive growths of moulds did not occur. The offensive odour of spent disinfectants, common in European subways, was not present. By Dr. Soper's advice the extensive use of disinfectants was discontinued at an early date and several hundred so-called disinfecting-machines were removed from the New York subway as useless and offensive. The sprinkling of station-platforms with water, which was a common practice in Europe, was soon discontinued in the New York subway. The cooling effect of the evaporation upon the atmosphere was negligible, the moisture on the cement platforms made the foot-hold uncertain, and the escaping water-vapour added to the discomfort due to the heat. Ventilation took place through the action of the trains upon the atmosphere moving freely through large openings to the outside air. It had been found that for a given volume of air-space in any section of the subway a certain area of opening was necessary and sufficient for good ventilation (*Fig. 29*). The secret of ventilating a subway of this type lay, in his opinion, in arranging openings to the outside air so that they should be of proper area and location. Experience with the New York subway had shown that, beside the amount of ventilation which could take place in this way, the exchange of air which could be produced under practical conditions by means of mechanically propelled blowing-devices was immaterial. At first the principal air-openings in the New York subway were at the stairways at the Dr. Soper.

Fig. 29.



Relation Between the Chemical Condition of the Air in the Subway and the Ratio of the Effective Area of the Openings to the Cubic Contents of the Air-Space at Different Stations.

stations, although there were some blow-holes in a part of the line above 59th Street. Later, many more blow-holes were opened through the roof. He had no knowledge of the need or efficiency of the automatic air-valves, electric fans, and cooling-apparatus which had been installed since the conclusion of his investigations. As nearly as could be judged without information as to the number of passengers carried at different times and in different parts of the subway, the analyses indicated that an amount of air entered and left the subway equivalent to a renewal of the whole atmosphere at least every $\frac{1}{2}$ hour. This was before any material changes were made in the original method of ventilation. Mr. Parsons's

Dr. Soper. arrangements for ventilation were, therefore, on the whole, abundant. To have installed fans or blowers would have been a useless waste of money. In order to improve local conditions it was only necessary to remove some of the vault-lights overhead. This could be done easily and quickly. Subways of this type breathed of themselves when given a chance. The removal of heat from a subway was an interesting problem. It was evident that the heat must pass through the walls and so be carried away by the surrounding material, or it must escape with the air. So long as a subway structure was surrounded by wet or moist material the conduction of heat through the walls might be considerable. With all subways it was so when the road was new; hence overheating did not occur at first. Most subways, however, gradually became warm with age, and it appeared that this rise in temperature was due to saturation of the structure and its surroundings by the heat which could not escape. Apparently there was only one way to prevent discomfort from heat in a deep subway, and that was by consuming less power. This was equivalent to saying that fewer trains must be run, they must be lighter, or they must be run at a lower speed. The economizing of power by regenerative control seemed not to offer sufficient advantages at the present time for extensive use in subways. In a subway of the type constructed by the Author, another method of keeping down the temperature was available. By providing very large openings to the outside air a substantial amount of relief could be afforded through ventilation. The quantity of air which could be moved in and out of a shallow subway under properly arranged conditions was enormous. The most important sanitary requirement in connection with subways was that they should be kept clean. He was not aware of any important subway in America or Europe that was maintained in such a way as to indicate that this necessity was fully appreciated.

Mr. Tait. Mr. W. A. Tait, having seen the work during construction, was greatly impressed with the enterprise that had been shown. At the same time, the ground passed through, in and near the busy parts of New York, seemed to be infinitely better, from a constructional point of view, than a great deal of the ground through which the Glasgow Central railway passed.[1] Regard must also be had to the facilities granted to and freely taken advantage of by the contractors for the temporary diversion of water- and other mains by means of trestles along the footpath. He did not recollect having ever seen similar facilities granted during the carrying out of underground railway-

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii, p. 120.

works. On the other hand, account must be taken of the frequent interruption of the works on account of labour-troubles, the intervention of the "strike-marshal" and so on. A good deal of the work, especially on the "down town" section seemed to him to be very light in design, and in view of the ever-increasing traffic overhead he could not help thinking that any renewals which might be required in future would be very troublesome to carry out. The sharpness of the curves at some stations, particularly at the one near to the Mayor's office, seemed to be objectionable and not altogether suitable for platforms which were liable at any time to be crowded. The long carriages which were in use necessarily left a considerable versed sine. No such arrangement would satisfy the Board of Trade. From American newspaper accounts of the flooding of the subway which took place in December, 1904, after the bursting of a 3-foot water-main at 86th Street, it was quite clear that this burst did very considerable damage in the subway, and for a whole day prevented the running of through traffic, as water accumulated to a considerable depth; indeed, at one station it appeared to have been running over the level of the platform. This water could only be removed by pumping in view of the gradients of the railway in the neighbourhood of the burst. Opinions differed as to whether underground railways should be deep or shallow, but it would seem not to be a point which could be decided off-hand. The lifts at several of the stations upon the London tubes were very inconveniently placed, and only brought passengers near to the platforms and to the street-level without bringing them actually to either. There was room for considerable improvement in this respect, though possibly a little additional expenditure on property would have been required if the widths of island platforms had been increased to make the necessary provision. In the cases of some underground railways, particularly the Caledonian in Glasgow, there was a great deal to be said in favour of a shallow railway. It was not likely that better tunnelling ground would have been obtained by going deeper on the line of streets, etc., actually chosen, while, on the other hand, the large sums spent by the Caledonian Railway Company on sewer-diversions had assisted materially in carrying out the works for the purification of the Clyde. Mr. Tait.

Mr. F. J. Waring, referring to the statement (p. 16) as to the $\frac{3}{4}$-inch horizontal rods forming the tension-member of a longitudinal truss on the top of the walls, failed to see the object of such a truss in that position: perhaps the Author would further explain the matter. As the subway was specially designed for rapid transit, and much should therefore be subordinated to obtaining this, Mr. Waring Mr. Waring.

Mr. Waring. thought the designs of the station-platforms were susceptible of improvement. For express trains consisting of eight cars, each 51 feet 5 inches in length overall, and for local trains of five such cars, he observed that the length of the platforms at both local and express stations was more than 50 feet less than the length of the trains. In the most favourable circumstances, therefore, namely with the centre of the train brought to a standstill exactly opposite the centre of the platform there would be available only one doorway for each of the end carriages, and owing to the presence of columns close to the edge of the platforms in stations of type A it was conceivable that one of these doorways might be practically useless. Further, these columns were stated to be 15 feet apart, while from Figs. 21, Plate 6, it would appear that the distance between the centres of the doorways of the carriage was 45 feet; if, therefore, the train was brought to a standstill so that one doorway of any intermediate carriage was opposite to a column, the other one would be similarly blocked, and it was thus possible that in a local train four doors out of the total of ten might be practically unavailable for rapid entrance or exit. He also observed that the central portion of the platforms at stations of the A type was 20 feet wide for a length of 100 feet, the platforms for the rest of their length, namely 50 feet in each direction, being only 10 feet wide; the natural tendency of passengers waiting for a train would therefore be, he thought, to congregate at the central portion, and then, in the event of the central carriages of the train being full, there would be a rush to the narrow ends of the platform, which he thought must entail a certain amount of delay and risk that would have been obviated to a considerable extent had the ends of the platforms been wider and the platforms of a uniform width throughout. In England columns were not allowed within 6 feet of the edge of a platform, and on a railway constructed specially for rapid transit he thought that any reasonable expense in avoiding the use of the columns so near to the edge of the platform would have been well warranted. Upon a railway of this character the platforms were a very important detail, and perhaps the Author would kindly explain their construction, as Mr. Waring failed to find in the Paper any details of this. Some of the platforms on the Metropolitan District railway were of fine concrete or artificial stone laid in situ without joints. When the stone was first laid the surface was roughened, but the roughness wore off comparatively soon, and the platforms became dangerously slippery, especially near entrances and exits. He therefore thought that the use of this material was to be avoided. The superelevation of the outer rail on the curves, as calculated

Mr. Waring.

by the formula given in the Paper, appeared to agree generally with that obtained by the usual formulas. Mr. Waring attached considerable value to the use of transition-curves, as enabling the superelevation of the outer rail to be gradually run out inversely to the radius of the curves, as it should be; but it was manifest that on mountain railways, where the use of reverse curves of the minimum radius permissible, with very short pieces of straight line between them, was often imperatively necessary, either from local conditions, or from the necessity of keeping down the cost of the work, the use of such transition-curves was impracticable. Mr. Waring was much interested in learning, from the results of the experiments described on pp. 45 and 46, that cement concrete broken up 24 hours after mixing and retempered would acquire an ultimate strength in excess of that of the same concrete left undisturbed, as this was quite contrary to the general experience of English engineers. Perhaps the Author could give some further information as to what this process of retempering was; but if, as Mr. Waring supposed, it meant merely working up again the partially-set concrete with only the addition of a little water, he thought the results obtained were very surprising.

The Author.

The AUTHOR, in reply upon the Correspondence, observed that reference had been made to the platforms and columns. In practice columns set near the platform edge had not been of serious inconvenience, as the car-doors did not swing outwards, and trains were started by bell-cord signal and not by hand from the platform. It was better, of course, to omit platform columns, but this could not be done always. Passengers were not allowed to enter or leave by the end doors of the train, so that the length of the train could exceed that of the platforms.

3 March, 1908.

Sir WILLIAM MATTHEWS, K.C.M.G., President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

HUGH DANIEL BADCOCK, M.A. (*Oxon.*)
FRANCIS JAMES BANCROFT, B.Sc. (*Lond.*)
SYDNEY LINTON BRUNTON.
JEAN BAPTISTE GUSTAVE ADOLPHE CANET.
GEORGE MUIRHEAD CLARK, M.A. (*Cantab.*)
DANIEL MEINERTS HAHN.
WILLOUGHBY ROCHESTER HUGHES.
WILLIAM INGHAM.
GEORGE LINGWOOD.
WALTER SERY NICHOLSON.
GEORGE HENRY PICKLES.
ALEXANDER REID.
FRED SNOWDEN.

And had admitted as

Students.

STANLEY GORDON BUTLER.
JOHN PROWETT LE GRAND.
CHARLES ESMOND NIGHTINGALE.
JOHN EDWARD OPENSHAW, B.Eng. (*Liverpool*).
FRANK HORACE LUMISDEN STRANGE.
ARCHIBALD RICHARD STURGESS.
HERMANN CARL ANTON THIEME, B.Sc. (Engineering) (*Lond.*)
STANLEY CECIL HAYTER WARREN.
EDWIN FREDERICK WARTH.
GRANT CARVETH WELLS.
RALPH WOLFENDEN, B.Sc. (*Manchester*).

The Scrutineers reported that the following Candidates had been duly elected as

An Honorary Member.

Sir ANDREW NOBLE, *Bart.*, *Capt.* R.A. *ret.*, K.C.B., D.Sc., D.C.L., F.R.S.

Members.

WILLIAM FREDERICK BEARDSHAW.
WILLIAM HENRY BREITHAUPT.
WILLIAM BROWN.
ARTHUR TREVOR DAWSON.
RICHARD AUGUSTINE STUDDERT REDMAYNE, M.Sc. (*Birmingham*).
SAMUEL JOHN SARJANT.
JOHN ALFRED VAUGHAN.
EDMUND JOSEPH WALSH.

Associate Members.

HENRY THOMAS ARMITT.
GEORGE NORMAN BAINES, Stud. Inst. C.E.
WILLIAM ARTHUR BURTON, Stud. Inst. C.E.
LIONEL CALISCH.
EDWIN CHAPPELL, Jun., Stud. Inst. C.E.
KUSUM KUMAR CHATTERJEE, B.A. (*Calcutta*), Stud. Inst. C.E.
FREDERICK HAROLD CLOUGH, Stud. Inst. C.E.
JAMES COWLEY.
JATIUDRA KUMAR DAS GUPTA, B.Sc. (*Glas.*)
STANLEY STEUART ELLIOTT, B.Sc. (Engineering) (*Lond.*), B.A. (*Cape*), Stud. Inst. C.E.
SIMPSON SHEPHERD FRANK, Stud. Inst. C.E.
JOHN GARDNER, Stud. Inst. C.E.
FRANK PERCY JENNINGS.
ERNEST FREDERICK STEPHEN LANGE.
JOHN NORMAN LAPAGE, Stud. Inst. C.E.
EDWARD SEARLES LINDLEY, B.A. (*Cantab.*), Stud. Inst. C.E.
FRANK LIVESEY, B.A. (*Cantab.*), Stud. Inst. C.E.
CAMPBELL JAMES NELSON.
ARTHUR TREVOR GEORGE POSNETT, B.A., B.A.I. (*Dubl.*)
REGINALD BRAHAM ROBINSON, Stud. Inst. C.E.
RALPH SEPHTON, B.A. (*Cantab.*), Stud. Inst. C.E.
HERBERT EDWARD STEINBERG.
STAFFORD TRACEY WATTS.
CHARLES WILLIAM WILLIAMS, Stud. Inst. C.E.
ARTHUR HAMILTON WILSON, B.Sc. (*Glas.*)

An Associate.

EDWARD HERBERT DAVIES.

The discussion on the Paper on "The New York Rapid-Transit Subway," by Mr. William Barclay Parsons, occupied the evening.

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10 and 17 March, 1908.

Sir WILLIAM MATTHEWS, K.C.M.G., President, in the Chair.

The discussion on "The New York Rapid-Transit Subway" occupied these evenings.

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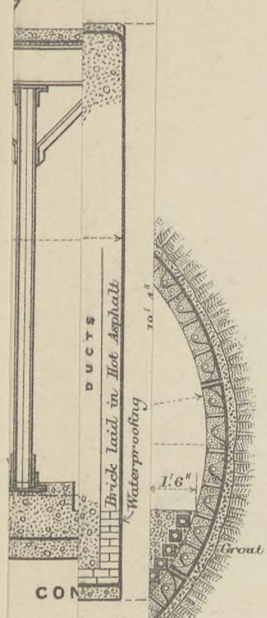
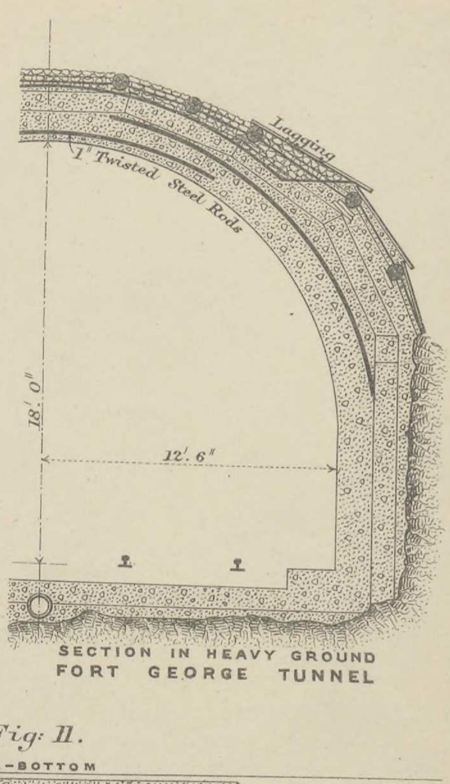
Fig: 4.



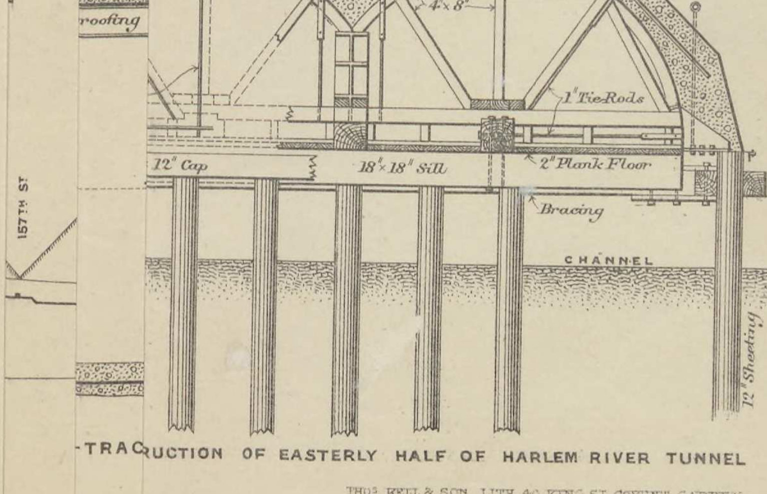
CON

Fig: 9.



SECTION IN HEAVY GROUND
FORT GEORGE TUNNEL

Fig: 11.



-TRACRUCTION OF EASTERLY HALF OF HARLEM RIVER TUNNEL

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

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NEW YORK RAPID-TRANSIT SUBWAY.

PLATE 5.

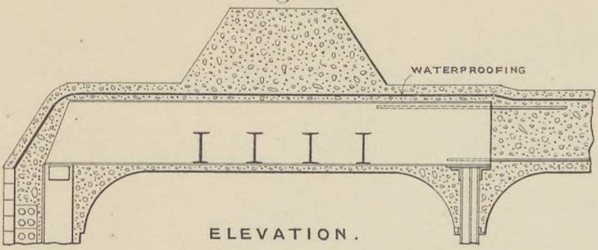
W. B. PARSONS.

Minutes of Proceedings of The Institution of Civil Engineers. Vol. CLXXIII. Session 1907-1908, Part III.

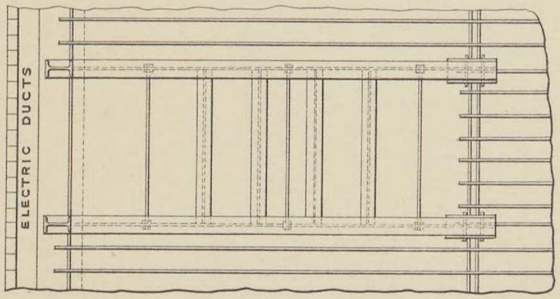
DRO. MEIL & SON, LTD. 40 KING ST. COVENT GARDEN

PLATE 6.

Figs 19.



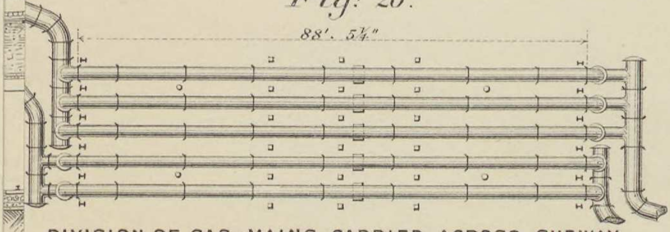
ELEVATION.



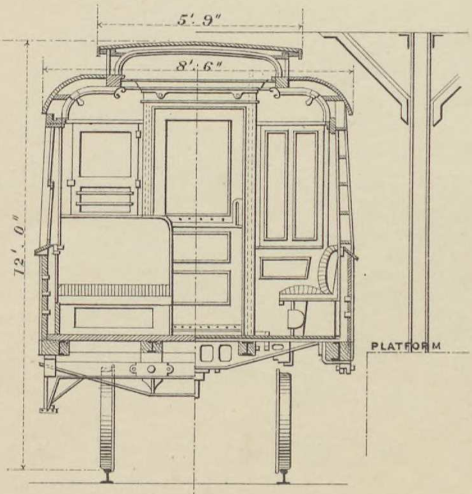
PLAN.

IETHOD OF SUPPORTING ELEVATED–RAILWAY COLUMNS.

Fig: 20.



DIVISION OF GAS–MAINS CARRIED ACROSS SUBWAY THROUGH THE ROOF.



: D CAR.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

NEW YORK RAPID-TRANSIT SUBWAY.

PLATE 6.

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THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.