

Foundation Drainage Performance at Gordon Dam

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SUMMARY In this paper, the drainage and piezometric systems of the 140 m high Gordon arch dam are briefly described. Experience in the operation of the relevant instrumentation, which included redrilling and duplication of a defective piezometer and extension of the coverage, is discussed with a view to improvements in the philosophy of the piezometric instrumentation of arch dams. The value of installing piezometers especially to monitor the efficiency of drainage systems is demonstrated. Use of a few key piezometers for interrogative and routine telemetering is explained.

The general picture of the distribution of interstitial fluid pressures in the foundation rock emerging from the results as the reservoir water level slowly rose is presented. Some comparisons are made of pore pressures observed with the corresponding values assumed in design calculations.

1 INTRODUCTION

Gordon Dam is a 140 m high, double curvature arch dam constructed on the Gordon River, in the south-west of Tasmania. Impoundment of water began in April 1974, the reservoir taking almost four years to reach a level close to full supply level at which it has remained sensibly constant for more than a year. (Fig. 4).

Provision was made during the design stage for monitoring the leakage flow through the foundation and for measuring of water pressures in selected areas of the abutments. Preliminary results were reported by Mitchell (1976). Five years of measurements now exist. This paper reports the findings, and discusses the behaviour of the drainage and piezometric system, including measures which were adopted to ensure that excessive pressure indications on one abutment were properly investigated.

2 DRAINAGE AND GROUTING SYSTEM

The dam is located in a narrow gorge of intensely folded rocks of Precambrian age. The rock sequence consists of fairly massively foliated quartzites containing thin interfoliated lenses of schistose chloritic and micaceous materials. Drill hole and adit investigation on the site revealed that the rock structure was generally very watertight, even where there was tectonic jointing. Water pressure testing in drill holes showed that water losses were confined to joints intersected by the drilling. The flow situation in the abutments could not therefore be considered homogeneous, and consequently the drainage and grouting system had to accord with the probability that most of the water which seeped through the rock around the dam would be confined to discrete joints.

Allen (1971) discusses the philosophy of drainage and grouting curtain location, and indicates the percolation pressure distributions which were used in the stability analysis. The positions of the drain and grout curtains are shown on Fig. 1, which also shows in diagrammatic form the distributions of pressure used for the stability analyses.

2.1 Drain Curtain

Drainage for the dam abutments was achieved by a series of adits about 30 m apart in elevation, oriented in the general direction implied in Fig. 1. Fig. 2 shows the layout, with a series of 75 mm holes at 4 m spacing on the left abutment and 6 m on the right, drilled from one adit to the next below. In the area between the top-most adit and the crest of the dam, holes were drilled upwards in the same general plane as the holes below. Similarly, in the lowest adits, holes were drilled from the invert to levels below the dam. Around the base of the dam, a network of about 34 holes collared near the downstream toe was sunk to intersect known faults and joints. Advantage was taken of a second stage diversion opening in the dam, at foundation level near the right abutment, to drill a fan of holes underneath the dam. Water from these was piped to the downstream side when the opening was backfilled.

In contrast to the situation with gravity dams, drains in steep abutments such as exist at Gordon Dam can be made free draining from adit to adit. Within the plane of the adits the drill holes were generally oriented to intersect the principal joints, which, as mentioned above, would be the main water carriers.

In a typical adit, water entering from holes above is collected in a side drain and measured by V-notch weir before it is dropped to the adit next below. In the valley floor, a small concrete flume collects the drainage from the toe holes and a V-notch weir is again used to measure the leakage. Any strong individual leaks into a drainage adit can be monitored in addition to the measurement of total leakage.

2.2 Grout Curtain

Because of the position of the grout curtain in relation to the drainage curtain, drilling for the injection holes was done from upstream chambers at the ends of the drainage adits. Fans of holes were drilled giving a linked net covering the abutments effectively half the dam's height (locally) beyond the arch contact. In the valley floor, the grout curtain was vertical and drilled immediately upstream of the dam.

3 PIEZOMETERS

3.1 Piezometer arrangement

For monitoring pore pressures in the abutments, 31 piezometers were initially installed in the left abutment and 3 on the right. The preponderance of installations on the left abutment reflects the findings of the exploratory drilling and aditing, which revealed many more water bearing joints on the left than on the right. The object of the piezometer installation was to provide a quantitative basis for regular review of the effectiveness of the drainage system in controlling the pore pressures in the abutments. Piezometer location (shown in Fig. 3) was designed to give a spread of measurement sufficient to allow a comparison to be made between the measured and expected pressures. Carlson-type electrical resistance piezometers (supplied by Kyowa) were installed in drill holes, the stages of which were pressure-tested and lengthened until the water loss reached a value of 0.022 l/s/MPa in the stage. It was considered necessary to do this because of the general water-tightness, especially on the right abutment.

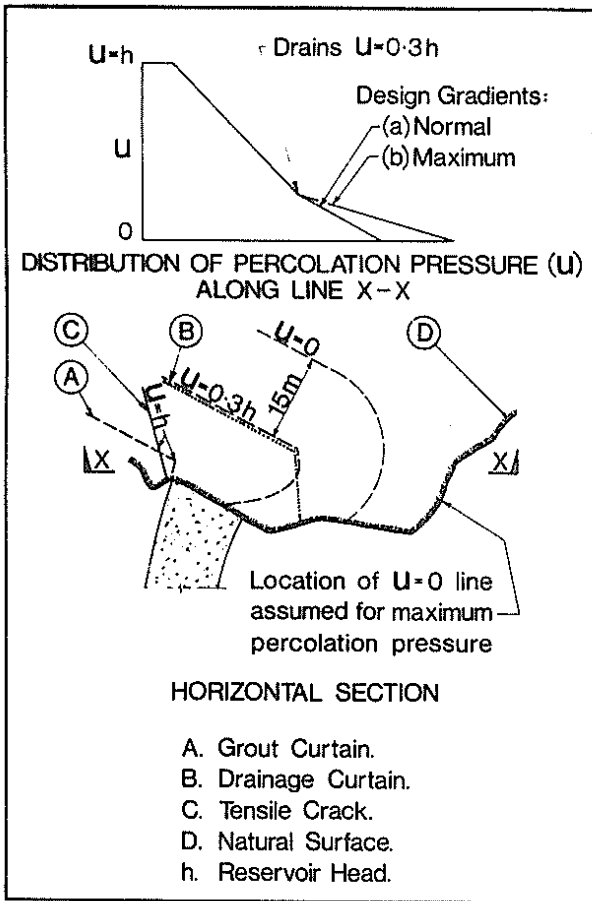


Figure 1 Design pore pressures (after Allen (1971))

3.2 Telemetering

Seven piezometer locations (six on the left, one on the right, shown ringed in Fig. 3) were chosen for remote monitoring, via a telemetry system, which also monitors twenty other instruments in the dam. It has been possible to telemeter for monitoring at very little cost, as a by-product of the remote control system for the nearby power station.

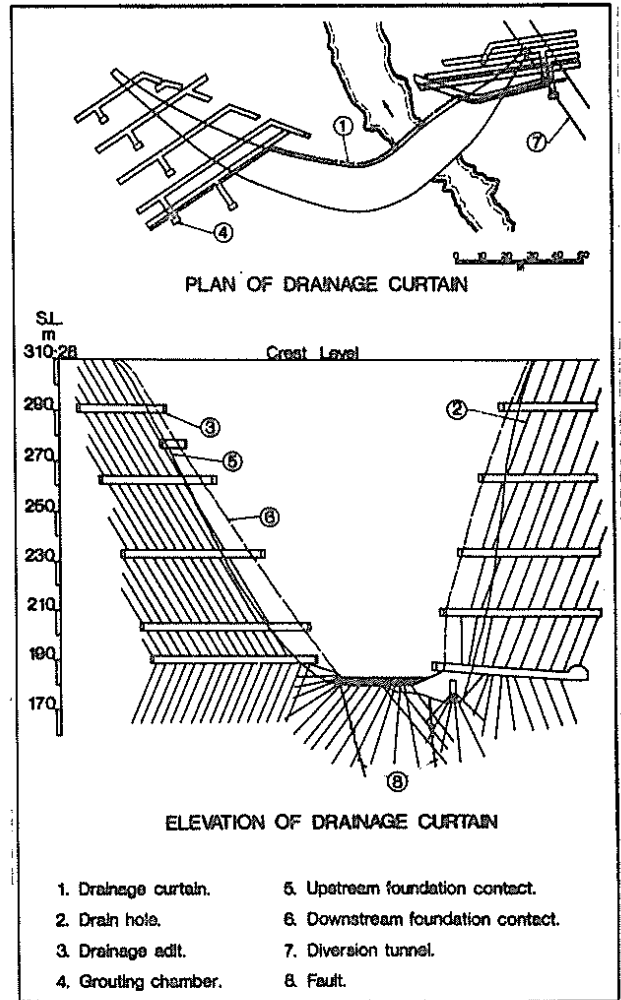


Figure 2 Drainage curtain layout

All the above instruments are continuously scanned and updated to a digital encoding unit near the top of the dam. This update is interrogated from Hobart automatically every thirty minutes, and transmitted to a display screen (in Hobart). The duty operator can call for a print-out at any time, day or night.

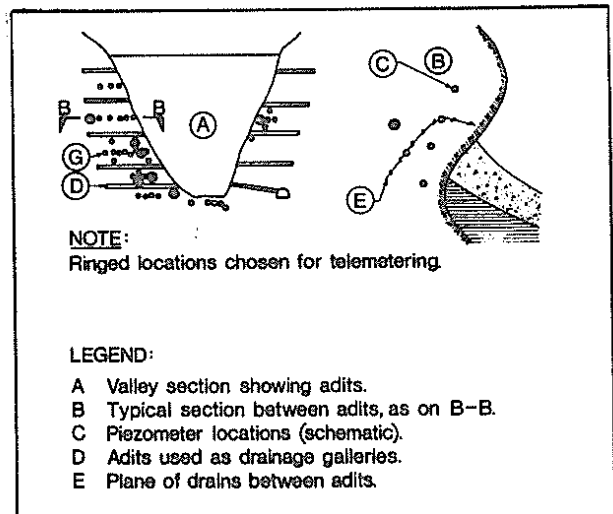


Figure 3 Piezometer location

4 PERFORMANCE

4.1 Leakage Measured

Fig. 4 gives a chronological picture of the leakage in various parts of the dam since filling of the reservoir began.

It can be seen that leakages have generally increased with lake level and stabilised at the attainment of Full Supply Level. It is also evident that the relative watertightness of each major section of the foundation can be assessed from information such as that presented in Fig. 4 and Fig. 7.

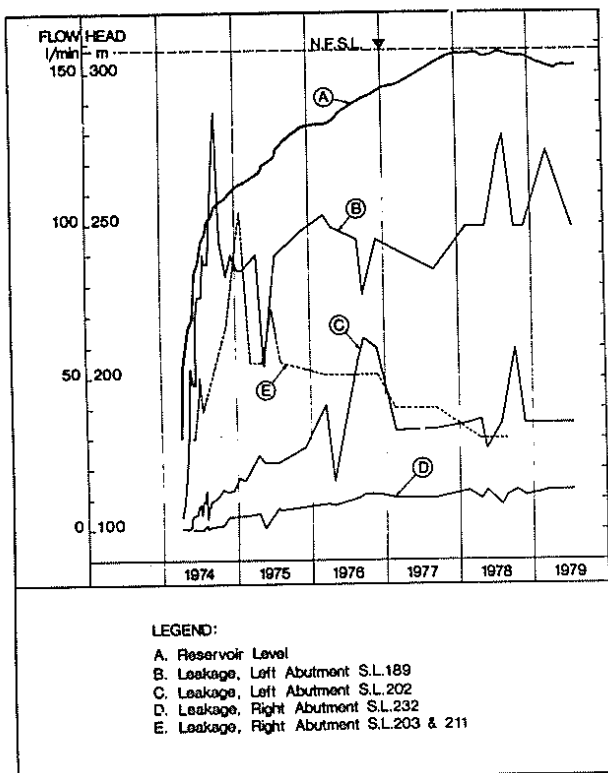


Figure 4 Typical leakage histories

4.2 Maintenance Problems

For the leakage results to have the same meaning in ensuing years as they do in the initial years of operation, it is necessary that a formal inspection procedure be utilized, which can, on a regular basis, give definitive reports about the state of maintenance of the system. We have instituted such a programme, and we find, for example, that even 75 mm vertical drain holes do become blocked occasionally, that V-notch weirs and their approaches need regular cleaning and that holes driven below the base of the dam become blocked. The sources of blockages were found to be as follows:

4.2.1 For the vertical drain holes, subsequent construction activity in the adits resulted in some construction materials finding their way into the holes. Also, displacement of some small rocks associated with joints crossed during drilling may be a contributory cause.

4.2.2 Some holes draining the base of the dam became clogged with calcium carbonate granules and encrustations. This was especially true of holes draining a known fault area which had been cement-grouted.

4.2.3 A gelatinous organic substance (of the nature of slime or yeast) formed at joints and shear zones carrying water. Growth seems more prolific in shear zones containing sand and rock chips, perhaps because of the greater surface area per unit volume of wetted rock. This made a thick (100 mm) covering over some surfaces and blocked V-notch weirs. Colour varies from red through brown to black depending presumably on the relative iron and manganese contents.

4.3 Remedies for the Blockages

4.3.1 For the vertical drain holes, jetting with water and rodding managed to clean them, and regular inspection makes sure that they are kept clean. It would be possible (as a last resort) to redrill or ream the holes from the galleries, because the adit size was made sufficiently large to allow a drilling rig to operate in them.

4.3.2 At the base of the dam, access for a drill rig was quite easy, by way of a haulage-way down the left abutment, but it was found that the percussion drilled holes could not, because of their winding nature, be redrilled. It was necessary to drill new holes to re-establish drainage paths which had been lost.

4.3.3 The rate of formation of the metalliferous slimes seems to be decreasing in recent years, but it is still necessary to remove them from a few locations where they reach the collector drains which run along the adit floors to the V-notches.

4.4 Piezometric Measurements

Of the 34 piezometers initially installed, 32 are still operational and 8 additional instruments (see 4.4.2 and 4.4.3) have been installed. Generally speaking, the pore pressure picture they indicate for the abutments and base is quite clear and confirms that the pore pressure assumptions made in design are on the safe side both in magnitude of pressure and in extent of foundation under such pressure (Fig. 7).

Several piezometers are purporting to record negative head. Assuming they have not developed faults this means the water table has dropped below them. Once suction is broken the piezometers can no longer follow the water table down.

4.4.1 Left abutment

Fig. 5 shows, for the left abutment, the pressures measured by three groups of piezometers as functions of time. One group is chosen near the bottom of the reservoir, one about a third from the bottom, and one about a third from the top. The labels A, B and C for each group refer to piezometer locations upstream of the drain curtain, at the drain curtain and downstream of the drain curtain respectively. Instruments at locations B and C show an essentially constant and low piezometric head, indicating that the drainage curtain is working and that high pressure water is not present downstream of it. Instruments A initially show a rise of pressure with the lake rise and then a generally constant pressure as the rate of rise of the lake has decreased. This accords with their

position between the source of head and the drainage curtain. The pattern is similar to that of data presented by Casagrande (1961).

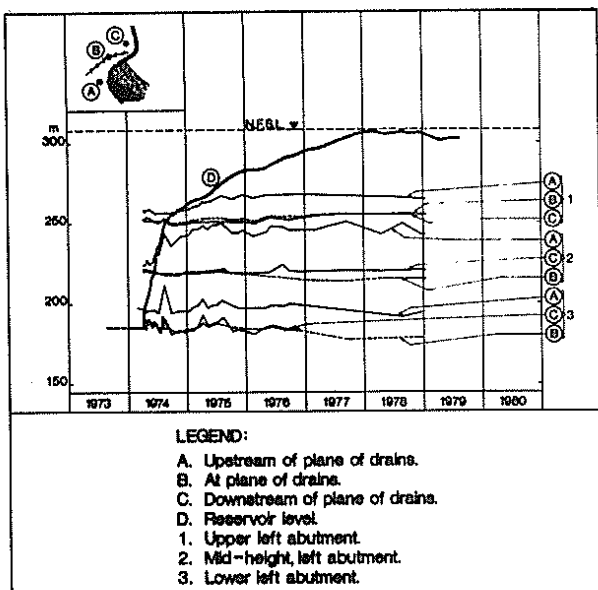


Figure 5 Typical L.A. piezometer records

4.4.2 Right abutment

For the right abutment, Fig. 6 shows a similar plot using the one set of piezometers initially installed, together with a replacement for a defective instrument.

At the drainage curtain, the piezometric head remained constant and low as the lake was rising, but at the instrument downstream of the curtain a pressure indication almost equal to that of the upstream instrument was consistently presented. Since there was no firm reason to disregard the instrument, and because the lack of instruments above and below it did not allow us corroborative evidence for or against the existence of a downstream pressure zone, we decided to drill some more holes into the zone in question. We could not be sure that a discrete joint was not carrying water past the drain curtain, or that water from above was not being trapped to the height implied.

During December 1976 and January 1977 eight diamond drill holes were placed in the right abutment, collared at the entrance to the drainage gallery at S.L. 231.70 m, where sufficient room for siting the drilling rig existed. Five of the holes were meant to augment the drainage, three being in the drain curtain plane and two approximately 10 m downstream of the drain curtain. Their orientation was chosen to intersect possible water bearing joints. The three remaining holes were positioned for installing piezometers to give a vertical coverage of about 35 m (between S.L. 225 m and 260 m) at a position 15 m downstream of the drain curtain.

Only two of the five drainage holes intercepted water sources. One of the three into the drain curtain leaked about 0.5 litre/minute, while one of the downstream holes had a "dripping" leakage too small to measure. Water from the first hole is consistent with supply to the area where high pressure was recorded.

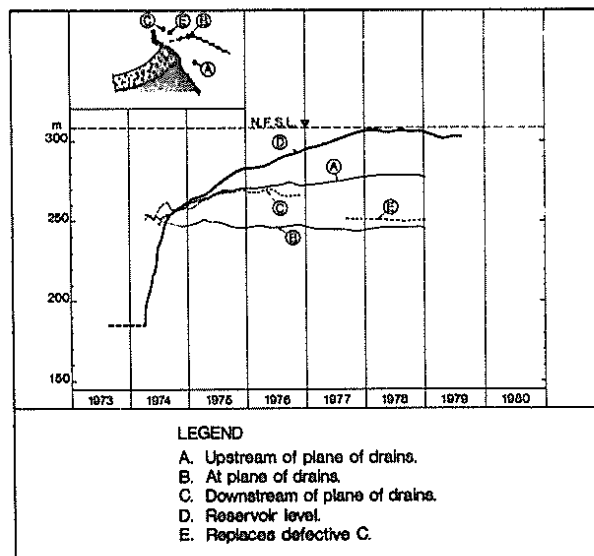


Figure 6 Right abutment piezometer data

The original piezometer registering the high downstream pressure became defective during drilling operations and this casts some doubt on the validity of its earlier record. Three piezometers were successfully installed and their readings (e.g. E on Fig. 6, which specifically replaces C) show that no high pressures have been recorded since.

4.4.3 Base of dam

The piezometers installed recently (1977) at the base of the dam are included in the general picture of Fig. 7. They monitor the effects of toe drains and faults in the river bed areas (and incidentally complement information from other sources such as rock deformation meters and V-notch weirs). Over their period of observation they have shown the same degree of stability as those plotted in Fig. 5.

4.4.4 Piezometric gradients

Information collected from the piezometers allows us to make some statements about the gradients of pressure, both in a horizontal section and between drainage adits, (see Figs. 7 and 8). A system of equipotentials can be constructed for a suitably chosen surface as an aid to interpolation between the piezometers.

The elevation in Fig. 7 is a projection on to a vertical plane of a curved and sloping section through either abutment and the base just behind the arch contact.

The piezometers are projected, in accordance with their positions in the flow path, on to contours of the surface at their respective installation levels (see plan view in Fig. 7). It can be seen that the drainage curtain is holding the piezometric head below the maximum limits assumed in design for abutment stability analyses. These limits are indicated in Fig. 1 and Fig. 7. Since there is no firm measure of the negative head near a negative reading piezometer, the equipotentials have been located as if such piezometers were reading zero excess pressure.

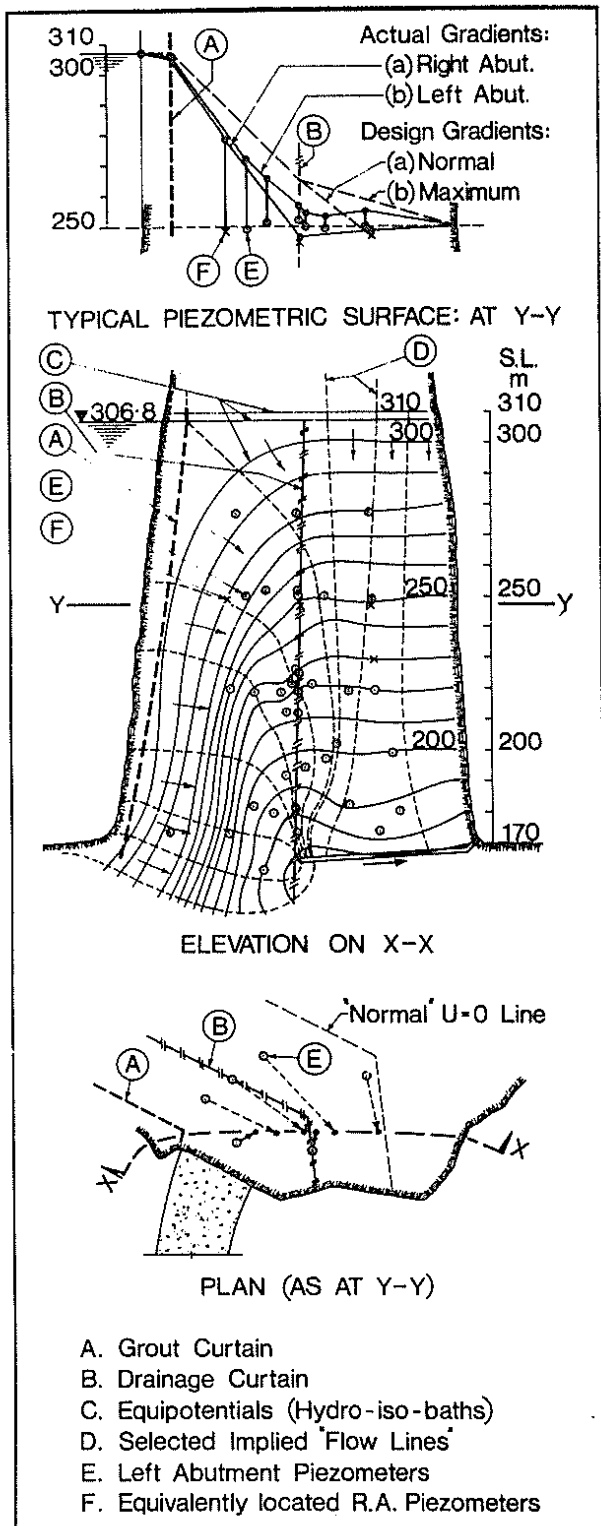


Figure 7 Record of all 40 piezometers, 29-8-78

The pattern of the dotted lines drawn at right angles to the equipotentials gives a general impression of the effect of the drainage curtain on abutment ground water movement.

Water represented as flowing down from above the lake surface level is from local run-off higher up on the abutment. The adits may be considered to be normal to the elevation on X-X, at the drainage curtain.

It would appear that the drainage and piezometer systems have intersected enough discrete joints in the otherwise impermeable rock mass to make such a representation realistic and useful.

There was some discussion at the design stage of an appropriate drain spacing. The observed values of pore pressure plotted in Fig. 8 as curve B (i.e. 0.041, 0.105, 0.043 MPa) are well below their "0.3 h" design equivalents (0.24, 0.26, 0.28 MPa). This indicates that the inter-drain pressures are adequately controlled with the chosen 4 m spacing for the left abutment, giving a fair margin for the effects of occasional blockages. The influence of the proximity to the adits is clearly shown.

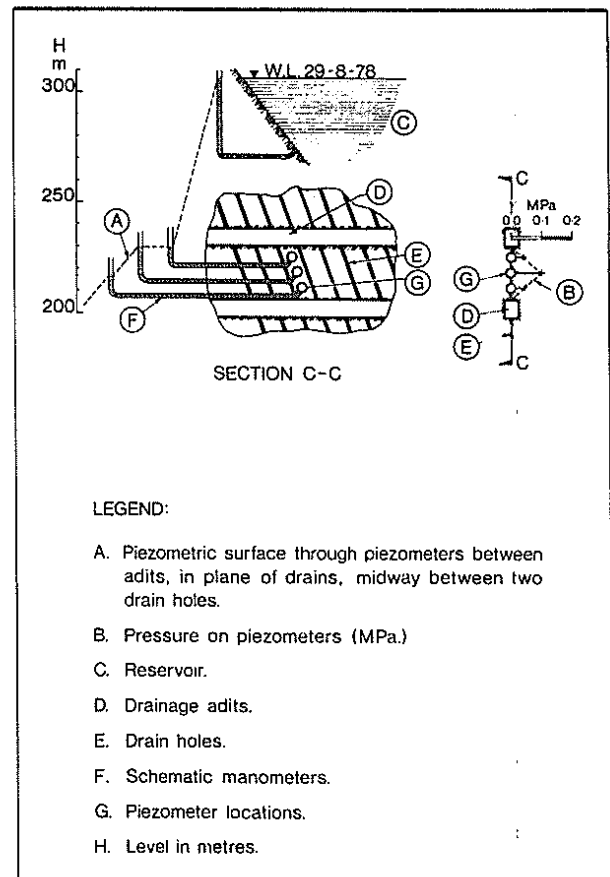


Figure 8 Pore pressures between drains

No similar piezometric check between right abutment drain holes, which are at about 5 m spacing measured perpendicular to the hole direction, is at present available. Because of a feeling of confidence in the right abutment stability which developed during the latter stages of design, even some piezometers appearing on 1974 revisions of the right abutment drawings were omitted.

5 CONCLUSIONS

Based on piezometer readings obtained to date, we conclude that the drainage system at Gordon Dam is effective. As Terzaghi has implied (Casagrande (1961)) we can never know how much leakage the grouting has prevented, but a grout curtain should prevent major piping.

Our experience at Gordon Dam vindicates the advice (ibid) that as well as a regular flow check on drainage facilities, a piezometric check must also be kept to ensure that a drop in flow rate is not accompanied by dangerous rises in pressure profiles.

Our maintenance programme has revealed that if one may have to clear or ream drain holes by drilling, then it is advisable for them to be diamond drill holes initially.

Piezometric measurements are important for indicating the current state of interstitial pressures in the foundations. Based on a regular flow of data, the plots can be used for making informed decisions about remedial action which might become necessary from time to time.

When designing piezometer installations for an arch dam, due regard must be given to the three-dimensional nature of the foundations, in order that anomalies in the readings might be assessed in the three dimensional context. This is the lesson to be learned from the drilling on the right abutment, which was done because of the absence of piezometers above and below the indicated high pressure location.

We believe that a tightly supervised inspection and maintenance programme with regular and comprehensive reporting is necessary for important hydraulic structures such as arch dams. Reliable records must be kept not only for total leakage, but for individual holes, adits, and so on. These should be included in the long-term record in order that a comprehensive picture of foundation pressures and percolations might be built up for any chosen time span.

6 ACKNOWLEDGEMENTS

The authors wish to thank Mr. J.R. Ashton, B.E., F.I.E. Aust., Commissioner of the Hydro-Electric Commission, for permission to publish this paper. Mr. W.R. Mitchell, B.E., F.I.E. Aust., is the Chief Civil Engineer. The assistance of other officers, in particular Mr. G. Clingeffer who prepared the illustrations, is acknowledged.

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