(*Students' Paper No. 435.*)

"The Construction of the Elan Aqueduct: Rhayader to Dolau."[1]

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THE Elan Aqueduct forms part of the new scheme which has been designed by Mr. James Mansergh, Vice-President Inst. C.E., to supply the city of Birmingham with water from Wales. This aqueduct, which is to convey the waters of the rivers Elan and Claerwen from Radnorshire to Birmingham, is now in construction under several contracts, the most westerly of which forms the subject of the present communication.

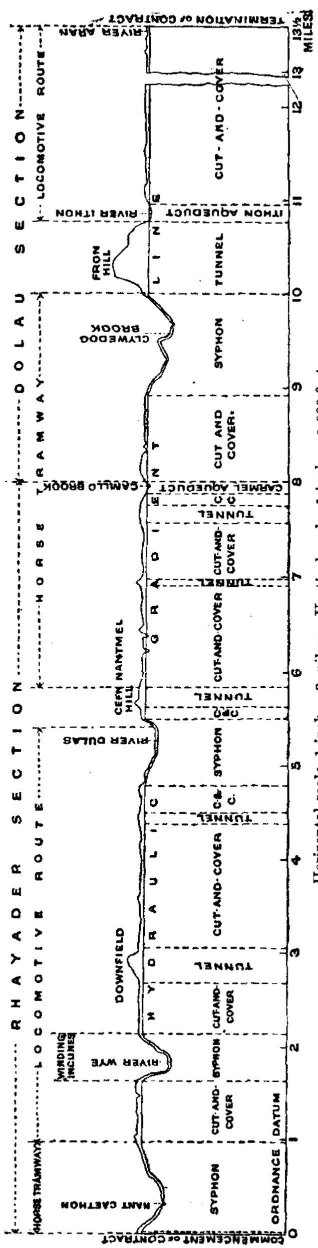
This contract commences at about 1½ mile west of the town of Rhayader, in Radnorshire, and a little more than 3 miles east of the proposed intake at the Caban Côch reservoir. It extends over a length of 13½ miles, and terminates at the Dolau railway station, in the same county, *Fig. 1.* The greater portion of the length consists of cut-and-cover work, practically contouring the hillsides, but falling throughout at a gradient of 1 in 4,000. There are a few short tunnels at the same gradient. Where the aqueduct crosses valleys of great length and depth, pipes are substituted for the cut-and-cover work, with a hydraulic gradient of 1 in 1,760. Dingles and narrow river valleys are spanned by aqueduct bridges, the conduit being carried over on arches.

The contract was let in May 1896 to Messrs. John Aird and Sons, London. From the commencement the work was divided into two sections, a western portion 8 miles long, and an eastern portion about 5½ miles in length. Each section, with its own plant, was worked more or less independently throughout.

Work was begun in June 1896. At the outset a wagon road was laid down and connections were formed at Rhayader and Dolau between the main railways and the works. The junction at the west end was made at about ½ mile south of Rhayader

[1] This Paper was read and discussed at a Students' Meeting on the 10th March, 1899.

Fig. 1.



Horizontal scale, 1 inch = 2 miles. Vertical scale, 1 inch = 1,000 feet.

LONGITUDINAL SECTION OF CONTRACT LENGTH.

Station, on a branch line belonging to the Birmingham Corporation, and running from the Cambrian Main Line to the Elan Valley Works. From this junction to the Rhayader depot a winding incline was constructed, and from the top of the grade a locomotive route, 4 feet 8½ inches gauge, for conveying plant and materials along the track, ran eastward, parallel to the centre line of the aqueduct, and terminated at the foot of Cefn Nantmel Hill, at a distance of 4½ miles from Rhayader.

On the Dolau section, a corresponding wagon road was laid down in connection with the London and North Western Railway at Dolau Station, whence a full gauge locomotive route was carried eastwards along the track to the foot of Fron Hill, at a distance of about 3 miles from Dolau Station. All plant and materials could now be conveyed at once to their required destinations, throughout a total length of 7½ miles, namely, 4½ miles from the Rhayader end of the track, and 3 miles from the Dolau end; but a central section of some 6 miles was still unprovided for. This gap, however, was soon filled in. From the termination of the western locomotive route a horse-road, 2 feet 8½ inches gauge, was formed, extending through the intermediate section to the western side of the Fron Hill. All goods required along this intermediate portion were delivered first at Pen-y-bont Station, and then conveyed along the high road, either by carts or by traction engines, and were transferred to the narrow-gauge wagons at the various points where connections were formed between the horse road and the high road, namely, at Fron, Gwystre, and Hirfron, distant from Pen-y-bont Station, 1 mile, 2 miles, and 3 miles respectively. Two 10-ton traction engines were in use, each capable of making four journeys per night from Pen-y-bont to Hirfron. Pipes were carried in special four-wheeled "whims." The locomotive routes were of the full 4 feet 8½ inches gauge, with 56-lb. rails spiked to the sleepers, which were "boxed-up" with material excavated from the trenches. The inner rail ran at an average distance of about 5 feet from the side of the trench.

The width of land allowed to the contractor was 66 feet, and at a distance of 33 feet from the centre line of the aqueduct, and on each side of it, fences were erected in advance of all work. In constructing the wagon-road, the high roads and lanes were crossed either underneath or on level crossings. In the former case the metalling of the road overhead was carried by a timber bridge. Temporary timber bridges were built also to carry the wagon roads over the River Wye and other streams. The slopes of the Wye Valley were found to be too steep for a locomotive route. Winding inclines were therefore laid down on both sides of the valley. A gang of about eighteen men was usually employed on each section, to form the wagon road, and was followed closely by a plate-laying gang of about twelve men.

The Rhayader depot was situated between ¼ mile and ½ mile south of Rhayader, adjacent to the aqueduct and at the head of the incline already referred to, which connected the main line with the works. The depot covered an area of about 5 acres, and consisted of a cement storage and cooling shed, a saw-mill and winding-engine shed, shops for masons, fitters, blacksmiths and carpenters, two stone saws, and a stone rubbing machine, general stores, a small cement-testing shed, a locomotive shed, and a few temporary dwelling huts. Ground not occupied by buildings was utilized as a depot for siphon pipes, brick, iron-work, and other materials. The buildings in the Rhayader depot were in use for 2 years. They were taken down in July, 1898, previous to the removal of the locomotive route, most of the work along this line being completed. The remainder of the work on the contract to the eastward was carried out from the depots on the Pen-y-bont connection on the Dolau Section.

The main depot for the Dolau Section was situated on a piece of ground adjoining Dolau Station on the London and North Western Railway. In addition to these chief depots, three minor depots were established at the termination of the western locomotive route at the Hirfron connection, and in the yard of the Pen-y-bont Railway Station; a cement-cooling-shed was also erected at Rhyd Llyn, about 1 mile west of Dolau.

The supply of "blue" stone facing, throughout the whole of the contract, was limited to two sources, Cerig Gwynion and Knighton. Stone for crushing purposes was obtained from Cerig-Gwynion, Carmel and Dolau. The freestone for copings, string courses, etc., was supplied mainly from Cefn, Ruabon, but a considerable quantity was obtained from Darley Dale, Derbyshire, and Grinshill, Salop.

The majority of the cuttings on the contract were through hard shales and flags belonging to the Silurian and Ordovician systems. These shales were overlaid by glacial boulder clay, often of great thickness, in one case as much as 30 feet. In "bottoms" or depressions, and near water courses, the clay was often found to be thoroughly water-logged, and in the cut-and-cover work this caused great difficulty in bricklaying.

The operations required for the permanent work can be grouped under four heads, namely :—

1. Pipe-laying.
2. Cut-and-cover work.
3. Tunnelling.
4. Building of aqueduct bridges.

Pipe-laying.—The siphons were designed for an ultimate number of six lines of pipes 42·12 inches in diameter, but on the contract under description only two were laid. The pipes are 1 inch thick, cast in 12-foot lengths, each pipe weighing about $2\frac{1}{2}$ tons. They were cast vertically, socket downwards, and of sufficient length to allow of 4 inches being turned off the spigot end in the lathe. Test bars, cast at the same time as the pipes, 2 inches deep and 1 inch wide, were required to stand, without fracture, and with a maximum deflection of $\frac{3}{8}$ inch, a weight of 2,800 lbs. applied at the centre of a 3-foot span. The pipes were coated with Dr. Angus Smith's composition, and, before leaving the works, were tested by oil to an internal pressure of 200 lbs. per square inch. They were cast by the Staveley Coal and Iron Company, at whose works an inspector was appointed by the Birmingham Corporation to superintend the tests, which were made prior to the pipes leaving the premises.

The width of the pipe trench was 10 feet 8 inches. The centres of the pipes being 6 feet apart, a clear space of 6 inches was left between their outside surfaces and the face of the trench. The excavation was carried out by stages. The turf, on removal, was piled up close to the hurdles, for relaying after the trench was filled in. The earth was thrown out to the sides of the trench until the level of the top of the pipes was reached approximately, when the remainder of the excavation was conveyed at once to the nearest spoil bank. The excavating gangs were followed by a few men getting out "joint holes" a few lengths ahead of the pipes already laid. Behind these men came the pipe-lowering gangs and the pipe-jointers, and, last, a few labourers filling in the trench.

The greater portion of the pipe-laying was carried out by means of a travelling timber gantry running on a temporary tramway of 30-lb. flat-bottomed rails, spiked to 9-inch by 3-inch planks on each side of the trench. On the top beam of the gantry a small iron traveller, fitted with rollers so that it could be run into any position along the beam, carried a differential pulley block for raising or lowering the pipes. In timbering the pipe trenches, the outside struts were so spaced along each waling that, on removing the centre strut, a pipe could be lowered between them. Through this gap the pipe was gently lowered, and, by running the gantry along, was moved into place. The bottom of the pipe was then packed on both sides with soft earth from the "joint holes," in order to keep it firmly in position during jointing.

At the bottom of the west slope of the River Wye there is a length of about 50 yards of pipes rising at a gradient of about 1 in 2. Here, of course, it was impossible to make use of a travelling gantry. The pipes were lowered into position with the aid of a crab placed higher up the hill, and were "socketed" either by means of shear legs or by a screw fixed to overhead balks. In crossing the River Wye the pipes were laid below the river bed to a depth of about 8 feet. The river waters were cut off from the trench itself by means of coffer-dams and earth-banks, and were carried over the trench in timber shoots. The pipes were lowered from an overhead platform on the bridge timbers by means of a screw. In preparing to run a joint, steel wedges were first driven between the spigot and socket in order to obtain a space of uniform width. This space was then well caulked with hemp, and the wedges were removed, the tightness of the packing keeping the joint true. A "clasp ring" of 1 inch by 1 inch metal was screwed up tightly against the socket, and a luting of clay was worked round it, a cup being left at the top into which to pour the lead for the joint. A little grease was smeared on the bottom of the cup to act as a flux, and the pipe was ready for jointing. The ladle, heated at a coke fire at the side of the trench, was placed on the trunnions of a saddle resting on the pipe, and was filled from several smaller ladles carried from the melting-pot until there was a sufficient quantity to fill the joint. When the lead had reached its proper temperature—judged by its colour—the joint was run by tipping up the ladle. The clay and the ring were then removed, and the joint was "set up." In "setting up," the lead was caulked round three times with $\frac{3}{16}$-inch, $\frac{1}{4}$-inch, and $\frac{5}{16}$-inch caulking tools in succession. The thickness of lead in the joints was $\frac{5}{8}$ inch.

The average number of men in each pipe-laying gang, including the excavators, was twenty-two. The average number of pipes laid and jointed per week was between forty-seven and fifty-one, or a little over eight pipes per day. The maximum number of pipes laid and jointed in a day was twenty-two, and the best week's work was a total of eighty-six pipes laid and jointed. On the Wye incline, owing to the steepness of the gradient and the consequent danger of rock rolling down, the number of men employed in excavating and pipe-laying was considerably less than usual, thirteen to fifteen only being employed in place of the usual forty on each siphon. Owing to this fact, and also to the length of time taken in continually fixing stages, lowering, etc., the rate of progress was here extremely low, about $4\frac{1}{2}$ months being required to complete a length of 50 yards.

Cut-and-cover Work.—The excavation for the cut-and-cover work was carried out by "stage" work in shallow cuttings, and by travelling cranes in deep excavations. In a few cases, where it was considered economical, the excavation was removed by means of a "Jubilee" gantry. On the horse tramway, cranes were used only for very deep cuttings. In these cases a short length of the full-gauge road was laid down as a crane road on the side of the trench opposite the narrow-gauge line.

The "Jubilee" gantry was a travelling timber structure, erected over the trench, and running on a temporary road, similar to the tramway used in pipe-laying. A long chain was passed over a system of pulleys on the structure, and round a pulley which was fixed to a post at the side of the trench, but at some convenient distance from the gantry. The ends of the chain were fastened to one empty and to one full wheelbarrow. To the centre of this chain one end of a short connecting-piece was fixed, the other end being attached to a horse, which, by walking either towards or from the gantry, raised a full barrow to an upper platform, and at the same time lowered an empty one to the bottom of the trench. The timber platform jutted over the wagon road at a sufficient elevation to clear the funnels of the locomotives. Two men wheeled the barrows from the top of the hoist to the edge of the platform, emptying them into the wagons on the road below. This method of getting out excavation was used only in cases where the frame of timbering at the level of the wheelers could be dispensed with, and where the ground was fairly easy to excavate —a combination of circumstances, however, rarely met with. Land drains and small streams were carried temporarily across the trench in timber shoots. On long stretches of sloping ground the land drains were intercepted on the uphill side of the trench and were carried across at the shallow ends of the cuttings in a similar manner.

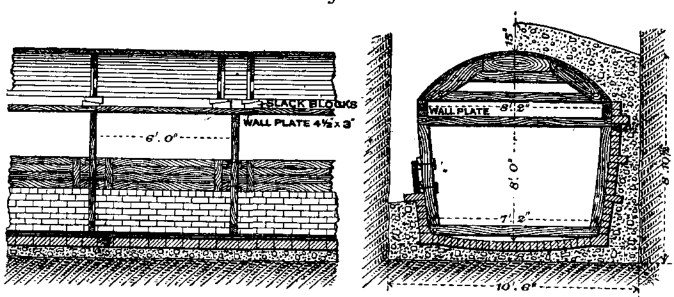
The average number of men employed in each gang excavating the cut-and-cover trench was twenty-four, including timbermen. There were six of these gangs constantly employed on the Rhayader Section. The ground was opened up at points 300 yards or 400 yards apart, and each excavating gang carried on the trench to the commencement of the next excavated section.

The Portland cement on this contract was obtained chiefly from South Wales, but a considerable quantity was supplied by Thames and Medway firms. The cement mortar used on the works was made throughout of sand and cement in the ratio of 3 to 2. The concrete ballast used was of three kinds, viz., (1) broken Cerig Gwynion stone from the Rhayader depot crushers; (2) broken Carmel stone from the crushers in the Carmel Quarry; and (3) broken Dolau stone from the Dolau crushers. Two classes of sand were in use, viz., crushed Cerig Gwynion or Carmel stone, and red sand from the valley of the River Severn. The red sand only was used on the Dolau Section; on the Rhayader Section an attempt was made to use only the crushed sand, but the machines were unable to satisfy the daily demand, and, consequently, the supply was supplemented by the river sand. The crushed sand gave more satisfactory results than the red, being better able to retain water, and giving a superior surface to faced concrete work. The sand crusher was first situated at Downfield, about 1 mile east of Rhayader. It was removed, in April 1898, to Carmel Quarry, as the work at that time lay within the last 4 miles of the Rhayader Section.

Sections of the conduit are shown in *Figs. 2.* It may be defined as a concrete culvert, lined internally on the sides and invert with blue brickwork. The sides are vertical externally, curved internally to arcs of circles, and faced with 4½-inch blue brickwork, with a course of headers every sixth course in height. The invert is a circular arc, lined with 4½-inch blue brickwork. The arch is entirely of concrete, in the same proportions as that in the sides and invert, namely, 6 to 1.

The following was the general methcd adopted in building up the cut-and-cover work. The trench having been excavated down to its proper level, wooden templates, shaped to the curve of the underside of the invert, were placed transversely, at intervals of 14 feet, along the bottom, and in such a manner as to leave a

Figs. 2.



Scale, 1 inch = 8 feet.

CUT-AND-COVER WORK.

6-inch "garland" on each side of the trench for draining off surplus water during the construction of the invert. Concrete was then placed between the templates, and was shaped to the proper curve for the brickwork. After this concrete had set, the blue-brick invert was laid, together with the corner or invert blocks, on which the facing to the side-walls commences. Frames were then erected along the invert, 6 feet apart, the external boundaries of which formed the required curve of the sides of the internal section. Resting on the invert blocks, and outside the frames, were fixed wooden shutters, 16 inches in height and 12 feet in length. These were supported by means of iron hooks [1] running round the side ribs of the frames, and fitting into staples

[1] These hooks were dispensed with towards the end of the contract owing to their continual disappearance, and the shutters were adjusted from the sides of the trench by short struts.

in the shutters, and were adjusted by wedges so that their external faces were $4\frac{3}{4}$ inches from the inside face of the side walls. The space between the shutters and the sides of the trench was then filled with concrete. In this manner the top of the concrete was brought up to the level of the underside of the first header course, the "garland" mentioned previously being filled at the same time. After a lapse of 48 hours, the minimum time allowed for the setting of the concrete, the shutters were removed, and the brick facing was built up to the lines given by the frames, as high as, and including, the first header course, which rested on the concrete already put in. On this last course the shutters were again set, and the same operation was continued up to the second header course, and so on until the springing of the arch was reached. Grooves were formed in the concrete in order to bind together the successive lifts; and the surface of each layer was washed well before new concrete was deposited.

In the original design for the cut-and-cover section, as already stated, the headers were spaced every sixth course. With full-sized bricks this would mean that after the third header course had been built, only three or four courses of stretchers would be required to complete the sides. As a matter of convenience the brickwork would be built first, and the remaining concrete, with that of the arch, would be put in afterwards, so that, while the arch centres were being fixed, a gap would be left between the facing and the sides of the trench into which dirt might fall from the surface of the ground and from the face of the excavation. The proper cleaning out of such a gap before concreting would be almost an impossibility. For this reason the contractors were permitted to carry up the third lift to within one course below the springing, and to build the topmost course of headers. By this method a very small space only was left, from which dirt could be more easily removed.

When the cut-and-cover work was commenced, wrought-iron frames of tee-bar, bent to the curves of the internal section of the aqueduct, were adopted. These were used for about 6 months, but owing to the difficulty of transporting them, on account of their weight, the length of time required to fix them and the centres for the arch, and also to the nuisance caused by the invert rib preventing water from escaping along the bottom, they were discarded, and were replaced by frames of timber. The bottom ribs of the timber frames were straight, with a 3-inch gap through which water could pass. The top ribs lay about 9 inches below springing level and supported a wall-plate, $4\frac{1}{2}$ inches by 3 inches, carrying "slack-blocks," which, in turn (when the side-walls were completed), carried the centres for the arch, and enabled them to be adjusted accurately to their proper level. The arch centres were 12 feet in length, were made in three segments for convenience in transportation, and were fixed together in position by ½-inch bolts. In turning the arch round curves (all of which are of 200 feet radius) the centres were made in lengths of 6 feet, curved in plan, and were removed bodily from point to point. The junctions between adjacent lengths of side-walls were formed by "stepping" the brickwork and concrete at the levels of the various lifts. At the end of each length of arch a "stunt-head" was fixed on the top of the centres. This left a V-groove in the concrete to form a key with the succeeding length. For tipping the concrete into the work, wooden hoppers were used. These were fixed under a platform spanning the trench, and to their undersides detachable timber shoots were hung, in order to direct the concrete into the side-walls or into the invert as desired.

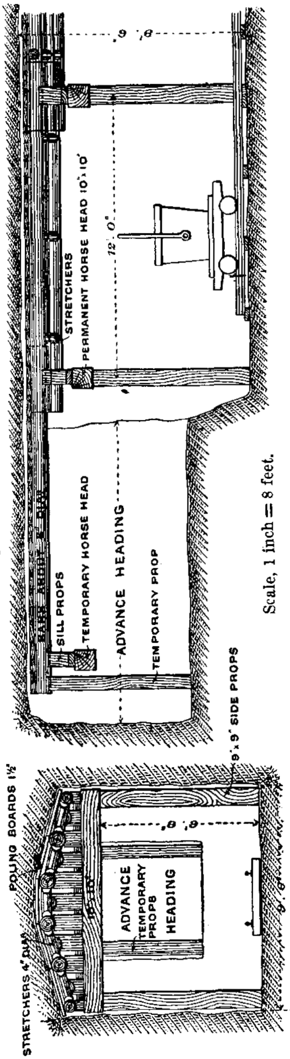
The water required for mixing concrete, watering the trenches during "filling in," etc., was brought from the nearest available stream courses, and was pumped through wrought-iron pipes, 2 inches in diameter, laid parallel to the centre line from one end to the other of the various conduit lengths. In passing through bad ground, as already stated, great difficulty was experienced in building the brickwork, in consequence of the water flooding the masonry. This frequently occurred to such an extent that the mortar was washed from between the joints before it had set. This difficulty was overcome largely by building in ½-inch or 1-inch iron pipes at the bottom of the side-walls. These pipes extended from the face of the excavation to the inside of the aqueduct, and allowed the water to escape along the invert. On the completion of the adjoining work these pipes were well caulked with hemp and neat cement. Leaks discovered in the side-walls after the work had set, were almost invariably found to be at the undersides of the header courses; that is, at the levels of the junctions of consecutive concrete lifts, the majority of such leaks occurring at springing level. On the detection of a leak the mortar was raked out from the joint, which was afterwards well caulked with hemp and filled in again with neat cement.

The average number of men in the concreting gangs on the cut-and-cover work was fifteen. The ratio of concreting gangs to excavating gangs, depending mainly on the depth of the trench, was naturally variable, but for an average depth of trench of 15 feet the ratio was about 2 to 3. With five excavating gangs and three concreting gangs, with the necessary bricklayers and labourers, an average length of 90 linear yards of completed conduit, at an average depth of 15 feet, could be done weekly.

Tunnelling.—When the depth of cutting on the cut-and-cover work exceeded about 30 feet for any considerable length, tunnels were substituted for the open cutting. As a rule the trench was excavated up to the commencement of the tunnel before driving was begun. In one or two cases, however, a shaft, 20 feet long, and having a width equal to that of the trench, was sunk at the commencement, and the driving was carried on from its base. The method of timbering the tunnels is shown in *Figs. 3.* In moderately good ground the tunnels were driven to their full width, leaving a benching, 2 feet 6 inches high, to be removed later. In bad ground a top heading, about 5 feet in width, was driven ahead of the finished timbering in order to allow of the introduction of a temporary sill to support the succeeding crown-bars and their poling-boards, *Figs. 3.* In very firm ground, all timbering was dispensed with.

By far the greater part of the driving was carried out by means of $1\frac{1}{4}$-inch ratchet drills, two drills being used at each face. When the heading was driven at its full width, eleven holes

Figs. 3.



Scale, 1 inch = 8 feet.

METHOD OF TIMBERING TUNNELS.

were drilled in the face, each hole being 4 feet 6 inches deep. Gelignite was used exclusively throughout the whole of the tunnel work. The average charge for each hole was about 15 ounces, and the average total expenditure of gelignite was about $12\frac{1}{2}$ lbs. per linear yard. The excavated material was filled into skips, which were carried on small trolleys running on a tramway of 2 feet gauge, and were run out to the commencement of the tunnel, where they were hauled up to the surface either by steam cranes or steam winches. Two of these trolleys were in use in each heading, two men running with each trolley.

Proper ventilation, and the removal of the gases generated by blasting, were both secured by means of centrifugal fans driven by portable engines, which were employed also for pumping at the ends of the tunnels. The fresh air was delivered through cast-iron pipes, 6 inches in diameter, carried up to within about 50 feet of the face. By this means the products of combustion were forced out towards the end of the tunnel. The tunnels were worked in two 10-hour shifts in the 24 hours at each face, each shift consisting of twelve or thirteen men and one foreman. About 11 linear yards per week was the average progress of tunnel-driving at each face in hard slate throughout the length of the contract. When in full swing, as much as 15 linear yards has been done in 1 week. At the inlet end of the Fron Tunnel a rate of only 8 linear yards per week was accomplished, the difference of progress being due to the relative hardness of the rock beds.

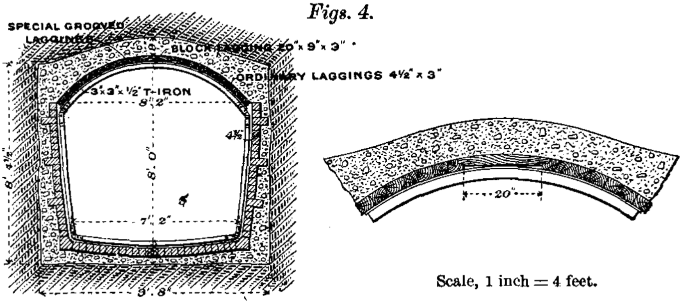
In lining a tunnel, the invert was, in general, first completed throughout the entire length of the tunnel, or portion of tunnel, to be lined, and the side walls were finished before the arch was commenced. The methods adopted in the building of the invert and side-walls were similar to those used in the ordinary cut-and-cover work, but the wooden top ribs of the frames were replaced by those of the original wrought-iron frames already mentioned. The construction of the arch, however, was carried out in a different manner, *Figs. 4*. Eight loose laggings, resting on the curved iron ribs of adjacent frames, were brought up from the springing on each side of the centre line. Concrete was then packed carefully between the laggings and the roof of the tunnel. Two more ordinary laggings, and one special "grooved lagging," were added on each side, and the space between the "grooved laggings" was filled in by special rebated "block laggings." Two "block laggings" were added at a time, and the space between the first lifts of concrete was filled in longitudinally.

In building the invert and side-walls a gang of fifteen concretors working 10 hours per day, with a gang of six bricklayers and seven labourers working intermittently as required, could complete weekly a length of 70 linear yards of invert or 40 linear yards of side-walls. On the arch, a gang of fourteen men, working 9 hours per day, completed an average length of 63 linear yards weekly.

Aqueduct bridges.—The two main aqueducts are situated at Bryn-Hyferth and Carmel, crossing the River Ithon and the Camllo Brook respectively. The former bridge consists of twenty-two segmental blue-brick arches faced with freestone, each having a span of 30 feet and a rise of 5 feet. There are six rings of brickwork, 14 feet in width, in each arch. The conduit is carried over the river on an eight-ring arch of 60 feet span. At Carmel there are eleven 30-foot arches and a steel tube, 8 feet 6 inches in diameter, which replaced the conduit over an occupation road.

The stonework on the Ithon aqueduct was set with two 3-ton

Figs. 4.



Scale, 1 inch = 4 feet.

Scale, 1 inch = 8 feet.

CONSTRUCTION OF TUNNEL-ARCH.

travelling steam cranes. Seven centres only were used for turning the twenty-two arches, about 6 months being spent in the operation. The centres were struck a fortnight after keying, except on the river arch, where they were left for a month. About thirty-six men were usually employed on this bridge. The total number of men employed throughout the contract averaged 900 to 1,000. As the works traversed a sparsely populated district, the accommodation in neighbouring villages and farms was insufficient for the number of labourers employed on the aqueduct; temporary wooden huts were therefore built by the contractors for this purpose on suitable sites conveniently near the works. Owing to the work progressing at a more or less rapid rate, and consequently extending to inconvenient distances from buildings already erected, the huts were taken down after a time and removed to more convenient situations. For ease in transport, and in order to increase the rapidity of re-erection, the sides of the huts were constructed in the form of large panels. Earth closets were provided for each hut. Trains for the workmen, from both Rhayader and Dolau, were run each morning along the locomotives routes, returning in the evening after the day's work.

The time allowed for the completion of the contract, from the date of commencement, is 4 years, but it is expected that little will remain to be done at the end of the year 1899, *i.e.*, about $3\frac{1}{2}$ years from the time at which the work was started.

The Author is indebted to Mr. James Mansergh, Vice-President Inst. C.E., for permission to make this communication; to Mr. W. A. Legg, M. Inst. C.E., the Resident Engineer, under whom the Author acted as Assistant, for providing facilities for the work, and for much valuable information; and to the representatives of Messrs. John Aird and Sons for supplying figures and drawings.

The Paper is accompanied by a map and drawings, from a selection of which the Figures in the text have been prepared.