DEPARTMENT OF TRANSPORT AND WORKS

MARY ANNE DAM - TENNANT CREEK

REPORT ON SEEPAGE

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INTRODUCTION

Mary Anne Dam first filled in the 1980/81 wet season, and minor seepage was noted from the base of the dam as is common with virtually all dams. However the seepage became disproportionally large as the lake neared top water level and hence a gauging station was installed and records have been kept since March 1981.

Seepage was also noted in the spillway area, some of which was directly attributable to concreting faults and was rectified as the opportunity arose. All seepages were clear and reduced significantly as the lake level dropped and hence there appeared to be little danger of an imminent erosion or piping failure.

As lake levels approached top water level in the 1982/83 wet season, the dam seepage again increased rapidly and was some 50% greater than that recorded in the previous year. Consequently, there were some fears that the dam may have suffered further damage which, if unchecked, might eventually lead to the dam being at risk. Even if there were no such risk, a check was required to determine if the leak could be minimised by some relatively simple method.

GHD was commissioned on 12th May, 1983, to examine the dam and report on the probable sources of seepage, any further testing that might be required, and to outline repair techniques that could possibly be used. Mr. J. Phillips who was involved with the initial design visited the site to make observations and collect samples on the 6th and 7th June, 1983.
LEAKAGE FROM DAM

At the date of inspection the seepage from the dam was issuing from a single point previously known as the upper seepage, whilst areas within a few metres and slightly lower in elevation were thoroughly saturated but with no measurable flow. The flow was issuing from rockfill where an opening of approximately 0.3 m diameter had been cleared through rubbly gravel that had been spilt over the downstream face of the rockfill toe of the dam. It was advised that much of the size of the hole was due to unofficial investigations by tourists and picnickers.

The water was of low turbidity which appeared similar to lake water. There was no sign of silt being dumped from this flow.

The co-ordinates of the leakage could not be determined without survey instruments, but appeared to be about chainage 107 m, thus coinciding with the previously existing creek bed.

FLOW DATA

Seepage data was provided by D.O.T.W. in graphical form and is reproduced as Figure 1. Some 31 positions were identified on this chart at approximately 1 month intervals or where significant changes were taking place, and these were replotted on a seepage flow versus lake level as shown on Figure 2. Trend lines have been shown, ignoring some of the deviations that are apparent. Precise data from readings taken immediately prior to the visit on 7th June are also plotted on Figure 2.

In some circumstances, deviations from the norm may be indicative of significant events, and hence these results were checked in the following two ways. To check reproducibility of results, the flow data from nine readings immediately prior to the site visit were plotted as per Figure 3. Whilst the calibration of the V-notch is unknown, it can be seen that in this range of flow the reading error (not the flow variability) is only of the order of 0.1 L/sec. At lower rates of seepage the reading accuracy of measurements by container would improve.
The V-notch is in a position such that it will measure rainfall runoff from the entire downstream face of the dam and some of the area downstream, as well as seepage. All results taken on rainy days should therefore be treated with caution. Additionally the downstream gravel face will absorb water during prolonged rainfall and slowly release it over a period of several weeks.

It is also noteworthy that the automatic reservoir level recorder has been damaged and has therefore been inaccurate for several periods of the record.

Whilst we do not have specific readings and their dates, an examination of the rainfall data that has been plotted on Figure 1 would indicate that points 16, 17, 30 and 31 could be of doubtful relevance. There still remain a few unexplained deviations. One possible but unprovable theory is that different flow paths occur from time to time within the dam, causing short term fluctuations in flow.

An examination of Figure 2 indicates that

1. When the water level is below approximately RL 371.2, the seepage is generally (point 29 is the main exception) at a low level of 0.2 L/sec or less, and is reasonably constant despite variations in water level. This level of seepage is well within acceptable limits.
2. When the water level is above approximately RL 371.2, the seepage increases quickly, almost in direct proportion to the depth of water above RL 371.2.
3. The seepage quantities when the water is above RL 371.2 are increasing year by year.
4. Seepage is greater when the dam is rising than when the dam is falling. This could be the rainfall effect mentioned above, a groundwater response to rainfall or could be related to say the temperature effects on widths of the cracks in the concrete face.
CHEMICAL DATA

The design of the dam was deliberately chosen to be stable under seepage conditions so as to minimise the initial cost of grouting which could have been as much as 50% of the total construction cost. The stability against water pouring through the face was demonstrated during construction when a major flood passed safely through the dam prior to the placing of the concrete face.

If there is a risk to the dam under seepage conditions, it would be in a situation where large seepages were passing through the foundations under the plinth and eroding the foundation in the process. Any eroded material may be deposited in the gravels and rockfill within the dam such that the seepage from the downstream face appears clear. It is sometimes possible to distinguish between water passing through the ground as compared with water passing through concrete by comparing the sodium/calcium ratio, by iron content, silicate content, carbonate content or similar factors. The data available to date does not have sufficient detail to carry out any such check.

With the particular construction of this dam, any seepage through the foundation need only travel say 4 metres in rock to bypass the foundation plinth, but may then have to pass through say 100 metres of gravel and rockfill before leaving the dam. It is therefore doubtful that sufficient trace chemicals could be picked up in 4 metres that would not be masked by chemical pick-up over the following 100 metres. Nevertheless, samples of fresh foundation rock were taken by digging into the side of the spillway cut, and these were submitted to D.O.T.C. for crushing and solute extraction to determine whether any trace chemicals exist. Four water samples were taken on 7th June from:

1. the reservoir 0.5 m below the surface near the main joint at the eastern end of the concrete face
2. the leakage below the dam
3. the leakage at the western end of the spillway structure
4. the leakage from the eastern end of the spillway structure
The results of analyses of all samples are given in Appendix 1.

It is understood that the reservoir shows both strong thermal and chemical stratification. If measurements are available on this phenomena then they may be used to trace the leak. Temperatures of reservoir and leakage are presently being taken, but reservoir temperature is measured at the surface of a shallow beach and is therefore subject to short term variations by solar gain or evaporation. It is recommended that these measurements be made near the face at a depth of at least 0.5 metres.

It would be preferable if the temperature profile could be measured, so that the temperature of the seepage could be matched against the profile. One difficulty with any matching is that the seepage has a long path through the dam, and the large thermal inertia of the dam materials may have a strong influence on the temperature of the seepage.

Any chemical stratification is likely to be significant only in the lower levels of the reservoir, and the seepage measurements indicate only minor seepage at these levels. To make use of the stratification phenomena there would have to be a distinct chemical change in the top two metres of the dam. This is considered unlikely but could be checked by D.O.T.W. The detection of the source of the minor leakage in the lower levels is regarded as an unprofitable exercise as this volume of seepage is well within acceptable limits.

PROBABLE CAUSE OF LEAKAGE

It should be stated at the outset that the position where the water drains from the dam is in no way related to the position of the leakage. As can be seen from Figure 4, any leakage either through the face or foundation at upper levels will not flow horizontally through the dam due to the low permeability of the silty and sandy gravels of Zone 1. Instead the flow would remain within the open gravels of Zone 2 and would follow the grade of the abutment parallel to the face until it reached the Zone 3A open rockfill in the base of the dam. This is the only exit point to the downstream
face, and is located only between chainage 90 and chainage 120. Any such flow would obviously gravitate to the lowest point of the valley and by examining dam drawing No. W79/2329 it can be seen that the point where the seepage exits corresponds within a metre or two of the original water course where it passes under the toe of the dam.

The previously described analysis of seepage flow would indicate that there is some feature of the dam above say RL 371.2 that influences the major part of the seepage. An examination of the drawings would focus attention on the spillway area which has a floor level of RL 370.9. The plinth in this area should extend to RL 371.4 where there is the major horizontal construction joint between plinth and slab, and another major construction/expansion joint where the main slab returns through a 45° angle to meet the spillway.

The plinth joint was not visible at the time of inspection, but should be inspected as soon as the water level is low enough. The vertical expansion joint was examined above water level and for about half a metre below and was found to be in a poor state of repair. Details of this joint are shown on dam drawing No. W79/2334, and are reproduced here as Figure 5.

Inspection of this joint showed that the exposed groove at the top of the joint is currently 100 mm wide to a depth of 50-75 mm instead of the original 20 mm width and that the wide groove had been plugged with cement mortar. The origin of this widened joint is unclear. This mortar was in a poor state of repair, was missing in some places, and had been forced out of the groove in most places. There was no evidence of the specified Thiolox sealant strip.

Discussions with D.O.T.W. staff at Tennant Creek indicated that a road repair gang had tried to "repair" the joint for unknown reasons, and had attempted to pour molten bitumen into the joint. However due to a personnel accident, most of the bitumen was spilled on the slab and joint "repair" was not properly completed. At a later date maintenance staff were asked to use cement bagging to cover the spilt bitumen for aesthetic reasons, and at the same time were asked to fill up the joint with mortar.
This last action effectively locked the joint against further expansion, with the following results:

1. Over most of the joint the infilling was physically forced out of the joint.
2. Where there was sufficient bond or interlock, the slab on each side of the joint spalled away, exposing reinforcing which in one location is visible.
3. A section of the vertical wall at the crest spalled and buckled.

The above actions and the absence of the sealing strip will allow debris to accumulate in the joint when it is open and will restrict the ability of the joint to close. Over a period of years a ratchet effect could develop, creating an ever wider joint until a structural failure becomes a possibility. The opportunity for leakage can increase as the joint widens particularly if the waterstop is missing or surrounded by honeycombed concrete as is evidenced on some spillway concrete work.

Calculations have been prepared to estimate the flow rate through an unchecked gap in the 150 mm thick joint. The physical gap was estimated to be about 5 mm, but the crack in the bitumen infill was approximately 2 mm where it was visible above water level. At full reservoir level, the calculated seepages were 22 L/sec for a 5 mm gap and 9 L/sec for a 2 mm gap. Since the observed leakage is less than 2 L/sec, it is apparent that the waterstop is operating for most of its length, or if the waterstop is missing then the gap is smaller or infilled for most of its length. The hydraulic calculations for lower reservoir levels support a hypothesis that if this joint is leaking then most of the leakage is at the lowest level in the joint.

A potential point of leakage is a "cold" construction joint which runs the entire length of the concrete face at approximately RL 370.8. Even though the face was placed in a continuous operation there were three distinct horizontal traverses of the placing operation. By the time one traverse was completed, new concrete for the next
traverse was placed against concrete which was well past initial set, thereby minimising the bond between pours. If the preparation of the old surface had not been carefully carried out then there could be a complete lack of bond between pours, allowing a crack to develop which could lead to leakage.

The reinforcement was doubled across the cold joint, so that even if there were no bond there should be negligible opening of this joint. The level of this joint is possibly a little low to be compatible with seepage patterns, but this is sufficient variability in the seepage results to allow the possibility of leakage at this level. Obviously this joint should be examined when water levels allow.

Another possible source of leakage is the multitude of cracks in the concrete face. These have been reported elsewhere, and have been attributed to placing concrete with a higher cement content and w/c ratio than specified, the placing of concrete in high temperatures, and the exhaustion of workers over the 26 hour continuous placing operation. GHD had previously advised on epoxy repairs to the major cracks and some of these had been carried out. Many of the repairs had since cracked, in particular those where the epoxy had been simply painted over the crack. There were some failures where the crack had been cut out and infilled with epoxy, but the epoxy did not appear to have penetrated beyond 5 to 10 mm into the crack. There was no evidence of the use of the capillary epoxy which might have bonded the crack for its full depth.

The crack pattern above water level was mapped as per Figure 6, and the positions of major cracks was noted, these being cracks with an observed width of approximately 1 mm. It can be seen that these are at reasonably regular intervals of about 8 metres, and at the present time these are probably acting as expansion/contraction joints. It is probable that the widths of crack beneath the surface of the slab are probably 0.5 mm or less, and the calculated flow through nine such cracks with an average immersed length of two metres is 20 L/sec.
The cracks are therefore a potential source of leakage, but if this were the case a larger seepage would be expected at reservoir levels in the RL 368 to RL 370 range. Nevertheless these cracks should be examined when further exposed to see if the openings are large only at higher levels and therefore giving seepage patterns similar to those indicated on Figure 2.

LEAKAGE FROM SPILLWAY

There are noticeable leakage areas at each end of the spillway and some through the main spillway wall, these latter being due to poor concrete construction. Some leakage was observed coming from under the main spillway slab and some of the slab joints are showing minor seepage. All leaks are clear with no indication of suspended or transported material.

At the western (dam) end of the spillway, most seepage is coming from the simple butt joint between the spillway floor slab and the inclined wall slab. Some seepage also comes from an area near the end of the inclined slab. On the inclined slab there is efflorescence approximately 0.5 m above spillway floor level, suggesting that there is water behind this slab to at least that height.

The watertightness in this area is achieved by the concrete face to the dam, the spillway foundation slab being laid in contact with the foundation rock and the various concrete to concrete joints. It is possible that if water is leaking behind the slab from a major construction joint as previously surmised, then some of this water could pass behind the wall to reappear downstream of the spillway. Alternatively the leakage could be coming along or through the foundation. Construction joints in the vicinity were straightforward and hence should be watertight, but should be checked as reservoir levels allow, particularly when the water level is below the plinth joint but still above spillway floor.

At the eastern end of the spillway, watertightness is achieved by embedding the vertical spillway into the natural ground in the manner of a cut-off wall. Concrete was poured against the excavated and cleaned trench, but did not penetrate far into rock due to
difficult digging conditions. The inclined walls are to prevent erosion and form no part of the water retaining system. The positions where leakage emits, at each end of the inclined slab at its base, are not directly related to the source of leakage.

This leak is significant in that it is the only location in the project where seepage is likely to be passing through natural soil, rather than through rock or concrete. The potential for piping in this area is therefore much higher than at other points, particularly in view of the observed flow. The area behind the inclined slab was inspected by Mr. Phillips for signs of subsidence or piping, but none were seen. A D.O.T.W. officer accompanying the inspection stated that early in the project a large cavity formed behind the upstream inclined wall. The hole had been filled by pouring a sand-cement slurry into it. Possibly this hole was due to inadequate construction techniques.

The leakage from under the spillway floor slab is possibly through a rock joint but is of no immediate concern. It is understood that repairs of leaks in the concrete walls are being undertaken as opportunity arises.
FURTHER INVESTIGATIONS

The only area that would benefit significantly from further investigations is the proving of the surmised position of the major leak. Apart from visual inspection as the water level falls, only two techniques appear to have any chance of success, and we would recommend that both be tried.

The first would involve the injection of a tracer into the suspect joint, probably using fluorescein which is not absorbed into clay particles as it passes through earth materials. Since the position of the leak is surmised to be near the base of the main vertical joint, the dye could be injected directly into the joint using syringe, squeeze bottle or similar. Flow calculations are of limited accuracy due to the need to estimate permeability data, but would indicate that it may take one to five days for the dye to appear in the seepage water. A continuous reading and plotting instrument would then need to be placed near the V-notch weir, and samples of seepage at the west end of the spillway could also be monitored.

If this test is unsuccessful, then injection of dye in the nearby plinth joint or cold construction joint could be attempted. This work will require a skindiver with aqualung equipment, and needs to be carried out in the near future whilst there is still a reasonable seepage flow through the dam.

A supplementary technique is to position geophones in various places below water level on the concrete face and to listen for sounds of water trickling through gravel filters and rockfill. The technique relies on the assumption that the gravel is not fully saturated (almost certainly correct) and that the water velocity is sufficient to create noise (less certain). Testing would have to be carried out in still and quiet conditions to avoid wave noise and background wind noise, etc. It is unlikely that this technique would identify the leak position to within 10 metres, but should at least identify if the leakage is from one abutment or the other. If from both it might support the hypothesis that leakage is coming through the construction joint extending along the full length of the dam.
When the water level has dropped below spillway floor level and presumably when the seepage has therefore diminished, all joints and cracks should be visually inspected. It is possible to pressure test any joint or crack that is suspected of being a major source of leakage by covering the area with a strong membrane that is sealed to the slab at the edges. This system will only sustain low pressures of one or two metres head, but should be sufficient for the leaks being explored. Such an exercise is, however, time consuming due to the difficulties of sealing and is therefore expensive. We would not recommend such a test unless other tests have failed.

If tests and visual inspection confirm that leakage is coming from either the plinth joint or main vertical joint, then a section of concrete near the most suspect length of joint (presently thought to be near the bottom of the vertical joint) should be carefully jackhammered out over a length of about 0.5 m, a width of 0.15 m each side of the joint and down to the waterstop (approximately 100 mm deep). The area should be examined for

1. presence of corkboard and other joint fillers as per the original drawings
2. the depth to the waterstop, its position and straightness
3. the integrity of the waterstop
4. the soundness and the watertightness of the concrete surrounding the waterstop

The waterstop itself should not be shifted unless it is obviously damaged, and the excavated hole should be repaired with epoxy concrete to match the geometry of the adjacent joint.

POSSIBLE REMEDIAL WORKS

The actual repairs will of course depend on more precise identification of the source of leakage than is presently possible. Based on the observations to date, the remedial works could include the following:
If the main vertical joint or plinth joint is leaking, it should have the Thiokol sealant stripped out (if present) and the joint thoroughly cleaned of bitumen, dirt and debris. If the self expanding corkboard or timber in the joint is loose it should be removed and replaced with compressed self expanding corkboard. The top of the joint should be recut with a diamond saw to create a joint approximately 25 mm wide and deep, or if a larger joint is necessary it should be as deep as its width. This joint should be thoroughly cleaned with dry compressed air and a new Thiokol seal inserted. Note that the success of this joint is highly dependent on geometry, cleanliness, the bond breaker strip, correct application of primer and correct installation of sealant. It should be carried out by personnel who are experienced with these materials. A successful new seal at the surface will compensate for inadequacies at the waterstop, but if there are obvious areas of honeycombed or fractured concrete these should be repaired prior to installing the seal.

Where the concrete slab has spalled near the vertical joint, concrete should be chipped out to a depth of 20 mm beneath the exposed reinforcement. Rust on the reinforcement should be cleaned up, the steel painted with a phosphate rust inhibitor solution and then painted with primer containing metallic zinc particles. The concrete surface should then be painted with Bondcrete and immediately repaired with a cement mortar, not epoxy. Carry out this repair in cool weather with minimum practical water in the mortar.

It may not be necessary to attempt further repairs to cracks or an opened construction joint in the concrete face depending on the outcome of testing. If required, only the major cracks need be treated. Repairs to vertical cracks with a capillary epoxy are likely to transfer the expansion/contraction movement to a nearby minor crack. With the number of cracks in the slab it is unlikely that the slab could now be repaired to a homogenous condition. Repairs could then concentrate on either repairing the horizontal joint with capillary epoxy or filling the major cracks with a sealant that can accommodate movement. Such sealants are unlikely to penetrate into cracks and hence the surface of the crack would be cut out to a depth of 10 mm and a width of 3 mm to 6 mm. This
groove would be cleaned and filled with a flexible silicone sealant, using primers as may be recommended by the suppliers. The surface of the sealant would be trimmed flush and smooth to inhibit vandalism.

Leakage on the eastern side of the spillway should be attended to, using pressure grouting around the vertical wall. Grouting would be by consecutively drilling vertical holes about 0.25 metres from the wall at 1 metre centres and grouting with a 3:1 water/cement grout. If there is negligible take, then a chemical grout such as Geoseal should be used. Techniques are similar provided that certain precautions are taken with the preparation of the chemical grout. Grouting pressures need only to be 2 to 4 metres at the top of the hole. If grout takes are large then no pressure should be applied, using only gravity head to supply the grout. Large takes could indicate that the grout is covering a large area, and any applied head could lift up some of the slabs in the vicinity.

Whilst the grouting equipment is on site, the leakage under the main spillway slab should be grouted.

At the western end of the spillway, repairs to the concrete face should reduce the leakage. However, the area around the spillway wall could be grouted as for the eastern end. The embankment material behind the wall should be a gravelly silt. If the first holes encounter a coarse open gravel (Zone 2) then grouting will be expensive and have little effect, and in these circumstances these holes should be filled with grout under gravity conditions and the grouting abandoned.

RECOMMENDATION

The following is a summary of recommendations made in this report.

1. Continue recording and plotting seepage and water level, taking into account effects of rainfall and problems with the water level recording instrument. Carefully plot results in the forthcoming period of falling water level to identify water level at which seepage returns to small values.
2. Shift location of recording of reservoir water temperature from shallow beach to near concrete face, and adopt a fixed depth of at least 0.5 m for recording. If possible, determine temperature profile.

Assess rate of seepage in spillway area as reservoir level falls. In particular note seepage at western end when reservoir level falls below the plinth joint but is still above spillway floor level.

4. Test suspect joints, starting near base of main vertical joint, whilst there is still a reasonable depth of water against the joint. Use fluorescein or similar tracer injected directly into joint and monitor main seepage and eastern spillway seepage. If no positive result, test nearby plinth or construction joints in a similar manner.

5. Consider the use of underwater geophones during still weather to listen for water trickling behind concrete face and record observations.

6. When the joints become exposed above water level, carry out detailed visual inspection removing mortar, dirt and debris. Establish most likely position of seepage and excavate concrete around joint to inspect joint details and waterstop as described in this report.

7. When the water level is at RL 370 or lower, examine cracks in concrete face in region of RL 370 to RL 372 to determine if there is an open construction joint or some feature of the crack pattern that would cause the major dam seepage that commences at these levels.

8. If above tests and observations are inconclusive, pressure test sections of joints and/or cracks in face.

9. Repair spalled areas near main vertical joint in face, including treatment of exposed reinforcement.
10. Use low pressure grouting to control leak at eastern end of spillway. Use chemical grout if necessary. Grout seepage under spillway base slab. If above tests do not positively link dam seepage with seepage at west end of spillway, try experimental grouting in this area, and if successful continue with detailed grouting.

The recommended observations and tests are of a nature such that it may be convenient for Departmental staff to carry these out with a minimum of involvement of our firm. Should the observations and tests positively support the findings to date then the repairs described in this report should be detailed and implemented. Should there be some anomalies or unexpected observations, we would be able to assist with the interpretation of these and to advise further as may be necessary. All tests and observations should be conducted by competent interested persons supervised and instructed by an Engineer.

Should the Department require, we would be able to assist with tests, detailing of repairs and supervision. In particular, if it is found necessary to use chemical grout in the spillway area we have recent and detailed experience in this type of operation.
MARY ANNE DAM
SEEPAGE Vs TIME
FIGURE 1