(*Paper No. 2165.*)

"The Mersey Railway."[1]

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THE Mersey Railway Company was incorporated by Act of Parliament in the year 1866, with the object of effecting a junction between the railway systems on each side of the River Mersey, and therefore between the city of Liverpool and the town of Birkenhead, situated on the Lancashire and Cheshire shores of the Estuary.

The authorized railways of the Company represent a total length of 5¼ miles of double line, on the standard gauge of 4 feet 8½ inches. The main line passes under the River Mersey near the Woodside ferry, and forms a junction at Birkenhead with the London and North-Western and Great Western joint railway from Chester. It will also be connected with the Wirral Railway, Hoylake, New Brighton, the Dee Bridge, Chester and North Wales; with the Dock lines on both sides of the river, and with the Central Station, Liverpool. The portion completed, and forming the subject of this Paper, extends from a junction at Union Street, with the Joint Railways of the London and North-Western, and Great Western Railway Companies, under the Estuary of the River Mersey, to Church Street, Liverpool, a total length of about 3 miles.

The works were begun in December, 1879, when a preliminary contract was entered into with Major Isaac, who undertook the risk of driving an experimental heading under the River Mersey. Borings taken with Sir John Hawkshaw's machine had shown that the New Red Sandstone rock extended generally across the river, but it was felt that nothing short of an actual heading could demonstrate the continuity of the rock, and its freedom from fissures.

It was not, however, until May, 1881, that this preliminary work had advanced to such an extent as to justify the commencement of the permanent works. The necessary contract having been made, the main works were proceeded with in August, 1881, and having been vigorously prosecuted by day and by night, were opened by H.R.H. the Prince of Wales, on the 20th of January, 1886, public traffic commencing on the 1st of February, 1886, a little over six years from the starting of the preliminary works.

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[1] The discussion upon this Paper was taken together with that upon the following one.

Owing to the main tunnel being on a falling gradient towards the river (Plate 3), the difficulty of keeping the working face free from water would have been very great. It was therefore proposed that shafts should be sunk at Birkenhead and Liverpool, to such a depth that a special drainage-heading could be driven with a slightly rising gradient, so as to meet the main tunnel under the centre of the river, and this suggestion has been carried into effect. The water thus gravitates to the bottom of the shafts, from whence it is pumped to the surface. It was also decided that the pumping machinery should be placed at the top of the shafts, and not underground, so as to avoid any chance of the pumps being drowned.

Drainage-Heading and Pumping-Machinery.

The works were commenced by sinking two shafts (Plate 4), one at Liverpool, 15 feet in diameter, and about 170 feet in depth, to the bottom of the sump; and one at Birkenhead, 17 feet 6 inches in diameter, and of similar depth. The distance between the quay-walls on the two banks of the Estuary, at the points under which the tunnel passes, is 1,320 yards, the distance between the pumping-shafts being 1,770 yards. The Liverpool shaft was lined with cast-iron tubbing, excepting those portions which were in solid rock, not yielding much water.

The cast-iron tubbing (Plate 4) is of the ordinary design, and consists of segments with the flanges on the concave side. They are fixed just as they come rough from the foundry, the joints being made of red-pine timber sheeting, $2\frac{1}{2}$ inches wide and $\frac{3}{8}$ inch thick, which, when all the tubbing is in place, is wedged tight by driving in very dry timber wedges, until even a chisel-point will not enter. At Birkenhead it was found unnecessary to do more than line a portion of the shaft with tubbing, where water-bearing strata occur between layers of sound rock. In this case a crib was set upon a properly prepared bed, and at the upper end an "up-over" crib was fixed in a similar manner, except that it was reversed, the rock-bed in the latter case being on the upper surface of the cast-iron crib. The space between the tubbing and the rock is usually filled with ordinary mould, or peat soil, but in this case no filling was provided. Under the advice of Mr. William Coulson, of Durham, a pipe, 2 inches in diameter, was provided, connecting the space behind the tubbing with the open air; this pipe being carried through the upper crib, and continued up the shaft to above the ordinary water-level. The object of this pipe was to allow any gas or air to escape, which otherwise might accumulate behind the tubbing, the pressure caused by such an accumulation having often proved destructive elsewhere. The Author does not attempt to explain how it is that the pressure, under any circumstances, should be greater than that due to the hydrostatic head, but such it is stated to be by those having extensive experience of pit tubbing.

Near the bottom of the shafts, standage headings, each having a capacity of 80,000 gallons, were driven, to secure to the miners sufficient time for escape, in the event of an accident to the pumps, or a sudden influx of water.

The pumping machinery at Liverpool consists of a pair of pumps, 20 inches in diameter by 6 feet length of stroke, connected by means of quadrants with a compound-engine manufactured by Messrs. Hathorn, Davey and Co., of Leeds; the low-pressure cylinder has a diameter of 35 inches, and the high-pressure cylinder a diameter of 20 inches, the length of stroke being 6 feet. The engine is fitted with their differential valve-gear, by which the supply of steam is automatically regulated according to the actual work done, and it has saved the pumping-machinery three times out of four when serious accidents threatened some portion of the machinery; also a pair of pumps 30 inches in diameter, of a similar character to those used at the well-known Whitburn sinking, near Sunderland, and driven by similar engines, having cylinders 60 inches and 33 inches in diameter respectively, and a length of stroke of 10 feet; and, lastly, of one pump 40 inches in diameter and 15 feet length of stroke, driven directly by an overhanging beam-engine, manufactured by Messrs. Andrew Barclay and Son, of Kilmarnock (Plate 4). In all cases care has been taken to provide pumps of sufficient diameter to enable both buckets and clacks being drawn from the top if required. The bucket- and clack-doors are also of ample size, to allow of their being changed at the door. The engine for the 40-inch pump is compound; the high-pressure cylinder has a diameter of 36 inches, with a length of stroke of 10 feet 6 inches, and a low-pressure cylinder 55 inches in diameter, with a length of stroke 13 feet, both cylinders being double-acting. This engine is of the type introduced by Mr. Barclay, and was adopted on account of its small liability to accident, and economy of floor-space. It is fixed vertically on its foundations near the mouth of the shaft.

The balance-beam of the engine is placed between the foundation-walls; this beam is 19 feet long from rocking centre to centre at the pump-rods, and 24 feet 6 inches long from the rocking centre to the end, the back end being furnished with a box having sufficient capacity to hold 20 tons of balance-weights; its depth is 4 feet 6 inches, and it is composed of steel plates, $1\frac{1}{4}$ inch thick, securely bound with distance-pieces of cast-iron. The main beam of the engine is composed of two plates, each 32 feet 6 inches long, between the extreme centres.

A connecting-rod, 38 feet 9 inches long, unites the point of the main-beam with the point of the balance-beam; this rod is composed of oak, with malleable-iron straps. At each side there is a malleable-iron rod, extending from the main-beam to a cast-iron crosshead below the point of the balance-beam. To it the pump-rods are attached, thus bringing these rods directly on to the main-beam, on which there is but $1\frac{3}{8}$ inch of lateral motion, and avoiding the swing at the point of the balance-beam. The fact of the rods travelling upwards and downwards, almost in a direct line, gives great smoothness of working, even with the long stroke of 15 feet. The pump-rods are made of wood, having four malleable-iron plates at each joint; the rods are bolted to malleable-iron forks, having tapered ends turned and fitted, one end to the cast-iron crosshead at the top, and the other to the plunger at the bottom.

The pump is of the ordinary plunger pattern, having a length of stroke of 15 feet, and a diameter of 40 inches, and is turned true throughout its entire length, the suction and delivery valves are of brass, mounted with strong steel lids having leather faces, malleable-iron guards, and fishing tackle. The working barrel is bored its entire length, slightly larger than the plunger; the clack-seats are provided with openings, 4 feet 6 inches by 3 feet 9 inches, to allow of easy access to the valves; the doors for these openings are of steel. The whole pump is set on two massive cast-iron girders, the suction pipe passing up between them. These girders rest at each end on oak bedded in concrete, set on strong cast-iron boxes fixed on the solid rock, at the bottom of the shaft, below the water-level.

The machinery at Birkenhead is similar to that above described, with the addition of a second 40-inch pump, with a 15-feet length of stroke.

Arrangements are made by which the water from both sides of the river can be collected at either shaft, thus giving ample facilities for any repairs to the engines or pumps. The capacity of the machinery, at ordinary working speeds, is 18,800 gallons per minute, and the quantity of water, to be permanently dealt with, is from 7,000 to 8,000 gallons per minute.

From each shaft the drainage-heading was driven under the river towards the centre, rising with gradients of 1 in 500, and 1 in 900. This heading was at first driven from both sides by hand, but the Birkenhead face was afterwards excavated by means of the Beaumont machine, which bored out a circular heading 7 feet 4 inches in diameter, somewhat resembling in appearance the rifling of a cannon. Hand-labour was stopped on the 15th of February, 1883, and the Beaumont machine taken down the shaft, and put in position at the face. The machine started work on the 26th of March, 1883, and by the 17th of January, 1884, the Birkenhead heading had been driven 696 lineal yards, and met the Liverpool heading, which was entirely driven by hand. This gave an average weekly progress of 17 yards, or, including the time taken in setting up the machine, of 14½ yards. The maximum week's work in this heading was 34 yards. The machine was afterwards slightly modified, and the cutters were better adapted to the rock; and during January 1885 the rate of progress was 54 yards per week through similar rock in a loop-heading. In the softer rock, met with in the Liverpool ventilation-heading, a speed of 65 yards per week was attained. The speed of driving by hand has been between 10 and 13 yards per week, giving a 9 feet by 8 feet heading, a size large enough for working double roads. The heading of 7 feet 4 inches diameter, produced by the Beaumont machine, requires to be both heightened and widened before it can be used, in order to work "break-ups." Only portions of the heading are lined, the rock being, for a greater part of the length, strong and solid.

It is remarkable that the wettest portions of the driftway were those under the land, and that, so soon as the work was proceeding under the river, the yield of water, in proportion to the area exposed, diminished. This is believed to be the result of clay and sand in the river filling the interstices of the rock.

For a portion of the drainage-heading, recourse was had to "plank tubbing," which answered admirably.

The setting out of this heading was a matter of some difficulty, and was carried out, with great precision, jointly by Mr. Irvine, the Resident Engineer, and by Mr. Davidson, the Contractor's Engineer. A correct survey was first made of the river, and the positions of the shafts were fixed by means of triangulation. As high warehouses intervened, the centre line had to be transferred to points on their roofs. As will be seen from Plate 3, the pumping shafts are not upon the centre line, that at Liverpool being connected with the heading by a cross-cut nearly at right angles, and 30 feet long, and that at Birkenhead by a cross-cut at an angle of 133°, and 103 feet long. It therefore became necessary to set out lines at the proper angles to the shafts on the surface. German silver wires, 23 B.W.G., or $\frac{1}{40}$ inch in diameter, were then suspended in the shafts, weighted with plumb-bobs, weighing 33 lbs. each, and arranged in correct line by means of a fine-threaded screw-adjustment, which allowed lateral movement. The shafts being used for pumping purposes, it was difficult to ascertain whether the wires were hanging free, and it was decided to test them electrically. By interposing a galvanometer between the battery and the plumb-bob, it was readily ascertained whether the wires, at any point, were in contact with the surrounding machinery or pumps.

The instruments used were a 5-inch transit theodolite, by Messrs. Troughton and Simms, and a 6-inch transit theodolite, by Messrs. Cook and Sons, of York, which latter was fitted with a special screw-adjustment under the bottom plate, by means of which the instrument (set up as close to the wires as possible) could be brought into the line of the wires below, to within one-third of their diameter, or $\frac{1}{120}$th of an inch.

It was found by trial that the lines could be transferred down the one shaft, which was on the centre-line of the tunnel, and with a wire base of 10 feet 5 inches, with an extreme error below of no more than $\frac{1}{8}$ inch in 433 feet; the operation being performed three times, starting each time from the surface line. At the other shafts, where angles had to be measured and re-set off, such accuracy could not be expected, but was sought for by taking the mean of a larger number of observations. The Birkenhead lines, which were prolonged to the junction of the headings, were thus the mean of eight observations, two of which, down the pumping-shaft, were worked from a 9 feet 10 inches wire base, and six others, down the working-shaft, from a 9 feet 8 inches base. These were connected when a staple shaft had been sunk from the tunnel to the drainage-heading, at 470 yards from the shaft. The same was done with the Liverpool lines at the staple shaft, 295 yards riverwards, past which the mean of five trial lines was carried to the junction.

The headings met at 1,115 yards from the Birkenhead working-shaft, and 639 yards from that at Liverpool, with an error of 1 inch in meeting, and of $2\frac{1}{2}$ inches maximum error at the centre from the true line as afterwards ranged through, both lines having diverged slightly to the south. As might have been expected, there was less error in the lines taken down by the working-shafts, 95 feet deep, than in those through the pumping-shafts, with bobs suspended at a depth of 163 feet.

Landwards, the lines were checked at temporary air-shafts, at 490 yards from the Birkenhead working-shaft, where, after going round 28° of a 15-chain curve, there was an error of $2\frac{1}{8}$ inches, and at 400 yards from the Liverpool shaft, where, after going round 35° of a 10-chain curve, there was an error of $1\frac{3}{4}$ inch. These were so insignificant that it was not necessary to alter the lines below ground, the tangent being adhered to up to the next curve in each case. Throughout the whole of this work the instrument, although kept in good adjustment, was never assumed to be correct, but inverse observations were made, and the mean point determined. This was done repeatedly for each point in transiting, these points being marked at intervals of about 80 yards as the work went on, longer sights being often prohibited by the smoky atmosphere.

The levelling was an easier process; the only special difficulty being due to the water from the roof in wet places before the lining was built.

The width of the river made it practically useless to try to level across it, and as small discrepancies between the neighbouring Ordnance benchmarks were discovered, the datum was fixed, on each side, from the mean result of several of them. The levels were transferred down the shafts by carefully checked steel tapes, and the final result was that when the headings met, on the 17th of January, 1884, a point which had been fixed as being 129·05 feet above datum, as levelled from Birkenhead, was found to be 129·04 feet above datum, as levelled from Liverpool. This afforded proof of the general accuracy of the Ordnance levels on each side of the Mersey. This work was carried out under great difficulties, the quantity of water being very large, and the ventilation often imperfect.

So long as the excavation in the tunnel or driftway was carried on by hand, and blasting used, bore-holes were kept in advance of the face, but when the Beaumont machine came into play, these were considered no longer necessary. Safety, or flood-doors, were provided, but, at the request of the workmen, they were removed, nor did any occasion arise for their being made use of.

The rock extends throughout the whole length of the heading, and is fairly homogeneous, but rather harder on the Birkenhead than on the Liverpool side. Only one fissure was found; this was 10 inches in width, filled with disintegrated sandstone and clay, and close to it the rock was much broken up, necessitating careful timbering. Much more water was found on the Liverpool side than at Birkenhead, the rock being considerably more broken up at Liverpool. The beds in the rock dip to the east, at an inclination of about 1 in 14. The heading was connected with the main works of the tunnel by small staple shafts and bore-holes, by which the works were kept free from water.

It was at one time intended to run the drainage-heading underneath the main tunnel, below the centre of the river, but it was afterwards decided to lower the levels of the tunnel, and loop-headings were driven by the Beaumont machine to connect the drainage-heading proper. The water from the land tunnels is carried along the top of the invert of the main tunnel in a brick culvert, of 1 foot 9 inches radius, until it finds its way into the drainage-heading.

The drainage arrangements have proved very efficient; and have resulted in the tunnel itself being remarkably dry. On the occasion of the opening of the tunnel by H.R.H. the Prince of Wales, the tunnel was lighted by gas, and thousands of visitors walked through from end to end, without so much as seeing a drop of water, the only complaint being that it was slightly dusty.

In the improbable event of all the pumps (six distinct sets) stopping at the same time, the standage capacity of the drainage-heading is sufficient to prevent the water rising so high as the rails in the tunnel for a period of five hours, thus giving ample time for any ordinary repairs.

One of the chief difficulties to be encountered was to keep the brickwork clear of the dripping water until the cement had set. This was accomplished by lining or roofing the top of the excavation in the tunnel with thin sheet-iron, or brattice cloth. The work was very carefully done, and the water led away to holes left near the invert. After the cement had thoroughly set, the holes were plugged up. The Author is of opinion that the remarkable dryness of the tunnel is, in no small degree, due to the care and attention that was devoted to this particular feature of the work.

River Tunnel.

The tunnel (Plate 4) is 26 feet in width, and, where in rock, is lined and inverted with brickwork in cement 2 feet 3 inches in thickness, the two inner rings with headers being of brindle brick. It is 19 feet high from the rails to the intrados, or 23 feet from the invert to the intrados, and it is provided with recesses for the platelayers on each side, at distances of 45 yards. After the work was commenced, additional intermediate borings were made, near the Liverpool shore, in the positions pointed out by local geologists as being probably the ancient course of the river-bed, and it was found that there was a depression in the rock at this point. The tunnel here has a total cover of 70 feet; but, for a length of 66 yards the crown is, to the extent of from 3 to 6 feet, above the level of the sandstone rock, and passes through a thin layer of red clay and sand, covered with strong brown clay. The tunnel was put in by well-timbered lengths of 9 feet only, and the brickwork in the crown was thickened to 3 feet: no difficulty was otherwise experienced. The remainder of the tunnel was proved to be in rock by boring upwards from the headings to a height of, in every case, 15 feet above the crown of the tunnel.

The minimum amount of cover between the extrados of the arch and the bed of the river is about 30 feet, and the depth of water at high tide is 100 feet. The tunnel was carried out by means of a heading driven through at all speed, and numerous break-ups, so that at one time work was proceeding from twenty-four faces, the whole being well drained by the arrangements previously described. Additional shafts were sunk both at Birkenhead and at Liverpool for winding purposes, and these were closed upon the completion of the works. The rock was brought to these shafts by inclined planes, worked by steam-engines, and was then carted away, excepting such portions as were used for rubble masonry and bottom ballast.

Explosives.

The whole of the 320,000 cubic yards of rock excavated in the tunnel, and more than 60 per cent. of that excavated in the drainage-heading, were taken out by hand-labour. No large shots, such as are made use of when using drilling-machines, could have been adopted without danger of letting in too much water, when under the river, or of annoying the neighbourhood, when under the town. Dynamite was at one time tried, but was given up because of the noxious fumes.

Gelatine, manufactured by the Nobel Company, was used to a limited extent, and proved to be very efficient, especially in heading-shots. With this explosive an increased rate of progress of 2 yards a week in headings could be made, as against other explosives tried. The explosive, however, which was mainly depended on throughout was cotton-powder, or, in mining parlance, "tonite," manufactured by the Cotton Powder Company, Faversham. Of this explosive about 120 tons were employed, and it proved to be both safe and reliable, as well as most efficient in doing its work under exceptional conditions.

Land Tunnels.

These tunnels are of similar dimensions internally to those of the river tunnel, and are generally lined with 18 inches of brick-work, no invert being added where the tunnel is in solid rock.

In some parts it was necessary to thicken the lining, owing to the rock being soft; and at Birkenhead, where the railway passes under the Joint Railway in soft ground, special construction was adopted. It was found at this point that the foundations would be in wet sand, and it was decided not to attempt to underpin the Joint Railway, which is itself in covered way.

The ground was opened from the surface; the covering and the walls of the railway were removed; balks were placed under the rails, and a closely-timbered excavation was carried down to the depth of the foundations. A strong concrete invert, surmounted by a tunnel in brickwork, was then constructed, and the works of the Joint Railway rebuilt.

Covered Ways and Retaining Walls.

A portion of the railway was constructed by cut-and-cover, that under the Joint Railway property having side-walls of concrete faced with brickwork and an invert of concrete, that under Borough Road having also side-walls and an invert of concrete, carrying wrought-iron girders with brick arches between.

A short length near the junction, and the Borough Road station ground, are retained by walls of rubble masonry, to a great extent constructed of stone brought from the tunnel.

The total number of bricks used in the lining of the tunnel and headings, and in the covered way, was 38,000,000. The two inner rings are of blue Staffordshire bricks, made by Joseph Hamblet, West Bromwich. The four outer rings are of red wire-cut bricks, supplied by the New Ferry Company, Cheshire, the New British Company, Ruabon, and the Brymbo Coal and Iron Company, Brymbo. Buckley "brindle" bricks were also used for the upper rings of the invert, being found to hold the cement better than the smoother blue bricks. The brickwork is almost all in cement, in the proportion of either 3, or in some parts, 2 to 1.

STATIONS.

Green Lane station is partially open, the Joint Railways of the London and North Western Railway and Great Western Railway Companies being carried over one side of it, by means of wrought-iron girders. The Borough Road station is an "open-air" station, and here are situated the locomotive-sheds and the carriage-sheds of the Company, with small repairing-shops, and the necessary gas-works, erected by Messrs. Pintsch and Co., for supplying the rolling-stock with gas. The Hamilton Street and the James Street (Plate 4) stations are excavated in the solid rock, and being near the river are necessarily at great depth; the rails at James Street are about 90 feet, and at Hamilton Square 100 feet, below the level of the booking halls. They are 400 feet long by 50 feet wide by 32 feet high, and are arched with brickwork in cement, 2 feet 3 inches in thickness, and lined, to a height of 12 feet above platform-level, with white glazed bricks, the subways hereafter referred to being lined in like manner. The platforms are connected by groined passages and a foot-bridge with an underground hall. From this hall open out: a foot-subway, 10 feet in width, leading by an incline of about 1 in 9 to the surface; a staircase of more than one hundred and sixty steps; and three passenger-lifts, each giving a floor-area of 340 square feet in the cage, and having a stroke at Birkenhead of 87 feet 9 inches, and at Liverpool of 76 feet 6 inches. These lifts and the staircase lead to the upper booking-hall, on a level with the public street, which is connected with the usual waiting-rooms and other conveniences. The station buildings, the architectural details of which were prepared by Mr. G. E. Grayson, of Liverpool, include hydraulic towers, in which are placed the water-tanks for the working of the hydraulic machinery. At James Street the upper floors above the station are utilized for extensive chambers.

Temporary sidings are laid in at James Street for shunting the trains, so that the traffic may run for the present between Green Lane and James Street Stations.

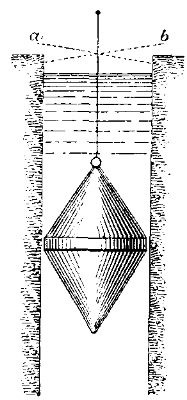
HYDRAULIC LIFTS.

The lifts, which have been manufactured by Messrs. Easton and Anderson, MM. Inst. C.E., are, it is believed, the largest yet constructed for passenger purposes.

After careful consideration of different proposals, it was decided that, to secure safety, a direct-acting ram, working at a comparatively low pressure, should be adopted. This necessitated the sinking of wells 40 inches in diameter and 90 feet in depth, for the reception of the cylinders, into the Red Sandstone rock; and, as time was of great importance, it was decided to place the work at James Street, Liverpool, in the hands of Messrs. Mather and Platt, of Salford, whilst Messrs. Timmins, of Runcorn, undertook the sinking of those at Hamilton Square Station, Birkenhead. The method adopted by Messrs. Timmins was to bore a hole, 18 inches in diameter in the first instance, to a depth of 90 feet. The hole was then carefully plumbed to ascertain if it was in any degree out of truth, and if so to what extent. This decided the size of the widening-out bar. It was then increased in diameter to 36 inches. The plumbing of the holes involved a good deal of thought, owing to the wells being in all cases full of water. The plumb-bob consisted of a double cone, each cone being 3 feet in length, and 39 inches in diameter at the centre.

This was suspended from a point 95 feet above the top of the well, cross strings being carefully fixed, as at *a b* in Fig. 1.

FIG. 1.



If the plumb-bob in its descent to the bottom of the well encountered any irregularity, the exact amount could be calculated by the travel of the plumb-line at the cross strings. In the case of the Liverpool wells the plumb-bob was also 39 inches in diameter. The three wells which were sunk at James Street Station were bored by Messrs. Mather and Platt's earth-boring machine, to the full diameter of each well, namely 40 inches, being bored at one operation. The bar when boring obtained the necessary percussive motion from the steam percussion-cylinder of the boring-machine, and after working a sufficient time in the bore-hole, was withdrawn, by means of a winding engine, also attached to the machine. The shell-pump was then lowered by the same winding engine, and by it the material broken up by the cutters of the boring-bar was withdrawn. These operations were successively performed until the required depth of the well was reached. Each of the holes when completed was perfectly round and plumb. In No. 1 well boring was commenced on the 23rd of March, 1885, and finished on the 11th of April. The depth bored was 76 feet 6 inches. The number of days occupied in boring was eighteen, and the average depth bored per working day was 4 feet 3 inches. The boring of well No. 2 was commenced on the

20th of April, 1885, and it finished on the 5th of May. The depth bored was 76 feet 9 inches. The number of days occupied in boring was fourteen, and the average depth bored per working day was 5 feet 6 inches. No. 3 well was commenced on the 25th of May, and it was finished on the 8th of June, 1885. The depth bored was 76 feet 10 inches, the number of days occupied in boring being thirteen. The average depth bored per working day was 5 feet 11 inches, and the work was carried on night and day. At Hamilton Street Station the wells were also 40 inches in diameter, but the depth was about 88 feet in all cases, the work being carried out with a heavy cutter, which was raised by means of the friction of a rope on a constantly revolving drum. By slacking the end of the rope which was held by the man in charge, the friction was reduced and the tool dropped. This method required far less preparation than that adopted at Liverpool, but there was little difference in the date of the completion of the wells at the two places.

In each of the stations there are three lifts, each arranged to accommodate one hundred passengers at a time. The time occupied on the vertical journey is about forty-five seconds, so that a train-load of three hundred passengers can be brought from platform-level to the surface in one minute. The lift consists of a room, or cage, 20 feet long, 17 feet wide, and 8 feet to 10 feet high, with seats on each side, and is fitted with handsome panelled sides of teak and American ash, and with a lantern-roof surrounded by mirrors, with a central gas-lamp.

The cage is supported on a stiff frame of iron girders, riveted to a central forged-steel cross, which at its centre is fitted to a hollow steel ram, 18 inches in diameter, which rises and falls in a strong hydraulic cylinder suspended in the well. A safety-bolt, passing through the ram, is firmly secured to the floor of the cage.

In the tower at the stations, at a height of about 120 feet above the pavement, there is a supply-tank holding 10,000 gallons of water, and at a depth of about 60 feet below the pavement there is a waste tank of similar capacity. The hydraulic pumping machinery is fixed on a floor intermediate between the upper and the lower booking-hall in the station. In the engine-room at James Street there are three marine boilers, and three pairs of Messrs. Easton and Anderson's duplex pumping-engines, each of which is capable of raising 30,000 gallons of water per hour, from the waste-tank below, back to the supply-tank in the tower above. These engines are also so connected that they can supply the lifts direct, either acting in unison with or without the supply-tank. An arrangement of interchangeable valves and pipes in the engine-room enables any main pipe, pumping-engine or lift to be shut off readily without disturbing any other part of the system. The lifts were severely tested by General Hutchinson of the Board of Trade on the 29th of December, with loads equal to about one hundred and forty passengers concentrated on one side of the cage, and they stood these tests most satisfactorily.

Ventilation.

The ventilation of the tunnel and of the stations has been the subject of much consideration. In the ventilation of mines the great aim of the mining engineer is to secure a constant current of fresh air in given directions, and to ensure this, all the roadways and workings, which branch off from the main air-ways, are either supplied with double doors, or are stopped by being bricked up and plastered over. In the Metropolitan and Metropolitan District Railways, holes have been cut in the roof of the tunnel communicating with the outer air. Through these holes the products of combustion are doubtless to some extent expelled, and fresh air is drawn in; but, in the absence of a complete system of mechanical ventilation, the result cannot be satisfactory.

The only practical method of dealing with the impure air in such cases is, in the Author's opinion, the adoption of ventilating fans placed about midway between the stations, by which a steady and continuous current of fresh air will flow in at each station, and thence through the tunnel to the fan. The air throughout the tunnel is thus changed, and not merely churned backwards and forwards.

The principle laid down for the ventilation of the Mersey Tunnel was that fresh air should enter at each station, and "split" each way into the tunnel. By this means the atmosphere on the platform is maintained in a condition of purity. The air has then to travel towards a point midway between the stations, whence it has to be extracted from the tunnel by means of the ventilating fans.

The first point to arrive at was the quantity of air required. Taking the consumption of fuel at 40 lbs. of coal per mile, the service of trains at five-minute intervals in each direction, equivalent to one train passing every two and a half-minutes, the greatest distance between the stations, namely, from James Street to Hamilton Square, as a little over 1 mile, and the quantity of noxious gas eliminated at 29 cubic feet per lb. of coal, the result is

464 cubic feet of noxious gas generated per minute. This, diluted to the extent of 1 in 500, would require 232,000 cubic feet of fresh air per minute to be drawn from the tunnel, or an average duty of 116,000 cubic feet per minute by each of the two fans hereafter described.

The air-drift was cut by the Beaumont boring-machine, and is circular in form, 7 feet 4 inches in diameter, and almost as true and smooth as a gun-barrel. It extends from Shore Road, Birkenhead, to Whitechapel, Liverpool, a length of about 2,250 yards.

It is connected by means of sliding-doors with the tunnel and the stations, so that the air can be extracted from any point desired.

Engines and Fans.

The fans are somewhat similar to the well-known Guibal fans, excepting that in the shutter (to which Guibal attached the chief value of his patent) an important alteration has been made. With the Guibal shutter the top of the opening, into the chimney from the fan, has a line parallel to that of the fan-shaft and of the fan-blades, and, as a consequence, as each blade passes this shutter, the stoppage of the discharge of the air is instantaneous, and the sudden change of the pressure of the air on the face of the blade whilst discharging, and the reversal of the pressure, due to the vacuum inside the fan-casing, causes the vibration hitherto inseparable from this type of ventilator.

Immediately at the opening into the chimney (*i.e.* at an angle of 45° from the horizontal line), this regulating-shutter, which has a Λ-shaped opening into the chimney, commences, and tapers to a point near the cross-girder which supports the chimney. The result of this gradually decreasing opening is to allow the air to pass in a continuous stream into the chimney, instead of intermittently, as was formerly the case, and to allow the change of pressure from the front to the back of the blade to be imperceptible, the action of the fan being thus rendered noiseless, and with an entire absence of vibration. To suit the varying circumstances under which fans have to work, the apex of the Λ can be raised or lowered.

As an illustration of the effect of the pulsatory action of the Guibal shutter; a fan having ten arms and running, say, sixty revolutions per minute, and working twenty-four hours per day gives ($10 \times 60 \times 60 \times 24 =$) 864,000 blows per day transmitted from the tip of the fan-vanes to the fan-shaft; the shaft is thus in a constant state of tremor, and sooner or later reaches its elastic limit. The consequent injury also to the general structure of the fan is obvious. The regulating-shutters are practically indestructible, being of wrought-iron plates, made very strong, and stiffened where necessary with angles and T-irons.

The action of this patent regulating-shutter has an important bearing upon the working of the ventilating-fans in their consequently increased durability and efficiency. In towns, like Liverpool and Birkenhead, any pulsatory action would be readily felt by the inhabitants. It is difficult to detect any sound whatever when standing close to the buildings containing the fans. The air is admitted on both sides, as it is found in practice that the fans run much more smoothly, and with the absence of the side thrust attendant upon those which have the air admitted on one side only.

The fans (Plate 4) are four in number: two are 40 feet in diameter by 12 feet wide, and two 30 feet in diameter by 10 feet wide, one of each size being erected at Liverpool and at Birkenhead respectively.

The engines for working the fans are all similar in design and construction, and are of the horizontal type, each fan having a compound tandem condensing engine with a horizontal condenser. and also a simple high-pressure stand-by engine, coupled direct to the fan-shaft: a very short time only is required to change from one engine to the other. For the 40-feet fans the high-pressure and low-pressure cylinders of the compound engine are 20 inches and 33 inches in diameter respectively, by 2 feet 6 inches length of stroke. The stand-by engine has a cylinder 33 inches in diameter by 2 feet 6 inches length of stroke. The engines of the 30-feet fans have, for the compound engines, high-pressure and low-pressure cylinders, 15 inches and 24 inches in diameter respectively, by 2 feet length of stroke. The stand-by engine has a cylinder 34 inches diameter, by 2 feet length of stroke.

As water for condensing purposes is not readily available for the fan erected in Hamilton Street, Birkenhead, the exhaust steam is cushioned, and rendered noiseless by being turned into a receiver before passing into the atmosphere, but advantage is taken of this by placing, inside the receiver, a water-heater, through which the feed-water for the boilers passes.

Each fan is supplied with a Harding's counter, worked by means of an eccentric on the fan-shaft, a steam-pressure gauge, a vacuum-gauge, and a water-gauge, the latter having a communication with the fan-drift by means of a short pipe. The engines throughout are made very strong, and careful attention has been paid to every detail, so that any accident thereto is of very unlikely occurrence. An overhead traveller is fixed over each fan-engine.

For the purpose of ventilation, the tunnel is divided into four sections, one of the above fans being allotted to each; but two fans at Liverpool and one fan at Shore Road, Birkenhead, can at any moment, through the medium of doors in the air-headings and passages, be made to do each other's duty as well as their own, and by this means any complete stoppage in the ventilation of the tunnel is rendered impossible.

The 30-feet fan erected at Liverpool ventilates, through the medium of a portion of the air-heading, the James Street station (connections being made from the roof of that station to this air-heading) and also the section lying between the said station and the terminus. This fan exhausts about 120,000 cubic feet of air per minute.

The 40-feet fan erected in Liverpool, ventilates the section of the tunnel lying between the James Street station and the centre of the river, there being "smoke-holes" at intervals between the main tunnel and the air-heading. This fan exhausts about 130,000 cubic feet of air per minute.

The 40-feet fan at Shore Road does similar duty to the 40-feet fan working at Liverpool, and ventilates the section lying betwixt the middle of the river and the Hamilton Square station at Birkenhead, there being "smoke-holes" also connecting the main tunnel and the air-heading. This fan, in addition, will ventilate the Hamilton Square station, by means of "smoke-holes" in the roof, which are connected with the fan by a separate air-way. The air exhausted by this ventilator is about 130,000 cubic feet per minute.

The fourth fan, of 30-feet diameter, exhausting about 200,000 cubic feet of air per minute, is erected in Hamilton Street, nearly midway betwixt Hamilton Square station and Borough Road station. This fan is connected directly to the main tunnel by a shaft 12 feet in diameter, and a cross-cut at the bottom of the shaft to the tunnel of similar sectional-area, and ventilates the tunnel between the two stations above named.

The fresh air enters through the respective stations, as well as through the entrances to the tunnel; but to relieve the stations from too strong draughts, the two pumping-shafts, the one at Liverpool, and the other at Birkenhead, are also used for the admission of fresh air, the quantity of which can be regulated.

At each of the "smoke-holes" connecting the stations and main tunnel with the air-heading, doors are placed for regulating the volume of air passing through.

The total yield of the four fans amounts to 580,000 cubic feet of air per minute, or about one-seventh part of the total cubic capacity of the tunnel. There is a considerable margin between the duty of the fans as given above, and their maximum exhausting capacity.

The ventilating-fans and fan-engines were made and erected by Messrs. Walker Brothers, of Wigan, and the shutter already described is their patent.

Lighting of Stations.

Some surprise has been expressed at the non-adoption of electric light for the platforms and signals. The Author is, however, of opinion that, so long as the smallest uncertainty exists as regards the regularity of electric light, a Railway Company is not justified in employing electricity as a lighting agent, unless gas is already laid on, so as to be readily available in case of breakdown of the electric-lighting machinery. Tenders were, however, invited both for gas-lighting and electric-lighting. The result of the tenders was remarkable. It was found that, allowing an equivalent light in each case, and excluding arc-lights, which for many reasons are objectionable in an underground railway, the first-cost of installing electric light would have been five times that of gas, and that the annual cost would be three times that of gas. It was therefore decided to adopt gas lighting; and this has been efficiently carried out by Messrs. Sugg and Co., who were represented on the work by Mr. S. R. Barrett. A 4-inch gas-main was laid through the tunnel, and connected at Liverpool with the mains of the Liverpool Gas Company, and at Birkenhead direct with the gas-holder of the Birkenhead Corporation. By these means, ample pressure has been obtained for lighting the lowest portions of the tunnel, whilst any waste of gas from the high pressure is effectually prevented by the automatic governors fixed inside each burner.

Permanent Way.

This railway having necessarily steep gradients, namely, a short length of 1 in 27, and considerable lengths of 1 in 30, with curves of 8 and 9 chains on the main line, it was deemed necessary to adopt permanent way of great strength.

The rails are of steel, of the bull-head section, weighing 86 lbs. to the yard, with deep fish-plates, and fixed in chairs weighing

54 lbs. each. The rails bear upon wooden cushions recessed into the chairs. To meet the requirements of the Corporations of Birkenhead and of Liverpool, two thicknesses of felt are inserted under each chair.

The sleepers, 10 feet long by 5 inches, are creosoted, and are laid closer together than usual, namely, thirteen sleepers to each 30 feet of rail. The ballast is composed of sandstone rock from the tunnel, carefully packed by hand into the invert to within 4 inches of the bottom sleeper, then of broken sandstone rock for a thickness of 4 inches, the top ballast being dry clinker ashes, 6 inches in thickness.

Signals and Telegraph.

The signals were manufactured by the Railway-Signal Company, Fazakerly; the telegraph, telephone, and electric-repeating arrangements having been carried out by Mr. John Lavender, of Manchester. Catch-points are inserted at several places, and the signals in the tunnel are fitted with gongs to attract the attention of the driver.

Locomotives and Rolling-Stock.

The locomotives, which have been specially designed for this railway, have been manufactured by Messrs. Beyer, Peacock, and Co., and the carriages by the Ashbury Carriage Company. The locomotives are six-wheeled, coupled tank-engines, with a four-wheeled bogie, making ten wheels in all, and have inside-cylinders, 21 inches in diameter, by 26 inches length of stroke.

They weigh, when in full working order, 67 tons 17 cwt. 1 qr., thus distributed—

	Tons.	cwt.	qrs.
Leading wheels	16	16	3
Driving ,,	17	10	0
Trailing ,,	17	5	0
Bogie ,,	16	5	2

Each locomotive is provided with a powerful steam-brake, as well as with an automatic vacuum-brake, and with the condensing-apparatus as used on the Metropolitan Railway. They are designed for trains of 130 tons gross, exclusive of their own weight.

The passenger-carriages are carried on four wheels, and are 27 feet long over the bodies, by 8 feet wide. The wheels are of special manufacture, giving increased strength to resist torsion. The wheel-base is 15 feet 6 inches.

The trains are fitted with the automatic vacuum-brake, and lighted by gas upon Pintsch's system.

Extensions.

The Company is now proceeding with its authorized extensions, as already described. The necessary junctions with the main line for these extensions have been already constructed, so far as excavation and brickwork are concerned.

The junction at Birkenhead is an ordinary double junction, and the one at Liverpool is a "fly-over" junction, to avoid any crossing on the level on the steep gradients.

Conclusion.

The work herein described, including the purchase of property, rolling-stock, Parliamentary and all contingent expenses, has cost about £500,000 per mile of double railway. The work on the whole, considering its special and somewhat difficult character, has been remarkably free from accident.

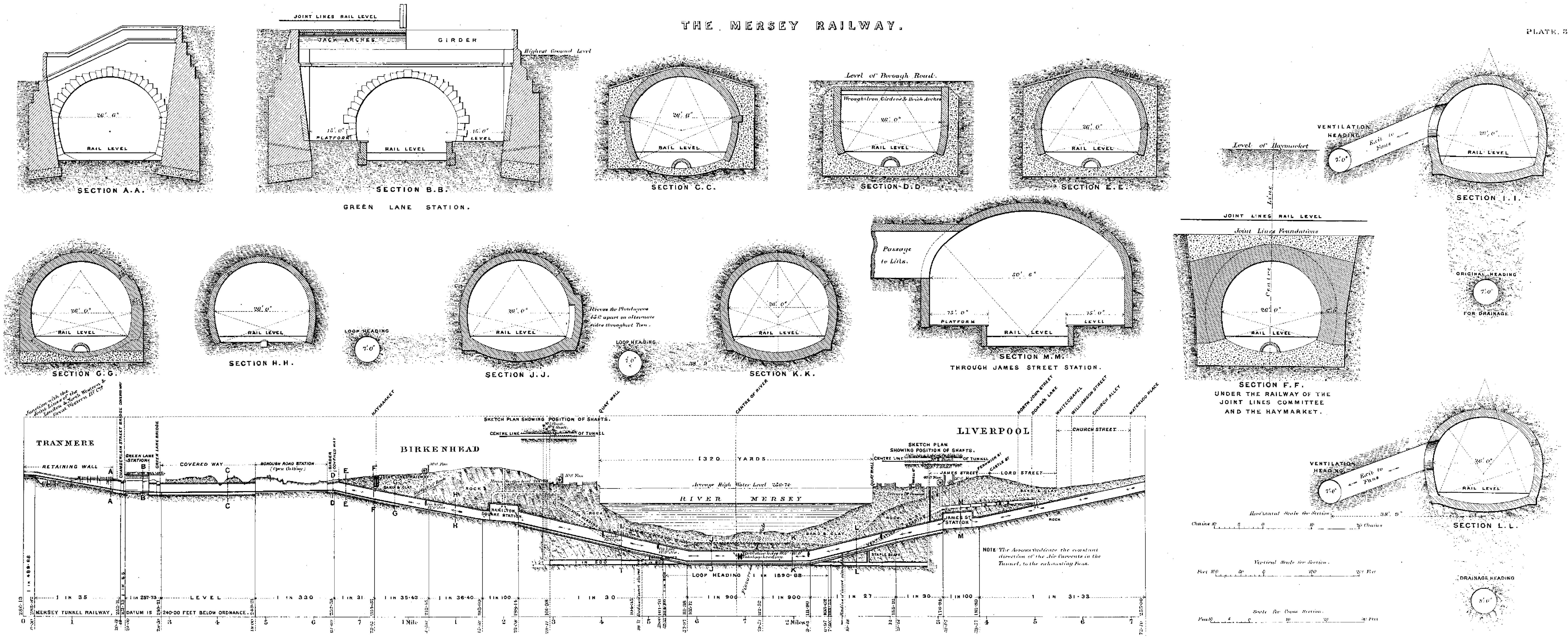
The Inspector of the Board of Trade, Major-General Hutchinson, R.E., sums up his report upon it as follows:—"In conclusion, I think it only just to remark that great credit appears to be due to the Engineers and Contractors, who have so ably carried out, and brought to so satisfactory a conclusion, this great and important work."

The Chairman of the Company is the Right Hon. Henry Cecil Raikes, M.P., and the Deputy-Chairman the Right Hon. E. Pleydell Bouverie; the joint Engineers of the Company are, Sir James Brunlees, Past-President, and Sir Douglas Fox, M. Inst. C.E., assisted by the Author; the Resident Engineer is Mr. Archibald H. Irvine, M. Inst. C.E., assisted by Mr. Ernest S. Wilcox; and the Contractors are Major Samuel Isaac, and Messrs. Waddell and Sons, represented by Messrs. James Prentice and D. A. Davidson.

This communication is accompanied by several diagrams, from which Plates 3 and 4 and the Fig. in the text have been engraved.

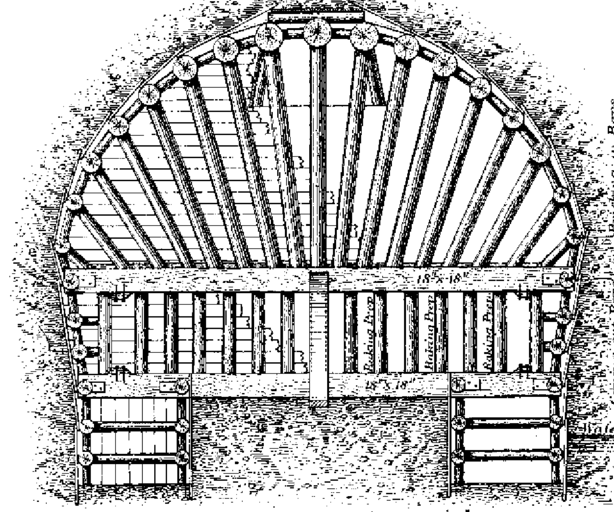
THE MERSEY RAILWAY.

PLATE 3.

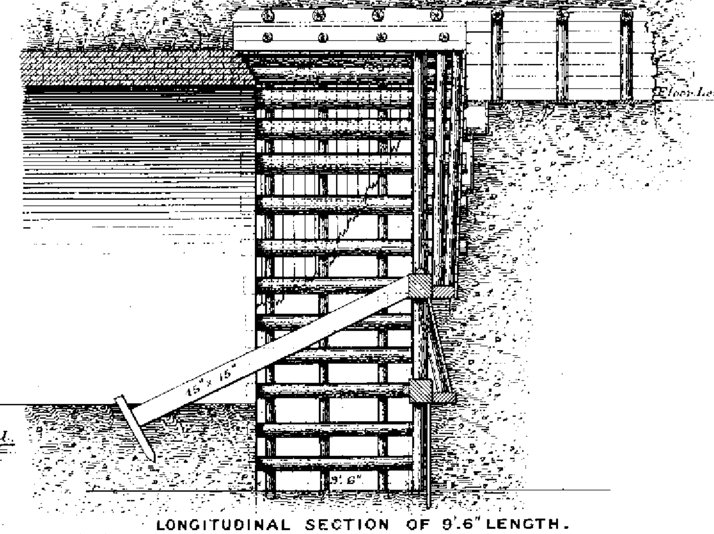


FRANCIS FOX, DEL.

THE MERSEY RAILWAY.

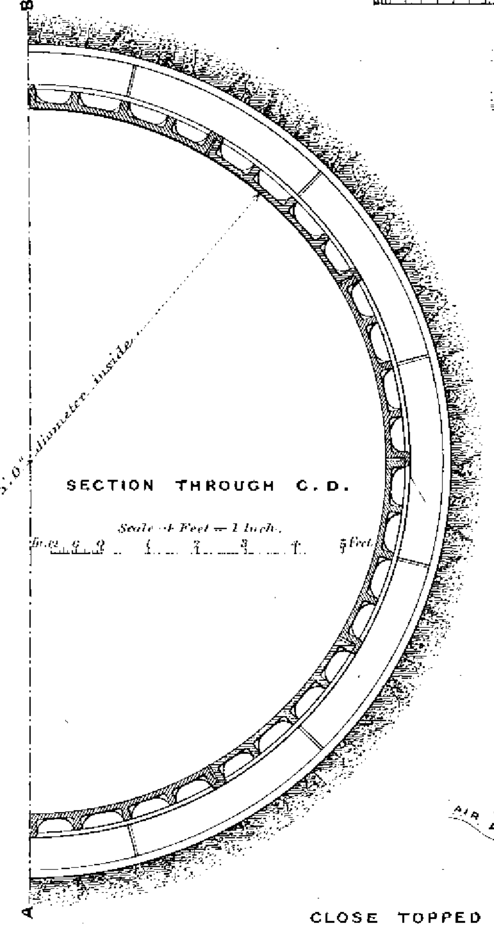


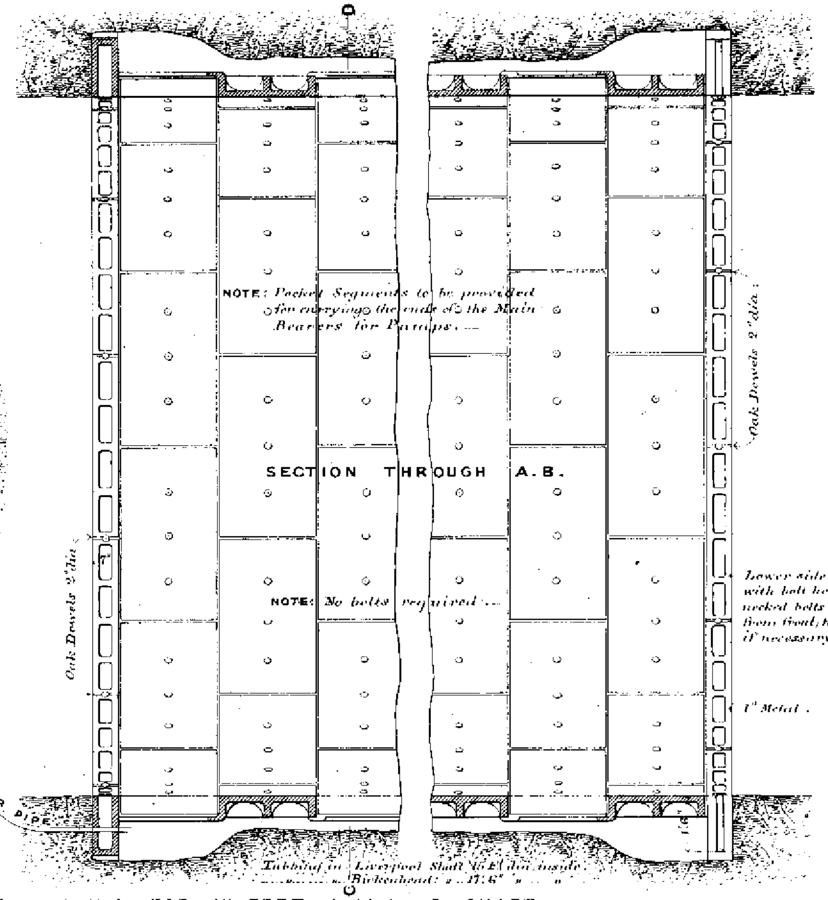
CROSS SECTION AT LEADING END OF 9.6" LENGTH.
(in running Sand.)



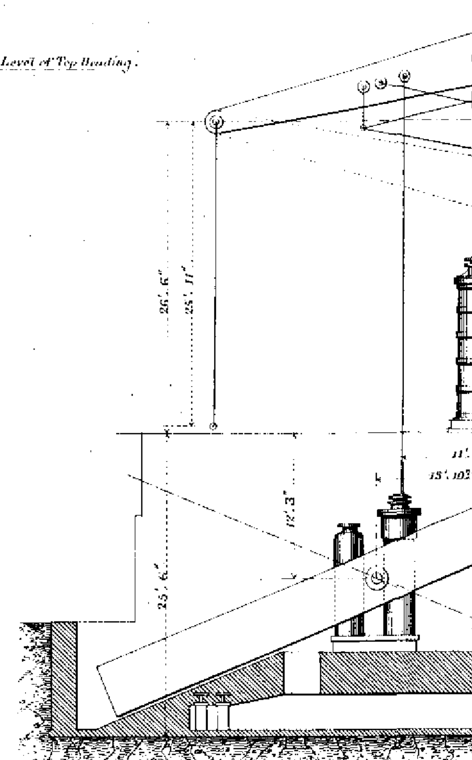
LONGITUDINAL SECTION OF 9.6" LENGTH.

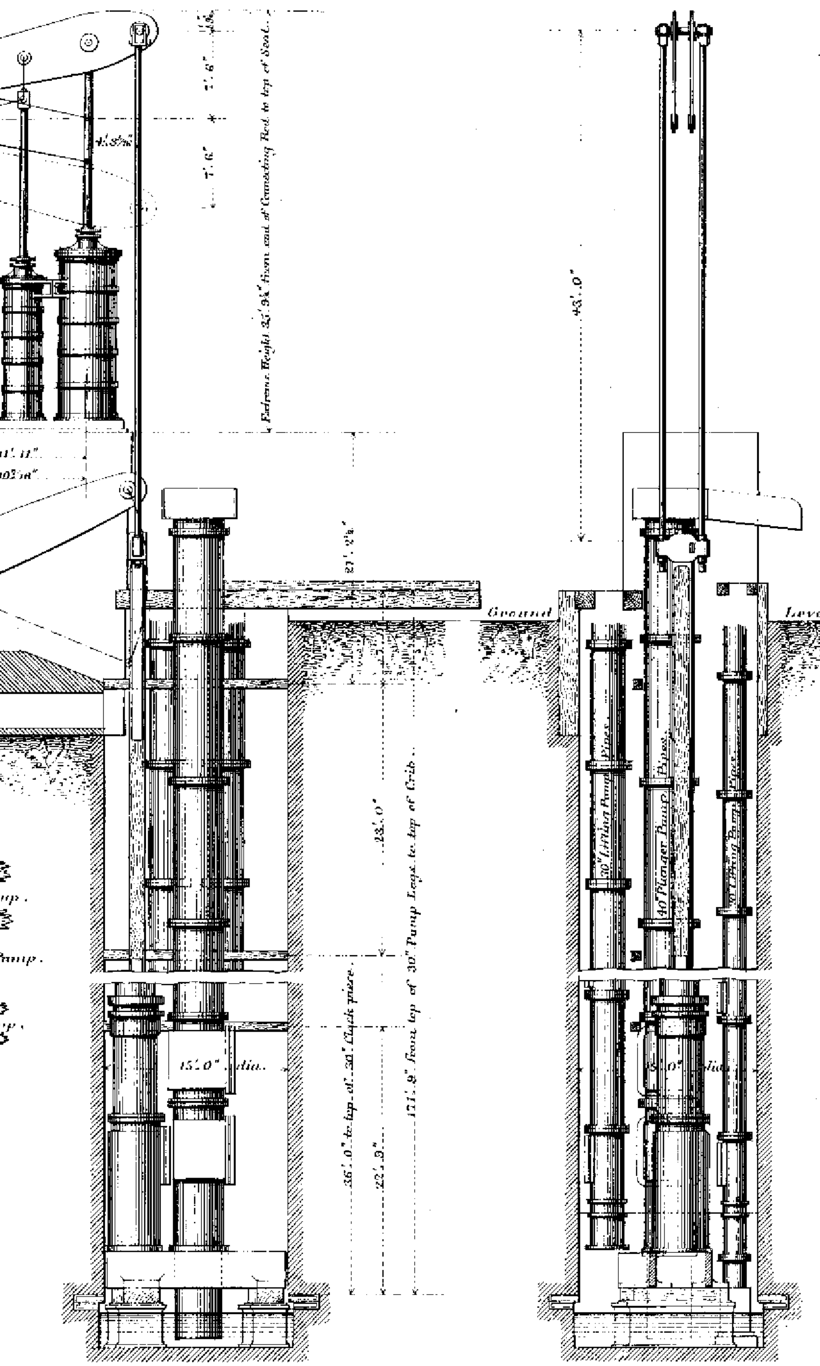
Scale: 12 Feet = 1 Inch.

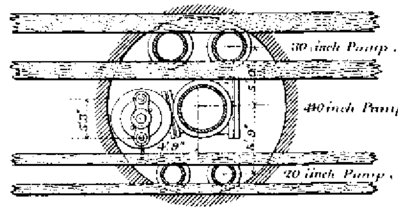




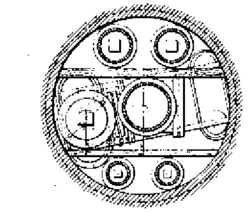
CLOSE TOPPED TUBBING FOR 15 FEET DIAMETER SHAFT.







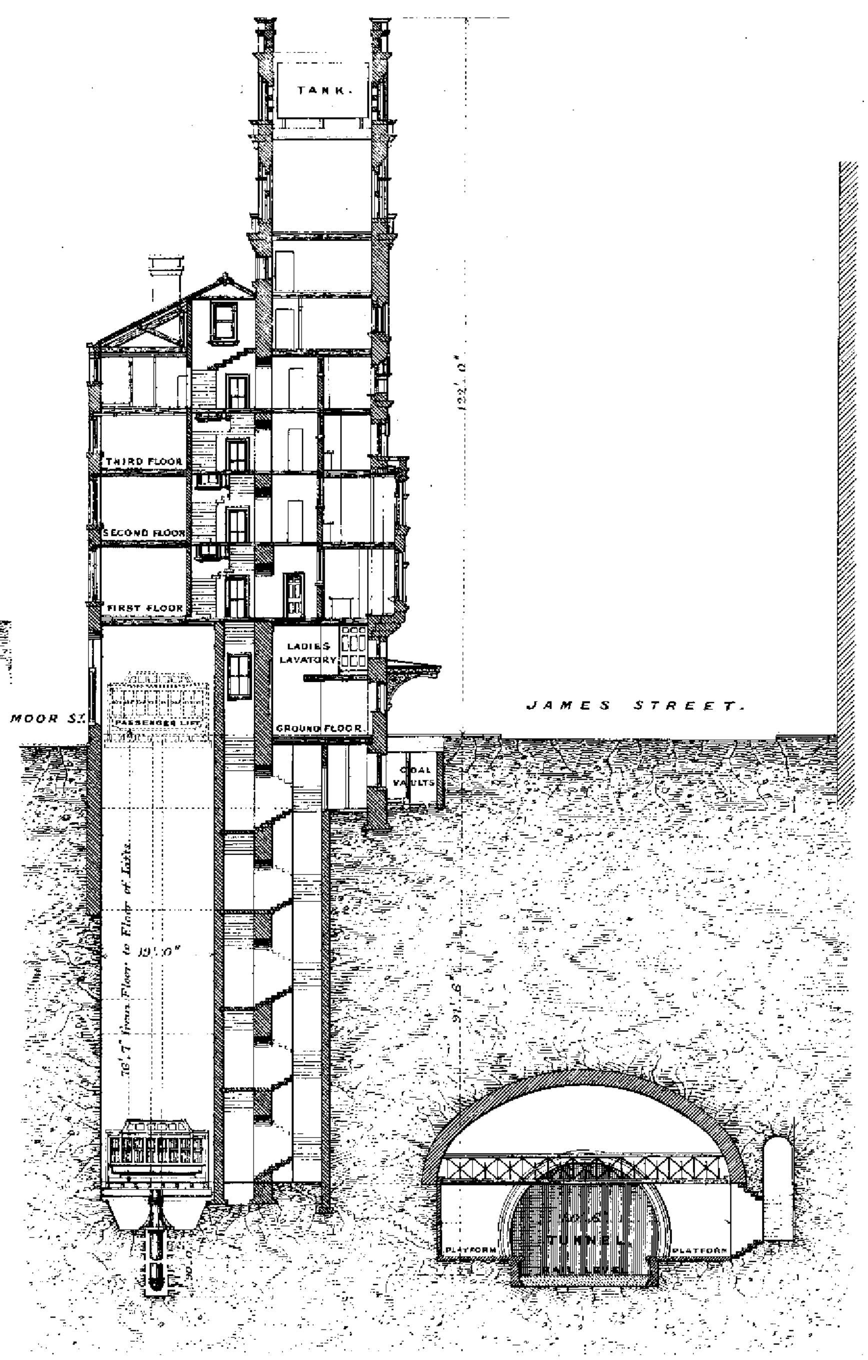
PLAN OF SHAFT AT MOUTH.



PLAN OF SHAFT AT BOTTOM.

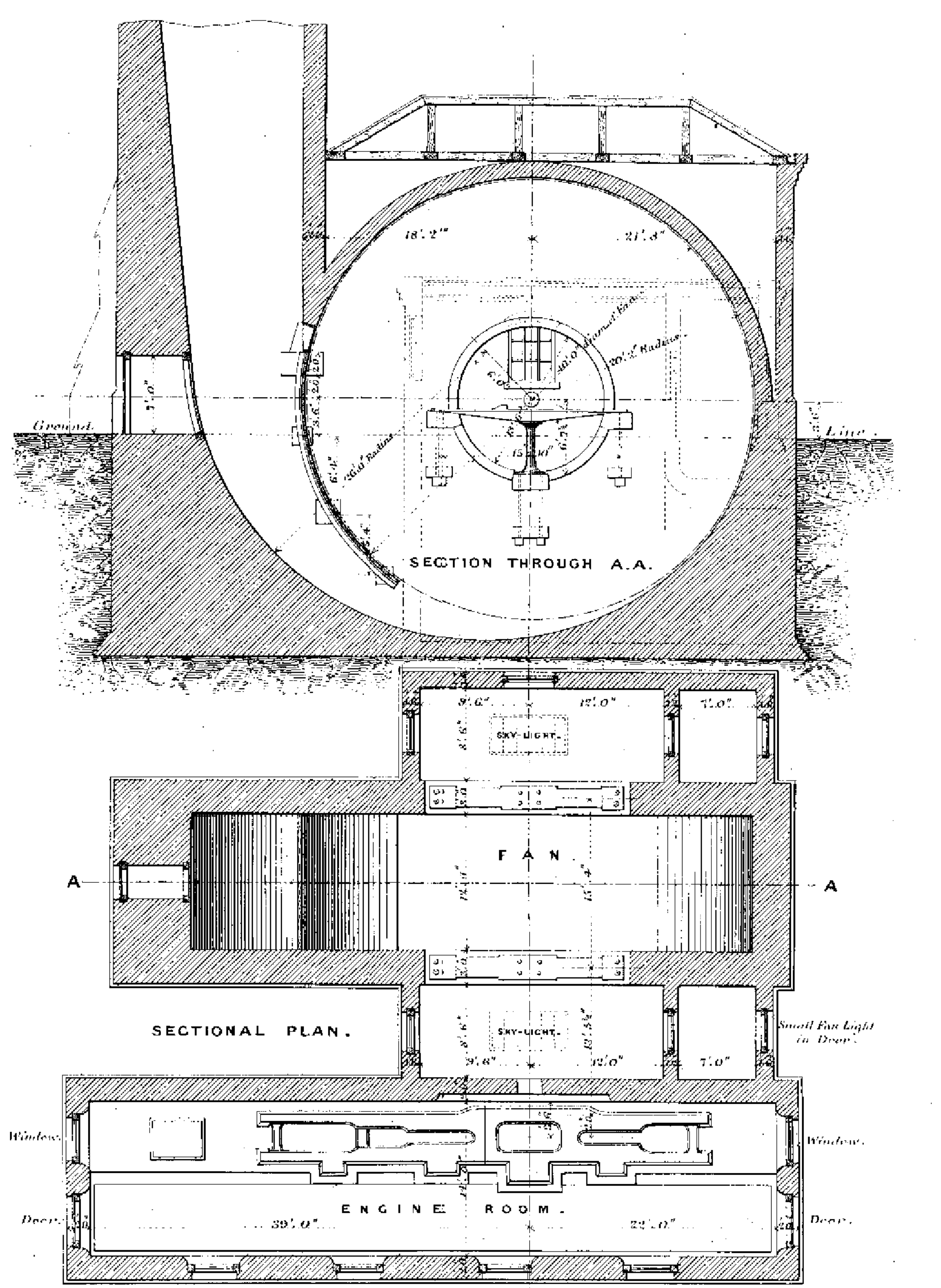
40 INCH PLUNGER PUMPING ENGINE, STROKE 15 FEET.

Scale: 16 Feet = 1 Inch.



SECTION OF JAMES STREET STATION.

Scale: 32 Feet = 1 Inch.



40 FEET VENTILATING FAN, BIRKENHEAD.

Scale: 16 Feet = 1 Inch.

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