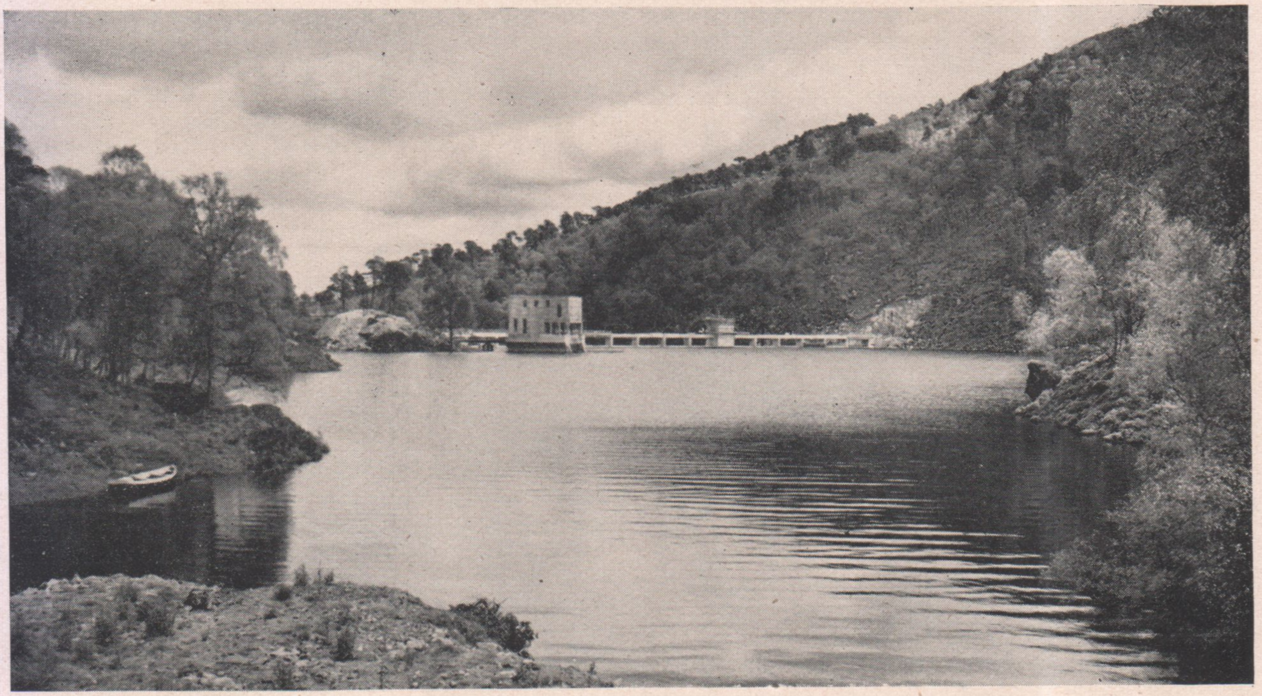

*Fig. 10. Benevean dam and intake viewed from upstream*

# The Glen Affric Scheme

## In this article we describe the construction of the Mullardoch-Benevean tunnel, the Benevean dam, and the Benevean-Fasnakyle tunnel.

PART TWO

THE Mullardoch-Benevean tunnel,* which, as stated in our previous article, is 5,738 yards long and of 15 ft. 9 in. equivalent diameter, falls 3 ft. from Mullardoch to Benevean, and is unlined except for a concrete invert throughout and full-section lining at the portals and at certain sections of weak rock. Owing to the local topography it was not feasible to construct adits, and the tunnel was driven from the two ends.

The equipment used at Mullardoch may be taken as generally representative of that employed at the Benevean face and also at the various faces in the Benevean-Fasnakyle tunnel. Compressed air was derived from three 850 cu. ft. per min. compressors delivering at 100 lb. per sq. in., surplus air being used as available on the dam. A 6 in. steel main with Victaulic joints led into the tunnel, and was provided with valves at suitable points, the face valve being carried forward continuously to enable air to be shut off rapidly in an emergency. Two 2 in. air hoses with Unicone couplings led to the drilling-carriage manifolds, from which 1 in. hoses led to the drifters. A 2 in. air-driven Hayward Tyler pump supplied water from the loch at high pressure to the drills. Ventilation was provided by a 3,500 cu. ft. per min. fan blowing through 18 in. ducting, reversible gates being fitted to enable blasting fumes to be extracted. A lighting supply was brought in at 440 V and was stepped down to 110 V at intervals of 1,500 ft. by 3 kVA transformers, 60 W lamps being disposed at intervals of 30 ft.

The rock was a tough and abrasive micaceous schist, ranging from pelitic to psammitic. In the earlier part of the contract, drilling was accomplished with Ingersoll Rand $3\frac{1}{2}$ in. jumbo-mounted drifters. The jumbo carriage ran on an 8 ft. gauge track, and incorporated a gauge ring to enable underbreak and overbreak to be observed immediately and the alignment of the ring holes adjusted accordingly. Hollow round drill steel of $1\frac{1}{4}$ in. diameter was used in conjunction with two types of cruciform detachable bit. The first type was screwed to fit into the end of the steel and could be sharpened three or four times, losing $\frac{1}{8}$ in. diameter each time. The later type had an internal corrugation which fitted over an oval spigot on the rod and locked itself on rotation. This bit could not be resharpened, but it was cheaper, the drill steel lasted longer, and it was easier to re-form the end of the steel when worn.

In the Mullardoch-Benevean drive trouble was experienced with the normal bits in certain sections of the rock, and a change was made to Atlas-Diesel equipment, consisting of light high-rotary-speed jack-

* A detailed account of the driving of the two tunnels on this scheme, but referring more particularly to the Benevean-Fasnakyle tunnel, was given in a paper, "The Mullardoch-Fasnakyle-Affric Tunnels" presented by G. G. Dillon, B.E., A.M.I.C.E., to the Institution of Civil Engineers on February 28, 1950.

hammers mounted on pneumatically extending legs and using tungsten-carbide-tipped Swedish drill steels. During the seven months in which this equipment was used, the average rate of advance was 7½ per cent. greater than during a similar period immediately prior to its adoption, but this is not regarded as a reliable comparison because the type of rock encountered varied considerably. It would have been possible to have saved six men on the drilling crew, but as the same men did the mucking the number was reduced by only three to avoid disorganising this operation. A saving in air consumption was secured of roughly 50 per cent. In the case of a face equipped from the outset on this system a light drilling carriage can be used which is cheaper and can be handled more easily than the normal heavy jumbo, but in this instance the jumbo originally used for the drifters was retained.

The drilling round was 9 ft. in depth and consisted of 57 holes arranged with a five-hole burn cut and 1 sec. delays up to a maximum of 9 seconds, giving an average pull of 8 ft. Polar ammon-gelignite A was used as the explosive for most of this drive, the amount varying considerably according to the rock encountered, but in the latter stages a large proportion of dynamite had to be used.

Mucking was accomplished by two Eimco shovels loading into 2 cu. yard skips which were withdrawn in rakes of six by Simplex diesel locomotives.

In several sections of the tunnel the rock was faulty and a lining had to be inserted. Most of these sections were lined with concrete, but two sections had to be supported by steel arches in addition to the concrete lining.

A view of the intake portal taken just before ponding commenced appears in Fig. 11. At a distance of 330 ft. from the intake portal a 120 ft. gate shaft was sunk and equipped with a 10 ft. × 11 ft. free roller control gate and a 10 ft. × 11 ft. 10 in. free rolling emergency gate. Both these gates are electrically operated and were supplied by Glenfield & Kennedy Limited. Immediately upstream of these gates is a venturi section designed to function in conjunction with a British Pitometer instrument to indicate and record the flow through the tunnel.

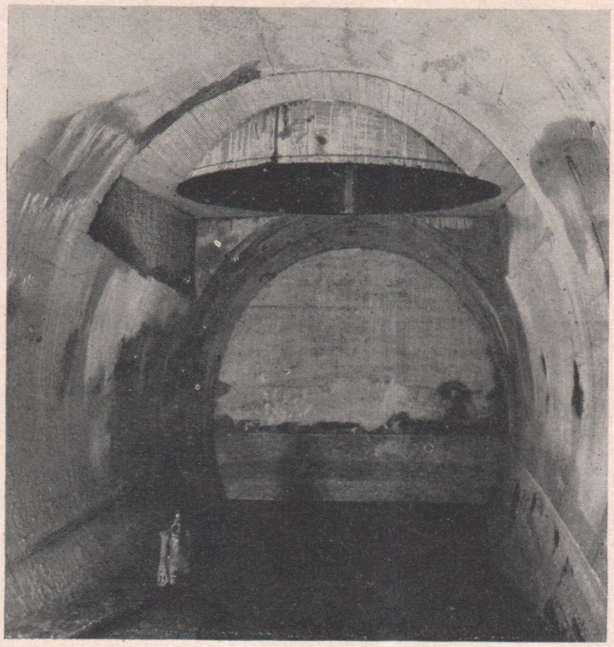

*Fig. 12. Discharge tunnel and turbine draught tube of Mullardoch subsidiary generating station*

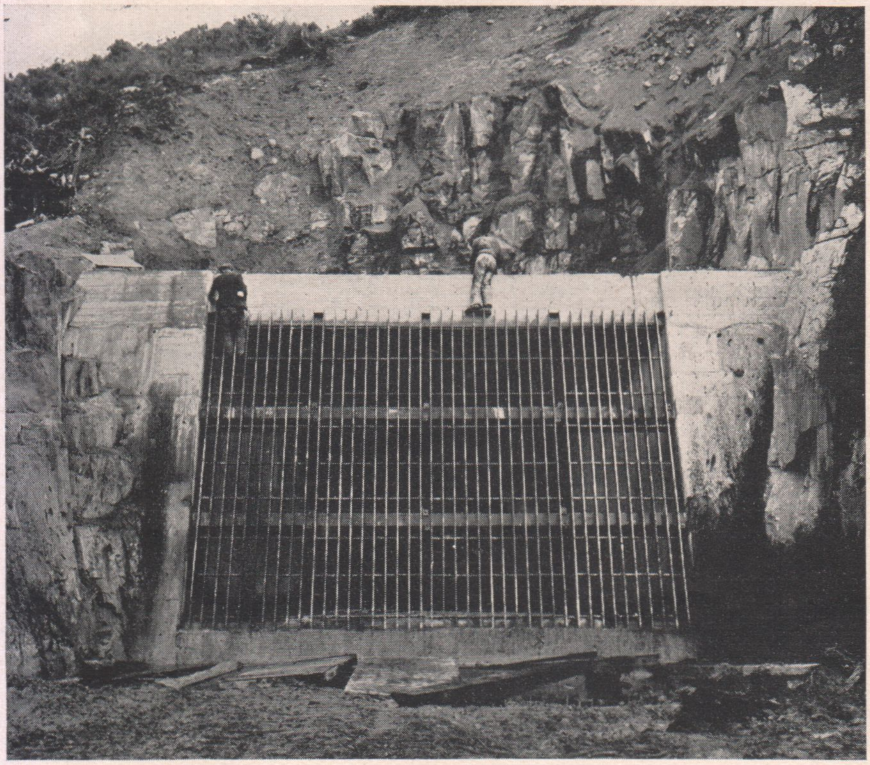

*Fig. 11. Mullardoch tunnel intake portal before ponding*

In order to make use of the difference in level between the two lochs—about 80 ft.—an underground subsidiary generating station is being constructed near the tunnel intake. The intake for this station is 200 ft. downstream of that of the main tunnel, and is of rectangular section with a semicircular roof, 10 ft. wide by 9 ft. 5 in. high. A venturi section is incorporated. On the discharge side the tunnel has been made of the same section as the main tunnel, enabling the same driving equipment to be used, and both tunnels have been concrete lined up to a point beyond the junction. A 20 ft. by 12 ft. access and gate shaft has been sunk to the power-house chamber, which is 32 ft. long, 26 ft. wide and 25 ft. high.

A vertical Francis turbine by Gilbert Gilkes & Gordon Limited will be installed here, flexibly coupled through gears

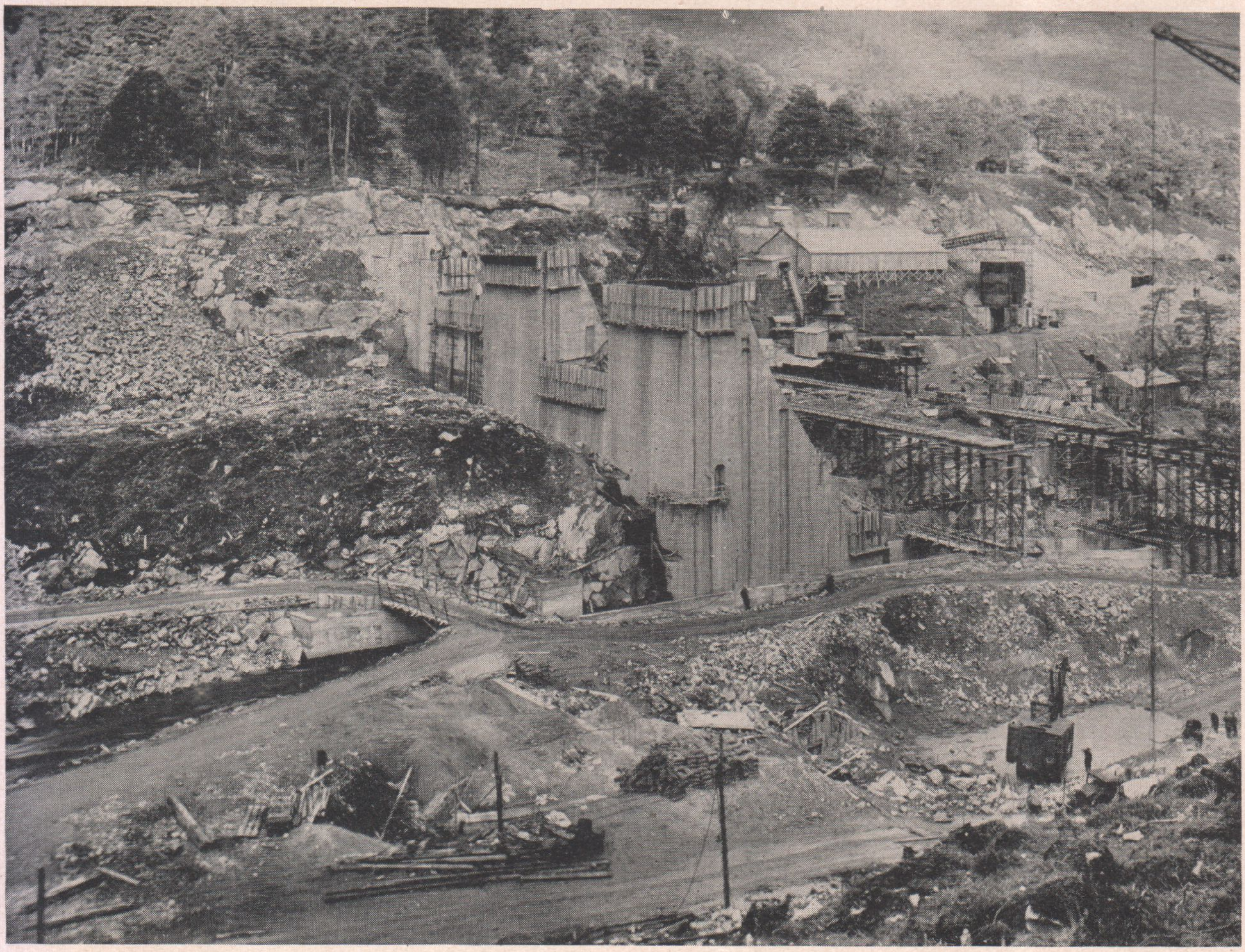

*Fig. 13. Benevean dam in the early stages of construction, showing the river diversion and excavation of the original channel in progress. The batching plant is on the far hillside to the right*

to a horizontal Bruce Peebles induction generator of 2,400 kW capacity—believed to be the largest machine of this type to be installed in this country. All mechanical and electrical controls for this set will be brought up to the winch house at the top of the access shaft.

Seeing that the main tunnel will be flooded for some considerable time before this station is ready, measures have been taken to isolate the station until it is complete. Over the mouth of the station intake a rectangular reinforced-concrete bulkhead has been fitted. It is temporarily latched in position and will be secured by the outside water pressure when the loch is filled, but it is inclined forward so that it will drop out when the intake tunnel is flooded. On the discharge side the draught tube, which is of steel, is fitted with a blank flange which can be dropped when desired.

The main tunnel outfall at Loch Benevean is arranged so that the tunnel can be drained for inspection, and to this end it is equipped with a Glenfield & Kennedy 10 ft. by 14 ft. 1 in. fixed roller gate with hand operating gear and incorporates a pump shaft communicating with the tunnel just behind the gate. A screen protects the offtake to the pump shaft, and four Beresford 120,000 g.p.h. portable submersible pumps are held at Fasnakyle power station.

**Benevean Dam**

Benevean Dam is 582 ft. long and 125 ft. high from cut-off trench to spillweir; is of the mass-concrete gravity type and involved the excavation to payment lines of 20,000 cu. yards of rock and the placing of 54,000 cu. yards of concrete. Drawings of the dam are given in Fig. 14, and various views in Figs. 10, 13 and 15. The spillway extends the entire width of the dam, except for the gatehouse, and as in the case of the Mullardoch dam, the final design of the spillway channel and stilling pool was determined by model tests. A series of steps controls the flow of water to the stilling pool, which is provided with two longitudinal weirs and a transverse weir, as seen in Figs. 14 and 15. A 6 ft. scour culvert is incorporated in the dam opposite the stilling pool, and is equipped with a 72 in. to 60 in. needle valve with jet disperser and an electrically operated free rolling emergency gate, 6 ft. span by 7 ft. deep. Compensation water is bled off from the scour culvert by an 18 in. electrically operated control valve. All this equipment is of Glenfield & Kennedy manufacture.

Some care was needed in preparing the dam foundations because a zone of shattered ground was found on the south side, and the rock in the river bed was open jointed and liable to shattering when blasted. The cut-off trench ranged from 5 ft. to 10 ft. deep,

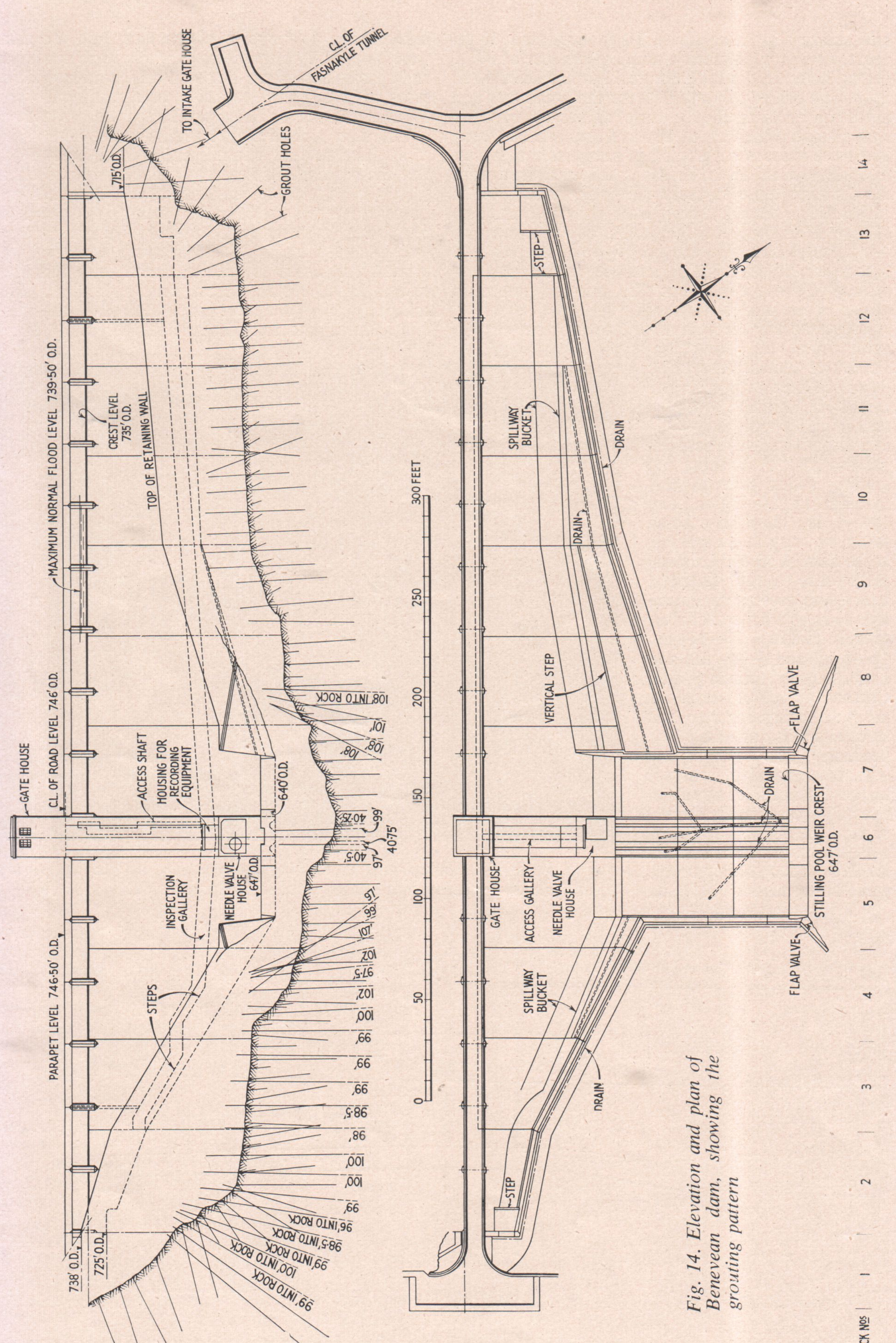


*Fig. 14. Elevation and plan of Benevean dam, showing the grouting pattern*

and primary grouting holes, 10 ft. deep and 10 ft. apart, were grouted under a nominal pressure of 10 lb. per sq. in. to fill the open fissures. Further holes 40 ft. deep were drilled midway between the first series and piped up through the concrete as the foundations were placed. When about 10 ft. of concrete had been laid these holes were grouted at pressures ranging up to 75 lb. per sq. in. In the river bed and throughout the shattered zone on the south bank, inclined holes 100 ft. deep were set down from the upstream step of the cut-off trench and grouted at 120 lb. per sq. in. —a value greater than the final hydrostatic pressure. Altogether, upwards of 50 tons of cement was expended in these operations. The grouting pattern is shown in the dam elevation in Fig. 14.

Aggregate for the dam was derived from suitable spoil from the Benevean-Fasnakyle tunnel. As will be described later, two adits were driven in opening out the tunnel, and a spoil dump was established midway between the two adits. A crushing and grading plant reduced this material to $2\frac{1}{2}$—$1\frac{1}{2}$ in. and $1\frac{1}{2}$—$\frac{3}{16}$ in., these sizes being taken by lorry to a stockpile at the dam. A second crushing plant—also to be described later—was erected at Fasnakyle to treat a deposit of river gravel, making $2\frac{1}{2}$—$1\frac{1}{2}$ in., $1\frac{1}{2}$—$\frac{3}{4}$ in. and $\frac{3}{4}$—$\frac{3}{16}$ in., and a crushed sand (minus $\frac{3}{16}$ in.). Crushed gravel was used for the 4 : 1 facing concrete and tunnel spoil for the 7 : 1 hearting.

A batching plant was set up on the north bank of the river a little way downstream of the dam, and was equipped with two 1 cu. yard Stothert & Pitt mixers. A Bailey bridge was built across the site immediately downstream of the dam, and the skips were handled by a travelling derrick on the north side and a steam derrick on the south side. Bottom-opening skips of 2 cu. yard capacity were used, and were brought from the batching plant by diesel locomotives.

The dam was divided into 14 blocks, nine being 45 ft. long and the others ranging from 20 to 51 ft. and the system of shuttering and general procedure were similar to those employed at Mullardoch. Low-heat cement was used for the north side of the dam, but owing to rising costs, ordinary Portland cement was used for the south side. The speed of placing was carefully regulated to prevent the mass temperature rising above 100°F. Great care was taken with scabbling. At an optimum period after placing—which ranged from 4 to 15 hours with the Portland cement

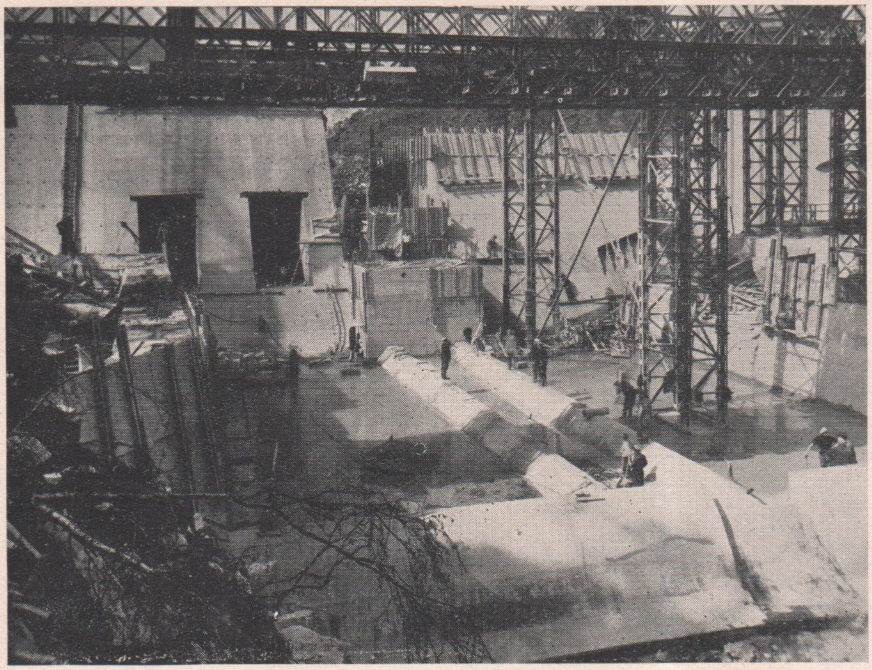

*Fig. 15. View of the Benevean dam, looking upstream, showing the temporary openings and the completed stilling pool in the foreground*

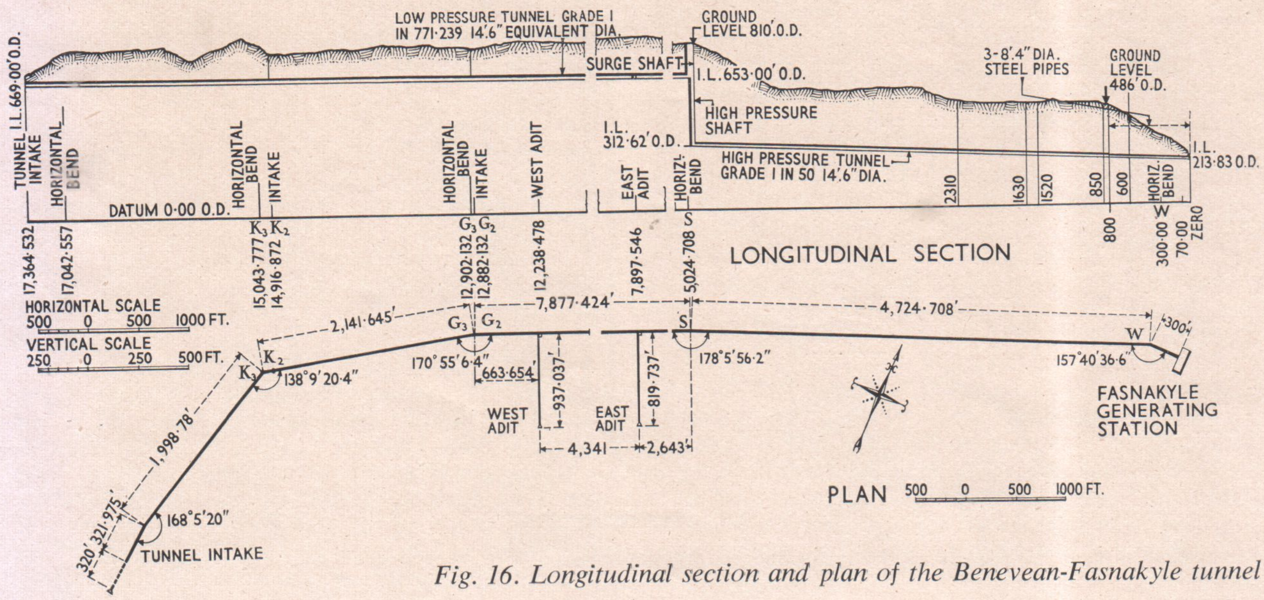


*Fig. 16. Longitudinal section and plan of the Benevean-Fasnakyle tunnel*

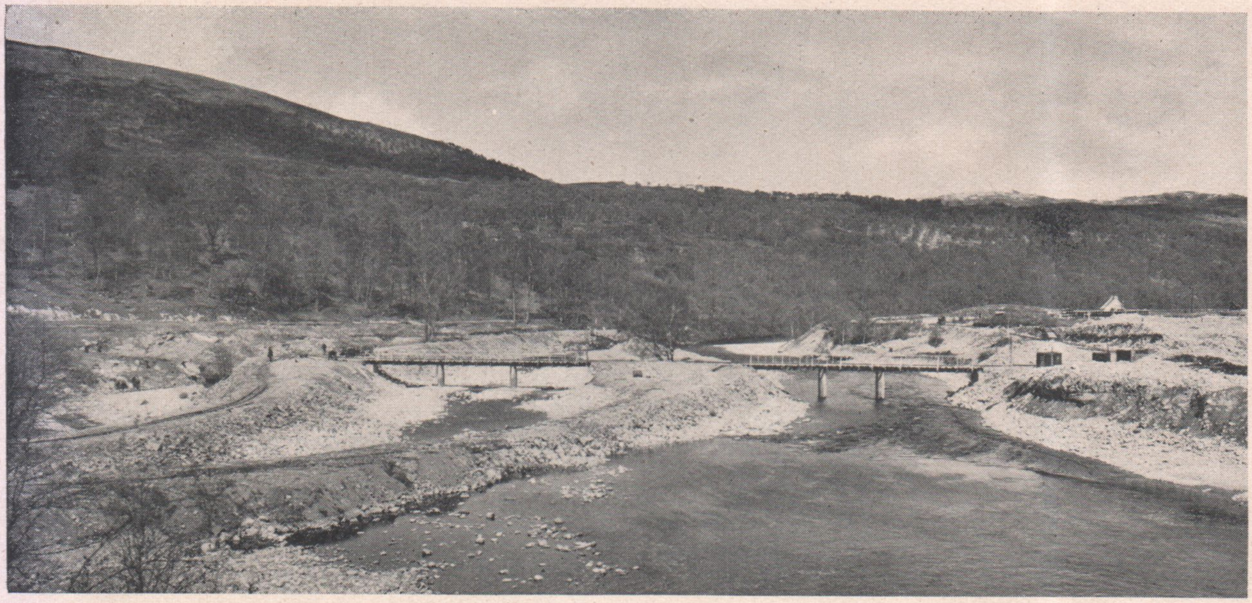

*Fig. 17. Downstream view of the river diversion at Fasnakyle. The site of the generating station is on the extreme left, and that of the crushing and dry-batching plant off the picture to the right*

and from 6 to 24 hours with the low-heat cement—the surface was thoroughly scoured with high-pressure hoses, and brushed until the exposed aggregate was completely cleared of cement. The use of picks was discouraged in order to avoid a layer of shattered concrete. Before placing the next lift a ½ in. layer of 2 : 1 cement mortar was laid over the surface. This care was justified by the event, for when the loch was filled the dam showed no sign of seepage.

The northern half of the dam, comprising blocks 9 to 14, was carried up first, as it was clear of the river and stood on satisfactory ground. To enable blocks 5, 6 and 7 spanning the river to be commenced a diversion channel was formed through the site of block 8. Three temporary openings were left, two in block 5 (see Fig. 15) and one in block 7, and the scour culvert was set in block 6, the river then being diverted back through these openings to enable block 8 to be proceeded with. Finally, during a dry, frosty period, one of the openings was closed in the dry, the others being sealed by temporary gates while they were being filled in.

**The Benevean-Fasnakyle Tunnel**

A plan and section of the Benevean-Fasnakyle tunnel are given in Fig. 16. A low-pressure section, of 14 ft. 6 in. equivalent diameter, extends a distance of 12,340 ft. to a vertical shaft, 341 ft. deep, leading to a circular high-pressure tunnel, 14 ft. 6 in. in diameter, 4,224 ft. long, and falling at a gradient of 1 in 50. A surge shaft 150 ft. high and 45 ft. in diameter surmounts the vertical shaft. Finally, the high-pressure tunnel divides into three steel-lined tunnels, each 800 ft. long and 8 ft. 4 in. in diameter leading to the three generating sets.

Two side-stream intakes communicate with the low-pressure section of the tunnel, and a third stream discharges into the surge shaft.

Work on the low-pressure section was greatly expedited by the construction of two adits at 5,126 ft. and 9,582 ft. from the intake respectively, and by opening up two faces from the west adit and one face, travelling east, from the east adit. Thus, including the drive from the intake, there were four faces at work in the low-pressure tunnel and one in the high-pressure tunnel (disregarding the three pipe tunnels) which was driven from east to west, the longest single drives being the high-pressure tunnel and the low-pressure section between the west and east adits.

Shafts were driven 120 ft. upwards to form the side-stream intakes, and on the site of the surge shaft a 9 ft. square pilot shaft was sunk and the surge shaft glory-holed out to full diameter when the drive from the east adit had been completed. The shaft between the low-pressure and high-pressure tunnels was cut by a combination of sinking and driving upwards.

The equipment for driving the tunnels was generally similar to that employed for the Mullardoch-Benevean tunnel except that drifters were employed throughout.

Some care was needed in cutting the entries of the three high-pressure pipe tunnels, because they passed imediately below the Cannich Glen-Affric road, which had to be kept open. Working space, also, was restricted by the proximity of the generating-station site, and it was necessary to run the 2 ft. gauge service tracks along the intervening space between the road and the station site, curving the tracks at a small radius to enter the tunnels.

In order to lay the foundations of the generating station the river had to be diverted, and cofferdams were built to direct the river into a temporary channel cut to the right of the normal bed, as seen in Fig. 17.

Unlike the Mullardoch-Benevean tunnel, the whole of the Benevean-Fasnakyle tunnel has been lined. In the low-pressure section the lining is 2 in. over points and 8 in. to payment line, and in the circular high-pressure section 10 in. over points and 16 in. to payment line. Originally a thin steel lining was considered for the high-pressure tunnel, but it was feared that in the event of the tunnel being dewatered, any hydrostatic pressure that might have built up around the tunnel might collapse the lining. Seeing that the rock was a sound mica schist it was decided to rely on it for impermeability and strength assisted by a comparatively thin concrete lining and by grouting. For the last 700 ft. from the power station the rock cover decreased rapidly, and it is at 100 ft. upstream of this point that the tunnel has been trifurcated, each limb being provided with a steel lining capable of withstanding all possible internal and external pressures.

Material for the concrete lining of the high-pressure tunnel was obtained from a gravel deposit on the right-hand bank of the river, and a crushing and grading plant was set up on the bank opposite to the power-station site. A Ruston-Bucyrus 37B shovel was used to dig the gravel, which was crushed to produce a graded aggregate $2\frac{1}{2}$ — $1\frac{1}{2}$ in., $1\frac{1}{2}$ — $\frac{3}{4}$ in. and $\frac{3}{4}$ — $\frac{3}{16}$ in. and a washed sand (minus $\frac{3}{16}$ in.). A batching plant was set up adjacent to the crushers, the dry batches being taken to the tunnel over the temporary bridges seen in Fig. 17 and mixed in two 1 cu. yard mixers located just outside the tunnel portals. Sand and crushed gravel for part of the Benevean dam were also obtained from this source.

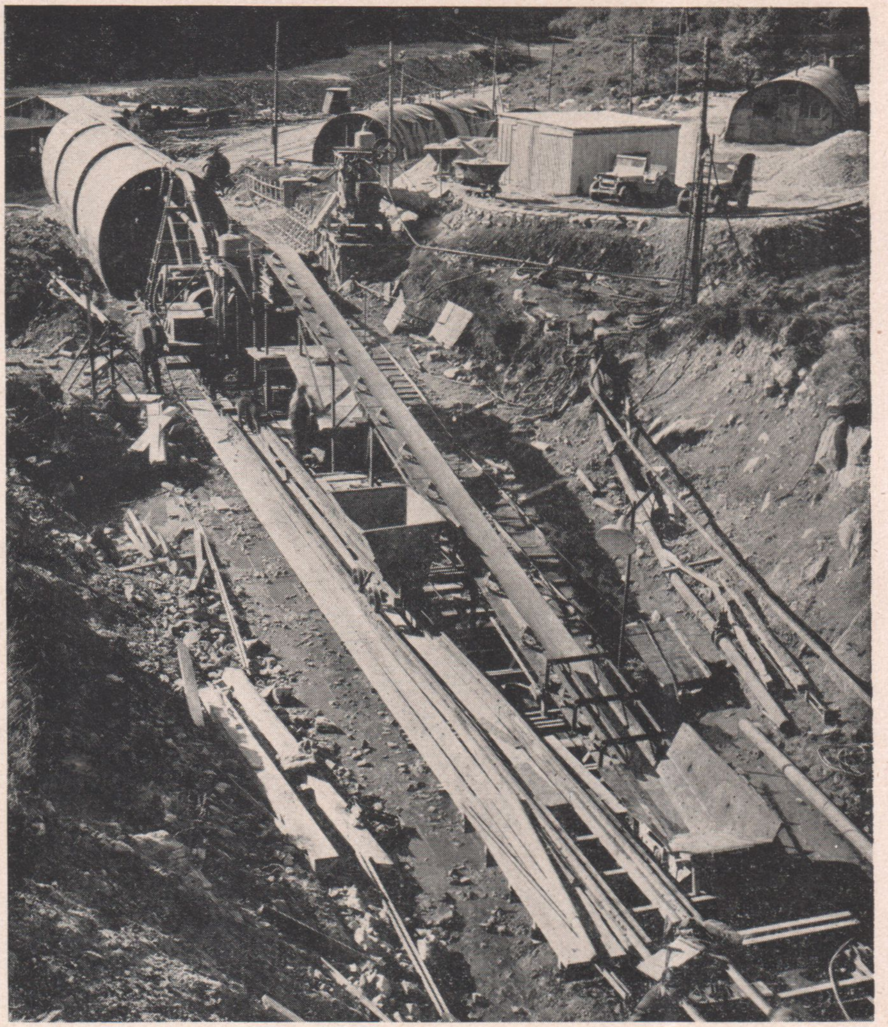

*Fig. 18. Travelling shutter, Pressweld placer and concrete plant assembled outside the Fasnakyle tunnel*

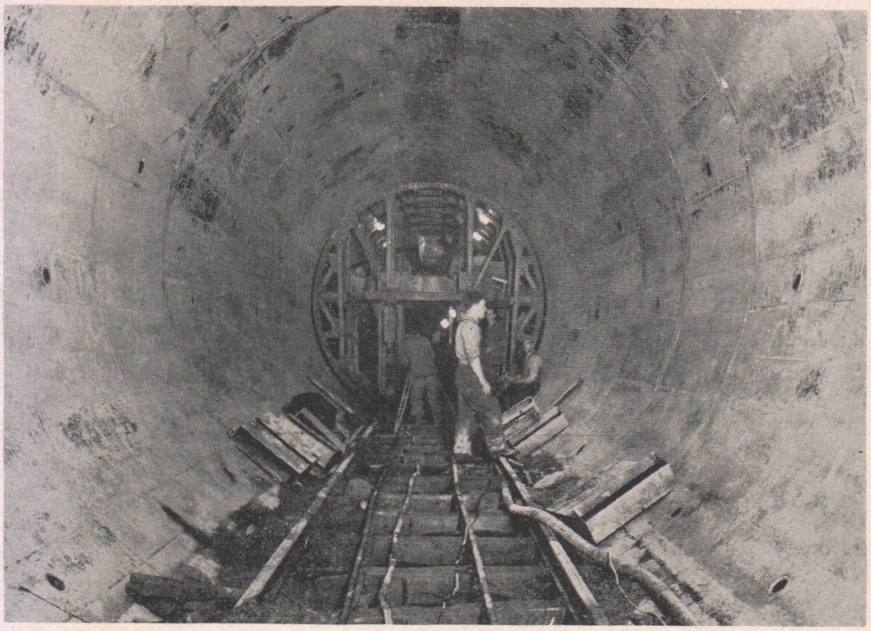

*Fig. 19. High-pressure section of Fasnakyle tunnel being lined. Note the grouting holes in the tunnel walls*

Aggregate for the lining of the low-pressure section of the tunnel was derived from the spoil heap and crushing plant which, as mentioned in our previous article, were established midway between the east and west adits, and provided graded psammitic schist for the Benevean dam and the road diversion. For the tunnel lining a batching plant was erected adjacent to this crushing plant, the dry batches being taken in skips by diesel locomotives through either the east or the west adit according to circumstances.

Fig. 18 is a view of the equipment used to line the low-pressure section of the tunnel, consisting of a travelling steel shutter, a Pressweld placer, a 1 cu. yard mixer, and a conveyor belt. The shutter, designed by Cyril

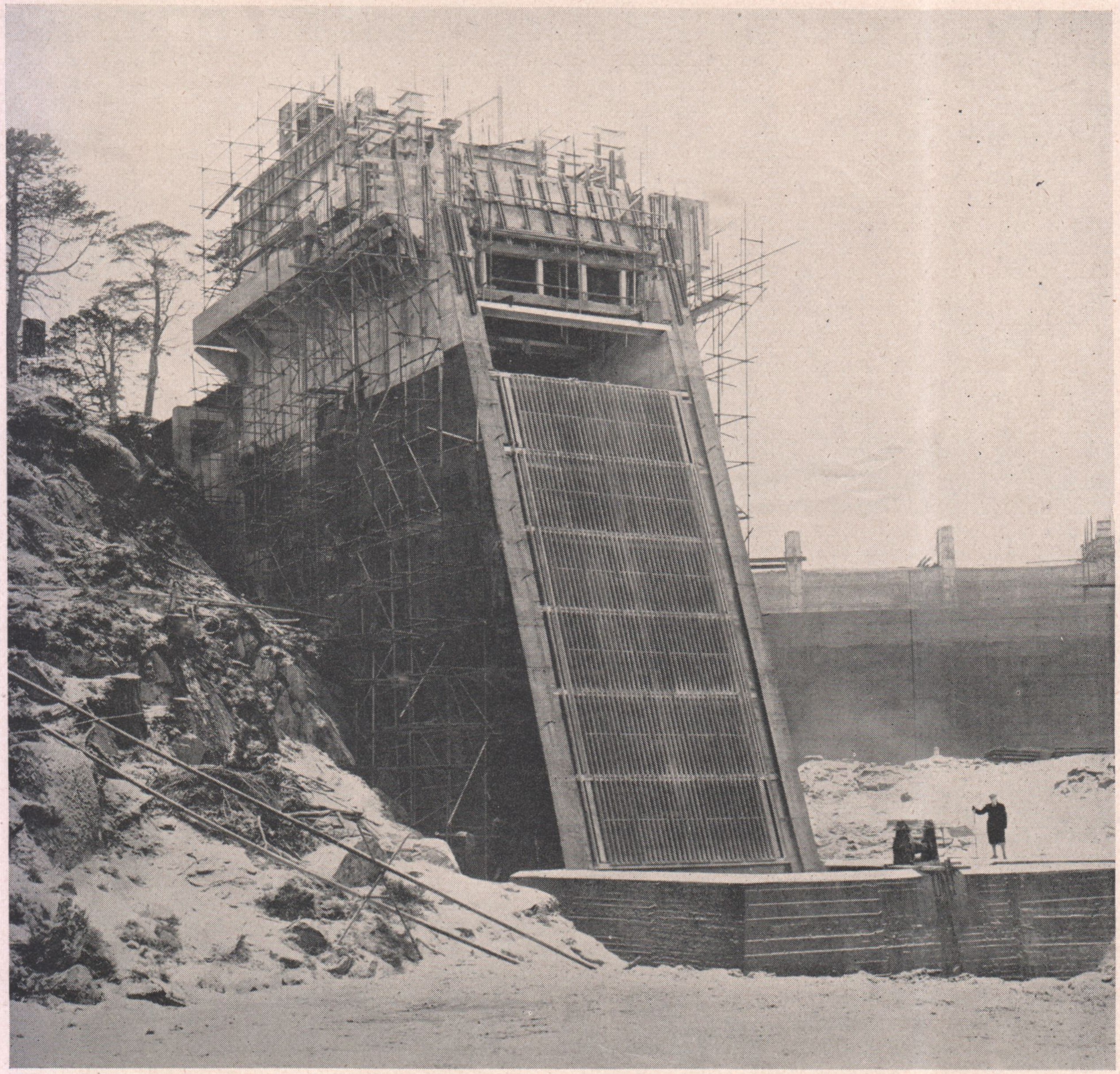

*Fig. 20. Fasnakyle tunnel intake structure, showing the gatehouse under construction. Benevean dam can be seen in the background*

Parry, was 85 ft. long and set the sides and arch in one operation. The invert was cleaned by hand in advance of the shutter and a rough layer of concrete placed to carry the shutter sleepers, the invert itself being placed after the shutter had passed. To save time, all these operations proceeded simultaneously in different parts of the tunnel.

One of the most interesting features of the lining operation was the introduction of the Pressweld placer. Dry mix for a cubic yard of 4 : 1 concrete, having a maximum aggregate size of 1½ in., was tipped into the boot of the conveyor and transferred thereby to the mixer, which discharged the completed mix to the placer. From the placer a 6 in. steel pipe extended over the crown of the shutter, as seen in Fig. 18, and the concrete was blown through this pipe by compressed air, lightly vibrated to induce flow off the crown of the shutter, and punned through side hatches. Mr. Dillon, in his paper referred to earlier in this

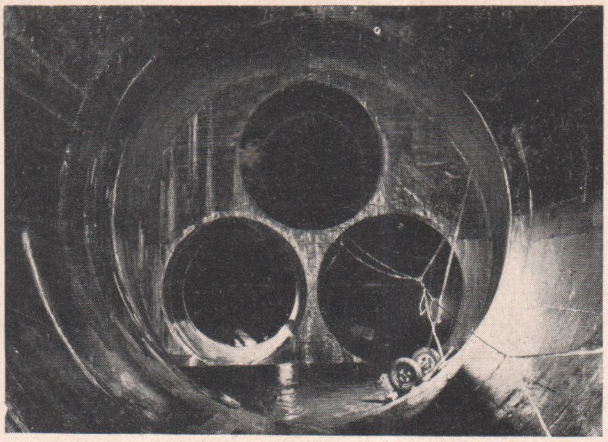

*Fig. 21. Trifurcation point and bellmouths of the high-pressure pipes in Fasnakyle tunnel*

article, stated that the machine was capable of placing up to 30 cu. yards of concrete per hour and required about 1,000 cu. ft. of compressed air per minute at a pressure of 100 lb. per sq. in. He also gave the cleaning and setting time for the shutter as four to five hours, the placing time as six hours, and the striking time as 18 hours. The desirability of reducing the striking time was considered to be evident.

Lining proceeded from the intake portal to the east adit, after which the equipment was turned round and the lining completed from the surge shaft to the east adit, this reversal being necessary to keep the conveyor boot addressed to the transport from the adits.

Concrete for the surge shaft and high-pressure shaft was also batched at the inter-adit plant, mixed at the foot of the surge shaft, and hoisted or lowered as required. The shuttering followed normal practice.

For lining the high-pressure tunnel similar equipment was used to that for the low-pressure tunnel, but the procedure differed in some respects. First, the sides were cleaned by hand and curb walls placed to take rails for a travelling bridge. This operation proceeded upstream from the trifurcation point, and cleaning and concreting took place simultaneously. The travelling bridge just mentioned was then erected to place the concrete for the invert; it was 150 ft. long and carried a double track. Work proceeded downstream from the high-pressure shaft, and was carried out in steps of 150 ft. corresponding with the length of the bridge. The invert was cleaned and concreted to 34° on either side of the vertical centre-line, the concrete surface being shaped by a 5 ft. drag screed carried under the bridge.

When the invert was complete, a track was laid on it to carry the travelling shutter and the Pressweld placer, but in this case a conveyor belt was not required as the travelling bridge used for the previous operation was available to bring the skips over the placer. The shutter for this tunnel was 60 ft. long and took its location from the invert.

One of the objections that have been advanced against the Pressweld placer is that the concrete is not placed horizontally but follows its angle of repose. In consequence, it is contended, there is a risk of segregation of the aggregate and of the formation of cold joints. Whether this objection is valid in practice is as yet a subject of controversy, but in order to avoid any risk of trouble on this score, the concrete in the high-pressure tunnel up to the horizontal centre-line was placed by hand, the remainder being placed by machine.

The final operation was grouting, which was carried out by the Cementation Co. Ltd. At longitudinal intervals of 5 ft., eight steel pipes, 12 in. long and 2½ in. in diameter, were placed in the concrete. The roof was cavity grouted immediately upon completion, and alternate grouting tubes were drilled through to a depth of 10 ft. and left to bleed for one month, after which they were grouted at 100 lb. per sq. in. The remaining holes were then drilled to a depth of 14 ft. and three months after the concrete had been placed were grouted at 300 lb. per sq. in.—a value greater than the hydrostatic pressure.

At the trifurcation point the tunnel was belled out to 24 ft. diameter and the mouths of the three steel-lined tunnels brought out on 120° axes, as seen in Fig. 21. A gully was formed in the floor of the bell-mouth leading to three 12 in. scour pipes.

The steel lining for the tunnels is 1¼ in. thick and was supplied in 8 ft. 9 in. lengths with treble-riveted butt joints by P. & W. Maclellan Limited, these lengths being welded together in pairs on site to form 17 ft. 6 in. strakes. An electric winch was located at the trifurcation point to draw the strakes in on bogies, concrete stools having been previously set to locate the strakes. An internal chamfer was cut on the ends of the pipe sections, and a watertight joint was made by caulking the chamfer with Philplug and covering it with a ⅜ in. by 3 in. steel strap which was fillet welded to the pipe wall on each side. The concrete stuffing was then filled in round the pipes. At the station the steel linings were carried forward from the tunnel portals to the station substructure, and were subsequently buried in concrete. Finally, the pipe interiors were shot-blasted and sprayed by Schori Metallising Process Limited with a layer of zinc and a layer of aluminium, followed by one coat of Bowranite bitumen red-lead paint and two coats of Super Black Finishing bituminous paint.

Returning to the intake end, the intake structure is built out into the loch, as will be seen from Figs. 10 and 20. A silt wall protects the toe of the structure, and a coarse screen of 20 ft. span by 87 ft. 6 in. deep covers the intake opening. Behind this screen is a fine screen 19 ft. span by 80 ft. deep, and both screens are provided with electrically operated rakes discharging to hand-propelled skips. A 12 ft. span by 15 ft. deep free rolling emergency gate followed by a free roller control gate of similar size control the entry of water into the tunnel. All this equipment was supplied by Glenfield & Kennedy Limited.

As already mentioned, one of the side-stream intakes flows directly into the surge shaft, but for each of the other two intakes a small dam has been thrown across the stream concerned, and the water taken through a screen to an offtake chamber on one side of the water-course. A syphon in this chamber transfers the water through a feed pipe to a vortex chamber immediately above the tunnel, a loop being introduced into the feed pipe near the syphon to aid priming. To remove any entrained air from the water before it enters the tunnel, the water is introduced tangentially into the chamber so that it forms a vortex; a vent pipe is taken from the roof of the chamber to the surface, and an aperture in the centre of the floor discharges the water to the tunnel.

Each of the adits is closed off from the tunnel by a concrete plug containing an access pipe which is normally blanked off. Provision is made at the two adits to accommodate the equipment required for flow measurement by the salt-velocity method when turbine efficiency tests are made.

*(To be continued)*

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**Hydro-Electric Projects in North Wales.** In our issue of May 1952, page 169, we gave particulars of the various proposals placed before Parliament by the British Electricity Authority to extend existing hydro-electric works at Dolgarrog and Maentwrog and to construct a new scheme in the vicinity of Blaenau Festiniog. It should be added that these projects are being engineered for the British Electricity Authority by Messrs. Freeman, Fox & Partners in association with Messrs. James Williamson & Partners. At the moment of going to press the Bill is in the Committee stage following the second reading in the House.