

23 January, 1894.

ALFRED GILES, President,
in the Chair.

(*Paper No. 2744.*)

“Tunnels on the Dore and Chinley Railway.”

By the late PERCY RICKARD, M. Inst. C.E.

THE proposal to connect Sheffield and Manchester by railway through the valleys of the Sheaf and Derwent, by a shorter route than that round by Ambergate, is of early date. Soon after the construction of the Liverpool and Manchester railway in 1830, a line was projected, as far as can be ascertained, upon nearly the same route as that followed by the present Dore and Chinley railway, which saves 32 miles compared with the Ambergate route. Again, in 1866, the London and North Western Company projected a branch from their Buxton line to Sheffield, which was to follow practically the route of the present Dore and Chinley line between Hope and Sheffield. In 1872, the Midland Company promoted a line from Dore to Hassop, which was, however, withdrawn upon a general arrangement between various railway companies.

Being cognisant of these facts, Mr. Edward Parry, M. Inst. C.E., proposed the Dore and Chinley route as by far the best line that could be laid down, both for connecting by the Midland Railway the important district of Sheffield with Manchester and Liverpool, and as an alternative route between the latter cities and the Metropolis—at the same time opening out a new district for local traffic. Leaving the main line at Dore, $4\frac{1}{2}$ miles south of Sheffield, the new line turns to the west, and, after $1\frac{1}{4}$ mile of open cutting, passes by the Totley tunnel into the Derwent Valley at Padley Wood. There it turns north-west, following the course of the Derwent past Hathersage as far as Bamford. It then follows the valley of the Noe, by Hope and up Edale, to Cowburn. After

passing Cowburn tunnel, the line joins the Manchester main line, $1\frac{1}{2}$ mile further on, between Chapel-en-le-Frith and Chinley stations. There are north and south junctions at each end of the line, the total length of railway being 21 miles of double line. The ruling gradient is 1 in 100, and the minimum curves, except at the junctions, are 40 chains in radius. The saving in distance is not the only advantage gained by the new route. The junction of the line at Dore, at an elevation of 392 feet, is on the north, or Sheffield, side of the summit of the main line, 474 feet above sea-level; whilst the junction at Chinley, at an elevation of 729 feet, is on the north side of the summit of the Manchester line, 982 feet above sea-level; and as Ambergate stands at an elevation of only 247 feet, there are two heavy inclines to be encountered in either direction by the old route. The gradients of the Dore and Chinley line rise from Dore to 548 feet at the summit level of the Totley tunnel; they then fall to 493 feet at Bamford, whence the line rises to an elevation of 863 feet at the east end of Cowburn tunnel, and falls thence to the junction at Chinley. By comparing these figures it will be found that there is a saving each way of nearly 300 feet in rise over the route *viâ* Ambergate.

The Dore and Chinley line was 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 forthwith commenced. 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 and Story, MM. Inst. C.E., of Nottingham and Derby. The works are 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 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 (Padley), Hathersage, Bamford, Hope (for Castleton), and Edale.

The Author proposes to describe the Totley tunnel and the

Cowburn tunnel in so far as it varies in construction from the former. Although of small dimensions compared with the St. Gothard and Mont Cenis tunnels, the Topley tunnel is second only in length to the Severn tunnel in this country; and the Author hopes that his Paper, if it does not present many original features in construction, may be acceptable to Members of the Institution as a record of English practice.

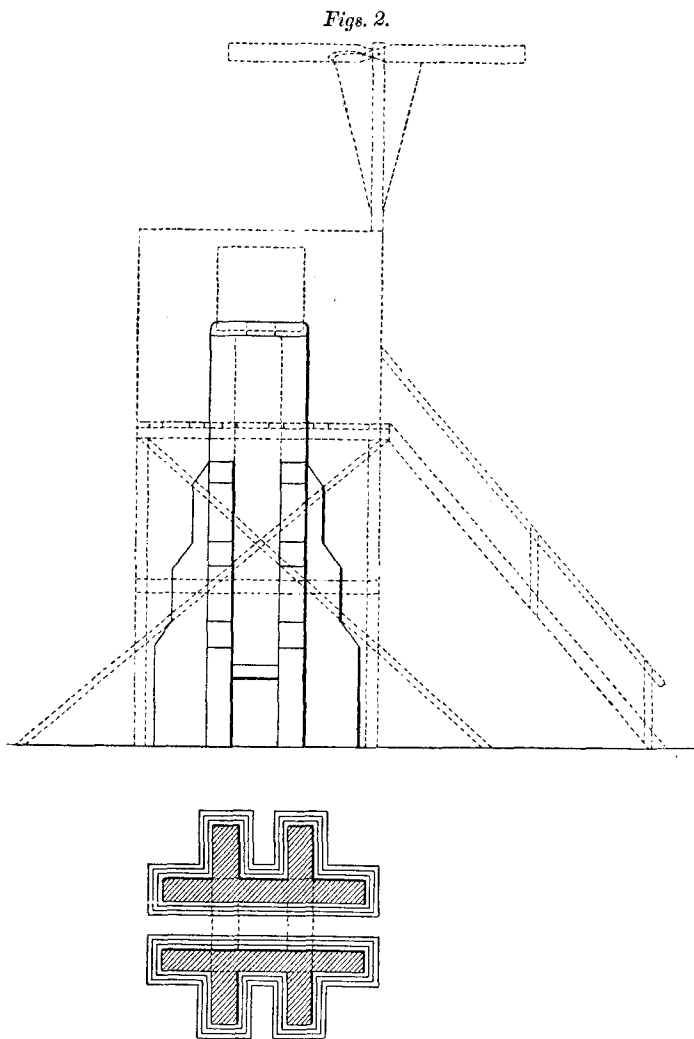
THE TOTLEY TUNNEL

Passing 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 rails, the Topley tunnel, which connects the valleys of the Sheaf and 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 $\frac{1}{4}$ mile into the tunnel, the subsequent gradients are 1 in 176, followed by 1 in 150¹ to the summit level, 10 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 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 4, 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.

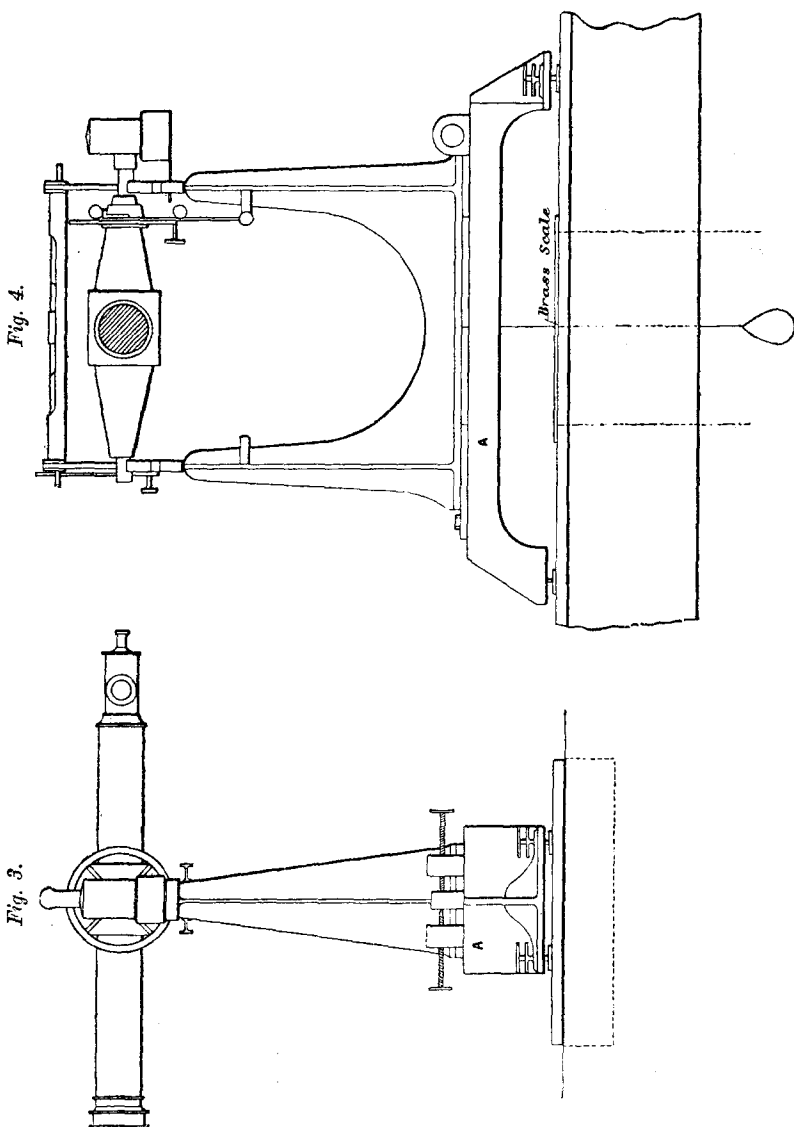
¹ An alteration owing to circumstances which arose during construction.

The observatories, *Figs. 2*, were built hollow of brickwork in cement and capped with stone. A large flat cast-iron plate, leaving 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, $1\frac{1}{2}$ inch 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 thus be let down through 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, *Figs. 3 and 4*. In order to

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

In setting-out the line, two points in that set by the small

Fig. 5.



Fig. 6.

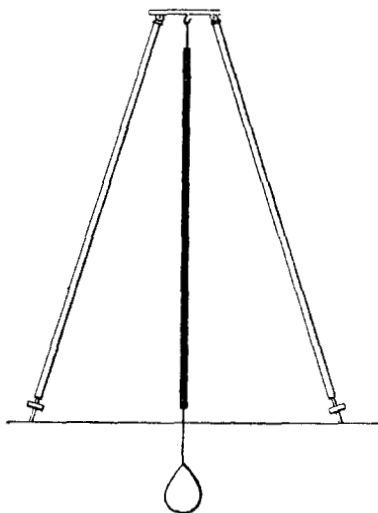
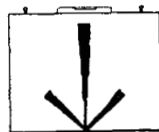


Fig. 7.



instrument were taken as fixed, viz., the summit and No. 1 west, Fig. 1, Plate 4, 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 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 on 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 out from No. 3 west, and checked from No. 2 west, and the external line was complete.

The objects found most easily distinguishable for sighting 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, *Fig. 5*. A large white calico screen was fixed behind the board, and a few feet away so as to avoid shadow, which was inclined towards the sun. This arrangement was used at the terminal stations, which were each more than 3 miles from the summit, but could only be clearly distinguished at that distance so long as the sun was in front of the screen. (2) An iron tripod, 6 feet high, *Fig. 6*, 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, *Fig. 7*, 2 feet by 1 foot 6 inches, faced with white card-board, 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.

For transferring the centre-line down the shafts, the apparatus shown in *Figs. 8* and *9* 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 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 sighted. The only times 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 could always be obtained 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

Fig. 8.

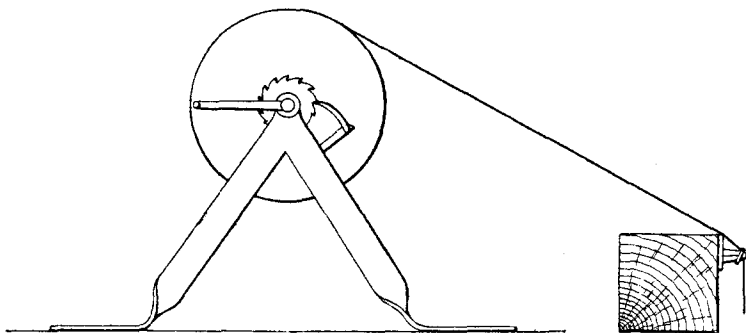
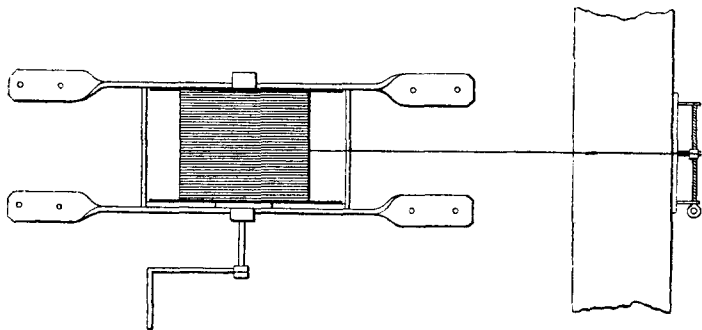


Fig. 9.



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. 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 $\frac{3}{4}$ mile; but, as the headings advanced, not more than 10 or 15 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, *Fig. 10*, fitted into a circular wrought-iron frame which was suspended by a wire; and (2) For short distances, for use with the smaller instrument, a carriage-candle, fixed in a weighted frame and suspended in the same way, *Fig. 11*. For signalling long distances with the large instrument, an electrical signalling-apparatus was employed, *Figs. 12 and 13*. 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 $\frac{3}{4}$ mile of single gutta-percha covered cable wound on a drum, mounted on a portable frame. The cable was thus readily payed out from the trolley on which the instruments were conveyed, every time it was used, and the return was made to earth through a galvanized-iron plate temporarily sunk into the ground. With this apparatus, messages could be sent in either direction, and to prevent misunderstandings 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 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 green hand-lamp was used. When the headings met, the difference between the centre-lines of the two headings was found to be $4\frac{1}{2}$ inches, and the difference between the levels was $2\frac{1}{4}$ inches.

Fig. 10.

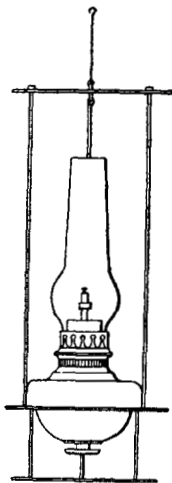


Fig. 11.



Sinking the Shafts.—Although powers were obtained by the Act to sink a ventilating-shaft at the summit-level of the tunnel, it was not considered advisable, for several reasons, to commence it at first. Four permanent shafts were sunk at the commencement, all of which are within $\frac{3}{4}$ 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 were sunk, when they were no longer necessary for haulage purposes. Three temporary shafts, A, B and C, were sunk in addition, A being at the east entrance, and B and C between that point and

Fig. 12.

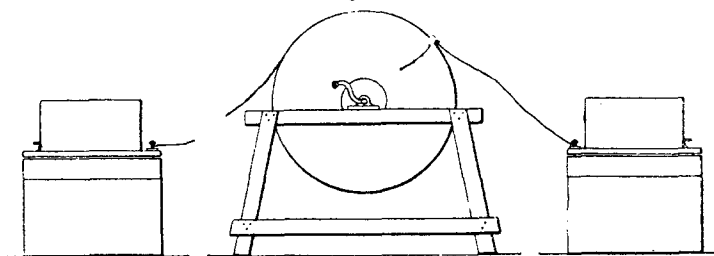
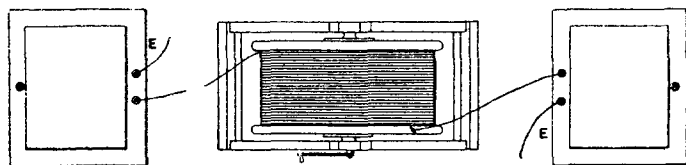


Fig. 13.



No. 1 shaft. Shaft A, commenced on the 24th September, 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 the 28th November, 1888, and the 3rd of January, 1889, respectively; they were sunk entirely in dry shale, which had been drained by A shaft.

The permanent shaft No. 1 was commenced on the 11th September, 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 the 30th October, 1888. Shaft No. 2 was commenced on the 17th September, 1888, in dry

shale. At 20 feet, thin beds of coal and fire-clay were cut through, then shale again as far as 80 feet, when more beds of coal, ganister, fire-clay 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 the 1st December, 1888. Shaft No. 3 was commenced on the 24th September, 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 the 27th March, 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 the 20th September, 1888, the first 50 feet traversing dry shale. Then a bed of coal and rock was reached, with large quantities of water. This was succeeded, at 80 feet, by beds of shale and rock, the rock in each case yielding more water. On the 30th January, 1889, a depth of 180 feet had been sunk, the quantity of water discharged then being 15,000 gallons per hour. It was decided to increase the size of this shaft from 10 feet to 15 feet internal 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 the 4th February, 1889. By the 9th April, 1889, the widening had been carried down to where sinking had been suspended. 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. These largely increased the quantity of water to be raised by the pumps. Shale was then passed through until the full depth of 280 feet had been sunk, on the 19th June, 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 was driven at the formation-level, or thereabouts. A commencement was made at Padley on the 27th September, 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, just 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 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 heading for four days—the pump at shaft A, discharging 26,000 gallons per hour, being unable to deal with it. The water then diminished, and work was resumed, the total discharge afterwards diminishing to 12,000 gallons per hour. After passing the fault, beds of coal, fire-clay and rock, were passed through. From shaft C only a very 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, fire-clay 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 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 the 26th May, 1889, No. 3 shaft was reached, and the water in it was liberated. Shale, coal, fire-clay and rock were successively passed, the rock bringing in more water. On the 21st September, 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 becoming drowned.

From the 15th February to the 4th September, 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 foundations 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 the 12-inch pipes proved insufficient to deal with it, and by the 3rd of July 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 was pushed forward. The pressure rose until, in ten days, it had attained 127 lbs. per square inch. Meanwhile the leakage through the fissures in the rock were more than a 4-inch pipe, which had been laid down the heading, would take, and a second wall, 18 inches in thickness, was built 70 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 lbs. 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 the 16th November, 1891, to 1,880 yards, when an inrush of water took place at the face which dwarfed anything

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, 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 by 2 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 throughout 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 the 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 was constructed up to the face of the head-way. The heading was also raised in the lower place to prevent it from being again flooded, and driving was resumed on the 26th February, 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 caused by the unexpected quantity of water tapped at Padley, owing to the insufficiency of means to carry it off, the Author would here remark 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.

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 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.

The plant employed consisted at Padley 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-HP. 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-compressors 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 small 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 $1\frac{1}{4}$ mile, when the machines were working, being sometimes as much as 15 lbs. or 20 lbs. 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 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 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 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 in Figs. 14, 15 and 16, Plate 4. 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 over-shooting, 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 the 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 have flanges cast upon them 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 fixed in any position. They 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-screw 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.¹ The selection of the machines was chiefly governed by their weight.

Method of Driving 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 7 feet from the bottom and about 4 feet from the face of the heading. The two machines were worked from a benching, 3 feet 6 inches above the bottom, by four men, one man being employed to put on the feed at each machine, and the other two watering the holes and changing the drills, the remainder of the gang being occupied in filling the debris from the previous round, fixing timber, and laying the road. The size of the drill commenced with $2\frac{1}{4}$ inches diameter, diminishing by three or four suc-

cessive 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 direction of the holes is shown in *Figs. 17 and 18*, 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

Fig. 17.

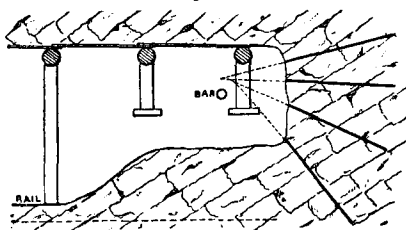
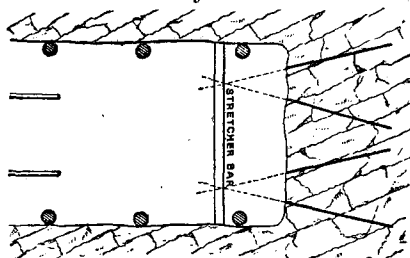


Fig. 18.



Scale 1 inch = 6 feet.

¹ Since the machines were supplied to Totley tunnel an improved form of drill has been brought out, from which these defects are absent.

varied from round to round; in shale ten to fifteen holes were sufficient, whilst in rock the number was greater.

Gelignite was the only explosive employed, 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 was 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 8½-inch gauge road, with 3-yard end-tip wagons, was employed to remove the debris 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 feet 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 8½-inch gauge, was substituted for the double road. Side-tip wagons, each of 4 yards capacity, were then employed until the completion of the works. 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 heading, 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 three shifts of eight 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.—ADVANCE OF THE HEADINGS BETWEEN FEBRUARY 1, 1890, AND OCTOBER 23, 1892.

	Totley.	Padley.
Machines employed	Two 3½-inch Larnuth drills	Two 3½-inch Larnuth drills
Cross-sectional area of heading, square yds.	12·2	12·2
Total period weeks	141	141
„ time lost „	29	45
„ „ worked „	112	96
„ progress made lineal yds.	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.—AVERAGE WEEKLY ADVANCE.

By Machine.

	Material.	Water.	Period of Test.	Advance.
			Weeks.	Yards.
Totley	Rock	Much	15	14·33
Padley	„	Little	10½	19·13
„	Rock & Shale	Much	15½	16·8
„	Shale	„	32	18·56
„	„	None	14½	29·87
Totley	„	„	71½	22·61
<i>By Hand, before February, 1890.</i>				
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 excavating is reckoned from the time the heading cleared after firing until the machines were re-started, although the filling of the debris was not completed until some time afterwards.

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

Material, dry shale.		Hrs.	Mins.
Drilling	{drilling, 2h. 47m.	3	48
	{changing holes, 16m.		
	„ drills, 45m.)		
Firing	{charging holes, 1h. 38m.	2	23
	{firing 45m.)		
Excavating		7	41
Lost		1	9
Average time for the whole round . . .		15	1

Machines employed	{Two 3½-in. Larmuth drills.
Average number of holes per round	13·4
„ length of each hole feet	6·25
„ number of drills per hole	3·8
„ pressure of air at drill . . lbs. per sq. in.	49
„ temperature of heading when drilling ° Fahr.	66
„ quantity of explosive per round . . lbs.	38
„ number of sockets per round	1·8
„ length of „ „ feet	1
„ width of heading „	11
„ height of „ „	9·92
„ area of „ square yards	12·12
„ advance per round feet	5·74
„ quantity excavated per round . cubic yards	23·18
„ advance per week linear yards	21·35
„ quantity excavated per week . cubic yards	258·76

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 five men, the allowance per man was under 300 cubic feet per hour. At Padley the ventilation was generally good; which 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, in piercing 350 yards of which 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, 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 was insoluble, and the explanation seemed to be, that it was air which had been robbed of its oxygen by the iron pyrites.

Permanent Works.—Cross-sections of the tunnel are shown in Figs. 19, 20 and 21, Plate 5. 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 are of brickwork in mortar, faced with brindled bricks. The arch is of brickwork throughout, faced with brindled 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-inch work being in the centre.

Small man-holes, 7 feet by 3 feet 6 inches by 1 foot 6 inches, Figs. 22, are built at every chain on alternate sides of the tunnel, and large man-holes, 10 feet each way, Figs. 23 and 24, 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. Man-holes, 4 feet by 2 feet 9 inches, are built in the culvert, and drain opposite every fourth man-hole 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 two chains, to drain the foundations of the side-walls. Weep-holes are 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 $4\frac{1}{2}$ 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 with brickwork in mortar, not less than 9 inches in thickness, and faced with brindled bricks. No. 4 shaft, Figs. 25 and 26, 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. 25), and the upper portion 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 foundation of the coning and the surface.

The tunnel fronts, Figs. 27 and 28, are built of block-in-course masonry, with millstone grit arch-quoins, and tooled ashlar cornice and parapet.

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 eleva-

tion. 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 realized, 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 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-foot 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. It was rolled to the thickness of No. 28 B. W. G., and was fixed in the same way as the felt. Owing to its extreme thinness it readily yielded 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 lbs. 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 employed 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.

The winding-engines employed at No. 4 shaft were of the double-cylinder horizontal type, having 22-inch diameter by 4-foot stroke cylinders, working at 70 lbs. per square inch steam-pressure. 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 the 4th of August, 1893, and the tunnel was completed and the permanent way laid by the 2nd September, 1893.

THE COWBURN TUNNEL.

Situated at the head of the Edale valley, out of which it springs almost perpendicularly, the arm of the Peak known as "Cowburn," rises to an elevation of 1,700 feet above sea-level. The tunnel, Fig. 29, Plate 4, 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.

The centre-line was first approximately set out with a 6-inch theodolite. A portable transit instrument, with 20-inch telescope, by Stanley, mounted on three legs similar to the smaller instru-

ment, was then employed. Two points, $\frac{3}{4}$ mile beyond the Chinley entrance, in the approximate line, were 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 in the 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 feet 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 the 18th of July, 1891, at 2,305 yards from the east entrance, the difference in line between the two headings was found to be less than 1 inch.

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 quantity discharged by the pumps reaching over 20,000 gallons per hour. The permanent shaft was commenced on the 3rd October, 1888, and was sunk through shale and several bands of rock, the quantity of water yielded amounting to 24,000 gallons per hour.

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 the 26th November, 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 $3\frac{1}{2}$ -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 the debris and laying the road at every round before the machines could be brought into action again, proved a serious hindrance to progress. For 1,070 yards from the Edale entrance the heading was driven by Elliott hand-power ratchet-drills. The progress obtained by the employment of these drills in soft material proved greater than by the use of compressed-air machinery. The drills are handy, take up but little room, and three or four can be at work simultaneously. The compressed-air machinery afterwards used as the ground became harder, consisted of a 16-inch compressor, working two $3\frac{1}{4}$ -inch Larmuth drills, the air-pipes being of cast-iron, 6 inches in diameter for the first portion, and wrought-iron, 3 inches in diameter, beyond. The progress of the Edale heading was stopped for six or seven weeks owing to the appearance of dry-rot in the timbering, and over 1,000 yards of heading had to be re-timbered. Old iron rails bolted together side by side, with a flitch of timber between them, were then largely substituted for timber head-trees. The pressure upon these, however, was so great that many failed and had to be renewed.

After the bottom headings met, the drills were transferred to the top headings of the lengths, and additional 3-inch Larmuth drills were also employed. An air-receiver was at the same time placed in the tunnel on the line of pipes, to increase the pressure at the drills, with satisfactory results—the difference in pressure between the compressors and the drills being reduced to only 5 or 6 lbs. The improved Larmuth drills, Figs. 30 and 31, Plate 4, latterly supplied to the Cowburn tunnel, had not the defects of those previously referred to. The chief alteration consists in the substitution of a solid piston-valve for the valve-spindle and D-valves, which is actuated by air from the valve-chest. The tappet is, however, retained to insure certainty of action, and to lock the valve in position. This arrangement has the advantage of reducing the wear of the tappet and main piston, besides removing the cause of the fracture of the valve-spindle, common in the old pattern. The cradle of the new pattern has been strengthened, without adding to the weight, by the substitution of aluminium crucible cast-steel for cast-iron. Also the square twist-bar, which wore rapidly at the corners and frequently broke, has been replaced by a grooved bar, which removes both these defects. The new machines are made with either a long or a short valve-chest, the latter being lighter, whilst the former is more economical of air.

The explosive used in the headings and in the lengths was gelignite, the total quantity consumed being 96 tons, or 51·8 lbs. per lineal yard of tunnel.

A record of the progress of the heading was kept, from which Table IV has been prepared. No work was done on Sundays, but the progress has been reduced to a seven-days week.

TABLE IV.—COWBURN TUNNEL. AVERAGE WEEKLY ADVANCE OF HEADINGS.

	Material.	Period of Test. Weeks.	Advance.
Edale, by Elliott hand-drills . . .	dry shale	34	Yards. 23·25
„ „ machine drills	shale & rock	69	21·0
Chinley, by hand	rock	24	8·6
„ „ machine drills	„	75	15·5

The cross-section and construction of the lining of the Cowburn tunnel are similar in all respects to those of the Totley tunnel. For 2,180 yards from the Chinley entrance the side-walls are of masonry, the remainder being of brickwork. As the ground is free from water, no culvert is required, 9-inch pipes being laid on each side to take any weeping which may occur. The absence of water favoured the construction of the lining in a more systematic manner than at Totley. The break-ups were made at uniform distances of about 85 yards, and as the junctions successively occurred, locomotives were taken further in the tunnel to remove the spoil. The ventilation of the workings was also more effectively maintained by this arrangement. A 16-foot diameter by 4-foot fan was erected at Chinley, and exhausted the foul air through a 5-foot by 3-foot shoot, which was laid as far as the continuous lining was constructed, and was carried forward as junctions were made in the lining.

Owing to the difficulty of access to the Edale valley, little was attempted with the lining there until the headings met. This allowed greater opportunity for pushing forward the heading from that end; whilst at Chinley the progress of the heading suffered to some extent through the vigour with which the lining was pushed forward. The last length of lining was keyed on the 22nd December, 1892.

THE DORE TUNNEL.

This tunnel, although only four chains in length, is worthy of notice on account of a certain peculiarity possessed by it. It passes under very steep side-long ground, at no great depth, and is on a curve of 12 chains radius. In order to allow for the necessary canting of the vehicles on so sharp a curve, and at the same time to enable the tunnel to sustain the unequal load imposed upon it, the cross-section is inclined from the vertical towards the inside of the curve, to fit the super-elevation of the outer rails of the permanent way, Fig. 32, Plate 5.

CONCLUSION.

Reviewing the experience gained in the Dore and Chinley tunnels, from the point of view of the possibility of an increased rate of progress in the construction of tunnels, the following considerations appear to the Author to deserve attention.

The fact that only $2\frac{3}{4}$ hours out of a 15-hours' round was consumed in actual drilling (in the shale), shows that increased speed must be looked for in the more rapid removal of debris. The cross-sectional area of the heading is a most important factor in determining the rate of progress, and the advance may, within certain limits, be said to vary inversely to it. The area of the heading, again, is dependent on the gauge of the road and the size of the wagons adopted. In the Totley tunnel, most careful organization for the marshalling of wagons was required, and it was only by vigilant care that a sufficient number could be worked in, filled, and worked out again in the six hours allowed; whilst the slightest accident caused much delay. No diminution in the size of the wagons or of the gauge of the road is therefore desirable. The Author believes that advantage might be gained by the use of much larger wagons, made with the body set low and capable of being lifted off the wheels to be tipped. In conjunction with these wagons overhead travelling-skips could be employed, suspended from carriers running on light iron rails attached to the head-trees. These skips could be filled from the top of the heap of debris, and would, after passing over the first wagon, discharge their contents into the second one. In this way additional men could be employed in filling, and much labour and expense might be saved as against casting the debris from wagon to wagon.

The Author, who was the resident engineer on the Totley tunnel works, desires to express his thanks to Messrs. Parry and Story, MM. Inst. C.E., for the assistance they have rendered him in the preparation of this Paper. He also wishes to acknowledge the help he has received from Mr. Thomas Oliver, the contractor for No. 1 contract, and his engineer, Mr. J. Lean, M. Inst. C.E. To Mr. Jas. Scott, agent, and Mr. G. E. Story, resident engineer of No. 2 contract, he is indebted for the information relating to Cowburn tunnel.

The Paper is accompanied by numerous drawings, from a selection of which Plates 4 and 5 and the *Figs.* in the text have been prepared.

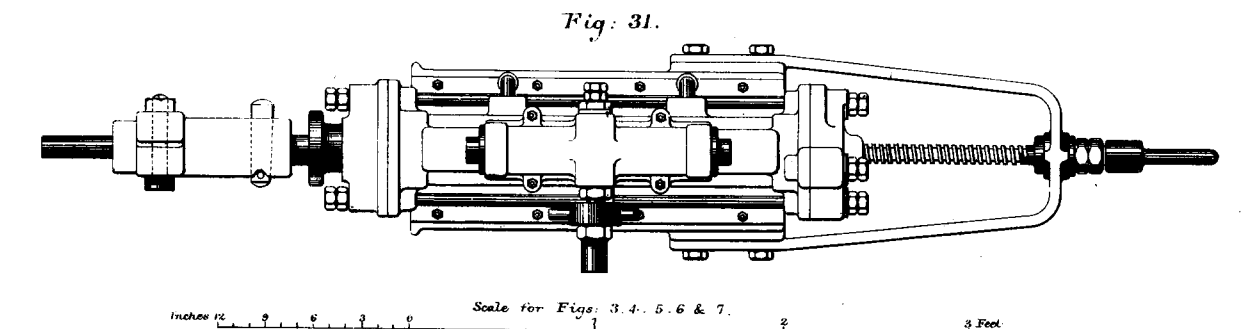
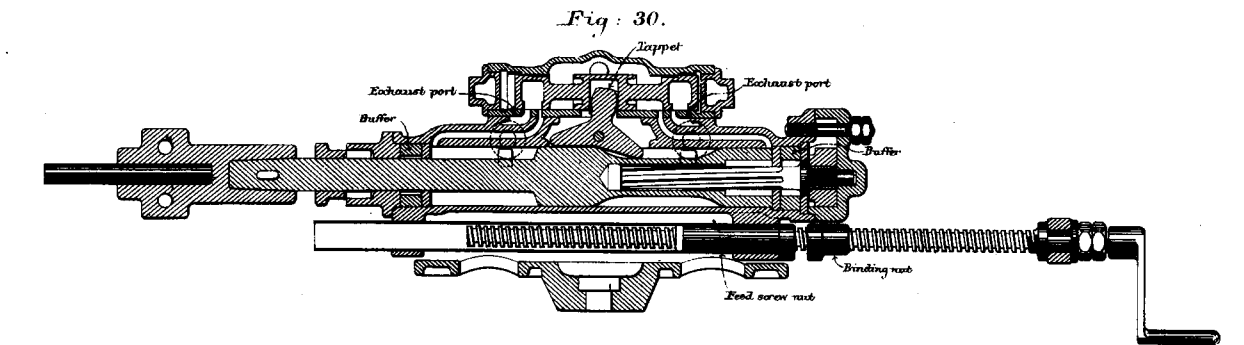
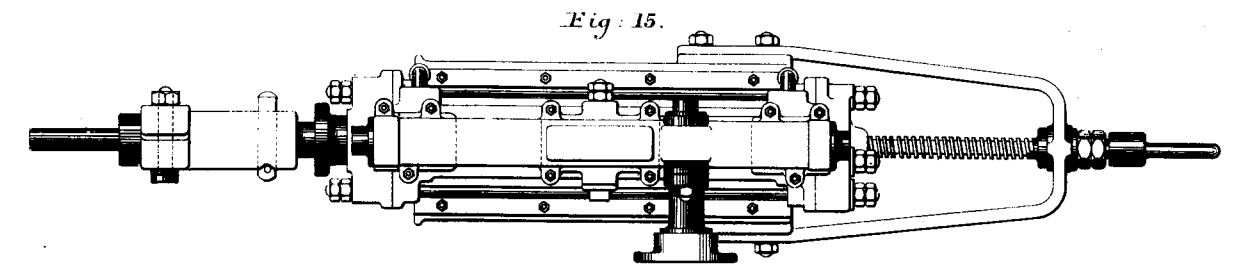
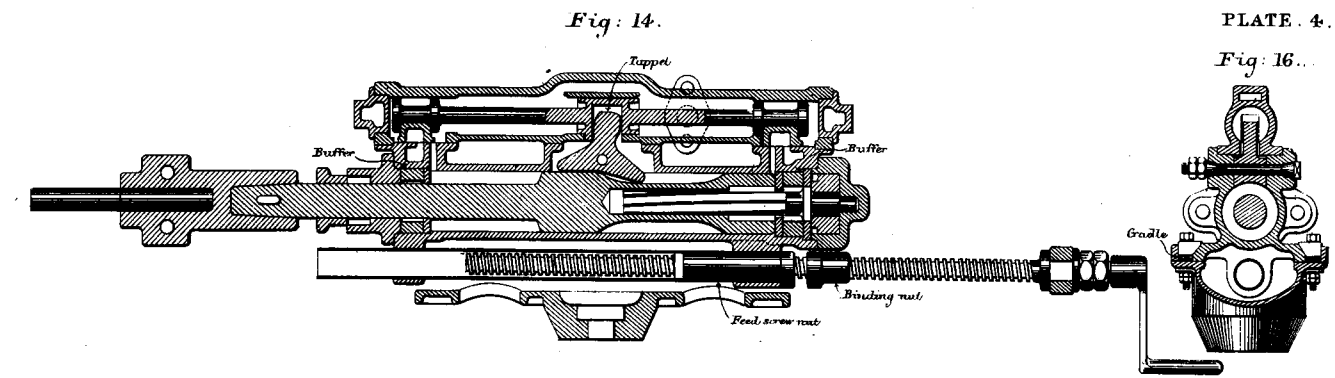
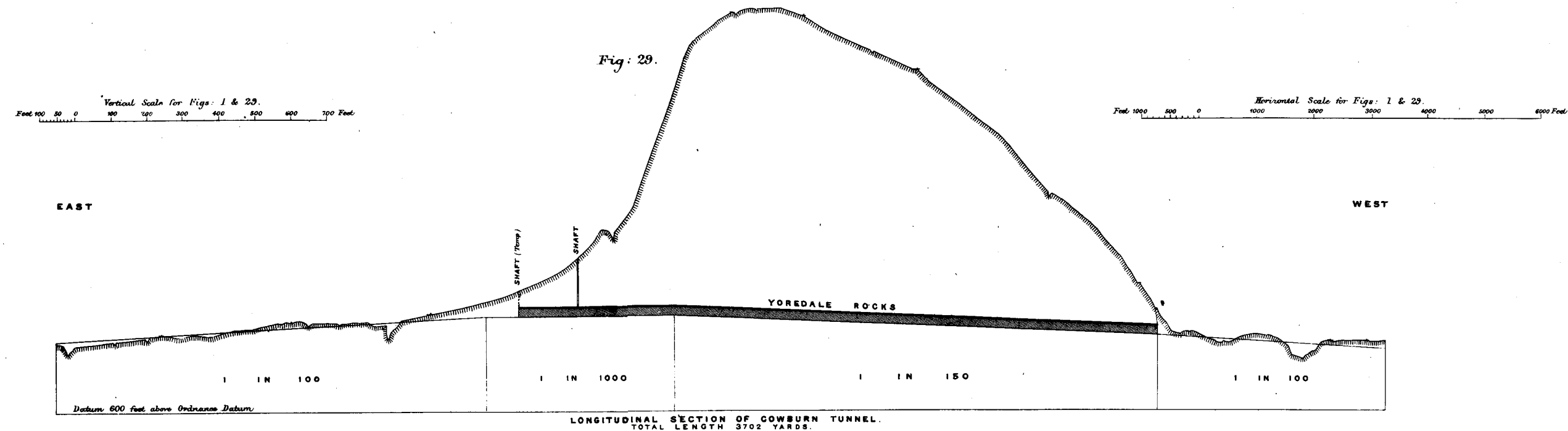
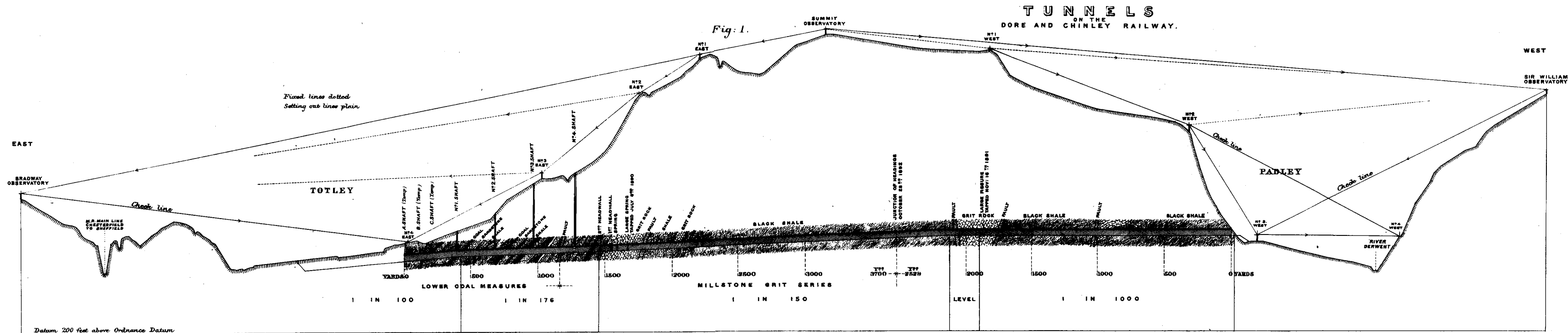
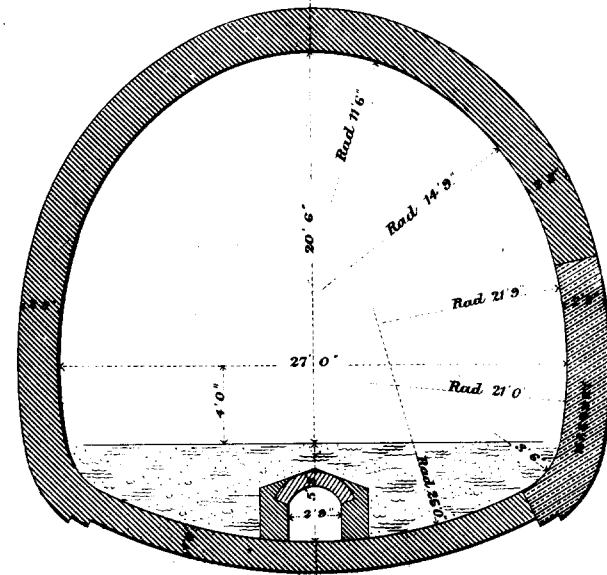
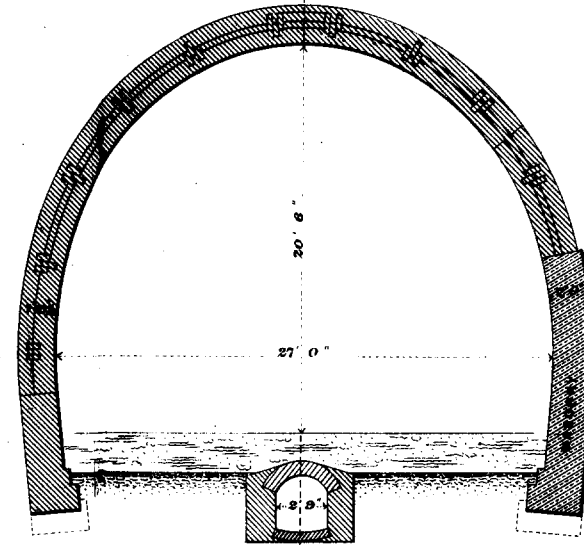


Fig: 19.



TUNNEL 2 FT. 3 INS. WITH INVERT
AT TOTLEY AT PADLEY

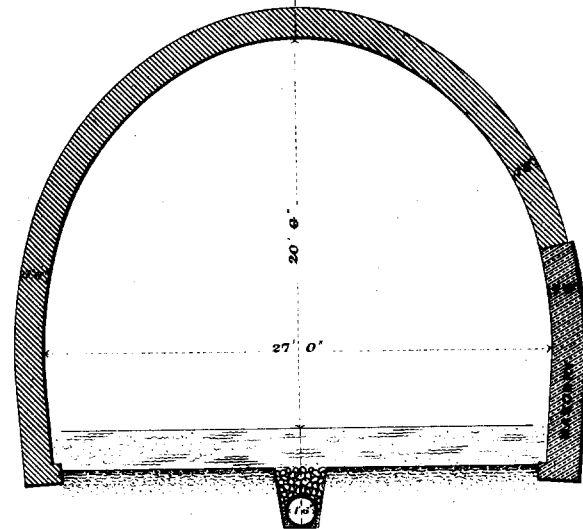
Fig: 20.



TUNNEL 1 FT. 10 1/2 INS. IN SHALE
AT TOTLEY AT PADLEY

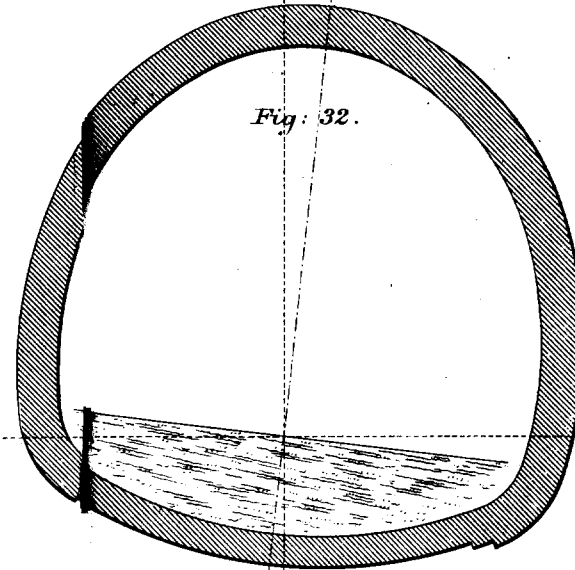
Scale, 1 Inch = 10 Feet.

Fig: 21.



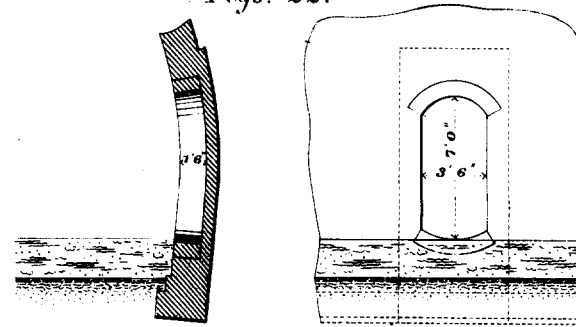
TUNNEL 1 FT. 6 INS. IN ROCK.
AT TOTLEY AT PADLEY

Fig: 32.



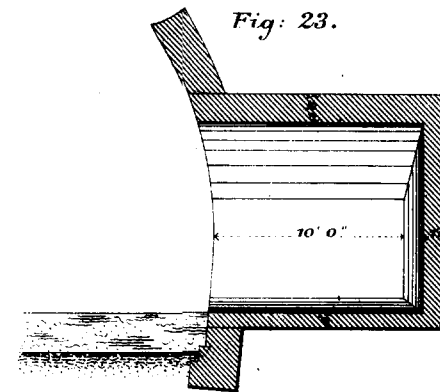
DORE TUNNEL

Figs: 22.



DETAILS OF SMALL MANHOLES

Fig: 23.



DETAILS OF LARGE MANHOLES

Fig: 24.

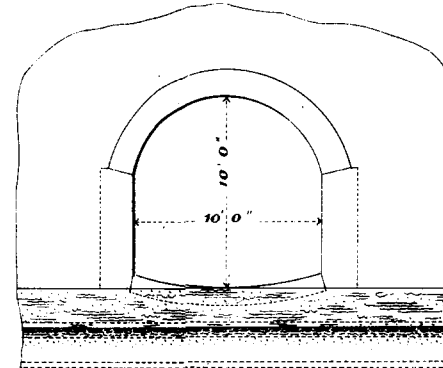
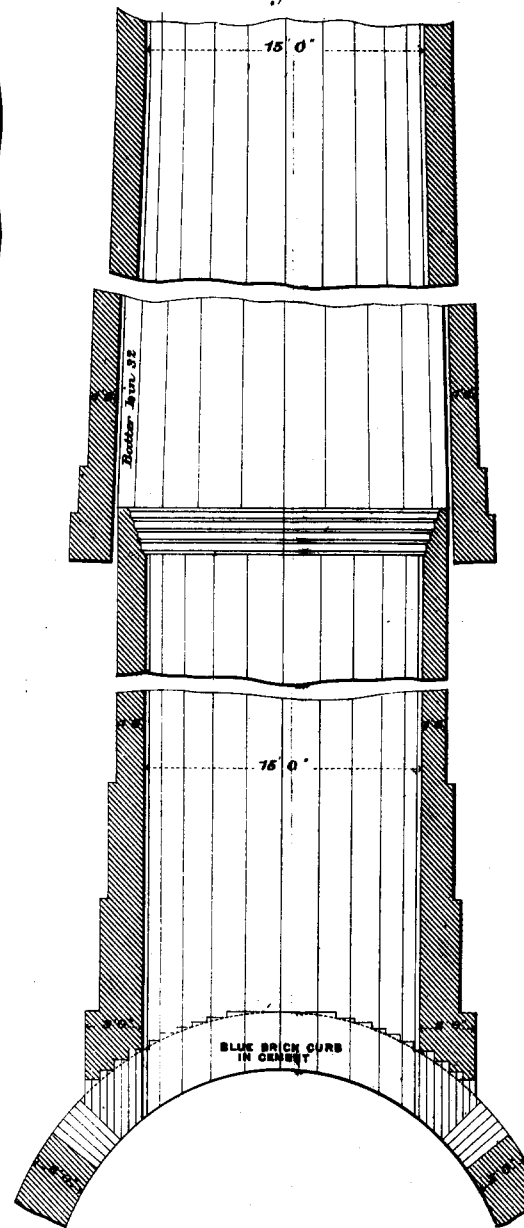
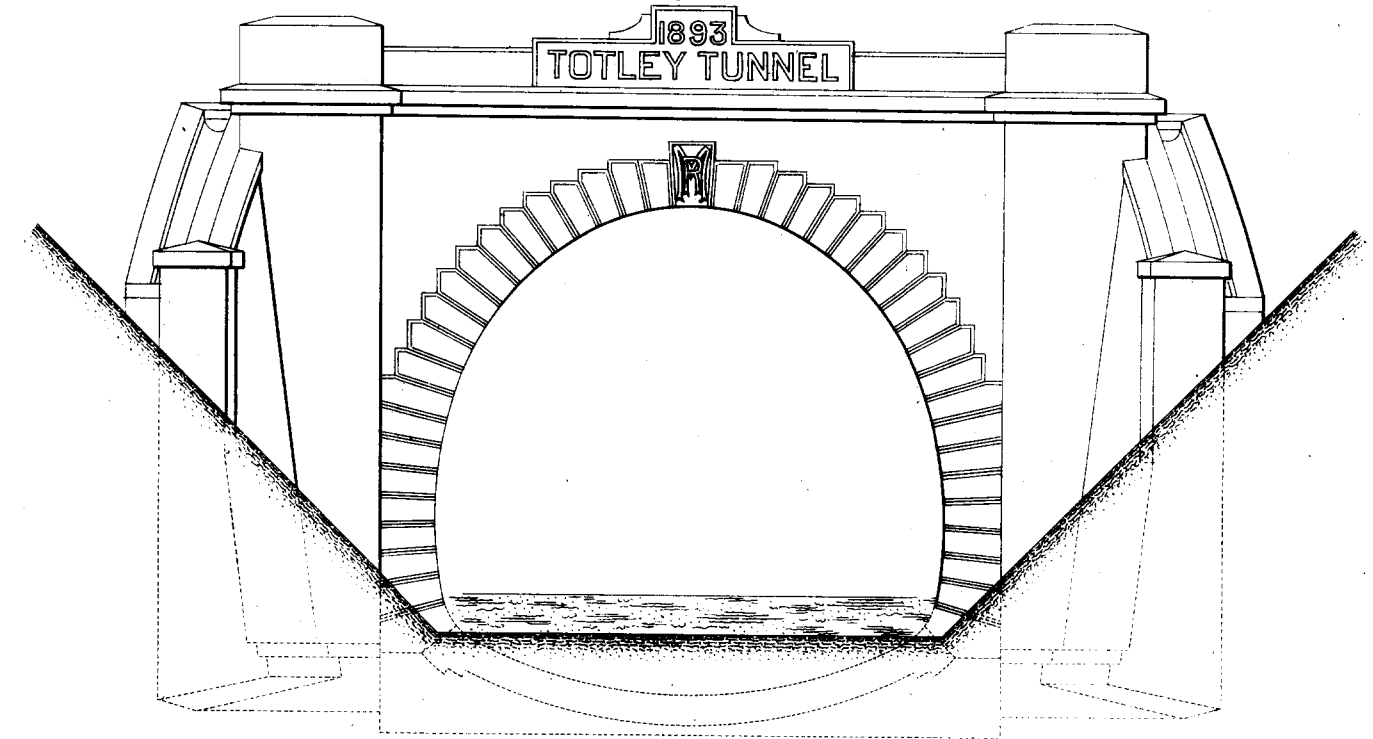


Fig: 25.



DETAILS OF NO. 4 SHAFT

Fig: 27.



ELEVATION OF TUNNEL FRONT

Fig: 26.

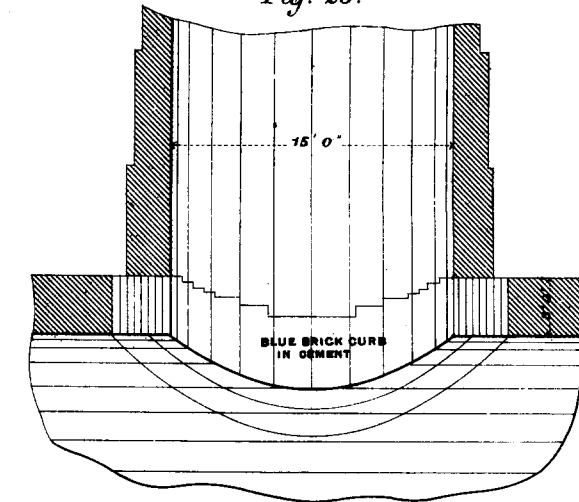
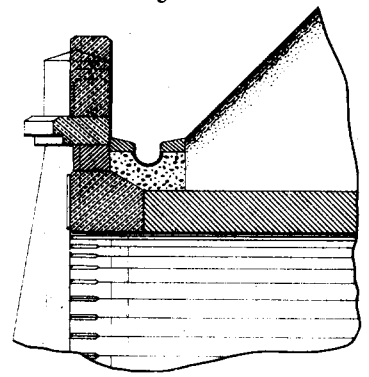


Fig: 28.



LONGITUDINAL SECTION THROUGH KEYSTONE