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Geology and related activities in the construction of Batu Dam, Kuala Lumpur

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Abstract: The construction programme of Batu Dam was started in July 1984 and completed in the middle of 1987. The dam and its various structures (embankment, outlet works, spillway etc.) are founded on the decomposed to fresh Hawthornden schist of Silurian age with the foliation dipping steeply downstream.

Rock bolt, concrete buttress and removal of overhangs are measures taken to stabilise the unstable rock slopes.

Various types of instruments (e.g. vibrating-wire piezometer) are installed at Batu Dam to monitor the performance of the dam embankment, foundation, abutments and structures during the construction and after the completion of the dam.

The grouting works consist of blanket and curtain grouting ranging in depth from 6.5 m to 40 m. The original design required a one row curtain grouting for the right abutment and a three row curtain grouting for the river valley, left abutment and spillway area. The conditions encountered necessitated minor changes to the hole layout.

INTRODUCTION

Batu Dam (Fig. 1) is situated approximately 20 km north of Kuala Lumpur.

The site investigation was started in 1975. Various design studies had been carried out since then, and the final design investigation was commissioned in early 1981 and ended in September of the same year. The construction programme was started in July 1984 and was completed in the middle of 1987 (Saim Suratman, 1987).

The Batu Dam is a multizoned earthfill dam with a central core zone (Fig. 2). The dam and its various structures (outlet works, spillway and stilling basin) are founded on quartz-mica schist with foliation dipping downstream at approximately 60°. This Hawthornden schist, of Silurian age is in sharp contact with granite immediately upstream as seen on the reservoir road cut-slope.

Instrumentation are installed to monitor the performance of the dam embankment, foundation, abutments and structures during construction, reservoir filling and subsequent operation. These instruments give information on pore-water pressures, vertical and horizontal movement, and seepage through the embankment.

The foundation grouting works were divided into blanket and curtain grouting (Baker, 1982; Saim Suratman, 1985; U.S. Dept. of the Army, 1984; U.S. Dept. of the Interior, 1984; Water Resources Commission N.S.W., 1980). The blanket grouting is carried out in areas which require it and the curtain grouting with a maximum of three lines in the river valley, left abutment and spillway area, and one line on the right abutment. All grouting was performed using split spacing method.

CONSTRUCTION GEOLOGY

The dam, is founded on schist with schistosity dipping downstream. This schist is in various degrees of weathering, from completely weathered to fresh. Two major lineaments were indicated by aerial photographs to cut across the dam site but none of them were found on the ground (Batu Dam Monthly Geological Report).

In the river valley, the weathering is deep with the fresh schist horizon found at an approximate depth of 20 m. On the left abutment, the fresh rock appears at a shallower depth but is much deeper in the right abutment.

Embankment

The core zone and the upstream foundation of the embankment are founded on weathered as well as to fresh schist while the downstream foundation is on an alluvial gravel layer.

For the core zone and upstream foundation in the river valley and the right abutment, the foundation is mostly completely to highly weathered schist with occasional zones of moderately weathered materials. On the left abutment the embankment is founded on rock consisting of moderately weathered to fresh schist. Several fresh quartz and decomposed granite dykes cross-cut the

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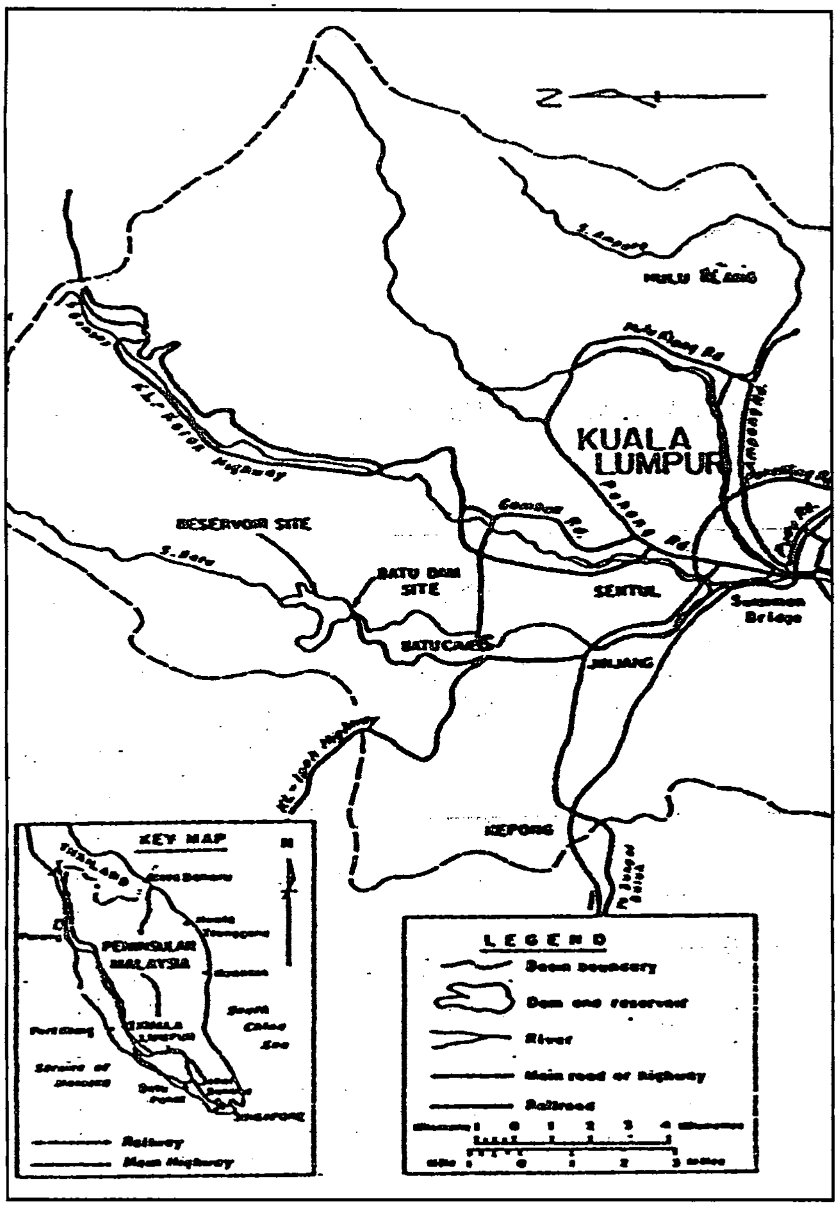

Figure 1. Location map.

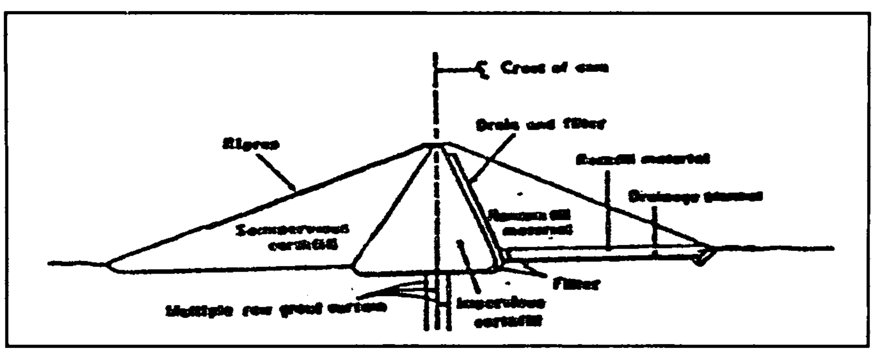

Figure 2. Typical section.

embankment foundation. Most of the quartz dykes are pervious and vuggy. The vugs are normally stained by iron oxide and filled with clayey to silty materials.

The downstream foundation of the embankment consists mainly of alluvial gravel layer except on the river channel and the right abutment. In these two areas, the embankment is founded on completely to highly weathered schist.

The right downstream blanket foundation consists of completely to highly weathered schist. Black graphitic bands provide excellent marker beds. The foundation of the upstream slope of the right abutment consists of either clayey silty slopewash or intensely weathered schist.

Outlet works

The schist forming the foundation of the outlet works on the left abutment is moderately weathered to fresh. Localised intense weathering is found on the downstream part of the foundation. In the outlet works inlet area, the excavation to the fresh rock is very deep due to the alteration in the schist by the granite intrusion nearby.

Several quartz dykes cross-cut the foundation. Normally, areas adjacent to the quartz dykes are highly silicious but quartz dykes on the downstream portion of the embankment are partly sheared. Stress relief joints run along the left wall of the inlet area and the right and left walls of the outlet channel. Such features dictates deeper excavation for the latter.

Three sets of closely spaced joints and stress relief joints formed potential wedge failure surfaces. Usually these joints are tight but occasionally they are opened or infilled by clay materials. The stress relief joints normally have clay-silt and schist fragments filling.

Spillway

Stress relief joints appear on the left and right slopes of the spillway excavation. These joints control the depth of excavation in a few parts of the foundation.

The spillway is located mostly on fresh schist but at the downstream end, the foundation is on moderately weathered schist with a few intensely weathered pockets. Quartz and granite dykes are also present.

The stress relief joints together with the closely spaced joints create potential slope instability.

Stilling basin

The foundation of the stilling basin consists of fresh schist with 2 quartz dykes cutting across form left to right.

Slope stability problem

In a few places where slopes are excavated for major dam structures, the rock slopes become unstable probably because of poor blasting practices resulting in excessive overbreaks and overhangs, and unfavourable joint orientations.

The remedial measures taken to stabilize the slopes include rock bolting, removing the overhangs and concrete buttressing. Extensive rock bolting was carried out where the unstable rock slope is permanently exposed.

INSTRUMENTATION

The instrumentation installed in Batu Dam is to monitor the performance of the dam embankment, foundation, abutments and structures during the construction stage and subsequently the operation stage. These instruments are necessary in obtaining information on pore-water pressure, vertical and horizontal movements, and water seepage through the embankment.

Various types of instruments installed in Batu Dam are as follows:-

i) Vibrating-wire piezometer
ii) Porous-tube piezometer
iii) Inclinometer
iv) Measurement points (embankment and structural)
v) Seepage measurement weir

The location of all the instrumentation is shown on Figure 3.

Vibrating-wire Piezometer

A vibrating-wire piezometer consists of a transducer capable of transforming a piezometric pressure into resonant frequencies which can be transmitted via a cable to a terminal box in this piezometer and displaying the frequency reading digitally (Soil Instruments Ltd., 1984). The pore-water pressure is calculated from this reading.

The positions of the vibrating-wire piezometers are shown in Figure 3 and 4. These vibrating-wire piezometers are installed in the foundation (in a drillhole) and in the embankment. A series of piezometers are installed at elevations 69.0 m, 79.0 m and 89.0 m of the embankment. Two of the foundation piezometers are installed in a quartz dyke that cut across the cut-off trench. The cables for the piezometer installation are laid in a trench.

Porous-tube Piezometer

This piezometer provides a reference for judging the reservoir effect on ground-water levels (Soil Instruments Ltd., 1984). Refer to Figure 3 for the location of this porous-tube piezometer. It consists

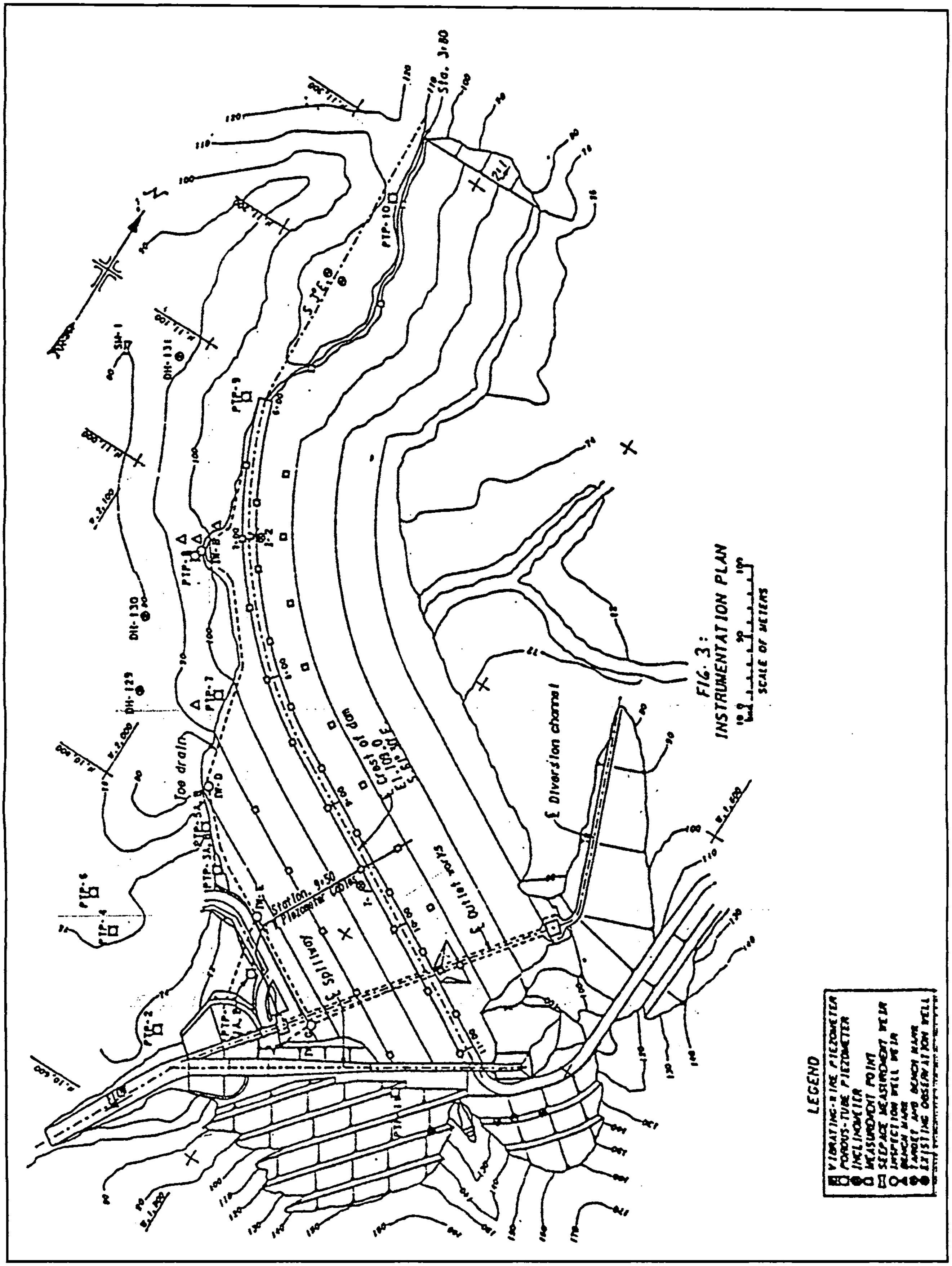

Figure 3. Instrumentation plan.

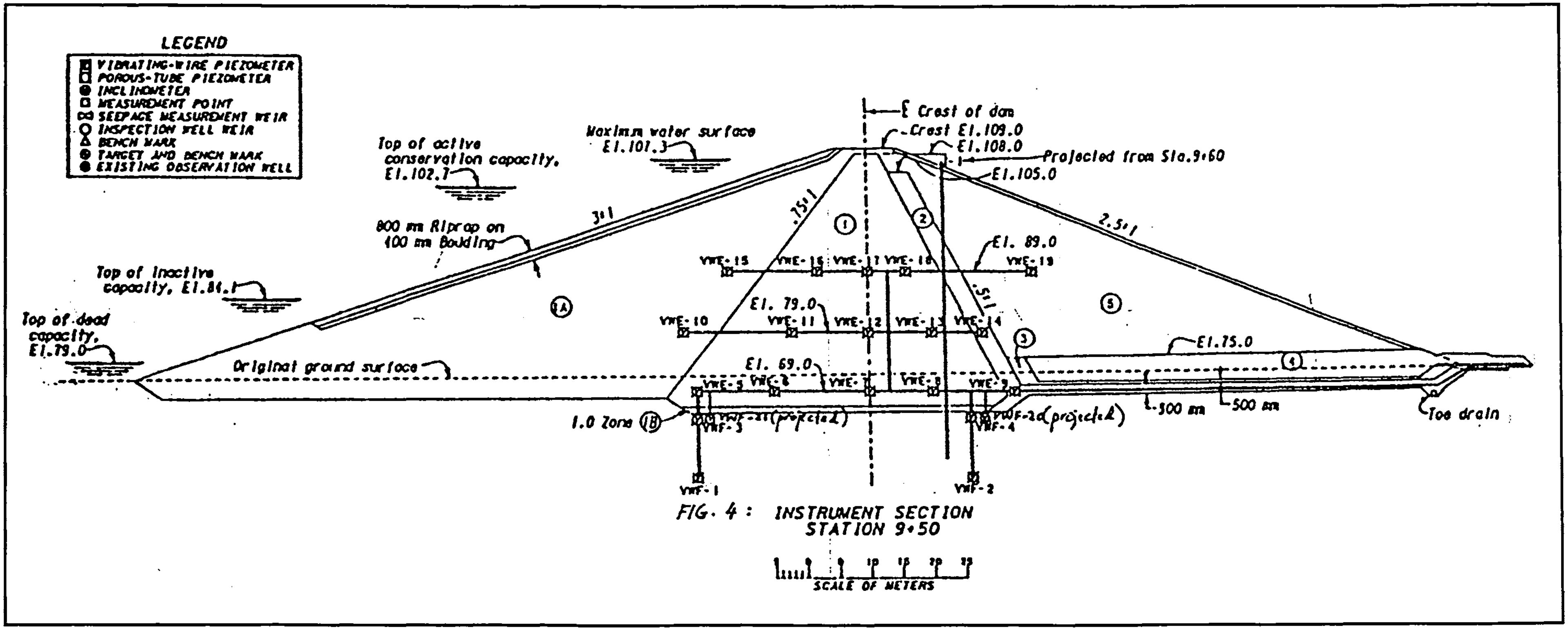

Figure 4. Instrument section, station 9+50.

of a standpipe tube with a porous tip at its lower end. This piezometer was installed down in a vertical drillhole.

Inclinometer

The inclinometer system consists of inclinometer casing, inclinometer probe, inclinometer cable, inclinometer cable reel assembly and readout unit (Soil Instruments Ltd., 1984). The inclinometer casing is installed in a vertical drillhole with one set of the grooves oriented parallel to and the other set normal to the centreline. The casing section in the drillhole is coupled with butt joint and grouted. Each casing section in the embankment is coupled with settlement joint with settlement flange attached in the middle.

The inclinometer probe which is gravity-sensitive and capable of detecting any inclination in the casing. A pair of wheels are mounted at each end of the probe to guide it in the casing. For measurement purposes, the probe is lowered down in the casing using the cable reel with the help of pulley assembly with the cable attached to the probe and the readout unit. This readout unit will display the inclinometer reading.

There are two inclinometer casing installed at Batu Dam as shown in Figures 3 and 4.

Besides being used to monitor the horizontal movement, the inclinometer casing is used to measure settlement (vertical movement) also. Reading is carried out by lowering down the settlement probe using the cable, and the cable and pulley assemblies.

Measurement Points

Bench mark and target will be established when the embankment is completed to provide a permanent reference for future readings of inclinometer coordinates and elevations, and for settlement and deflection of the measurement points on the embankment, the walls of the spillway, and the outlet works conduits and walkways. The permanent targets and bench marks will be located on natural ground surface on the abutment. Refer to Figure 3 for locations of measurement points.

Seepage Weir

The seepage measuring weir is located on the right abutment ridge downstream of the embankment (Fig. 3). This weir will provide readings on the water seepage through the right abutment ridge.

FOUNDATION GROUTING

Grout Design

The grouting work was performed in two parts; blanket and curtain. The curtain grouting was carried out to cut off seepage under the dam while the blanket grouting was carried out to prevent underflow through weathered or partially disintegrated rock, highly fractured rock, or previous dykes that cross the foundation where curtain grouting would not be sufficiently effective.

Table 1. Typical depth sequence.

TYPICAL DEPTH SEQUENCE	
Location	**Depth Sequence (m)**
Single row curtain	All holes @ 20
Multiple row curtain – STA 8+70 to 10+29	20-13-20-13-20
Cutslopes for spillway and outlet works	20-6.5-13-6.5-20
Faulted areas	40-13-20-13-40

The curtain grouting was required in one row from Sta 7+00 to 8+70 along the dam centre line (Fig. 5). From Sta 8+70 to the end of the grout curtain, at approximate Sta 11+50, three rows were required. They were the upstream, centre line and downstream rows (Fig. 6). The final spacing between rows was 2 meters. The depth of holes ranges from 6.5 m to 40 m (Table 1). Where three rows of grout holes were required, the rows were drilled and grouted with the downstream row first; the upstream row second; and the centre line row third. Drilling and grouting of the second and third rows was not started until all grouting operations within 15 m in the preceding row were completed.

The primary holes were spaced at 16 m (16 m pattern) and the final spacing between holes in each row along the total length of the curtain is as necessary to close out the curtain. The final spacing of the grout holes in the upstream and downstream rows could not exceed 4 metres. Final spacing for the middle row was as required.

In areas with many surface cracks or where the rock is weak, grout nipples are necessary to help control surface leakage and provide firm collars on holes.

A grout cap was required along the upstream grout row under the outlet works structure. This cap is extended to the cut-slope and under the spillways. This grout cap forms a near-surface seepage barrier. It also provides good surface grouting works and as a control for uplift (heave) monitoring and inspection. This grout cap extends to the end of the river valley floor (Sta 9+83).

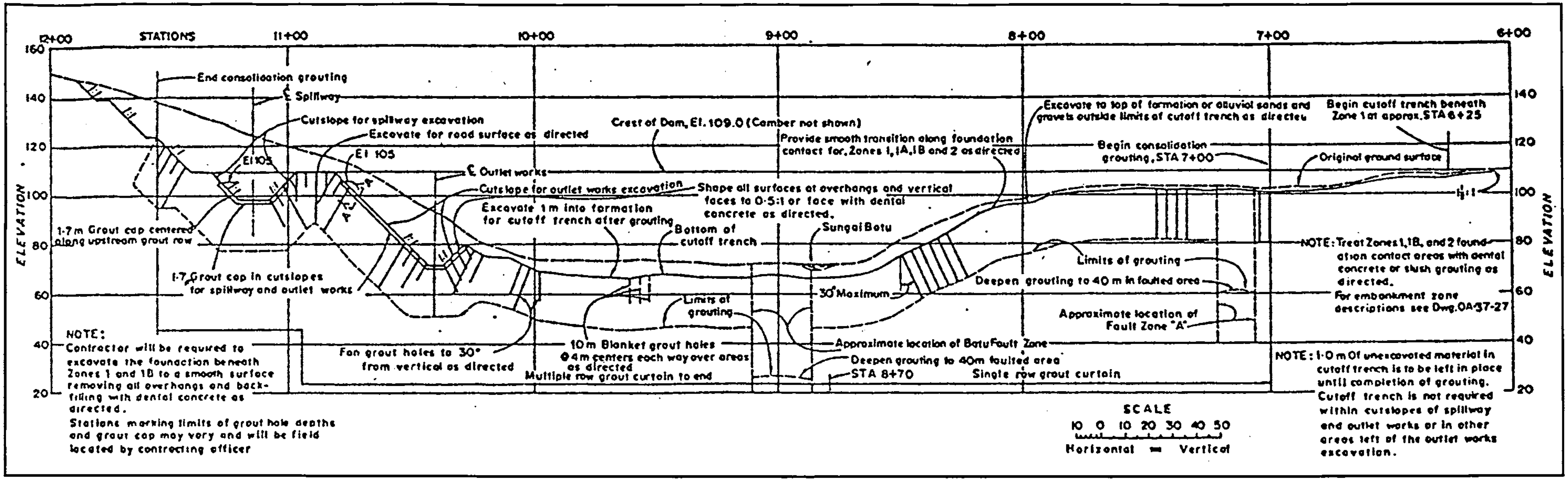

Figure 5. Profile along a crest of dam (one row of typical grout holes projected, not all grout holes are shown).

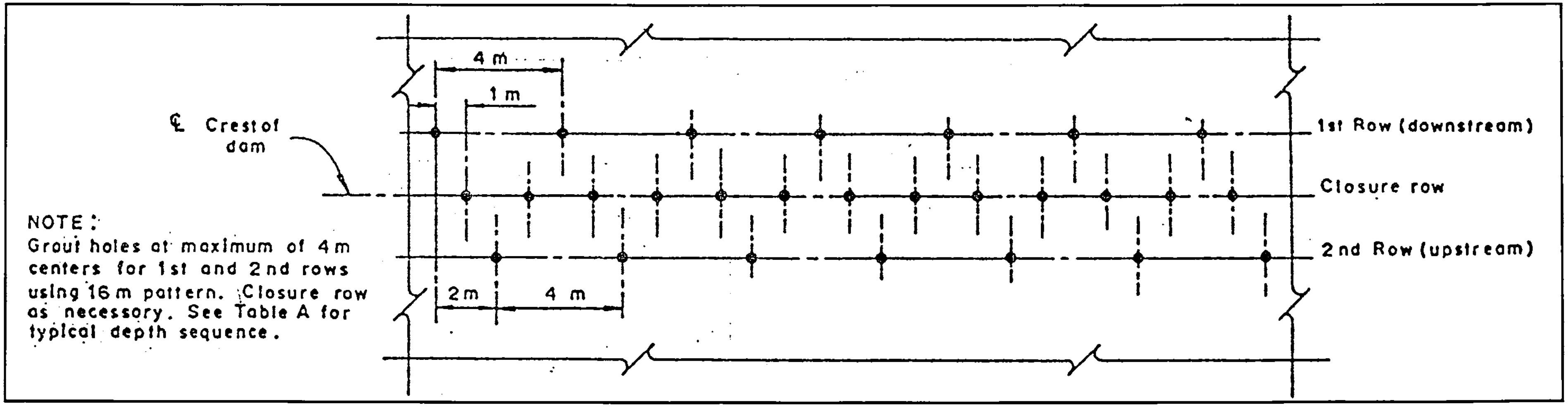

Figure 6. Typical grout hole pattern.

Grouting Equipment

For the Batu Dam grouting works, a high speed colloidal mixer (ELE of England) was utilized for thorough mixing of cement and water. The grout from the mixer was transferred to the agitator (Koken LAM-250 of Japan) to keep the grout stirred while awaiting injection. The moyno pump (PCM of France) was used for pumping the grout into the hole or grout connection. It has a helical screw type of rotor to give a steady pumping pressure without pulsation. A manifold consisting of a system of valves and a pressure gauge was located on the line at the collar of the hole to permit continuous circulation, accurate control of the grouting pressure, bleeding and regulation of flow into the grout hole.

Grout supply pipes and packers of suitable types are used to properly inject the grout into the hole. Packers seal the drill hole at specified depths.

Execution of Grouting Works

The grouting works was carried out by using the split spacing method (Fig. 7). The grout hole was bored by rotary drills of Ex size (38 mm) or larger. Where required, grout nipples were installed and grouted in place before drilling was continued. Water tests were run before each stage is grouted. The water test washes out cracks in the rock, provides an estimate of the rock permeability and grout take, and checks the packer seating. The pressure for water testing and grouting is the distance from the ground to the centre of the stage multiplied by 0.2 kg/m^2 (= 1 psi/foot).

The grout was mixed in the high-speed colloider mixer and then pumped to the agitator. The moyno grout pump delivered the grout to the hole. For Batu Dam, the mixes were specified from 5:1 (water-cement ratio by volume) to 1:1. With the starting mix of 5:1, thickening of the mix was done when necessary, i.e. when the hole continues to take grout for a long time or the hole has surface leaks. Starting mix of 8:1 was carried out in the right abutment.

Downstage and upstage grouting were carried out. In the river valley area where caving or packer setting was a problem, each stage (maximum length 6.5 m) was drilled, washed, water tested and grouted successively form the surface downward. In better foundation condition, upstage grouting was carried out. This method was done by drilling the hole to the first stage and washing and water testing that stage; drilling, washing and water testing and second stage; drilling, washing and water testing the next stage. When drilling and water testing were completed, grouting of each stage was started from the bottom stage upward.

PVC casing was installed after grouting stage 1–7 m, where hole caving was bad. This casing seals the grouted stage, keeps the hole from caving and provides a good seat for a packer. In extreme cases, perforated PVC pipe was installed for grouting.

When surface leaks occurred, caulking, plugging or intermittent pumping was carried out. The mix was thickened in stages to 1:1. Grouting was continued until refusal was reached or when the take was 30 litres/20 minutes or less.

In stages where significant takes occur, adjustments to the planned hole depth and adjacent hole depths and spacing were made. Any hole that takes considerable grout in the bottom stage (i.e. 5 bags or more) in one of the stages, has the adjacent holes drilled to that stage depth and any hole that has a large take adjacent to a previously grouted hole, has an adjacent hole drilled.

Extensive blanket grouting was carried out in the quartz dykes area that crosses the main dam foundation. The hole depth ranges from 7–33 m. The quartz dykes in the right abutment upstream water passing through the abutment.

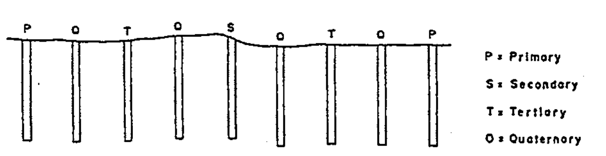

TABLE A

TYPICAL DEPTH SEQUENCE	
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Cutslopes for spillway and outlet works	20-6.5-13-6.5-20
Faulted areas	40-13-20-13-40

Figure 7. Grouting sequences.

CONCLUSION

The various structures of the dam are founded on schist with various grades of weathering ranging from completely weathered to fresh. The upstream and core zone foundations consist of schist while the downstream foundation of the embankment is founded on a gravel layer or completely to intensely weathered schist. Quartz and granite dykes often cross-cut the foundation.

No major problem was encountered in the foundation except for over excavation to reach the required grade of rock (moderately weathered) in the downstream part of the spillway and outlet works. In the inlet area of the outlet works, overexcavation was carried out to reach the fresh rock. In general, the embankment foundation is excellent although some foundation treatments like slush grouting and dental concrete were carried out to seal off open joints and stress relief joints and to face overhand which cannot be trimmed. The gravel layer of the downstream embankment foundation acts as a natural filter to prevent fines from the foundation entering the free-draining materials (in the drainage blanket) and relieving the pressure by releasing water seepage under the embankment.

Rock bolt, concrete buttress and removal of overhangs are effective measures taken to stabilize the unstable rock slopes.

Instrumentation installed at Batu Dam plays a very important role in monitoring the performance of the dam.

The grout take was relatively higher on the left abutment when compared to the river valley area. Here the rock is moderately weathered to fresh and has more prominent jointing. The average grout take for curtain holes was 0.77 bags/meter. Blanket grouting was concentrated on the quartz dyke areas because the dykes show relatively high permeabilities. To suit site conditions, changes were made to the layout of holes hole. Hole spacing, hole depth and closure requirements were modified during grouting.

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