across to the front wall, enabling the rock walling to be commenced. The hard rock suddenly cutting out stopped all work in this quarry, and the men were shifted into a small quarry, No. 5, on the opposite bank, pending the opening up of No. 6.

No. 1 quarry was started almost immediately after No. 2 in front of the embankment on the southern side of the river, and showed throughout a splendid face of very hard rock. The floor of this quarry was opened on the 20 feet level, which completed the filling of the gorge to that height, and later the tramway was raised 10 feet higher, and the rock pulled up an incline, bringing the front wall of the dam to the 30 feet level for a length of 550 feet.

This arrangement was finally cut out by the advancing tip from No. 6, and the quarry was abandoned.

No. 6 quarry (situated about 12 chains to the south of the dam, and 70 feet vertically above the finished level of the rock work) was discovered a month before No. 3 had to be abandoned, when it was almost ready for working. A self-acting tramway or gravity plane was installed to convey the rock on to the embankment site and running grades were secured by making cuttings from 4 to 9 feet at the lower end, and from 1 to 5 feet at the upper, bridging a gully between by 224 feet of trestling. The final grades then became:—top end 1 in 8.4 to 9.8, middle (with turnout) 1 in 18, bottom 1 in 4.15. In calculating these grades the rolling friction was taken as 1/40 of weight or 56lb. per ton. Weight of empty trucks 1,700lb. Minimum weight of full truck 7,500lb. The friction factor is rather low for the type of truck, but was justified by results, there being no difficulty whatever in sending down the above-mentioned load as soon as the axles and bearings had worn smooth. Due allowance was also made for the friction in drums and on haulage ropes. The track was made with three rails and a turn-out in the middle for the trucks to pass.

At the head of the grade the line divided into two, swinging either side of the brake-house, and these again were divided into two more to serve as additional loading stations and for shunting purposes. A horse was used for pulling the trucks out to and in from the head of the incline. At the bottom end of the tramway the three rails were turned into two by a swinging rail, where it ran on to the embankment.

Two loading winches were used and six trucks. In front of the winch-loading stations timber ramps were placed, against which mullock was heaped to a gradual slope, allowing the stones to be easily dragged up to the edge, and dropped into the trucks. This obviated the necessity of pulling the truck back each time a stone was hoisted. For loading small stones shallow wooden skips were used on iron runners, a short chain being attached to each corner by means of which the skip was hauled up to the top of the ramp, and, the two front chains being detached from the hook, its contents were tipped into the truck as the winch continued to hoist the two rear chains.

The haulage rope for the tramway was of ⅝ inch galvanised steel wire, and was passed round two 4 feet wheels in the brake-house with 2 and 3 grooves respectively. The rim brake passed round the treble grooved wheel and was actuated by a lever screw and hand wheel.

To open up this No. 6 quarry a large amount of stripping had to be done, which when finished, left a working face 100 feet long, and 10 to 30 feet high. (These dimensions increased as the quarry advanced to 150 feet in length, and from 30 to 54 feet in height). The rock was of good hard quality, though much jointed by heads in every direction.

Quarries General.—The capacity of the trucks used in Nos. 1, 2, 3, and 5 quarries was 1.7 cubic yards. For convenience of loading, these trucks had only two side boards 8 inches deep, and no head or tail boards; laterly even the side boards were dispensed with. In the case of the No. 6 quarry the front end of the truck body was built 14 inches higher than the back, so that coming down the steep incline the truck bottom would be nearly horizontal. In addition it had a back and sides sixteen inches deep, giving an average capacity of 2.8 cubic yards.

Drilling.—The holes were at first taken down to 6 feet with hammers and drill (two strikers and one turner) and then continued with jumpers. It was found more economical, however, to continue the hole down to 10 and 11 feet before trying the jumpers, especially in No. 6 quarry, where the number of cross heads rendered the jumpers more apt to fitcher than the drills. The size of the steel used in the large holes was 1⅛ inches, ⅞ inch steel being used for "pops." The depths of the long holes usualy varied from 13 to 18 feet, and the burden put on them did not generally exceed 4 feet, though where the country was large, as in No. 1 quarry, 9 to 10 feet was used with economical results.

Close records were kept of the work, and detailed Cost Sheets made up every fortnight.

The following represents average working costs under fair conditions for the different quarries, exclusive of preliminray and capital expenditure.

QUARRIES.

	No. 1.	No. 2.	No. 3.	No. 5.	No. 6.
Total quantity dumped	5,680	4,010	5,520	1,450	16,340
Drilling and charging holes per cub. yd.	17·35	13·90	3·16	8·74	10·17
Drill Sharpening	3·16	1·64	1·52	2·70	3·41
Explosives..	2·53	2·75	3·22	·94	1·61
Trucking	12·63	17·92	13 27	8·18	10·17
Winch	3·48	3·03	2·91	2·53	3·75
Dumping	3·75	6·95	2·21	3·11	4·82
Administration	3·16	2·91	2·53	2·53	1·28
General Charges	6·95	3·92	3·79	5·69	3·75
Total	53·01	53·02	32·61	34·42	38·96
Feet drilled per cub. yard, broken ..	0·304 to 0·536	0·270 to 0·541	0·128 to 0·385	0·167 to 0·284	0·360 to 0·458
Pounds of Explosives, per cub. yd., broken — Gelignite	·127·085	·123·084	·023	·032	·040
Powder	—	·129	·315	—	—
Cheddite	·026	—	—	·029	—
Rack-a-Rock..	·077	—	—	—	·108
	3 Men.	3 Men.	2 Men.	2 Men and 3 Men	3 Men.
Feet drilled per set, per day	8·01 to 11·50	7.54 to 9·14	8 50 to 21·33	8·46 to 9·00	8·45 to 14·05
Cost of drilling per foot. Pence ..	35·95 to 25·00	35·00 to 31·51	22·59 to 9·00	28·35 to 26·65	34·10 to 20·48
Number of bits used, per foot drilled ..	4·45 to 8·07	—	—	2·89 to 3·81	2·60 to 5·05
Cost of sharpening, per bit	1·61d. to 2·47d.				

In explanation of these figures it should be remarked that they are from averages compiled each fortnight.

In the drilling figures, a hole being once pitched, a set of three men could drill from 12 feet to 15 feet, if there was no fitchering. With regard to explosives, powder could only be used in No. 3 and partly in No. 2, the rock elsewhere being too hard to bull the hole sufficiently large to receive a powder charge. Cheddite was tried, but proved unsuitable. Finally rack-a-rock was used with very satisfactory results in all the deep holes, being cheaper and breaking well to the bottom of the hole without shattering. In No. 5 quarry the shooting was exceptionally good, due to a number of parallel heads and floors.

9. *Walling.*—A gang of from three to twelve men, according to the size of the tip, built the front wall as the tips advanced.

Stones up to 2 tons in weight were used, those with flat surfaces being selected, packed into place with Trewhella jacks and wedged with "Spalls" to the proper angle as given by guide lines. Behind these front stones the interstices were packed with small rocks for a distance back of 10 feet.

The back of the embankment was left rough.

The walling cost from 3s. to 4s. per sq. yard, according to the size and shape of the stones and the state of the tip head.

10. *Concrete Facing Wall.*—A foundation trench was cut the whole length of the embankment, varying in depth from 10 feet to 4 feet, according to the depth of the water at the different points. Where hard and unfissured rock was met with only so much was shot out as was necessary to give the concrete a firm hitch; the surface of the rock being roughened to facilitate the bond.

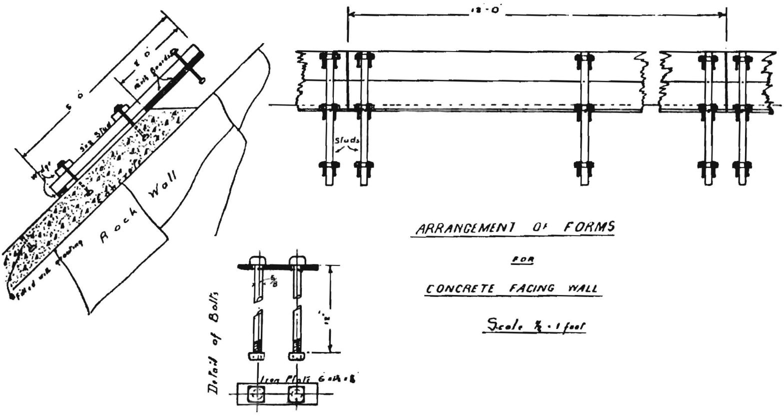

FIG. 4.

On the South side of the river and partly on the North the solid rock was intersected with floors and heads up to 1 inch in width, filled with soft material. These floors and heads were followed until they finally cut out, the cutting being about 12 feet deep and 40 feet long. This being completed the trench was filled in with rubble concrte of an average thickness of 18 inches along its whole length, and a start made on the wall proper at the bottom. The thickness at this point was 3 feet 6 inches and originally was to have decreased to 1 foot at the top, but when the wall reached to the 40 feet level it was decided to reduce the thickness there to 18 inches, decreasing to 6 inches at the top. At first the concrete was wheeled into place in barrows, the mixing plat being shifted further up the hill as the level of the concrete wall rose, but as the length of course increased this proved too expensive a method, and for that reason, and because it was desired to shut the sluice gate and conserve as much water as the increasing height of the concrete wall would allow the materials were centralised in a convenient place as high up as could be managed, and the mixture conveyed into place by a flying fox. This latter was entirely home made, $\frac{5}{8}$ inch steel wire ropes were spliced to give necessary length and anchored at convenient stations. The plat was fixed at about 50 feet from the South anchorage, and a derrick pole 30 feet high erected at the end of the plat. The carrying rope was then picked up by another $\frac{1}{2}$ inch rope passing through a single block at the end of the pole, thence down through a snatch block at its foot and round a crab winch barrel situated about 15 feet away. The buckets were built of wood and bound with iron straps underneath and at corners. and at one end a sheet iron lip was fastened in. The carrying pulleys were made out of two 5 inch snatch blocks, stiffened with a wooden distance piece. To the ends of the under frame was attached an endless $\frac{1}{2}$ inch hemp rope passing round a pulley at the far end and taking three turns round two winding wheels, above the plat, the main or driving wheel being fitted with handles. The bucket was picked up just below its centre of gravity by two 1 inch iron hangers fitting over 1 inch pins bolted to the sides on which it rotated when the catch was lifted.

Two buckets were used, one being filled while the other was travelling to and fro from the point of work. To change the buckets the catch was released, and the hangers slipped off the carrying pins.

The operation in conveying the material was as follows:— The wire carrying rope was first bowsed over by a hemp rope on the north side of the course to be filled until it hung directly over the work. Then the bucket being loaded and attached to the hangers, two men on the winch lifted the carrying rope until the bucket was clear of the plat, and at such a height that on reaching the other end it would be about 2 feet above the course, while the men on the windlass wound the hemp hauling rope out. On arriving over the point of work the winch was lowered by brake until the bucket was almost touching the small portable plat, 5 feet x 2 feet 6 inches, resting on top of the forms; the placing man then knocked the catch up, emptied the bucket, righted it, refastened the catch and signalled to return. The whole operation of running out 500 feet, emptying and returning took 2 minutes under fair conditions. Before placing the concrete the unevennesses of the wall were first packed out with flat-shaped stones to the proper distance shown by a gauge stick measuring from the inside of the forms. Owing to the small thickness of the wall, and to the fact that it lay in a batter of 1 to 1 the placing of the material so as to ensure a decent facing was a difficult matter. The forms were built of two 12in. x $1\frac{1}{2}$in. x 12ft. boards, cleated together by three 3in. x 2in. studs, 4ft. 6in. long. These studs were clipped and wedged to the proper line and angle in the following manner:—Holes were bored about 6 inches from the top of the upper board on each side of the studs, through these ⅝ inch bolts 12 inches long, were passed, nut end inwards, the heads being held together by a short piece of 1½ inch x ¼ inch iron plate with two holes, 3 inches apart, bored to receive bolts. Next day, while the concrete was still green, the bolts were turned slightly to prevent them adhering to the material; and as soon as the boards were ready to be lifted, they were unscrewed altogether and removed, leaving the nuts embedded. The boards were then pulled up bodily and the bolts replaced on each side of the stud. By this means the projecting end of each stud was held in place by two pairs of bolts with plates, and could be wedged tightly into position, while a third pair hung loosely in the boards ready to be built in. As the boards were raised the lowest pairs of bolts were removed, fitted with fresh nuts, and put on one side ready for use again. This made a very convenient and portable method of holding the boards; any method of scaffolding being out of the question owing to the slope of the wall and the means of conveying the material. Two men were employed continuously raising the boards where the concrete was set, while work was going on in another place; and the wall, as soon as the stone work was carried far enough forward was brought up in one long horizontal course, with the exception of one portion, 72 feet in length, which was always kept 4 feet lower to act as a bye-wash in case of flood.

Rubble was worked into the mixture in decreasing proportions as the thickness of the concrete lessened; the stones being kept 3 inches back from the inside of the boards. The proportion of rubble to the total mixture was 23 per cent. at the bottom of the wall, decreasing to 3 per cent. at the top.

The metal was hand broken, chiefly by piece work, to 1½ inch size, and cost from 6/- to 8/- per yard, according to the character and accessibility of the stone.

The sand was sifted in the first place through ¼ inch mesh sieves, but latterly the mesh was increased to ⅜ inch, costing from 2/6 to 1/6 per yard respectively; carting from pits to stock heaps cost 2/9 per cubic yard.

Mixing and placing cost 4/- to 6/- per batch in the lower courses, where the materials were handy and thickness was greater, and from 6/- to 8/- in the upper courses where the mixture had to be carried from a greater distance and the thickness was less. General charges, including raising of forms, breaking and placing packing stones where the stone wall was uneven or out of line, and alteration to hauling gear, etc., ran from 2/6 to 7/- per batch, Administration from 2/6 to 4/-;

cost of cask of cement landed on works, 24/-. The total price of concrete in place varied from 44/- to 52/- per batch, according to accessibility to the working course and the amount of packing, etc., required.

11. *Byewash.*—To allow for bye-washing when the dam filled an opening was left in the embankment 178 feet 6 inches long and 3 feet deep. This was levelled down and a concrete floor, 4 inchs deep, laid over it. On the down stream slope smaller rocks were wedged tightly in between the larger ones, and at the bottom an apron of rough rocks was left to prevent the water scouring out the backing to the embankment.

The bye-wash allowed for an overflow of 2,000 Tas. Sluice Heads with a depth, or head, of 14.6 inches, or 1,000 T.S.H. with a depth of 9.2 inches.

12. *Sluice Gate and Walkway.*—The valve was of the ordinary sliding gate type, and operated by gearing at the top of the main tower, to which it was connected by a 2½ inch valve rod. The main tower was built with 9 inch mine column cast-iron pipes, braced with 2½ inch angle irons. From the main tower a walkway, 84 feet long, extended to the embankment, supported at three intermediate points by braced angle iron towers.

13. *Miscellaneous.*—The number of men employed averaged 100 for six months, and 60 for the remainder of the actual building time. Labour was plentiful, and there was little difficulty in getting good men.

Cost sheets were made up every fortnight, and copied on to cards; costs per unit being run out at the same time.

The card system was used throughout, both for cost and progress, measurements, etc. In addition a progress plan was kept up to date as the work advanced.