PRACTICAL TUNNELLING

BY

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FOURTH EDITION, REVISED AND GREATLY EXTENDED

WITH ADDITIONAL CHAPTERS ILLUSTRATING RECENT PRACTICE

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CHAPTER XXVIII.

TUNNELLING IN HARD ROCK (CONTINUED)— TUNNELS ON DORE AND CHINLEY RAILWAY (MIDLAND SYSTEM).

The Bill for the Dore and Chinley line was first introduced into Parliament in 1884, with the support of the Midland Company, and sanction was obtained for the incorporation of the Dore and Chinley Railway Company and for the construction of the line. On the failure of that company, in 1887, to raise the necessary capital, the Midland Company obtained sanction in 1888 for the acquisition of its powers, and the works were commenced forthwith. Two contracts were let; the first $10\frac{1}{2}$ miles being taken by Mr. Thomas Oliver, of Horsham, and the remainder by Mr. J. P. Edwards, of Chester. The engineers were Messrs. Parry & Storey, M.M.Inst.C.E., of Nottingham and Derby, and the works proved to be of an exceptionally heavy character. There are three tunnels: the Totley Tunnel, over $3\frac{1}{2}$ miles in length; the Cowburn Tunnel, over 2 miles long; and a short tunnel of over 90 yards on the Dore South Junction Curve. There are also two large viaducts, one at Hathersage, 130 yards in length, and the Milton Viaduct, 250 yards long and 105 feet high, forming the South Junction Curve at Chinley. There is also a heavy road and river diversion in the Edale Valley, and a 100-foot span bridge over the Derwent at Bamford. There are five stations—viz. Grindleford, Hathersage, Bamford, Hope (for Castleton), and Edale.

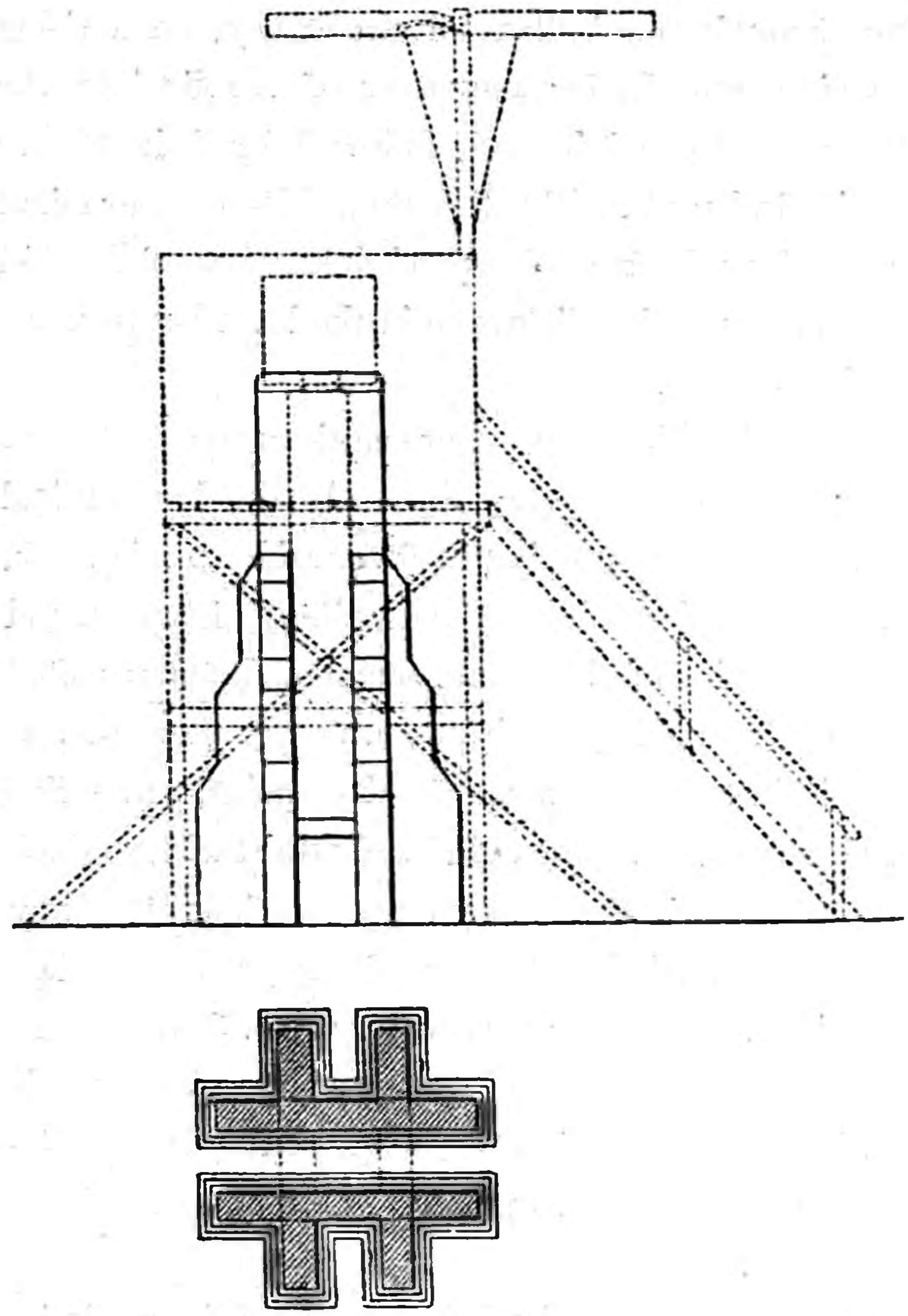
THE TOTLEY TUNNEL.

The Totley Tunnel passes for the greater part of its length under moorland, which rises upwards of 1,250 feet above sea level and is 730 feet above the level of the rails. It connects the valleys of the Sheaf and the Derwent; lies nearly due east and west; and, with the exception of 100 yards at its western end, is straight throughout, the curved portion being to a radius of 40 chains and deflecting northwards. Approached from Dore by a long cutting through the bottom of the valley, on a rising gradient of 1 in 100 which extends for a quarter of a mile into the tunnel, the subsequent gradients are 1 in 176, followed by 1 in 150 to the summit level, ten chains in length. The line then falls on a gradient of 1 in 1,000, and emerges abruptly from the precipitous face of the hill 130 feet above the bed of the river, the difference in the level between the two ends of the tunnel being 77 feet.

The Alignment above ground.—The greatest precautions were taken to secure the accurate setting out of the centre line. As the longitudinal section (fig. 1, Plate XXI.) shows, the profile was favourable to this work, distinct changes in the surface taking place at convenient distances, and high ground beyond each extremity of the tunnel accommodated terminal stations, which could be seen from the summit observatory; there was no need to reverse the transit instrument except at that point. The line having been fixed with as much accuracy as could be obtained with a 6-inch theodolite, brick observatories were built at the extreme stations (Bradway and Sir William), and at each end of the changes of the ground surface over the tunnel. In addition to these, an observatory (No. 3 west) was also built beyond the entrance at Padley, at a level to command the heading on the 1 in 1,000 gradient; and a station was fixed at the foot of the hill beyond (No. 4 west) to enable these two points to be seen from within the heading whenever necessary.

The observatories (figs. 2 and 3) were built hollow, of brickwork in cement, and capped with stone. A large flat cast-iron plate, having a hole 6 inches wide in the centre, was let into the cap and run with cement; upon this the transit instrument rested. A brass scale $1\frac{1}{2}$ inches wide, divided into inches and twentieths of an inch, was fixed across this central hole in the plate, and a plumb line from the centre of the instrument could then be let down from the hole in the plate to touch the side of the scale. The transit instrument was of the fixed type, with a 3-inch object glass and a 30-inch telescope.

In order to enable it to be used with facility at different observatories, as required, an extra cast-iron base was added, resting upon three levelling screws, and upon it the ordinary standard rested. The latter was pivoted on one end, and was secured between two slow-motion adjusting screws at the other. A hole 3 inches in diameter was made in this baseplate to allow the plumbing hook to pass freely through it from the bottom of the standard to which it was attached. The extra baseplate enabled the instruments to be levelled with accuracy, and also provided a slow horizontal movement similar to that of an ordinary theodolite.



FIGS. 2 AND 3.

In setting out the line, two points in that set by the small instrument were taken as fixed—viz. the summit and No. 1 west (fig. 1, Plate XXI.), and from the summit observatory the line was set upon the extreme observatories east and west and upon No. 1 east. The instrument was then removed to No. 1 west, and, with the Sir William observatory as a fixed point, the line was set on No. 2 west. The instrument was then removed to No. 2 west, and the line was in the same way set upon No. 3 west, and similarly upon Nos. 2, 3, and 4 east. The instrument was subsequently set up at Bradway and Sir William observatories, and the centre lines of No. 4 east and No. 3 west were checked. No. 4 west was then set from No. 3 west, and checked from No. 2 west, and the external line was complete.

The objects found most easily distinguishable for lighting upon in the open were: (1) A board with a 3-inch central white line painted upon a black ground fitted with a plummet and fixed by guy ropes. A large white calico screen, which was inclined towards the sun, was fixed behind the board, and a few feet away so as to avoid shadow. This arrangement was used at the terminal stations, which were each more than 3 miles from the summit, but could only be clearly distinguishable at that distance so long as the sun was in front of the screen. (2) An iron tripod 6 feet high (fig. 4), with adjustable screwed legs, from which was suspended a heavily weighted fine steel wire. On this wire was centred a 1-inch blackened tube, 5 feet long. This instrument was used against the sky, as at the summit observatory, the adjustment screws being used to bring the fine wire exactly to the right division on the scale. (3) A broad-arrow board, 2 feet by 1 foot 6 inches, faced with white cardboard on which was drawn a broad arrow with varying widths of shaft. This was levelled with a spirit level and supported from the back with light iron stays, and was used for short distances.

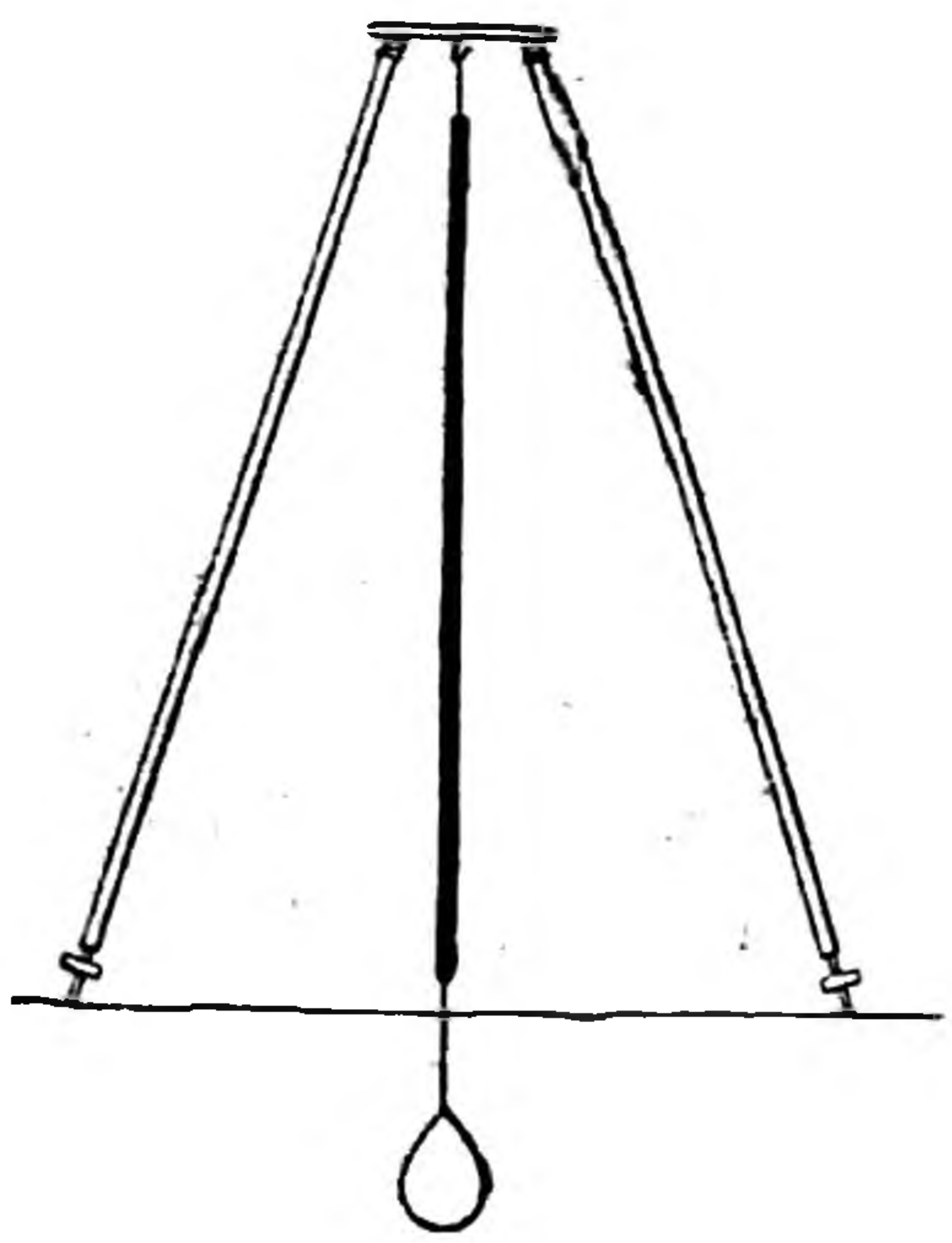


Fig. 4.

For transferring the centre line down the shafts the apparatus shown in figs. 5 and 6 was used. It consisted of a winding drum carrying the wire, mounted upon an iron frame with a ratchet and pawl to secure it in any position. The wire passed over an adjusting screw, and was brought into line by turning the screw in either direction as required.

Great difficulty was experienced at the outset in finding favourable weather for fixing the line upon the terminal stations, as it was essential that

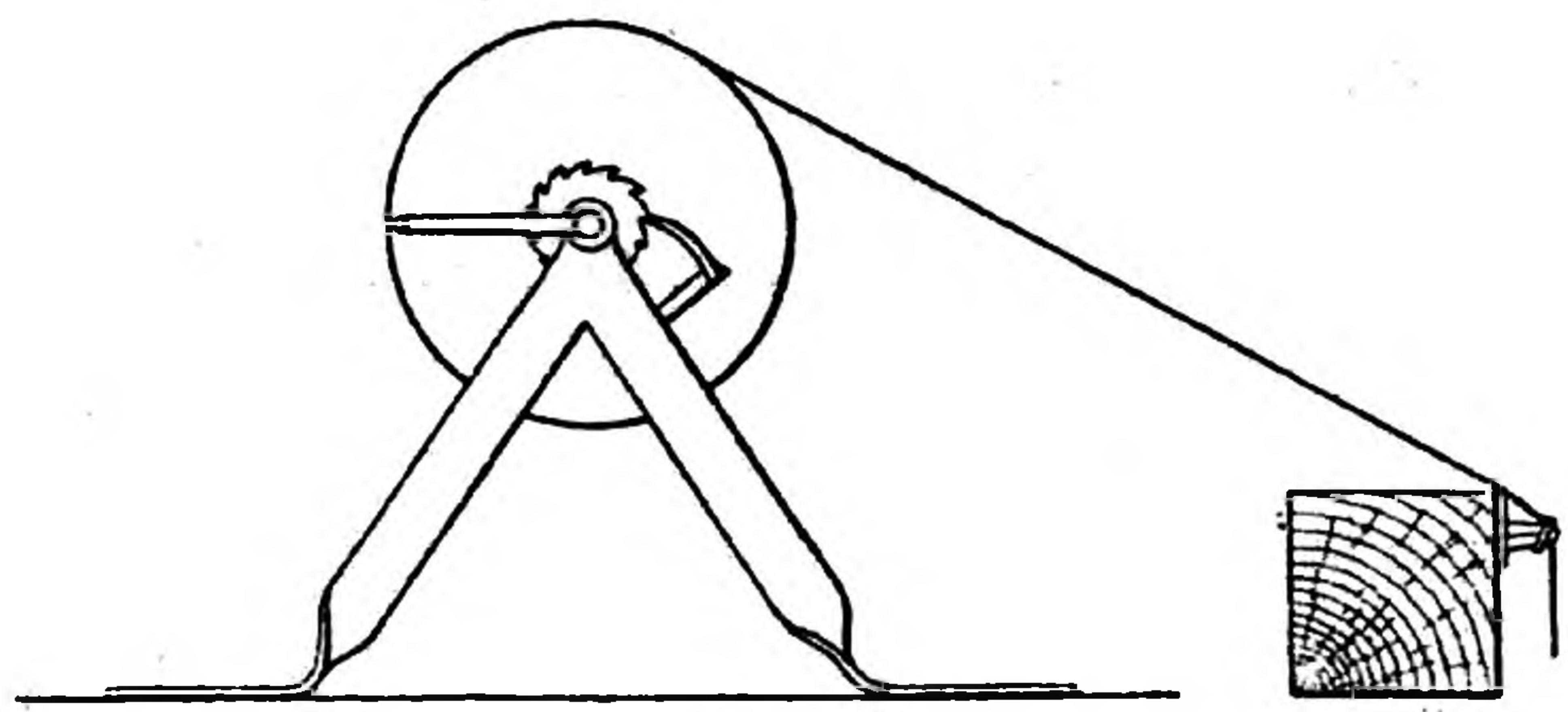


FIG. 5.

the atmosphere should be clear, sufficiently cool to prevent aberrations due to heat, and yet still enough for the observatory to be free from vibration. It was also necessary that the time of day should be such that the sun would illuminate the front of both screens behind the objects to be

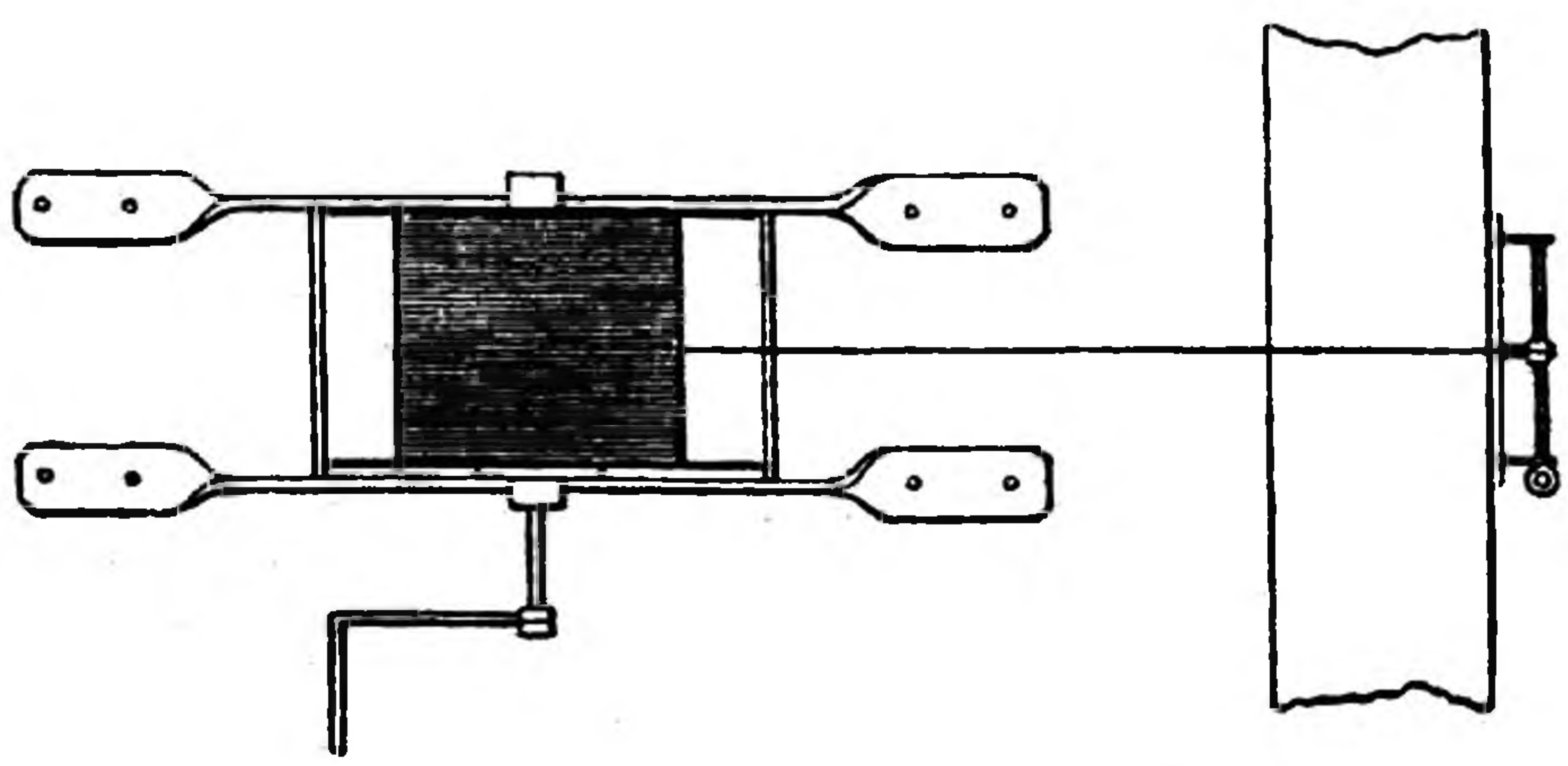


FIG. 6.

sighted. The only time when the weather answered all these requirements were rare occasions in the spring and autumn between the abatement of a high wind and a fall of rain; and as these could not be predicted beforehand and a day's preparations were necessary, much time was wasted. The greatest difficulty was found in sighting across the Derwent valley westwards, but excellent opportunities for sighting east were always obtainable at sunset after a warm summer's day.

The Alignment underground.—After the centre line had been fixed upon the observatories at the surface, the positions of the four shafts at Totley were set out from them; and when the shafts had been sunk, the centre line for the headings was transferred below, in the ordinary way, by weighted wires suspended from the top, the lines being produced underground by a small theodolite until the headings met between the shafts. The brick lining was then proceeded with, and the centre line was again carefully transferred below upon byats fixed securely into the brickwork at No. 4 shaft and at B shaft (fig. 1, Plate XXI.). With this bearing, the line was produced by the large transit instrument westwards into the heading as required. At Padley the line was produced into the heading direct from the observatory (No. 3 west). When used underground, the large transit instrument rested upon a balk of timber, which was supported at each end so as to clear the temporary road. The extreme range of the instrument below ground, when the air was clear, was about three-quarters of a mile; but as the headings advanced, not more than ten or fifteen chains could be seen under the most favourable circumstances, and the small instrument was then used in preference. The line was marked with a file upon iron dogs driven into the byats, or head trees, in the usual way, and to avoid instrumental errors the line was set out twice, the telescope being turned over transversely in the bearings between the operations. The mean of the two results was the centre line adopted.

The objects used for sighting upon underground were: (1) for long distances, a large circular-wick oil lamp of 40-candle power, fitted into a circular wrought-iron frame, which was suspended by a wire; and (2) for shorter distances, for use with the smaller instrument, a carriage candle fixed on a weighted frame and suspended in the same way.

For signalling long distances with the large instrument, an electrical signalling apparatus was employed (figs. 7 and 8). It consisted of two similar instruments, in each of which a 7-inch single-beat bell was mounted, with a battery enclosed beneath, together with a three-quarter mile single gutta-percha covered cable wound on a drum, and mounted on a portable frame. The cable was thus readily paid out from the trolly on which the instruments were conveyed every time it was used, and the return was made to earth through a galvanised-iron plate temporarily sunk into the ground. With this apparatus messages could be sent in either direction, and to prevent misunder-

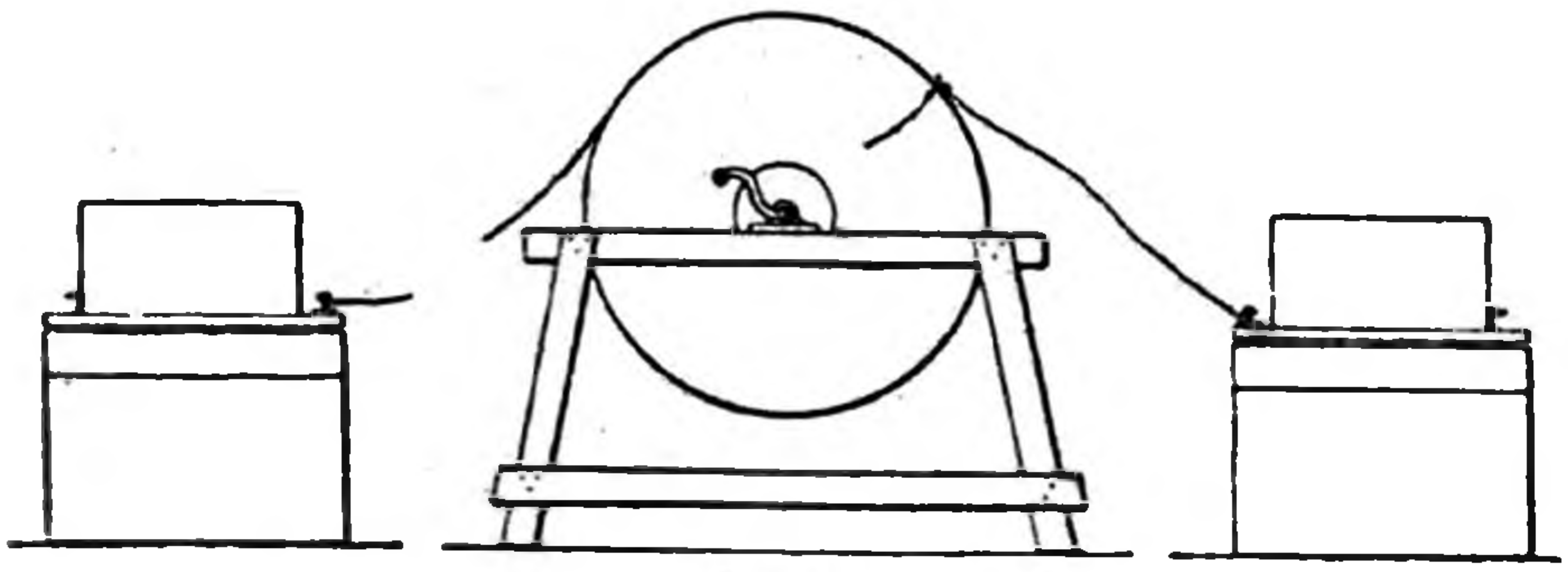


Fig. 7.

standing all signals were repeated by the receiver, and any error in transmission could then be corrected by the transmitter. The advantages of electrical signalling were incalculable, for, besides overcoming the difficulty of setting out at such a long range in a narrow heading, it saved that straining of the eye for signals on the part of the operator which is so trying under ordinary circumstances, and thus favoured better work. For signalling short distances with the small instrument, a red, white, and

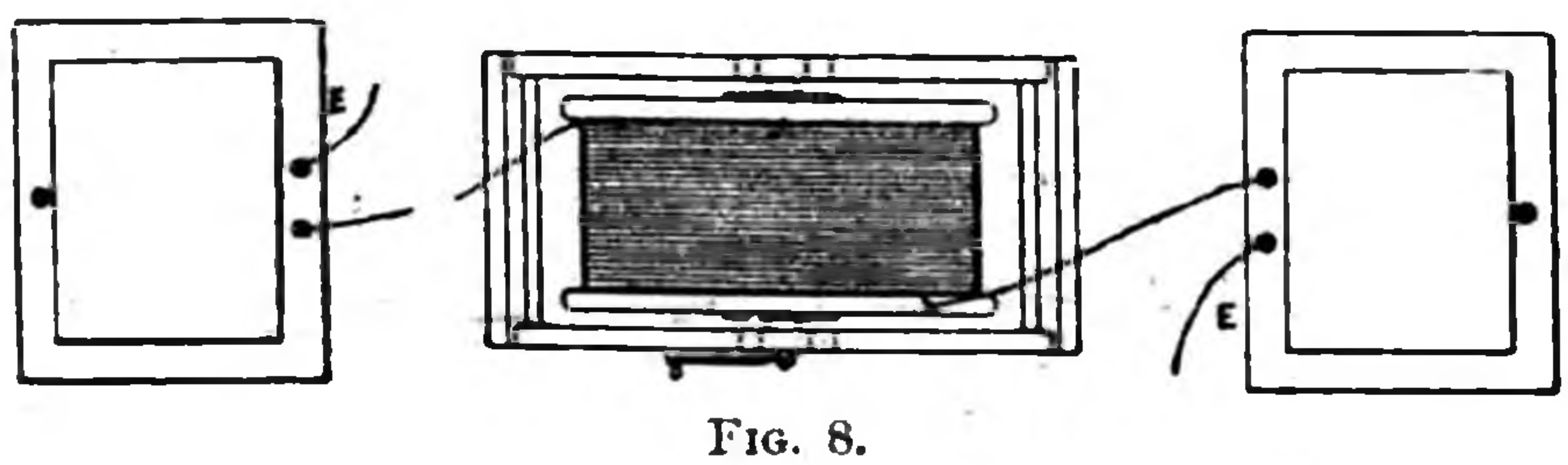


Fig. 8.

green hand-lamp was used. When the headings met, the difference between the centre lines of the two headings was found to be 4½ inches, and the difference between the levels was 2¼ inches.

Sinking the Shafts.—Although powers were granted by the Act to sink a ventilating shaft at the summit level of the tunnel, it was not considered advisable, for several reasons, to construct it at first. Four permanent shafts were sunk at the commencement, all of which are within three-quarters of a mile of the Totley entrance. To facilitate the driving of the headings and the lining of the tunnel, they were not lined with brickwork until some time after they had been sunk, and when they were no longer necessary for haulage purposes.

Three temporary shafts, A, B, and C (fig. 1, Plate XXI.), were sunk in addition, A being at the east entrance and B and C between that point and No. 1 shaft. Shaft A, commenced on September 24, 1888, was used for a pumping station until the cutting had been excavated and the drainage could flow out naturally. It was sunk wholly in shale. Water was met with at a depth of only 8 feet, increasing in quantity until the full depth was attained in November 1888, when the discharge amounted to 10,000 gallons per hour. Shafts B and C were commenced on November 28, 1888, and January 3, 1889, respectively. They were sunk entirely in dry shale, which had been drained by A shaft.

The permanent shaft No. 1 was commenced on September 11, 1888. The material traversed was dry shale, with one 4-foot bed of rock, which brought in a large quantity of water. The full depth of 87 feet was reached on October 30, 1888. Shaft No. 2 was commenced on September 17, 1888, in dry shale. At 20 feet, thin beds of coal and fireclay were cut through, then shale again as far as 80 feet, when more beds of coal, ganister, fireclay, and rock were found, with a large quantity of water. These were succeeded by shale and another 6-foot bed of rock, and finally shale again to the full depth of 141 feet, which was reached on December 1, 1888. Shaft No. 3 was commenced on September 24, 1888, the material passed through in the first 160 feet being shale, with several beds of rock a few feet in thickness, but without water —the same beds having been previously intersected and drained by shafts Nos. 1 and 2. Then followed rock with a considerable quantity of water, which continued to the full depth of 235 feet, reached on March 27, 1889. The quantity of water discharged was 8,000 gallons per hour. Soon after the shaft had been sunk the pump became drowned, and nothing further was attempted until the heading from No. 2 shaft was driven so far forward as to liberate the water. Shaft No. 4 was commenced on September 20, 1888, the first 50 feet traversing dry shale; then a bed of coal and rock was reached, with large quantities of water; and this was succeeded at 80 feet by beds of shale and rock, the rock in each case yielding more water. On January 30, 1889, a depth of 180 feet had been sunk, the quantity of water then discharged being 15,000 gallons per hour. It was decided to increase the size of this shaft from 10 to 15 feet diameter, so as to accommodate a pair of cages for winding gear. Further sinking was therefore stopped, and the widening of the shaft was commenced from the surface on February 4, 1889. By April 9, 1889, the widening had been carried down to where the sinking had been suspended, and the enlarged shaft was then continued. At 185 feet, a 15-foot bed of rock was passed through, followed, after 5 feet of shale, by another bed 18 feet thick, the quantity of water to be raised by the pumps being largely increased. Shale was then passed through until the full depth of 280 feet had been sunk on June 19, 1889. The quantity of water discharged by the pumps finally reached 26,000 gallons per hour.

The Headings.—The size of the heading throughout was 10 feet by 9 feet clear of timber, large enough to take a fully loaded wagon, and it was driven at the formation level or thereabouts. A commencement was made at Padley on September 27, 1888, the first 530 yards being driven by hand power only. After penetrating a few yards of gravel, black shale was reached, accompanied by water from the roof, which gradually increased in quantity as the heading proceeded, and was carried off by an open grip. In June 1889, the first break-up was made at this end, and, as much difficulty was found in excavating the foundations of the side walls, owing to the water finding its way from the grip through the fissures in the shale, it became desirable to carry off the water at a lower level than the foundations. The heading was therefore stopped from June to August 1889, whilst a 12-inch drain was laid from the open end below the invert level. When the driving of the heading was resumed, it was found that sinking the drain at so great a depth hindered the work, and the contractor was allowed to run the heading down hill, and to proceed at a level 4 feet lower than the formation, in order to save time and labour in excavating the drain. This was done at 400 yards from the entrance.

At Totley the headings were started as soon as the shafts reached their full depths, and were driven in both directions from each shaft until they met. From shaft A the heading was entirely in the shale, and yielded a large quantity of water. From shaft B eastwards dry shale only was pierced, which had been drained from shaft A. Westwards the black shale terminated in a fault, where a large spring was tapped which flooded the headings for four days, the pump at shaft A, although discharging 26,000 gallons per hour, being temporarily unable to deal with it. The water, however, diminished and work was then resumed, the total discharge afterwards was reduced to 12,000 gallons per hour. After passing the fault, beds of coal, fireclay, and rock were passed through. From shaft C only a few yards were driven in dry ground before the headings met in both directions.

From No. 1 shaft, eastwards, the heading was entirely in dry black shale. Westwards, 100 yards were driven in the shale, when another series of beds of coal, fireclay, and rock were cut through, the latter formation yielding much water, the quantity discharged amounting to 25,000 gallons per hour. In ten days' time this quantity had diminished by one-half. After leaving the rock, black shale was again reached, and it continued until the heading met that from No. 2 shaft. From No. 2 shaft eastwards black shale, with a bed of rock, was passed through, and westwards a similar bed of rock was pierced, the quantity of water from both amounting to 10,000 gallons per hour. After passing through more shale and a bed of coal, rock was reached. On May 26, 1889, No. 3 shaft was reached, and the water in it was liberated. Shale, coal, fireclay, and rock were successively passed, the rock bringing in more water. On September 21, 1889, the heading met that from No. 4 shaft. From No. 4 shaft only a few yards were driven each way, owing to a stoppage of the pump, followed by a total disablement, the pump being drowned.

From February 15 to September 4, 1889, at 1,167 yards, all the water discharged into the headings was lifted at shaft A, the maximum quantity reaching 2,250,000 gallons per day. The same trouble was now found with the water in the foundation of the side walls, as had been previously experienced at Padley, and a 12-inch pipe was therefore laid from the entrance to drain them, which, by January 1890, was carried as far as No. 4 shaft, an open grip sufficing beyond that point. The quantity of water encountered was, however, so great that the 12-inch pipes proved insufficient to deal with it, and by July 3 the driving had to be suspended. The 12-inch pipes—which had been found very difficult to lay properly through the uneven beds of rock and hard shale, and much more difficult to keep free from silt when laid—were taken up, and a grip 2 feet 6 inches square was cut along the bottom of the heading instead and covered with 3-inch planking. At 1,560 yards, a wall 4 feet 6 inches thick, having a camber of 6 inches horizontally, was built across the heading in brickwork in cement. Seven 4-inch wrought-iron pipes, one of which was furnished with a pressure gauge, were built in through the wall, having plug-cocks fitted at their outer ends, which remained open until the brickwork had set. The cocks were closed, and the work of excavating for the drain pushed forward. The pressure rose until, in ten days, it had attained 127 lb. to the square inch. Meanwhile, the leakage through the fissures in the rock was more than a 4-inch pipe, which had been laid down in the heading, would take, and a second wall 18 inches in thickness was built 71 yards below the first one, to increase the discharge of the pipe by increasing the head of water. The covered drain was then carried as far as the outer wall, which was removed. The pressure on the inner wall was tested, and was found to have risen to 155 lb. per square inch. The drain was then carried forward until, by August 11, it had reached the inner wall. This was then removed, and driving was resumed after a stoppage of six weeks. More rock, with water, was passed through, and finally, at 2,070 yards, dry black shale was again reached, which continued as far as the junction at 3,700 yards.

Similar difficulties occurred in the heading at Padley. It had advanced on November 16, 1891, to 1,880 yards, when an inrush of water took place at the face which dwarfed everything previously met with. A round of holes had been drilled in the rock, and were about to be charged, when a plug of soft earth was forced out of a fissure in the roof and about a yard from the face, and a stream of water issued, which rapidly increased from a few square inches in area to the full width of the heading and two feet across. Tons of sand, silt, and stones were hurled down the fissure, and were carried far down the heading by the torrent. A natural reservoir was discharging itself, and the water, rushing down the heading, was impounded where the level dipped, and eventually cut off all access to the face. It was decided to proceed at once with the permanent drain from the entrance to where the lining was completed, and to substitute a covered grip for the 12-inch pipes through the heading. A puddle dam was constructed in the lined portion, and a large air-shoot, which had been used for ventilation, was lined with felt, and made available to carry off water. The construction of the permanent drain was then proceeded with. The quantity of water discharged by the shoot was ascertained to be 5,000 gallons per minute. When the culvert had been carried as far as the dam, the latter was removed, and the covered grip constructed up to the face of the headway. The heading was also raised in the lower place to prevent it from being again flooded, and driving was resumed on February 26, 1892. The difficulty of keeping the foundations of the side walls free from water was afterwards met by the employment of Tangye pumps, driven by compressed air. The quantity of water discharged from the fissure gradually diminished. From the fissure, onwards, the heading was driven at the formation level. At 2,090 yards dry shale was reached, and the heading was carried on a descending gradient to meet that from Totley, the junction taking place at 2,529 yards from the Padley entrance.

With regard to the hindrances unexpectedly caused by the quantity of water tapped at Padley, owing to the insufficiency of means to carry it off, it may be here remarked, that experience shows, that the best means of drainage during construction is a spacious grip in the centre of the heading, covered with timber, and therefore easily accessible; that the heading should not be carried below the formation unless the tunnel is inverted; and that the drainage of the foundation of the lengths of lining is best obtained, in cases where there is much water, by the employment of compressed air pumps.

Timbering.—The timbering of Totley Tunnel is shown in figs. 9 and 10. In the section, five drawing bars are shown. The usual number was either four or five. In some places where the ground was good only three were used; at other places there were five or six, chiefly at the open ends. Fig. 11 represents the general section of the lining with the centering used during construction. The leading ribs were composed of three elm-planks bolted together, and the intermediate ribs of two planks. This figure also shows the sheet iron, which was put outside the brick-work to protect it from the water during construction, and which had been very successful in practice, for it must be remembered, that at both ends of the tunnel two large streams of water, amounting to two to three million gallons a day, were flowing, whilst from the crown, there would probably not drip enough to fill a $1\frac{1}{2}$-inch pipe. The Inspectors were each supplied with a printed book, in which they entered the thickness of the side walls, the number of miners excavating, and all other particulars. These returns were subsequently handed to the Resident Engineer, and were posted in the usual way.

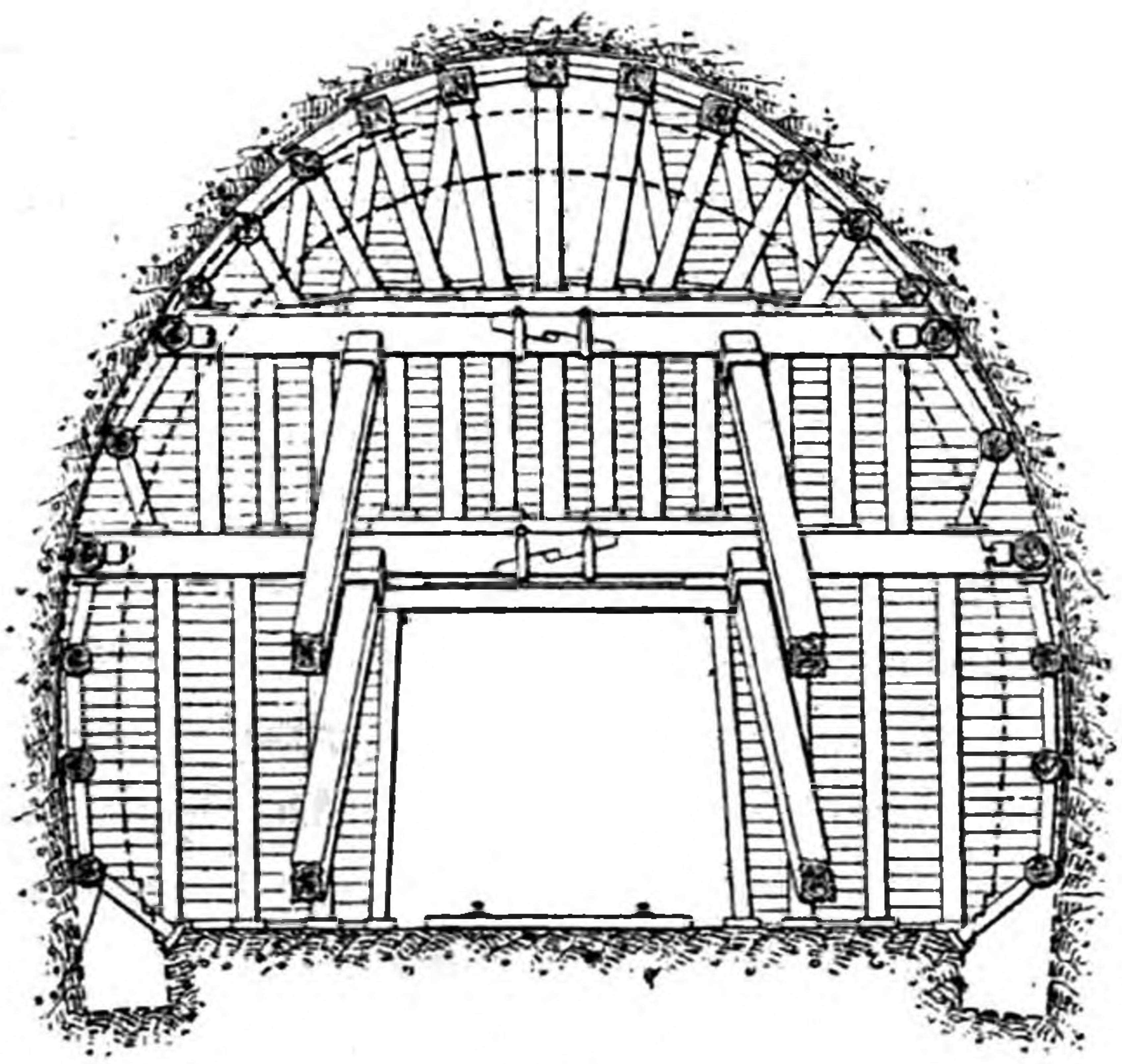


FIG. 9.

Compressed-air Machinery.—The whole of the headings, with the exception of 880 yards at Totley and 530 yards at Padley, were driven by means of compressed air drills. In addition to these, compressed air drills were used in the top headings both at Totley and Padley. Compressed air was also almost the sole agent of ventilation. The plant laid down for the heading at Totley consisted, in the first instance, of one 10-inch Schram air-compressor, which was fixed at the No. 2 shaft, and two $3\frac{1}{4}$-inch Schram drills, the pipes being of wrought iron, 2 inches in diameter. When No. 4 shaft was reached in July 1889, this plant was superseded by an 18-inch Schram air-compressor, which was laid down there, and two $3\frac{1}{2}$-inch Schram drills, the pipes being 3 inches in diameter. This plant remained in use until October 1890, when, at 1,740 yards, two $3\frac{1}{4}$-inch Larmuth drills were substituted for the two $3\frac{1}{2}$-inch Schram drills, and with this plant the heading was completed. The plant laid down in each case served the heading only, except that one break-up was ventilated from the same pipe until March 1892, after which date, owing to want of pressure at the face, the pipes were used solely for the heading.

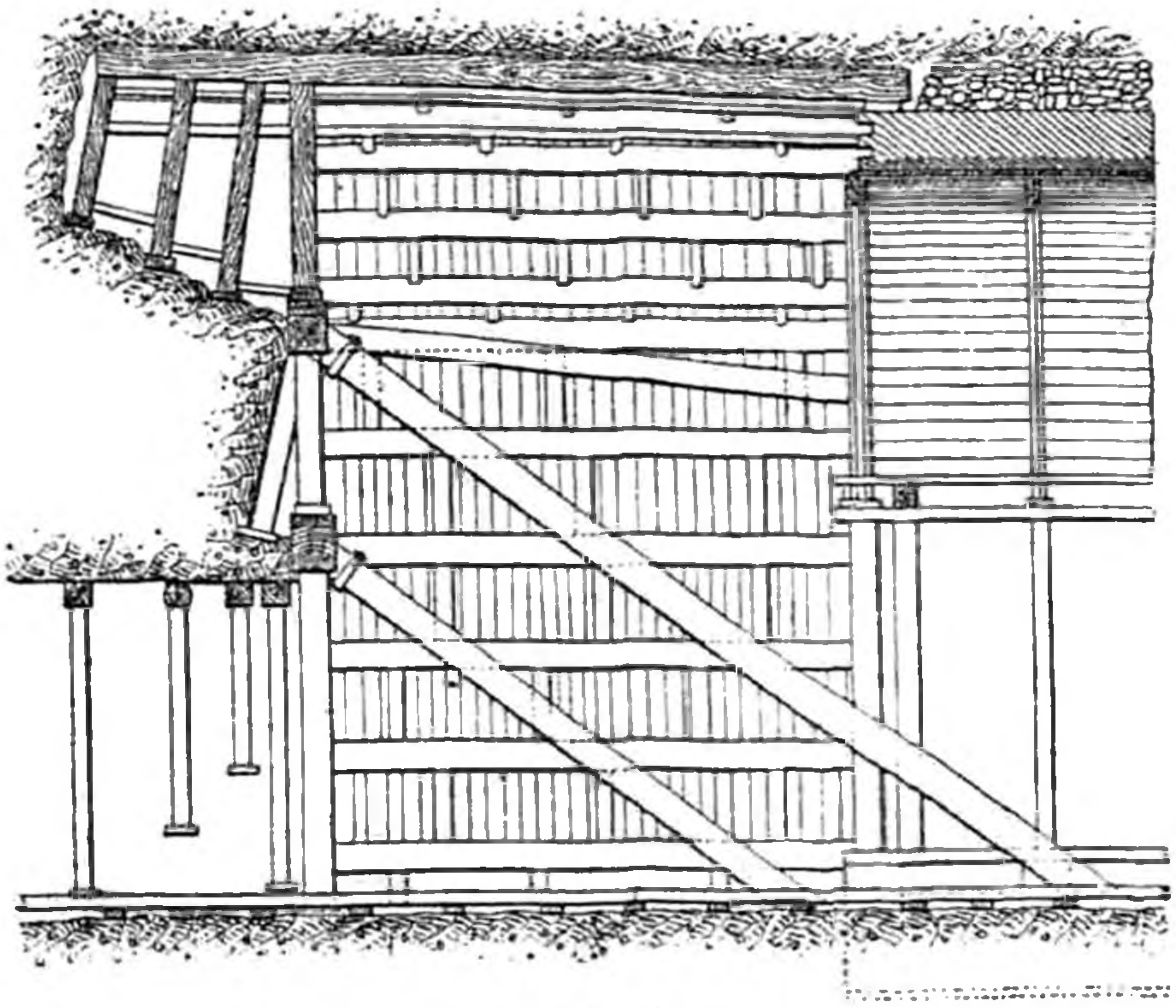
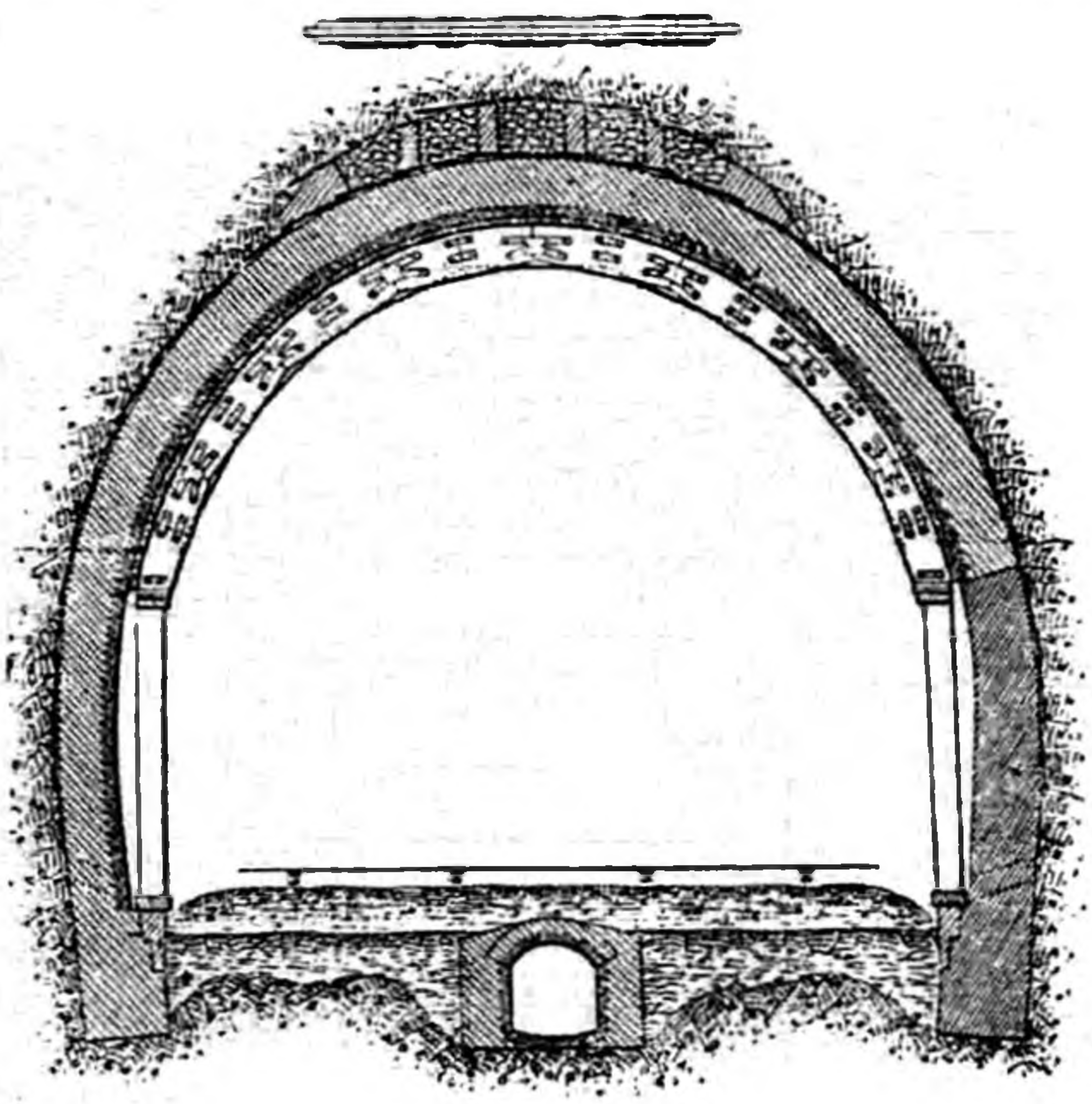


Fig. 10.

The plant employed at Padley consisted of a 12-inch Schram air-compressor, driving two $3\frac{1}{4}$-inch Schram drills in the heading, through $2\frac{1}{2}$-inch pipes, which also supplied air for ventilation. This plant was discarded in June 1890, when a 40-h.p. compound engine, driving two 16-inch air cylinders, was erected, and 4-inch pipes were substituted for the $2\frac{1}{2}$-inch pipes to the face. In September, 1890, at 950 yards, the $3\frac{1}{4}$-inch Schram drills were replaced by two $3\frac{1}{4}$-inch Larmuth drills in the headings.

In November 1890, air drills were used in the lengths at Padley. The Fowler air-compressor being insufficient to work the whole of the drills and to supply air for ventilation, a second Fowler air-compressor, similar in all respects to the first, was erected, with $2\frac{1}{2}$-inch pipes to the heading; but only one air-cylinder was worked, the other being held in reserve. The $2\frac{1}{2}$-inch pipes were reserved entirely for the heading, no air being drawn from them either for the lengths, or for ventilation. The smaller diameter of the pipes, when the headings were within a few hundred yards of meeting at 2,529 yards, was found to cause a great deal of friction, the difference in air pressure between the compressor and the face of the heading, at a distance of $1\frac{1}{4}$ miles, when the machines were working, being sometimes as much as 15 lb. or 20 lb. per square inch. As break-ups were commenced in the rock and hard shale, additional drills were worked in the top headings of the lengths, the total number driven by the double compressor, besides the air supplied for ventilation, being two $3\frac{1}{4}$-inch Schram drills and two 3-inch Larmuth drills. For drilling the top headings, and for ventilation at Totley, the 10-inch Schram compressor



Scale 1 inch = 10 feet.

FIG. 11.

from No. 2 shaft and the 12-inch Schram compressor, which had been superseded at Padley, were laid down at No. 4 shaft, and were coupled to 3-inch pipes. In April 1891, these two air compressors were replaced by two 18-inch Schram compressors, coupled to a 4-inch pipe down the shaft, and 3-inch pipes beyond. These, in addition to ventilating, worked four

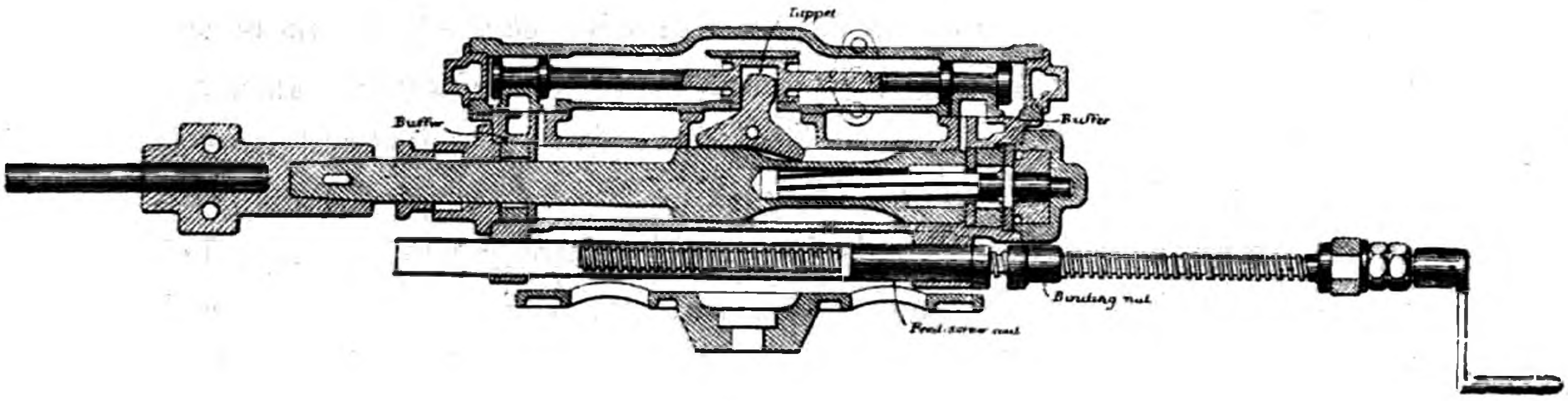


Fig. 12.

3-inch Larmuth drills, and one $3\frac{1}{2}$-inch and one $3\frac{1}{4}$-inch Schram drill in the top headings. In January 1892, one of the 18-inch compressors was converted into a low-pressure machine by the substitution of a 4-foot cylinder, and was coupled to an independent range of wrought-iron riveted

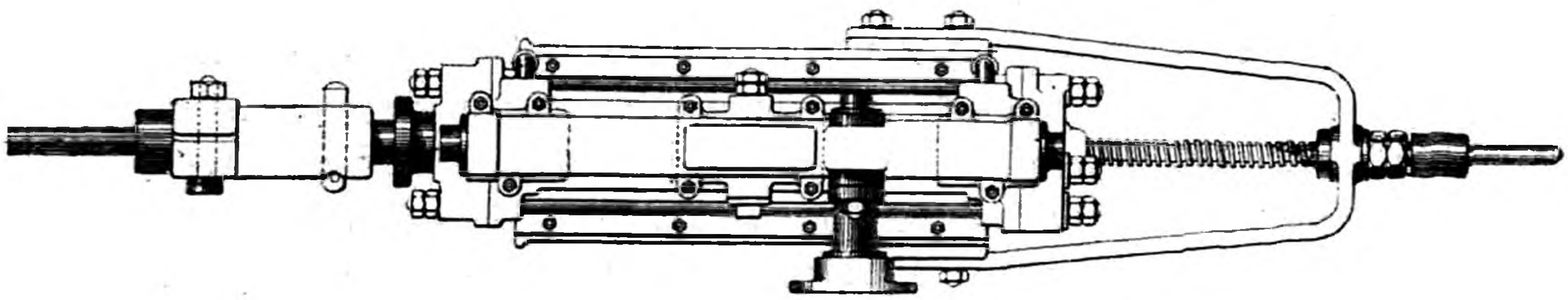


Fig. 13.

pipes, 8 inches in diameter, which were carried as far as 2,970 yards and used for ventilating purposes only.

The Larmuth machine drills were found to work most satisfactorily. Their special feature is the mode of actuating and locking the valve, which is effected by the piston through the medium of a tappet. The machines supplied to Totley Tunnel are illustrated by figs. 12 and 13. The piston is long, and is turned to fit the cylinder truly, without packing. It has a recess in the middle of its length into which one end of the three-armed tappet drops, as the other end is lifted and held by the cylindrical part of the piston. The tappet is thus made to rock upon its pivot, and to actuate the valve spindle into which its upper arm is fitted. The valve spindle in its turn actuates the D valves, which fit between two collars on the spindle at each end. There is no air-cushioning at the front end of the cylinder, and a very hard blow is therefore obtained from the machine. In cases of overshooting, the momentum of the piston and drill is destroyed by a thick india-rubber buffer. The twisting motion of the drill is obtained by means of the usual square twist-bar, working through a nut in the end of a piston, which is moved round at each stroke, and is secured by ratchet and pawl at the back end of the cylinder. The long screw, by which the feed is supplied, has an arrangement for taking up the wear. A second binding nut is added, and each of the nuts has flanges cast upon it, through which two bolts pass. These are tightened up as the thread wears, and are secured by lock nuts. The machine is fixed in the usual way by a conical spigot cast on the under side of the cradle, which fits into a socket on the carrier, and is secured to it by a central bolt, whilst the carrier clamps the stretcher bar by two bolts. The machine can thus be moved on either a vertical or a horizontal axis, and be fixed in any position. The drills were found to work with very little attention in the way of repairs, as no packing of the piston was required, and it was not necessary to send them to the fitting shop, except for renewals. The chief wear occurred in the feed screws and nuts. The piston required renewal once every year. The only defects found in the machine, were the breakage of the valve spindle by the sudden shock with which it was actuated; and an insufficiency of strength in the cradle to resist the strain produced by the workmen hammering the drills when they had become jammed in the holes; but an improved form of the drill has, it is understood, now been brought out which is free from these defects. The selection of the machines was chiefly governed by their weight.

Method of Drilling the Headings.—The drilling apparatus in the bottom headings consisted of two machines, mounted upon the horizontal stretcher bar, which was screwed tight across the heading. This was fixed seven feet from the bottom, and about four feet from the face of the heading. The two machines were worked from a benching, three feet six inches above the bottom, by four men; one man was employed to put on the feed at each machine, and the other two to water the holes and change the drills. The remainder of the gang were occupied in filling the débris from the previous round, fixing the timber, and laying the road. The size of the drill commenced with $2\frac{1}{4}$ inches diameter, diminishing by three or four successive sizes to $1\frac{1}{4}$ inch diameter, the full depth of hole in the shale being 6 feet 6 inches. The depth of hole in the rock was less and varied considerably according to the joints &c. The directions of the holes are shown in figs. 14 and 15, from which it will be seen, that the position of the machine on the bar remained the same for all the holes, the direction of each hole varying with its position on the face. The number of holes varied from round to round; in shale, ten to fifteen holes were sufficient, whilst in rock the number was greater.

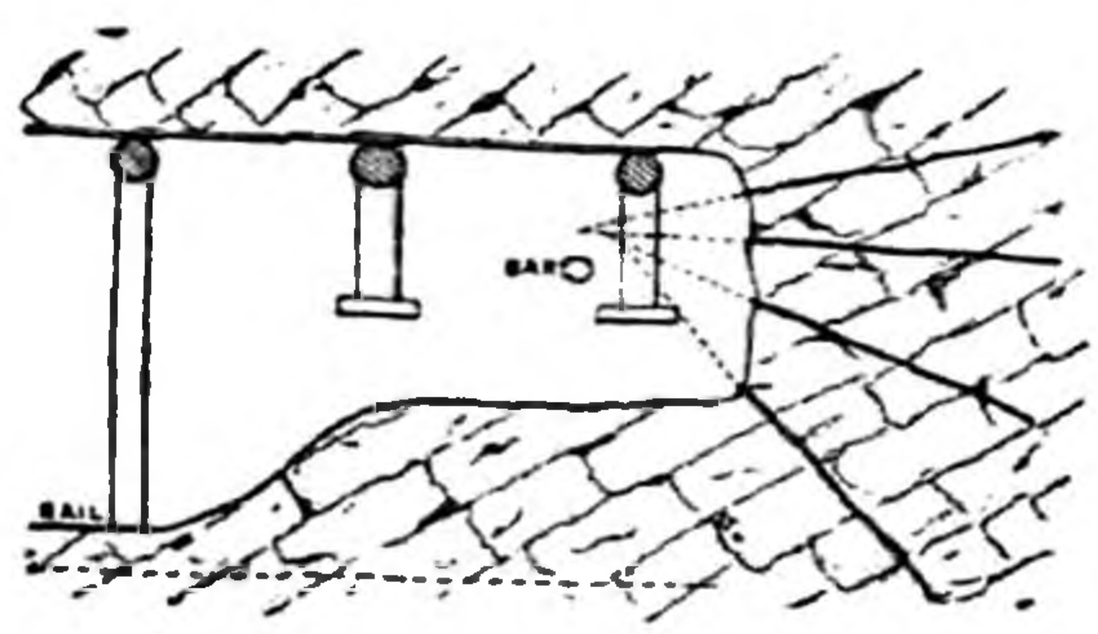
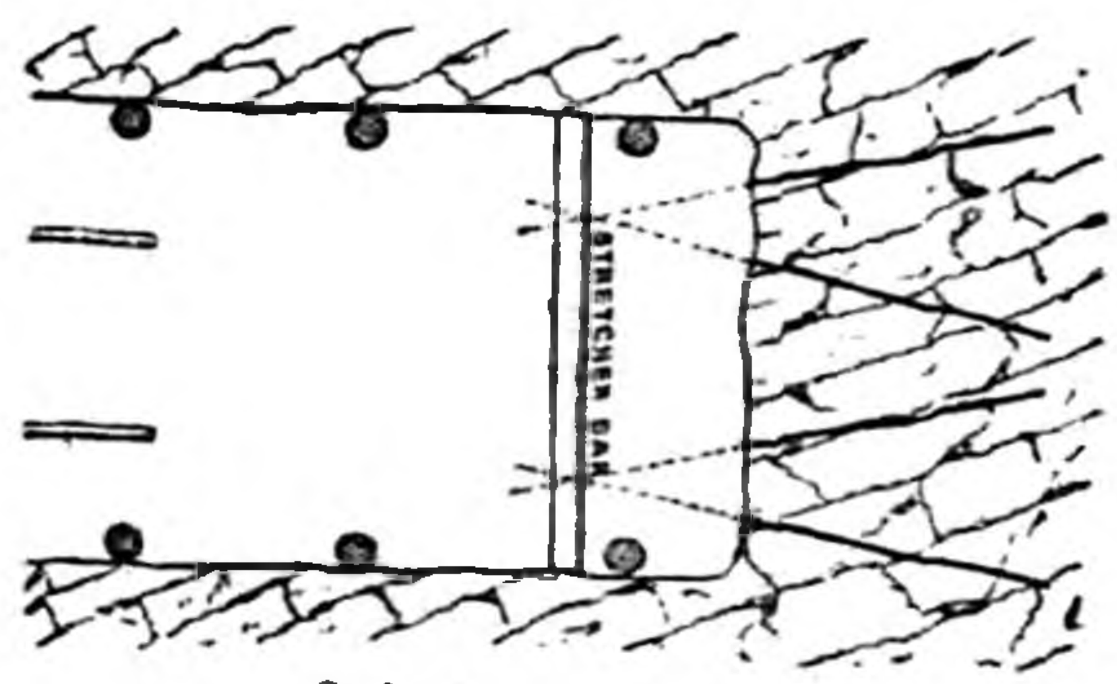


FIG. 14.



Scale 1 inch = 6 feet.

FIG. 15.

Explosives.—Gelignite was the only explosive used, and as the progress of the headings was of so much importance, no limit was set to the quantity that might be used by the miners. The consequence was that an excessive quantity was consumed, the holes being generally one-half or two-thirds filled. The holes were all charged together, but were fired in two or three series, primers, with detonators and fuse, being inserted separately for each series. The bottom series of holes was fired first, the inner holes of each series being given a start of the others. Sockets, when they occurred, were only found in the shale in the upper series of holes. To clear the heading of dust and smoke after firing, the air pipe was turned off some distance from the face, and the pipe on the heading side was filled with water; the air was then turned on again, and the water discharged into the heading in spray. A few repetitions of this process were sufficient to render the heading clear enough for the men to return to work.

Progress of the Headings.—Previous to February 1890, the heading at Padley had been driven by hand power only; and, at Totley, the completion of the headings between the shafts was so urgently needed to liberate the water and permit lining to proceed, that they were not always driven to the full size, and no record of them was kept. From the commencement, at Padley a 4-foot $8\frac{1}{2}$-inch gauge road, with 3-yard end-tip wagons, was employed to remove the débris from the face. At Totley, the size of the wagons was limited by the winding cages in the pit, and a double road, of 2-foot gauge, was laid down. Side-tip wagons were used, each holding $\frac{3}{4}$ cubic yard, and the trains of wagons were drawn by ponies. This arrangement was, however, found to be inadequate, as the number of break-ups to the west of No. 4 shaft increased. The double cages in the shaft were therefore replaced by a single cage in May, 1891, and a single road of 4-foot $8\frac{1}{2}$-inch gauge was substituted for the double road. Side-tip wagons, each of 4 yards capacity, were then employed, until the completion of the work. Owing to the much greater quantity of lining being done at Totley than at Padley, a break-up was always in progress close to the face of the heading, and no room could be spared for a turn-out for the wide gauge. The train of wagons for the shaft had, therefore, to be run into the headings, and filled, one from the other, until the set was full. This required a large increase in the number of men in the heading, and not infrequently caused slight delays. At Padley, the heading was always much in advance of the break-ups, and a turn-out was kept for the heading wagons near the face, which obviated so much labour in filling. The number of men employed at the face of each heading averaged eight or ten at the commencement, and increased to nearly twenty per shift, the increase in the number being chiefly due to the larger number required for filling at

Totley, and for the construction of the temporary drain at Padley. The day was divided into 3 shifts, of 8 hours each, and, until the beginning of 1891, one shift only was worked on Sundays. After that date, it was optional for the men to work the other two shifts.

In Tables I. and II. the rates of progress are reduced to a seven days' week, after deducting all time lost by the men; but minor delays, not amounting to a full shift, due to accidents, meal hours, changing shifts, &c., are not deducted.

TABLE I.—TOTLEY AND PADLEY TUNNEL.
ADVANCE OF THE HEADINGS BETWEEN FEBRUARY 1, 1890, AND OCTOBER 23, 1892.

—		Totley Heading.	Padley Heading.
Machines employed:		Two 3¼-inch Larmuth drills	Two 3¼-inch Larmuth drills
Cross-sectional area of heading	sq. yds.	12·2	12·2
Total period	weeks	141	141
,, time lost	weeks	29	45
,, ,, worked	weeks	112	96
,, progress made	lineal yards	2,300	1,897
Average weekly progress	,,	20·53	19·76
Maximum ,, ,,	,,	28	33
Average number of cubic yards excavated per week		250	241
Maximum number of cubic yards excavated per week		342	403

TABLE II.—TOTLEY AND PADLEY TUNNEL. AVERAGE WEEKLY ADVANCE.

—	Material.	Water.	Period of test.	Advance.
		By machine after February 1890		
			Weeks.	Yards.
Totley	Rock	Much	15	14·33
Padley	,,	Little	10½	19·13
,,	Rock and shale	Much	15½	16·8
,,	Shale	,,	32	18·56
,,	,,	None	14½	29·87
Totley	,,	,,	17½	22·61
		By hand before February 1890		
Padley	Shale	Much	34	16·6

With a view to obtain detailed information of the heading driving, the time occupied by each operation was taken during 137 successive rounds, the results of which are given in Table III. The time of excavating is reckoned from the time the heading cleared after firing, until the machines were re-started, although the filling of the débris was not completed until some time afterwards.

TABLE III.—HEADING DRIVING AT TOTLEY DURING 137 SUCCESSIVE ROUNDS, DECEMBER 10, 1891, TO MARCH 10, 1892.

Material, dry shale.

			Hours.	Min.
Drilling	Drilling	2 hours 47 minutes	3	48
	Changing holes	16 ,,		
	,, drills	45 ,,		
Firing	Charging holes	1 hour 38 ,,	2	23
	Firing	45 ,,		
Excavating			7	41
Lost			1	9
Average time for the whole round			15	1

Machines employed	Two $3\frac{1}{4}$-inch Larmuth drills
Average number of holes per round	13·4
,, length of hole	6·25 feet
,, number of drills per hole	3·8 ,,
,, pressure of air at drill	49 lb. per square inch
,, temperature of heading when drilling	66° Fahr.
,, quantity of explosive per round	38 lb.
,, number of sockets per round	1·8
,, length of ,, ,,	1 foot
,, width of heading	11 feet
,, height ,,	9·92 feet
,, area ,,	12·12 square yards
,, advance per round	5·74 feet
,, quantity excavated per round	23·18 cubic yards
,, advance per week	21·35 linear ,,
,, quantity excavated per week	258·76 cubic ,,

Ventilation.—Until the headings met, the ventilation beyond No. 4 shaft from Totley depended entirely upon air supplied by the compressors. In addition to the exhaust from the machines, 2-inch ventilating pipes discharged air from the main in each break-up. Each of the 18-inch Schram compressors discharged 450 cubic feet per minute, whilst the 4-foot compressor, which replaced one of the 18-inch compressors in January 1892, discharged 2,000 cubic feet per minute. The smallest allowance per man was between April 1891 and January 1892, during which time, allowing 15 feet per hour for each candle, and reckoning one horse as equivalent to 5 men, the allowance per man was under 300 cubic feet per hour. At Padley, the ventilation was generally good; this was due to the large quantity of water streaming from the roof, which dissolved the exhaled carbonic acid and other soluble gases.

The progress of the heading at Padley was, however, frequently stopped by the discharge of impure air into the workings during certain periods, concurrently with every fall of the barometer.

The first occasion on which foul air was met corresponded with the first occurrence of rock; and in piercing 350 yards of this, the heading was stopped from this cause on seven different occasions, the delays aggregating seven days. For the next 1,450 yards, which was wholly in shale, no stoppage occurred from foul air, but, after passing the larger fissure in the rock at 1,880 yards, the heading was stopped on sixteen different occasions, an aggregate of twenty-one days being lost from that cause. In every case, the foul air was discharged from the fissure, when the air at the face was good, and the heading was stopped, owing to the lights being extinguished there. The impure air discharged there was insoluble, and the explanation seemed to be, that it was air, which had been robbed of its oxygen by the iron pyrites. To assist in the permanent ventilation the cross-section was enlarged, thus giving a width of 27 feet.

It may here be mentioned that there would appear to be nothing better for lining purposes than brindle bricks. Blue bricks are not considered suitable. In one case, where a very smooth glazed brick had been used, an invert had been blown up by hydrostatic pressure; whereas the brindle, a less expensive brick, was rougher on its surface, and, therefore, held the cement more tightly. In the case of the glazed bricks referred to, the bricks came away, leaving the face of the cement perfectly smooth; but when the brindle brick was substituted, the strength of the invert was much increased, whilst, at the same time, the cost of the brickwork was much reduced.

Permanent Works.—Cross-sections of the Totley and Padley Tunnels are shown in figs. 16, 17, and 18, Plate XXII. For 1,940 yards from the Padley entrance, the side walls are of block-in-course masonry; the side walls for the remaining 4,289 yards were of brickwork in mortar, faced with brindled bricks. The arch is of brickwork throughout, faced with brindle bricks, set in Lias lime-mortar through the dry ground, and in Portland cement where there is water. The depth of the foundations below the rails is, in rock, 2 feet 9 inches, in hard shale 4 feet 3 inches, and in softer shale 5 feet 3 inches. The thickness of the masonry side walls, through rock, which was much jointed, is 1 foot 9 inches, through shale 2 feet, and in heavy ground 2 feet 3 inches. The brickwork side walls are of the same thickness as the arch, which is 1 foot 6 inches through rock, 1 foot 10½ inches through shale, and 2 feet 3 inches in heavy ground. There are 434 yards of inverted tunnel near the Totley entrance, and 356 yards at the Padley entrance, the invert being of brickwork 1 foot 6 inches in thickness. Old English bond is employed throughout. The rings of brickwork, in the side walls and arches, are bonded together in pairs, the odd ring in 1 foot 10½ in. work being in the centre. Small manholes, 7 feet by 3 feet 6 inches by 1 foot 6 inches, are built at every chain, at alternate sides of the tunnel; and large manholes, 10 feet each way, are constructed at every half-mile for the convenience of plate-layers.

A 2-foot 9-inch culvert of brickwork in cement is built under the 6-foot way, and extends 2,112 yards from the Totley entrance and 1,920 yards from the Padley entrance. An 18-inch glazed and socketed drain-pipe, bedded half-way in cement concrete, laid with open joints, and covered with rubble, is laid for the remaining distance. Manholes, 4 feet by 2 feet 9 inches, are built in the culvert, and drain opposite every fourth manhole in the lining throughout the tunnel. Weep holes are left in the culvert at every 6 feet on either side. 4-inch pipe drains, covered with broken stone, are laid across the formation, at intervals of 2 chains, to drain the foundations of the side walls. Weep holes were left in the side walls, two on each side in every length; and, in all wet lengths, 3-inch drain pipes lead the water from the arch to the weep holes. At each end of every wet length, a collar of brickwork, 9 inches wide by 4½ inches deep, projects from the arch, to prevent the water from running down the gradient of the tunnel, and finding its way through the mortar joints of dry lengths.

Shafts Nos. 1, 2, and 3, are 10 feet in internal diameter. They are lined in brickwork with mortar, not less than 9 inches in thickness, and faced with brindled bricks. No. 4 shaft (figs. 19 and 20, Plate XXII.), is 15 feet in internal diameter, and is lined with brickwork, in cement, on account of the water. The brickwork is not less than 18 inches in thickness, built solid to the ground, and is likewise faced with brindled bricks. To prevent the possibility of the shaft at No. 4 being crippled by the excessive weight of the shaft lining, the lining is broken off at 75 feet from the crown of the arch (fig. 19), and the upper part is set off to an 18-foot internal diameter, upon a bed of rock which lies at that level, and is coned over, at an inclination of 1 in 32, until the 15-foot diameter is reached. Two additional sets of footings project from the outside of the lining, at uniform heights between the foundations of the coning and the surface.

The tunnel fronts (figs. 21 and 22, Plate XXII.) are built of block-in-course masonry, with millstone grit arch-quoins, and tooled ashlar cornice and parapet.

A most important point in dealing with long tunnels is at once to put in thoroughly efficient drains. A very full-sized drain is, in fact, an economical thing; and further, it should be a drain, not inaccessible in a pipe, but covered with flags, so that it may easily be opened if there should be a stoppage.

In the Totley Tunnel, the brindled-brick lining was laid in alternate courses of 4½ inches and 9 inches, so as to bond the work properly together. The work was not built in single 4½-inch rings, but the 1-foot 10½-inch work was built in two 9-inch rings, with 4½ inches in the centre, bonded where they came together.

The Lining.—For the construction of the lining, the contractor was fortunate in having close at hand the Totley Moor brick works, where very good common bricks were obtained. The brickyard was about half a mile from No. 4 shaft, and at a slightly higher elevation. A light tramway was laid down, and the bricks, after being examined, passed, and counted, were sent down the shaft in tunnel wagons. The brindled bricks were forwarded from Staffordshire to Dore and Totley station. Until the headings met, all the bricks for the lining at Padley had to be carted or sent by traction engine from Totley; and, as men were scarce at Padley, owing to its isolation and the excessive quantity of water in the workings, the quantity of brickwork done there was much less than at Totley.

The total number of break-ups was 51; their position was determined by the ground, very wet places being avoided, in the expectation that by leaving them for a time the quantity of water would gradually diminish. This expectation was generally realised, but, on the other hand, in many cases ground, which was quite dry before a break-up was commenced, proved the reverse when broken into. Where the ground for a long distance was continuously dry, the break-ups were made at uniform distances of about 100 yards. The number of lengths was 1,128, the most common being 15 feet and 18 feet long, the former being worked in the softer more perishable shale, and the latter in the hard shale. In the soft shale the lengths were 10 feet, and in the running sand and detritus at the west entrance, 9 feet lengths were worked. The brickwork for break-up lengths, and in some cases the side lengths also, were in every case built a ring thicker.

During the construction of wet lengths, special precautions were taken to keep the water from the work until the joints had set. Felt was used at first, being fixed outside the timbering; but sheet iron was afterwards used with more success. This was rolled to the thickness of 28 B.W.G., and was fixed in the same way as the felt. Owing to its extreme thinness, it yielded readily to pressure, whilst the space behind the brickwork was being packed, and yet stood the firing of the shots without being injured.

Before commencing to break up in very wet places, it was found advantageous to drive the top heading through from the previous break-up. By this means the water was carried away through the heading, and the men were thereby spared the discomfort and inconvenience of breaking up amid streams of water from overhead. With the exception of those used in the top headings, no machine drills were employed in excavating for the lining. In the lengths, as in the bottom headings, gelignite was the only explosive employed, the total quantity consumed in the tunnel being 163 tons, or 52·3 lb. per lineal yard. As junctions were made between the break-ups, and the continuous lining from the entrance increased in length, locomotives were taken further into the tunnel and used for haulage, horses being used in the headings and break-ups beyond. Turn-outs in the break-ups, except in cases where they were unusually far apart, were not found practicable.

Winding Engines.—The winding engines employed at the No. 4 shaft were of the double-cylinder horizontal type, having cylinders 22 inches in diameter and with a 4-foot stroke, working at 70 lb. pressure per square inch. As gas was not available at No. 4 shaft, an electric lighting plant was laid down there, to illuminate the workshops and engine sheds. The pit-bank was also illuminated at night by 500 candle-power glow lamps. At the bottom of the shaft were two 50 candle-power lamps, and for 300 yards, the shunting operations were illuminated by 16 candle-power lamps, spaced 50 feet apart on alternate sides of the tunnel.

As the opening of the whole line from Dore to Chinley depended upon the time occupied in the construction of the Totley Tunnel, it was of the utmost importance that it should be completed within the shortest possible space of time. In this connection, it may be mentioned that during the year preceding the junction of the headings, the material being dry shale, 1,000 lineal yards of heading were driven, and over 1,500 yards of lining were built at that end alone.

The last length of lining was keyed on August 4, 1893, and the tunnel was completed and the permanent way laid by September 2, 1893.

One remarkable circumstance was the accuracy with which this tunnel, 6,300 yards in length, was set out, and the fact, that when the two headings met, they were not above $4\frac{1}{2}$ inches out of the centre line. The time during which the tunnel was under construction was about five years, which showed a rate of advance of about $3\frac{1}{2}$ lineal yards per day.

The experience gained in the construction of this tunnel appears to suggest that more use should be made of concrete in the lining of tunnels, especially when the water has been removed, or where the outflow of water is but moderate. Concrete was exclusively used in two tunnels on the North British lines from Forth Bridge to Perth. One of these was lined entirely with concrete, and, in the case of a tunnel through rock, concrete has been shown to be far better than either brickwork or masonry, if good material be available, for the reason that, if properly put together, every inequality is filled up by the former. One of the tunnels on the Glen Farg line has also been built of concrete, including the arch, and the results have been most satisfactory. The concrete in this case was made of broken whinstone and some sand, in the proportion of six parts of stone and sand to one part of concrete. Some holes were made in it for the Government Inspector, who pronounced the work to be infinitely better than brickwork; and all who have had experience of tunnels are aware of the trouble that generally arises with tunnel bricklayers and their labourers. In the concrete tunnel, a good foreman was able, with ordinary labour, to put in the lining.

Reference may here be made to a new and peculiar form of locomotive which was used in the construction of the Duckmanton and Bolsover tunnels. This locomotive was so designed, that it could work through a 9-foot heading. Tip wagons of the ordinary size were used. The trucks could, therefore, be hauled out in a much shorter time and with much greater convenience, than by any arrangement with horses or hand labour. The locomotive drew the wagons right away from the heading to the tip. It was practically the same as the ordinary contractor's locomotive, except in the peculiar design of the footplate, which was so low that the driver's head was only about 8 feet above the level of the rails, and the funnel, by a telescopic arrangement, shut up when the locomotive entered the heading. The plan adopted for working these tunnels was to excavate the cutting at the face to within about 20 feet of the formation, and then to form an inclined line, with a gradient of 1 in 16, down to the mouth of the tunnel. This greatly expedited the construction, the headings being driven at the rate of about 10 yards per week from each face.

In connection with the use of compressed air for driving the pumps, it may be stated that, when previously used, it had been found to be an expensive method, both at the Blackwall and Hudson Tunnels. At the former, there had been a considerable amount of water, which, working down grade, had all run to the face. The air did not seem to be cooled as much as it should have been by the water jacket, and, owing to the heating of the air during compression, about 25 per cent. of the work done was lost. To the contractor this is a serious matter. To obviate this, it was arranged to put water jets into the cylinders, so that the air might be cooled whilst it was being compressed.

An invention has been in existence for many years, which has for its object the transmission of power to long distances, not by compressed air, but by exhaustion, the engines being worked, at the ends of the main, at about half an atmosphere of pressure. In the exhaust pump, precisely the same thing occurs with regard to generation of heat, as in the compressor pump; that is to say, the air, in passing through the mains, becomes heated practically to the temperature of the earth; it then comes into the pump, is exhausted, then the piston returns and compresses the air to atmospheric pressure to open the head valve and escape, and in this way heat is generated, just in the same way as in the compressor pump.

Cost.—The actual cost of the tunnel cannot at present be definitely stated, but approximately the Totley Tunnel has cost something like 75*l.* or 76*l.* per yard; the Cowburn tunnel, of which a description follows, 2*l.* or 3*l.* per yard less; and the Dore Tunnel—excluding the fronts, which in a short tunnel amounted to a considerable portion of the total cost—about 53*l.* or 54*l.* per yard.

With regard to the time occupied, the average progress was about 3 or 4 yards per day. In the earlier stages of the work, owing to considerable difficulties with the water and the men, the progress was not so rapid, but latterly the rate increased considerably. From July 1889 to July 1890, the rate of progress was only 16½ yards per week; but from July 1892 to July 1893, it rose to 48 yards per week.

The geological formation from the Totley end to near No. 4 shaft was the lower coal measures, and at the Padley end it was millstone grit and shale. Very few bars were built in, except at the junction lengths, and as there was no great weight upon the timber in any part, nearly the whole of the bars were subsequently removed. The levelling was done in the usual way with an ordinary spirit level.

COWBURN TUNNEL.

Situated at the head of the Edale valley, out of which it springs almost perpendicularly, the arm of the Peak known as the 'Cowburn' rises to an elevation of 1,700 feet above the sea. The tunnel (fig. 23, Plate XXI.) cuts the axis of the hill at right angles, and lies in a west-south-westerly direction at its base. It is 3,702 yards long, and is straight from end to end. The gradient rises from the Edale entrance, at an inclination of 1 in 1,000 for the first 913 yards, to the summit of the Dore and Chinley Railway, and then falls to the Chinley entrance, at the rate of 1 in 150, the difference in level between the two ends being 53 feet.

Alignment.—The centre line was first approximately laid out with a 6-inch theodolite. A portable transit instrument, with 20-inch telescope by Stanley, mounted on three legs, similar to the smaller instrument, was then employed. Two points, three-quarters of a mile beyond the Chinley entrance in the approximate line, were then taken as fixed, and from these the line over the tunnel was set by the larger instrument on pegs, driven into the ground at every change of surface, and on two pegs in the Edale valley, situated 70 chains apart beyond the eastern entrance. This operation was repeated many times, until the centre line was exactly established. Hollow observatories of masonry, 6 feet by 4 feet, capped with ashlar, and from 6 to 8 feet in height, were built over the pegs, and the two pegs beyond each end of the tunnel were surrounded with masonry to prevent their being disturbed. The centre line was then transferred from the pegs to the stone caps. From the centre line thus obtained, the shafts were set out, and the line was produced into the headings from both ends by means of the 6-inch instrument only. When the headings met on July 18, 1891, at 2,305 yards from the east entrance, the difference in line between the two headings was found to be less than one inch.

Shafts.—Owing to the ground rising steeply over the tunnel at each end, there is only one permanent shaft, situated at 335 yards from the Edale entrance, and 10 feet in internal diameter. A temporary shaft was also sunk at the east entrance. In sinking the temporary shaft, successive beds of shale and rock were passed through, which brought in large quantities of water, the quantities discharged by the pumps reaching over 20,000 gallons per hour. The permanent shaft was commenced on October 3, 1888, and was sunk through shale and several bands of rock, the quantity of water yielded amounting to 24,000 gallons per hour.

Headings.—The size of the tunnel heading was 10 feet by 9 feet clear of timber, and was driven at formation level. For 120 yards beyond the permanent shaft, there was a considerable quantity of water, but for the remaining distance to the junction the heading was dry. The material for the first 1,170 yards was shale, the remaining length consisting of rock intermixed with thin beds of shale, which was found very difficult to pierce. A commencement was made with the heading at Chinley on November 26, 1888, the material pierced being rock, accompanied by a little water for the first 1,300 yards, the remaining distance to the junction being dry. The strata throughout the tunnel dip, towards the west, at about 1 in 16 At Chinley, only 234 yards were driven by hand, after which compressed-air machinery was brought into use. The plant consisted of one 12-inch Larmuth compressor, and one 12-inch Fawcett-Preston compressor, working two 3½-inch Larmuth drills mounted on a drill carriage, the pipes being of cast iron, 6 inches in diameter for the first portion, and afterwards of wrought iron 3 inches in diameter. The drill carriage was soon discarded for the simple stretcher bar, as the necessity for removing

CHAPTER XXXVIII.

THE ALIGNMENT OF TUNNELS.

THE setting out or alignment of tunnels may be classed under three heads: first, ranging or alignment above ground; secondly, the alignment below ground, either in a heading or in the full section of the tunnel; and thirdly, what may be termed the vertical alignment, or the transference of the surface line to the subterranean one. Should the tunnel be constructed without shafts, as in the case of the longest two existing at Mont Cenis and Mont Saint-Gothard, the vertical alignment is not required, as presumably the tunnel would be ranged from points observed directly from each extremity. In other words, the line of direction being given by the fixation of a couple of terminal points at any visible distance from the ends of the tunnel, the alignment may be obtained either by setting up the instrument, whether a plane transit or a theodolite, over the nearest point sighting backwards, reversing, and ranging forward, or by absolutely ranging the line backwards from the fixed points. It is extremely rare that the contours of the ground beneath which the tunnel is situated are sufficiently favourable to allow of one extremity being visible from the other; that is, to permit of the total length being ranged forward in either one direction or the other. The more general case is that in which, whilst the ends of the tunnels themselves are not sightable the one from the other, yet a summit level obtains from which, as a common point—even if, as frequently occurs, the ends are not visible—points in the direction of the line of trace can be accurately determined, marked, and rendered available for the alignment of the face headings or driftways. The distance at which these points are located from the mouths of the tunnels will depend upon the physical features of the surface, but it is really a matter of little moment how far off they may be situated, so long as they are fairly within the range of the instrument employed. With this proviso, the farther off they are the better, as they admit of a more accurate and delicate adjustment by the cross wires of the telescope. In the Bletchingley Tunnel these terminal points were situated at a distance of two miles from the extremities of the tunnel, and consisted of small, solidly-built brick piers, painted black, with a white line in distinct relief upon them.

In setting out the Totley Tunnel (of the construction of which a full account has been given in Chapter XXVIII.), terminal points were also used. They were aligned by forward and backward sighting from a summit level, where an observatory had been built from which a view was obtained of a very extensive tract of the whole country. These two points were about 9,000 feet and 7,000 feet, measured horizontally, from the respective extremities of the tunnel. The distance of the same points from the summit observatory was over three miles, but by employing as a mark a board painted black, with a 3-inch white line on it, fitted with a plummet and fixed by guy ropes, and placing behind the board, at a few feet from it, so as to avoid shadow, a white calico screen, the mark could be distinctly distinguished so long as the sun was in front of the screen. These satisfactory results appeared to agree with those generally obtained in a similar manner. It is now well established, both by past and present experience, that for long distances white against black shows up best, and *vice versâ* for short distances. In the setting out of both the Totley and Cowburn Tunnels, the latter being on the same line of railway as the former, a black board, 2 feet by 1 foot 6 inches, faced with white cardboard, on which was drawn a broad arrow with varying widths of shaft, was levelled with a spirit level and supported from the back with light iron stays, and used for short distances.

At each of these two terminal points described, as well as at six other stations, placed where marked changes in the contours of the ground occurred, observatories were built for the location of the transit instrument used in aligning the tunnel. They were hollow, of brickwork in

FIG. 1.—LONGITUDINAL SECTION OF TOTLEY TUNNEL. TOTAL LENGTH, 6,229 YARDS.

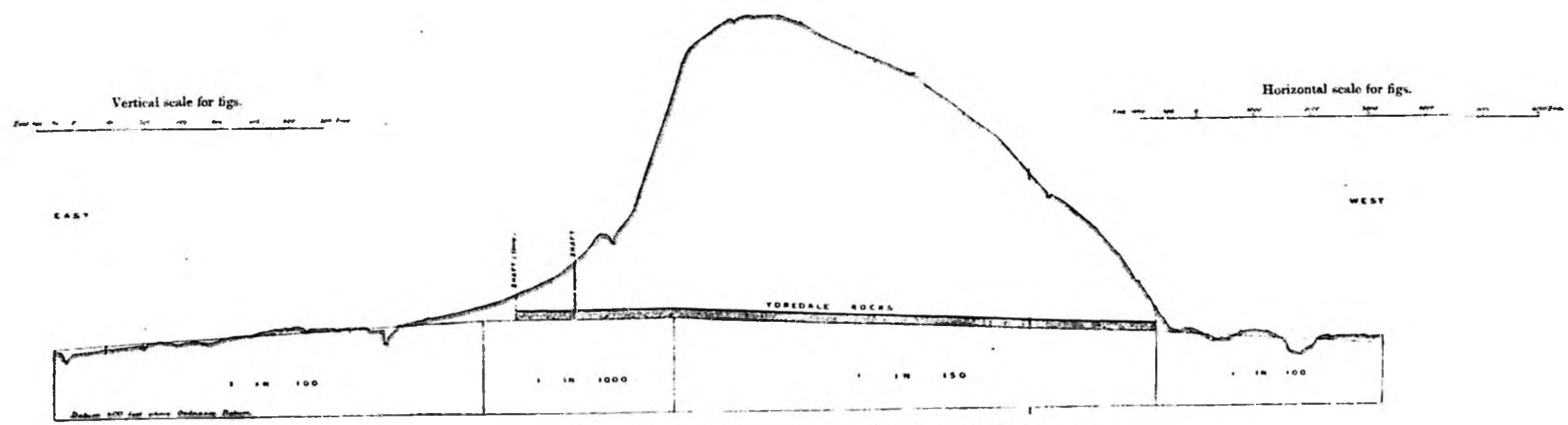


FIG. 23.—LONGITUDINAL SECTION OF COWBURN TUNNEL. TOTAL LENGTH, 3,702 YARDS.

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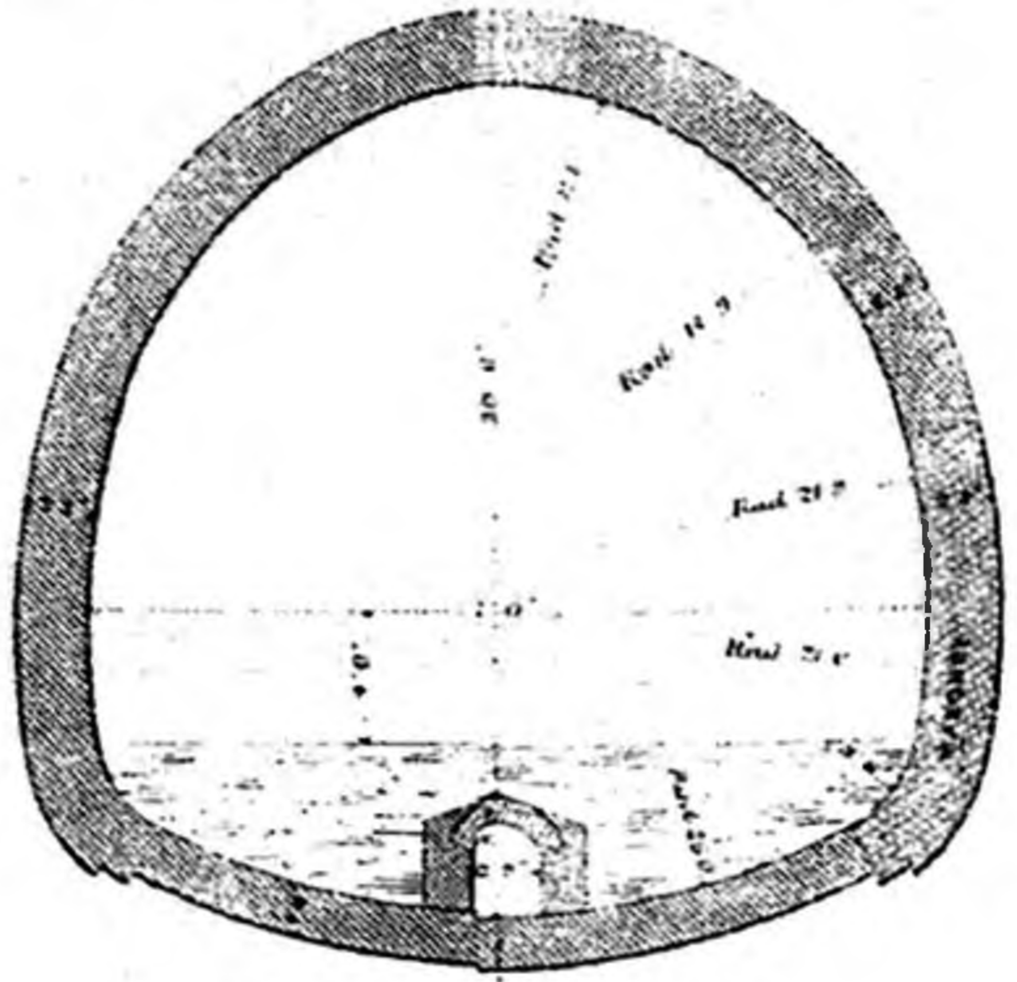
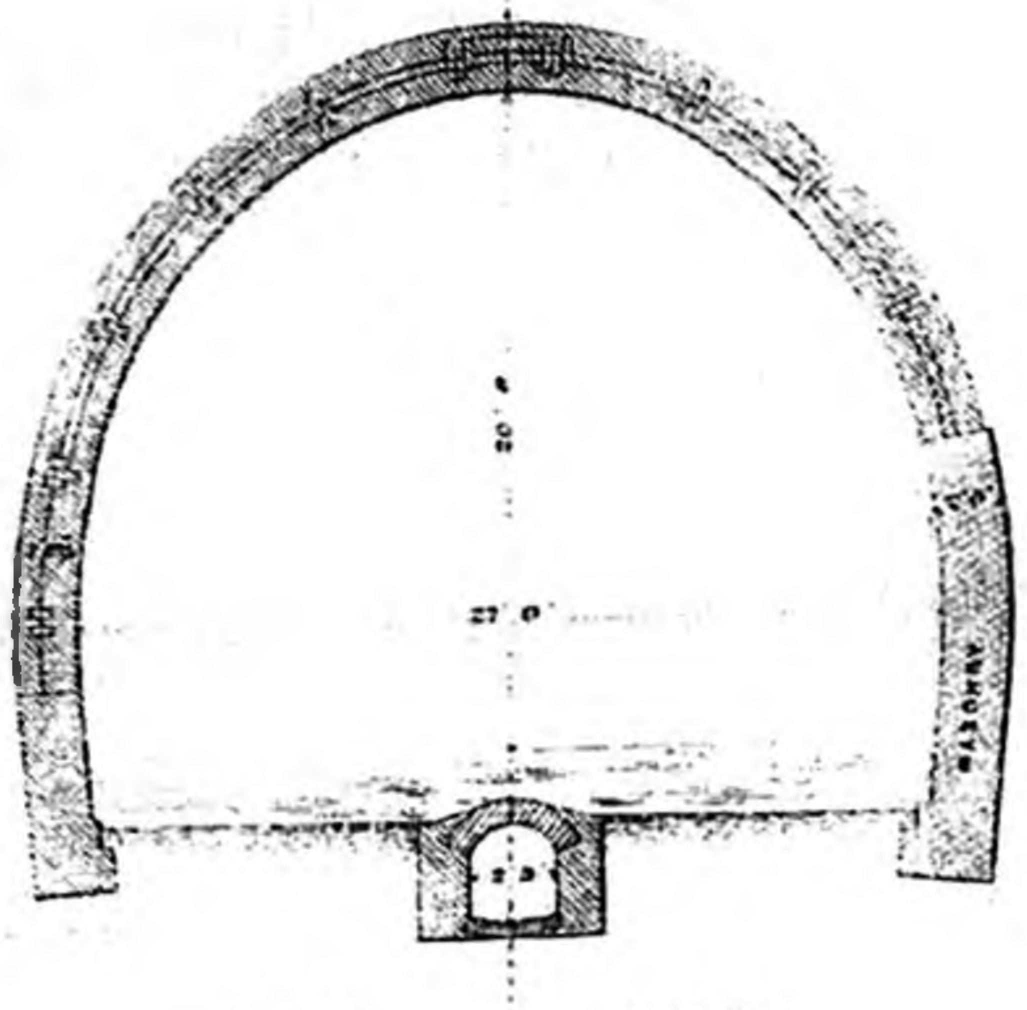
Tunnelling in Hard Rock—Tunnels on Dore and Chinley Railway

Plate



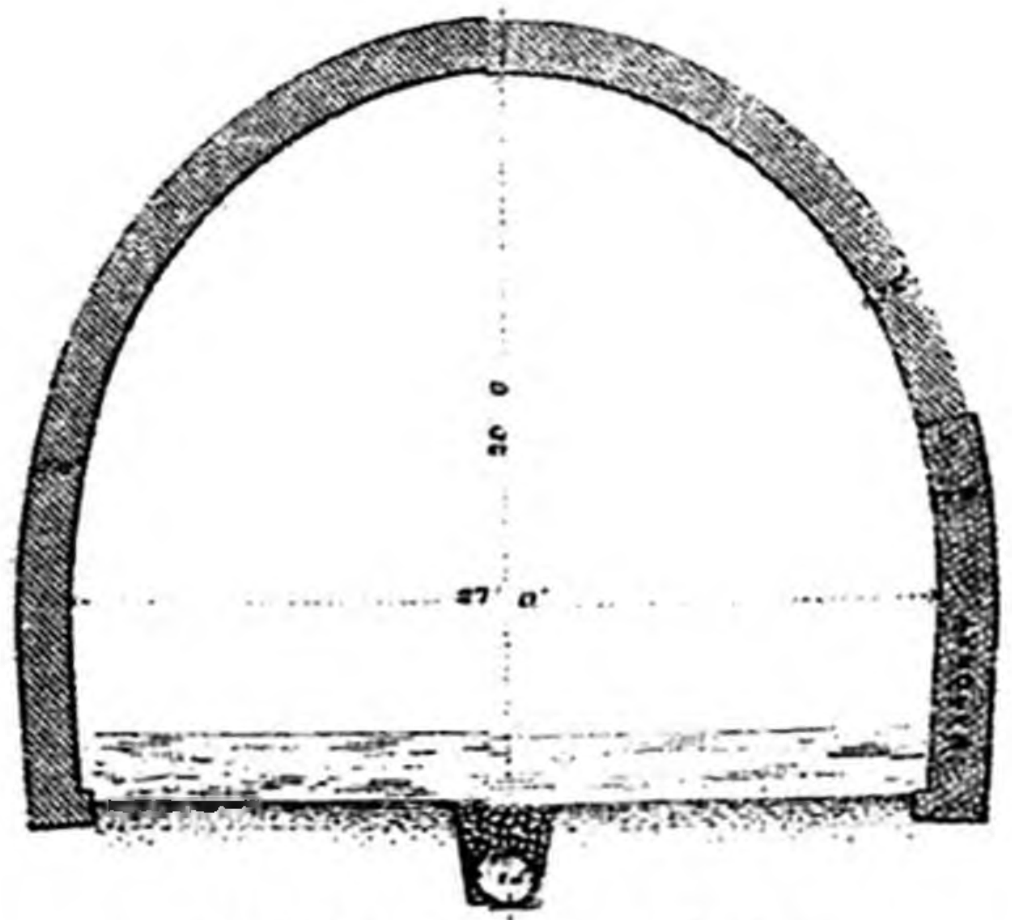
At Totley. At Padley.

Fig. 16.—Tunnel, ? ft. 3 in., with Invert.



At Totley. At Padley.

Fig. 17.—Tunnel, 1 ft. 10½ in., in Shale.



At Totley. At Padley.

Fig. 18.—Tunnel, 1 ft. 6 in., in Rock.

Scale, 1 inch = 10 feet.

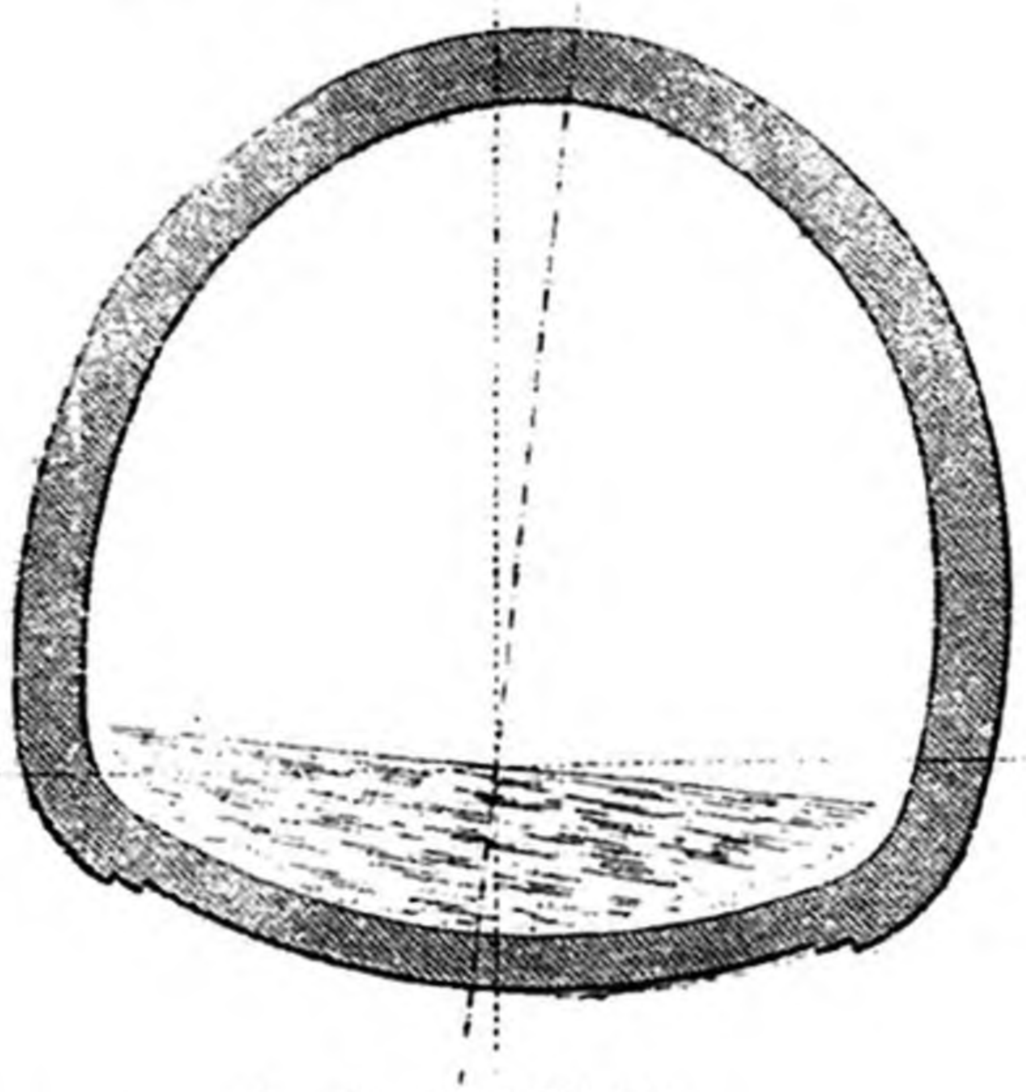


Fig. 26.—Dore Tunnel.

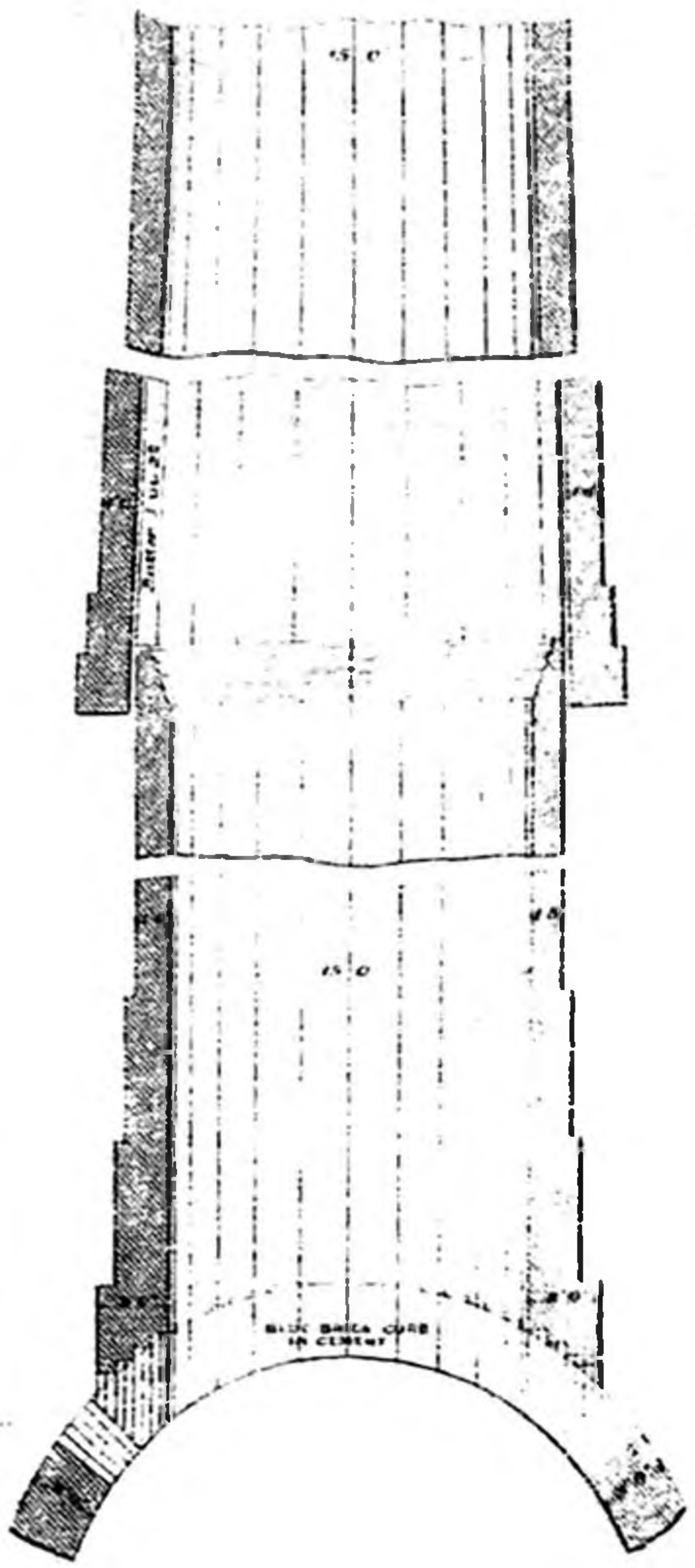


Fig. 19.

Details of No 4 Shaft

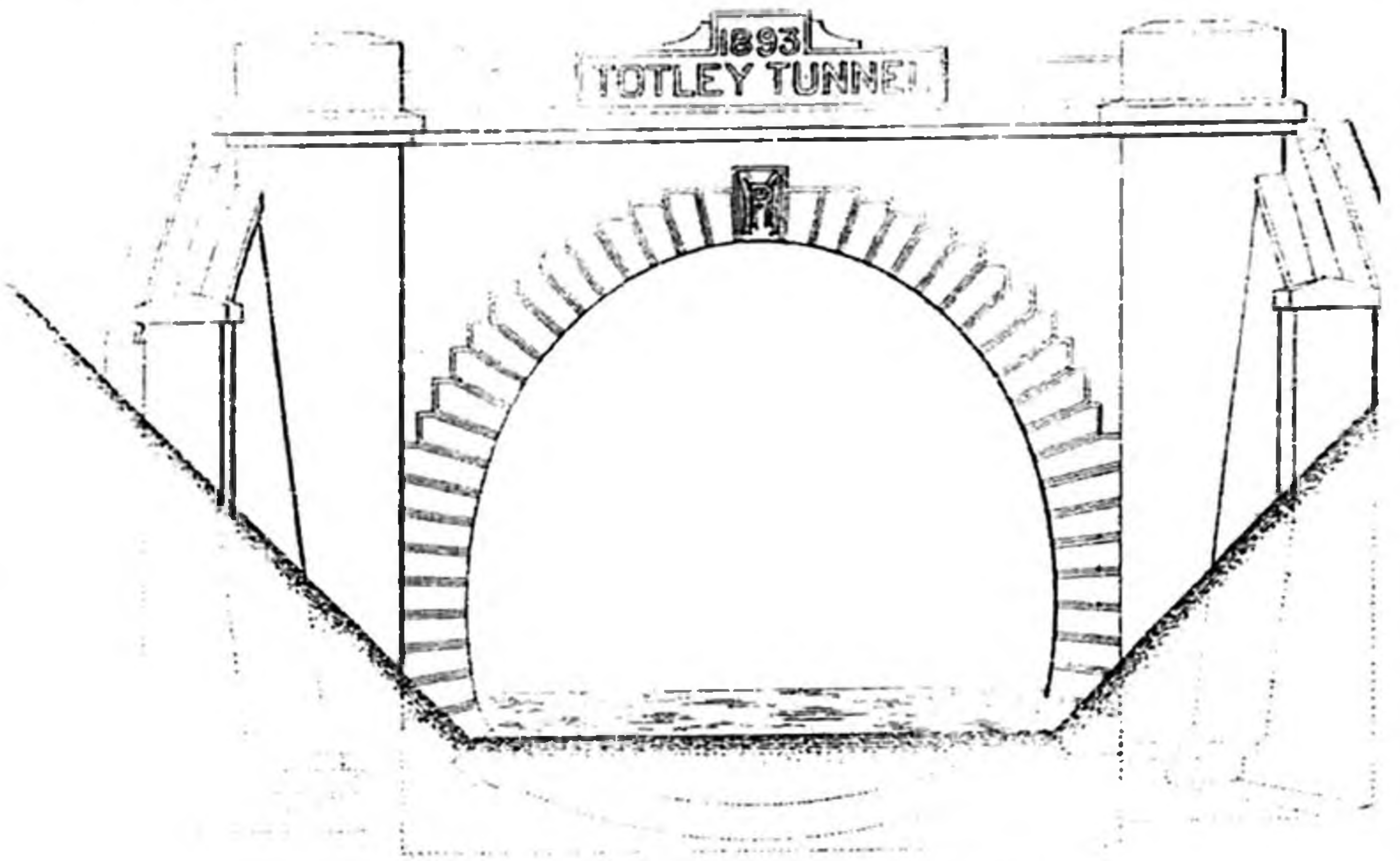


Fig. 21. Elevation of Tunnel Front.

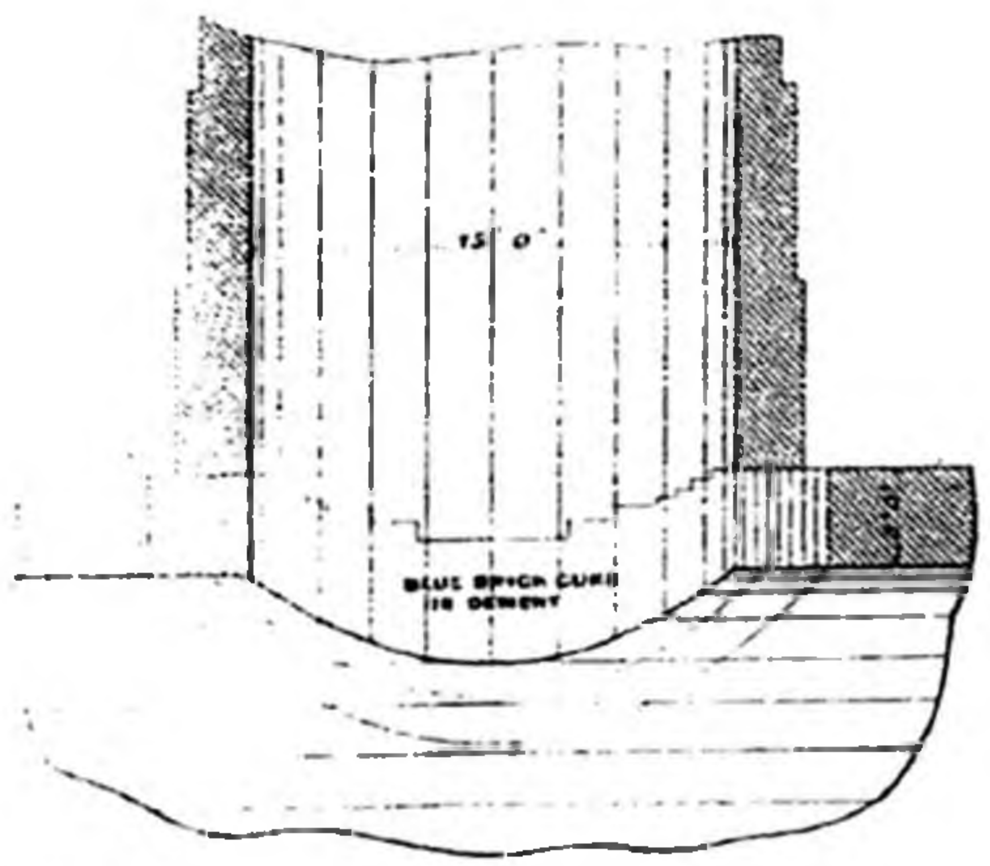


Fig. 20.

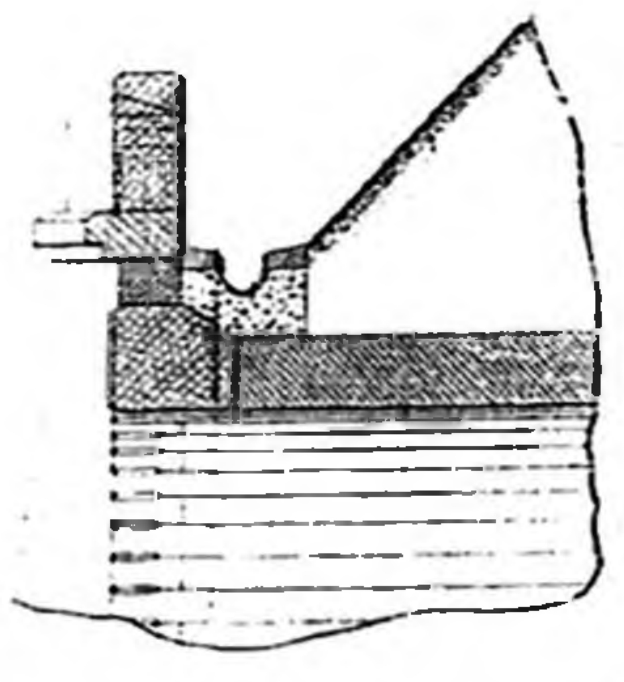


Fig. 22. Longitudinal Section through I

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