# APPENDIX B

## RCC PLACEMENT BY LANE METHOD – BWA'S PROPOSAL, TRP COMMENTS ON PROPOSAL AND BWA'S PROPOSED SPECIFICATION CHANGES 25-27 JULY 2012

Bulk Water Alliance

# Memorandum

19 JULY 2012

Reference No: GHD-ECD-GEN-DAM-TMM-0101-0

| | |
|---|---|
| **SUBJECT** | ECD – RCC placement methodology |
| **TO** | [redacted] |
| **FROM** | |
| **REVIEWER** | |

## Executive Summary

Space on the dam has become quite constricted as the placement area has narrowed, now that we are closer to the top of the dam. This has had implications on RCC placement in terms safety, production and quality. To mitigate the extent of these issues, the construction team has requested for the specification to be relaxed for a small zone of the dam, to allow placement of RCC in two lanes, which extend from abutment to abutment. The details of the proposed methodology are presented along with the associated risks and benefits.

The risks associated with placement of lanes over a limited zone within the upper portion of the dam, in a staggered approach as proposed is minimal. The Design team (including [redacted] are willing to relax the Specification to allow for placement of RCC in lanes as defined herein. This is on the understanding that tangible benefits will occur in terms of the safety, quality and production issues that are currently being encountered.

## Introduction

Space on the dam has become quite constricted as the placement area has narrowed, closer to the top of the dam. This has had implications on RCC placement in terms safety, production and quality. To mitigate the extent of these issues, the construction team has requested for the specification to be relaxed for a small zone of the dam, to allow placement of RCC in two lanes, which extend from abutment to abutment. This memo outlines the details of the proposed methodology and the associated risks and benefits.

## Proposed methodology

The proposed methodology is to place a lane (or strip) of RCC against the upstream form. The downstream edge of the RCC would be rolled off and compacted as the lane proceeds from one abutment to the other. The downstream portion of the dam would be completed by the next lane of RCC.

The details are as follows:

- The location of the lanes will be as per the attached sketches (Refer Appendix A). The lane placement methodology will not continue above the level shown (RL 533.3m). Other placement strategies will be adopted beyond this level, which may include an external pedestrian access way and drive on access in some areas.
- The interface between the lanes is offset from the one below by 1.5-2m. The intended arrangement has a lane ending in the same plan position only on every fourth layer.
- The upstream lane will not be less than 10m wide to ensure the upstream 6 m can be suitably protected..

- The downstream edge of the RCC will be "rolled off" at approximately 6H:1V (as per the specification) and will be covered with wet hessian after compaction. The slope of the roll-off makes it difficult to continuously water cure via other means.
- The lanes will be marked out by survey.

## Risks

The specification (Section 15.4.4, subsection "Layout of Placement Area") prohibits the placement of RCC in lanes because repetitive placement of lanes in the same plan position could develop a plane of weakness in the dam, which could increase the potential for cross-valley cracking. The design team consider that the risks of generating a cross valley crack have been adequately mitigated with the current proposal on account of the following:

- This placement methodology will only be adopted for a small part of the dam (a zone that is 8.4m high). This means that any potential weakness is confined to an isolated area in the upper portion of the dam.
- The likelihood of upstream to downstream tensions and therefore the risk of cross-valley cracking is not as great in the upper portion of the dam as it is near the foundation (as demonstrated through previous thermal modelling).
- The interface between the lanes has been offset on subsequent layers so that the intersection of lanes occurs in the same plan position only on every fourth layer. This minimises the potential for a continuous plane of weakness to be developed.
- The potential of a poor bond being formed at the interface of the lanes is being managed by ensuring the exposed edge is properly cured between placement of adjoining lanes. Furthermore this will be treated as a warm or cold joint as appropriate if placement of the subsequent lane is delayed.
- The slope of the roll-off is quite flat and such a vertical plane of weakness though the layer will not be formed.
- Survey mark-out of the lanes will ensure the position of each lane is carefully controlled

The fact that some cross-valley cracking has already occurred in the dam was considered (i.e. those which occurred following the extended delays to RCC production after the floods, refer GHD-ECD-GEN-GN-RPT-6103-0-0-Cross Valley Cracking). Modelling to date however indicates that the potential for cracks propagating upwards into this part of the dam due to thermal stresses is minimal (refer GHD-ECD-DAM-GN-TMM-0004-0-0-ECD – Thermal Analysis – Cracked Section). There is also considerable vertical separation (13.6m) between the existing cracks and the proposed location of the lanes. Further structural analysis is ongoing.

Whilst the placement of RCC in lanes is prohibited in the ECD specification, several large RCC dams have been built in this way, including [redacted] (Vietnam). For these dams, the lanes are typically staggered on every other layer only.

Another risk associated this methodology is that the upstream 6m, which plays an important role in the sealing of the dam, will be damaged by plant and equipment when it is parked on the lane as it is completed. The upstream lane has been kept to 10m wide (minimum), to enable the upstream 6m to be left clear for curing, with minimal traffic following compaction. The plant and equipment will be parked on the remaining space left on the lane (4m wide minimum).

## Benefits

### Safety

Our current safety policy prohibits interaction of (and requires delineation between) moving plant and personnel. Whilst this policy has been in place since RCC construction commenced, it has become increasingly difficult with the reduced width of the placement area. There are also significant congestion issues, partly relating to the fact that there is currently no drive on/off access.

The dam is currently being placed in one pass from left to right. This means that at any one time GERCC has to be placed on both sides of the dam with RCC placement in between. Maintaining separation between plant and personnel is therefore difficult and the potential for breach of safety protocols is high. Providing pedestrian access from the right to the left abutment is also a challenge as active workfaces can be ongoing across the full width of the dam.

Placement of RCC in lanes means that pedestrian access can be limited to one side of the dam, away from moving plant. It allows the RCC to be spread and compacted with the GERCC team following behind with limited need for plant/personnel interaction. It allows for simpler delineation and the potential for safety breaches is reduced.

### Quality

Our current placement methodology combined with our safety policy (no plant/personnel interaction) has meant that several quality issues are occurring. For example, the specified time from placement of RCC to compaction, or to completion of grout enrichment is repeatedly not being achieved. A total of eleven non conformances have been raised for this issue alone in the last twelve layers, over the preceding nineteen days. Other similar quality issues have arisen.

Placement of RCC in lanes may serve to reduce these quality issues. With the current methodology the GERCC workload is very variable. It is intensive at the start of each layer where GERCC is required against the abutment, in the wingwall, around the gallery and against the upstream at the same time. With placement in lanes, smaller GERCC areas would more consistently be opened up and the GERCC process should be able to follow steadily behind the dozers and rollers without interruptions associated with avoiding plant interaction.

### Production

In an attempt to manage the safety and quality issues outlined above, production is being affected. For the 38 shifts in July, our average rate is 467m3 compared to the 735m3 per shift for the 47 non-greencutting shifts in May. The percentage of warm joints has also increased as a result. Placement of RCC stops regularly to enable the GERCC to catch up to the RCC, for gear to be leapfrogged over the RCC as the working front advances across the dam and for delineated access ways to be adjusted.

The proposed placement methodology will allow the RCC process to flow more smoothly. This should lead to production benefits, which should in turn improve the quality of the RCC being placed.

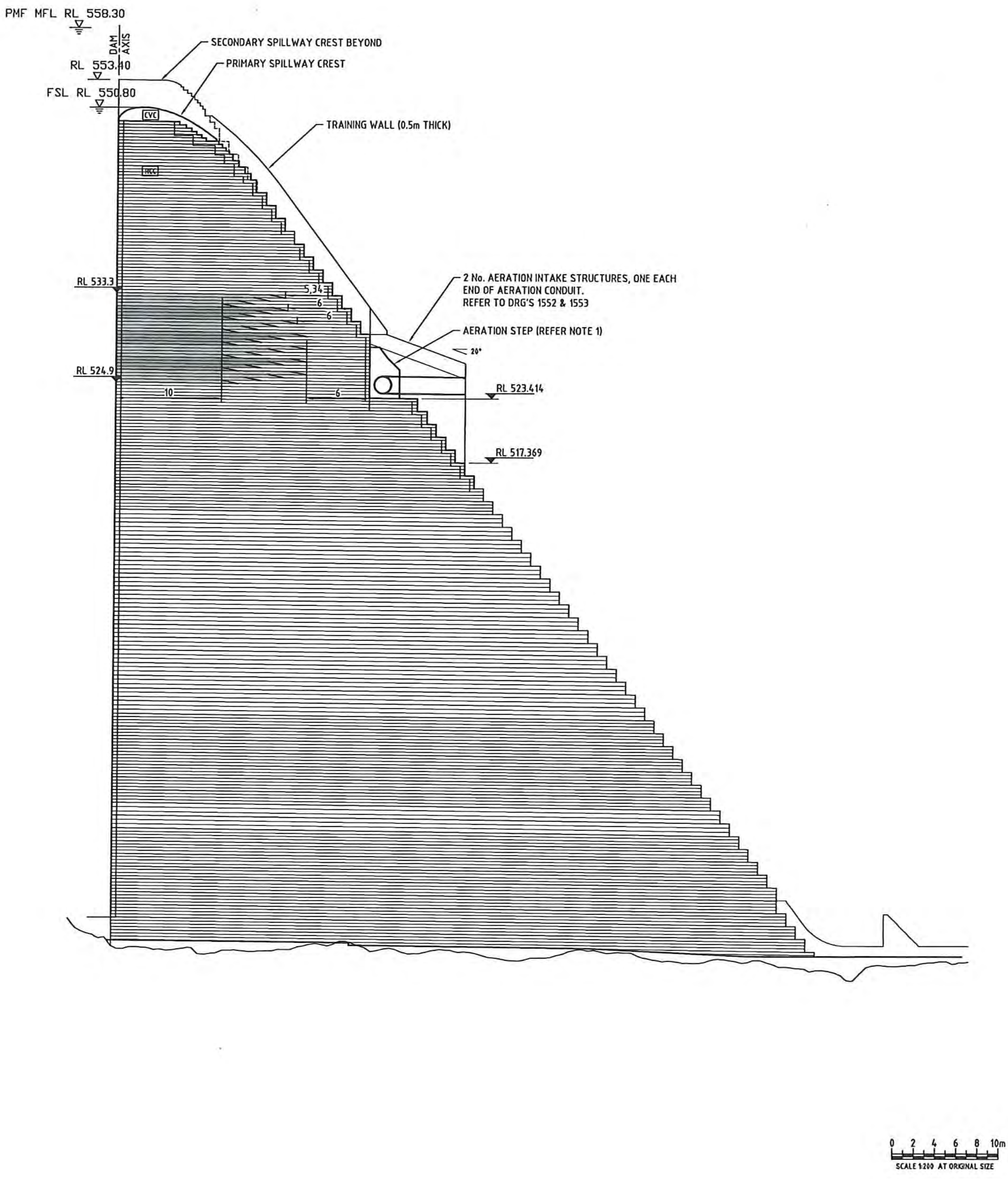
## Conclusion

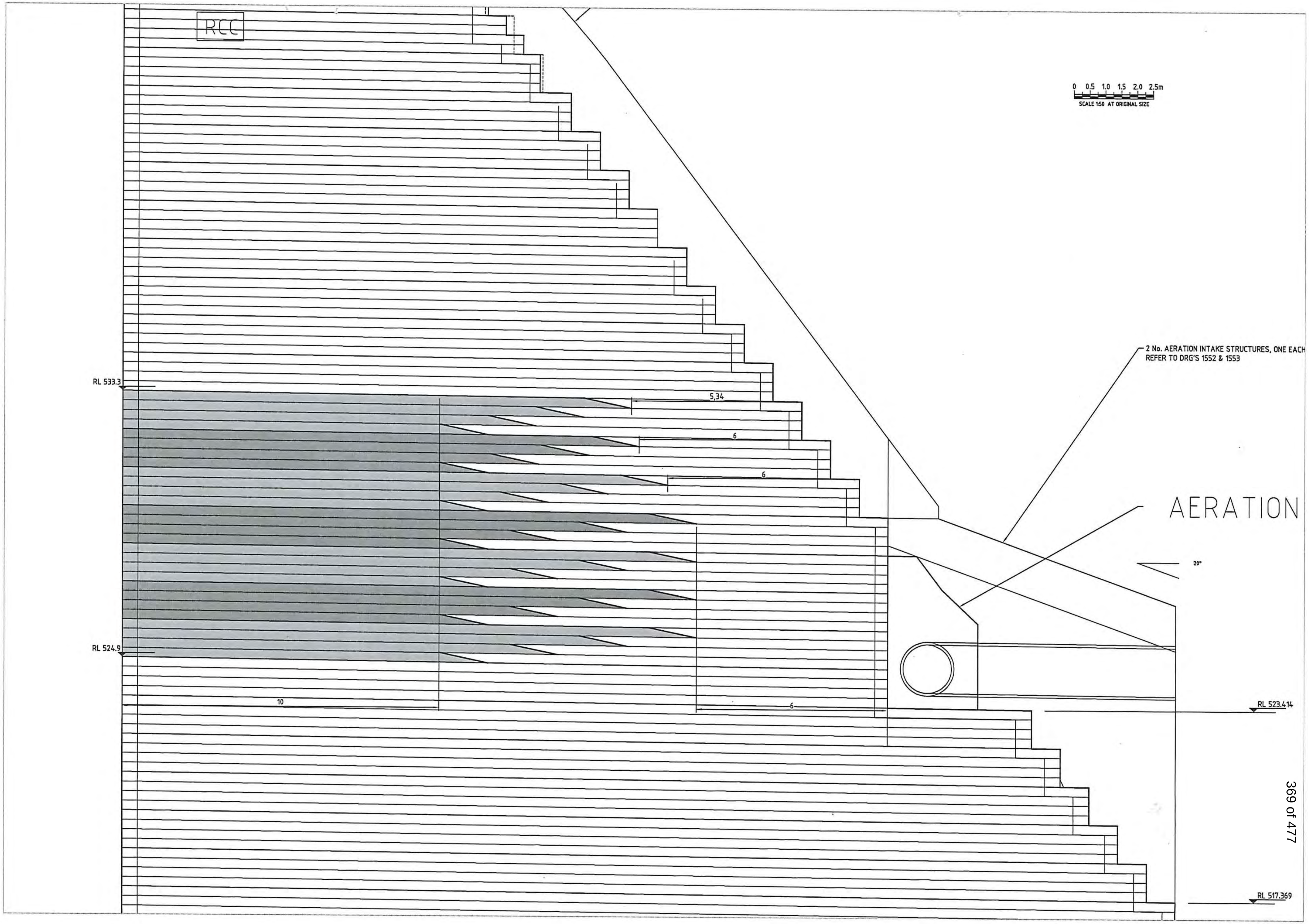
Placement of RCC in lanes was prohibited by the specification as it could increase the risk of cross-valley cracking in the dam. The limited space currently available on the dam combined with our current safety policy (of no moving plant/personnel interaction) has had implications on RCC quality and production. Adopting a placement strategy that involves placement of RCC in lanes could provide considerable safety, quality and production benefits.

The design team consider that the risks associated with placement of lanes over a limited zone within the upper portion of the dam (up to RL 533.3m), in a staggered approach as proposed is minimal. Whilst some residual risk remains, this is offset by the potential benefits outlined above. The design team (including Brian Forbes) are therefore willing to relax the specification to allow for placement of RCC in lanes as defined herein. This is however on the basis that tangible improvement will be made in terms of the current safety, quality and production issues. It is proposed that RCC placement in lanes be trialled for two steps of placement and if improvements are not made, then placement in lanes would be discontinued. Please advise your acceptance of our proposal.

We would be pleased to discuss the issue further with you and/or the TRP or regulator if required.

# Appendix A **Lane Configuration**


PMF MFL RL 558.30
DAM AXIS
RL 553.40
FSL RL 550.80
SECONDARY SPILLWAY CREST BEYOND
PRIMARY SPILLWAY CREST
CVC
RCC
TRAINING WALL (0.5m THICK)
RL 533.3
RL 524.9
5.34
6
6
10
6
2 No. AERATION INTAKE STRUCTURES, ONE EACH END OF AERATION CONDUIT. REFER TO DRG'S 1552 & 1553
AERATION STEP (REFER NOTE 1)
20°
RL 523.414
RL 517.369
0 2 4 6 8 10m
SCALE 1:200 AT ORIGINAL SIZE



RCC
0 0.5 1.0 1.5 2.0 2.5m
SCALE 1:50 AT ORIGINAL SIZE
2 No. AERATION INTAKE STRUCTURES, ONE EACH
REFER TO DRG'S 1552 & 1553
RL 533.3
5,34
6
6
AERATION
20°
RL 524.9
10
6
RL 523.414
RL 517.369

## EMAIL OF 25 JULY 2012 FROM TRP (THROUGH [redacted] TO BWA ON ACCEPTANCE OF PROPOSED CHANGE TO RCC PLACEMENT BY LANE METHOD

[redacted]

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I have read the submission and can see why the team is wanting to go this way, the safety risks together with the real quality issues probably don't give us much option. I would certainly prefer not to place in lanes but have experienced this before due to similar issues on another project. The proposed methodology has been very carefully thought out and appears ok for the section proposed provided there is a REAL improvement during the proposed trial lifts in all areas of Safety, Quality and Production. The staggered interface is endorsed. I would make the following points:-

1 The staggered interfaces are to be closely monitored

2 The rolled over edges are to be compacted correctly with any resultant feather edges cleaned back and adequately treated. Curing of the rolled edges is critical, the use of wet hessian or similar is required and should be closely monitored.

3 Ensure that the proposed treatment of the U/S 6 m is enforced. This section should be treated as a "sacred" zone with traffic disturbance kept to an absolute minimum.

4 The congestion and related safety concerns will only increase as we get higher which highlights the need for drive on/off access where possible.

5 The proposed change to the specification should be restricted to the section proposed up to EL 533.3 provided the trial lifts demonstrate a real improvement in safety, quality and production. Thought needs to be given now to construction methodology for the remaining dam above EL 533.3.

Give me a ring if you have any queries and once again apologies for the delay.

Regards

[redacted]

**EMAIL OF 27 JULY 2012 FROM BWA (THROUGH [redacted]) TO [redacted] COPY TO TRP, ADVISING OF PROPOSED CHANGES TO TECHNICAL SPECIFICATION FOR RCC**

As you letter of 26 July (Doc# A7354155), please find the amended Specification for Roller Compacted Concrete for the Cotter Dam which now incorporates changes to allow placement of RCC in lanes under specific conditions of approval.

Below is an extract from the document showing the amendment.

***Layout of Placement Area***

RCC will be placed in the dam advancing from one abutment towards the other, extending across the dam between upstream and downstream faces, unless approved otherwise.

Unless otherwise approved by the BWA only one layer will be placed at any one time.

Where it is necessary to terminate a layer for longer than 24 hours before completion of the entire layer, in a line running either longitudinally or transversely with the dam axis, the termination lines will be determined such that the offset between it and any other similar termination line, other than transverse joints, in the lower 2 m of RCC is at least 3 m. Unless otherwise approved, transverse termination lines are to coincide with a transverse contraction joint.

A plan recording all the termination lines will be kept by the BWA. All termination lines will be rolled off at an
approximate slope of 6H to 1V. Where the layer below is a warm or cold joint (and where directed by BWA),
the feathered edge of the RCC is to be cut back to a minimum thickness of 100mm, in an approved manner, prior to placement of the adjoining layer.

Around waterstops at the upstream end of transverse joints, the RCC/GERCC is to be terminated 3m either side of the waterstop and rolled off as per above.

Long deliberate lanes of RCC will not normally be permitted. There may be isolated locations within the dam
where placement in RCC lanes may be permitted, if prior approval from the Designer and Owner is obtained.
Where permitted, the methodology will include the following;

- The interface between the placement lanes must be offset from the one below by a minimum of 1.5m. The lane arrangement should ensure that no lane ends in the same plan position within every fourth layer.
- The lanes must be marked out by survey on the placement beforehand.
- The upstream lane must not be less than 10m wide to ensure the upstream 6m can be suitably protected. As per the requirements of Section 15.4.4, plant movements or parking of plant on the upstream 6m of the dam is to be avoided.
- The downstream edge of the RCC lane must be "rolled off" at approximately 6H:1V (as per the requirements above) and the rolled off edge will be covered with damp hessian after compaction to ensure the edge is suitably cured.

If approved, the layers that can be placed in lanes will be defined by the Designer before any placement commences.

Commencement of RCC placement using the amended section of specification is yet to commence, however is likely to be early next week.

Regards

[redacted]

Chief Engineer & Operational Implementation
Water Security Projects
ACTEW Water

GPO Box 366 Canberra ACT 2601
[redacted]

www.actew.com.au

ACT Dam Safety Comittee Regulator

[redacted]

Bean
300 RCC
Bers
300 RCC
sand
geotech

Sand at R 511.3
Flood at R

cracking 1 month after flam

in gallery June July

Bulk Water
**Alliance**

# Enlarged Cotter Dam
## Cross Valley Cracking

**July 2012**

# Certificate of approval for issue of documents

| | |
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| **Document number** | GHD-ECD-GEN-GN-RPT-6103 |
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| **Title** | Enlarged Cotter Dam |
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|---|---|---|---|---|
| 0 | [redacted] | 05/07/2012 | Issued For Construction | [redacted] |

# Contents

# 1 Introduction

RCC placement at the Enlarged Cotter Dam was halted from 27th February to 5 th May 2012 due to heavy rainfall and subsequent flooding. The flood event was estimated to be in the order of a 1 in 100 AEP. The flood waters overtopped the partially constructed dam (which was at RL511.3m) by approximately 2m at the peak of the flood. The dam continued to be overtopped for eleven days thereafter. Clean-up works were undertaken and it was approximately ten weeks before RCC placement resumed.

Throughout the RCC placement downtime, routine surveillance inspections of the dam were completed in line with the requirements of the Cotter River Dams Dam Safety Emergency Plan, Addendum 2. Over the Easter long weekend (6th - 9th April) a cross valley crack was found in what was then the left abutment monolith (Monolith D). In the days prior a less significant crack was being monitored in this area (which tended upstream-downstream close to the abutment). After the Easter break, the crack had been intercepted by the cross-valley crack.

As cleanup of the RCC surface progressed in preparation for placement to continue, cross valley cracks were found to extend most of the way across the dam. This updated memorandum summarises the location and extent of all cracks found prior to RCC placement recommencing on the 5th May. The treatment of each crack to prevent propagation up through the dam is also detailed. Further work to be undertaken is also discussed.

# 2 Crack Details

Plans, sections and photos of the cracks found have been included in Appendix A. These should be referred to in conjunction with the following.

## 2.1 Cross Valley Cracks

The cross valley cracking extended most of the way across the dam. Details of the cracks in each monolith are described below. Drawing 1801, provided in Appendix A, shows the location of each monolith.

Monolith D:

The cross valley crack intercepted the downstream crack that is adjacent to the abutment and extended across the full width of the monolith. This is located approximately 27m from the upstream face of the dam.

Monolith E:

Cross valley cracking extended the full width of this monolith, at approximately 19.7m from the upstream form. The cross valley crack noted in Monolith D (refer above) also extended 7.5m into this monolith.

Monoliths F to J:

Cross valley cracks were noted in each of these monoliths, extending the full width of the monoliths. The offset of the cracks from the upstream form ranged from approximately 15m to 23.3m. In monoliths I and J, the crack was located at the same offset.

Monolith K:

The cross valley crack noted in monoliths I and J extended approximately 2.5m into monolith K before the crack could no longer be traced.

The location where the crack 'ended' in monolith K was in the vicinity of recently placed RCC under the gob hopper. Furthermore, one layer of RCC had been placed in the right abutment monolith (Monolith M) in the week prior to the cross valley cracks being found on the dam. This part of the dam had been left low prior to the flood.

The depth of the cracks is unknown. It is possible that they extend to the foundation, or may ultimately do so. While it was not possible to core one of the cross valley cracks, the initial crack found adjacent to the left abutment was cored and the crack could be clearly seen at the base of the 450mm deep core hole.

The sections in Appendix A show where the cross valley cracks are located with respect to the dam crest and downstream face.

## 2.2 Other Cracks

In addition to the cross valley cracks, other short cracks (up to 7.5m long) were also found prior to placement recommencing. Three tended roughly upstream/downstream adjacent to the left abutment. The most significant of these extended approximately 7.5m from the upstream face and connected to the abutment.

Another crack extended from the left abutment towards the corner of the inclined gallery steps blockout.

A small crack was also found in the then right abutment monolith (Monolith M), which extended from the abutment to the downstream corner of the inclined gallery blockout (on RL510.9).

# 3 Cause of Cracking

## 3.1 Thermal Cracking

The thermal analysis conducted prior to construction of the dam identified the potential for thermal stress induced cross valley cracking. As the warm concrete in the dam cools and shrinks, the foundation remains at a fairly stable temperature and therefore provides resistance to the concrete from shrinking. This restraint imparts tensile stress on the RCC, which can lead to cracking.

In a similar fashion, the exterior of the dam cools before the interior. The internal concrete therefore serves as restraint to the exterior concrete as it cools and similar stresses and crack potential arises.

During production, subsequent layers of RCC serve as insulation on previous layers. When production stops, the concrete surface cools, which presents a risk of cracking as the surface shrinks relative to the interior of the dam (which remains warm). Thermal cracking of this sort has occurred in several dams after extended delays to RCC production. This is believed to be the cause of the cross valley cracking at the Enlarged Cotter Dam.

## 3.2 Abutment Irregularities

The abutment contours (shown in Appendix A) show the presence of minor irregularities in the foundation profile in the vicinity of the cross valley crack. Two subtle 'spurs' are present on the excavated abutment either side of a Set 2 defect which may have provided differential restraint, which could have influenced the orientation of the cracking.

Abutment irregularities may therefore have been a contributing source of the cracks running adjacent to the left abutment.

## 3.3 Seepage Affected RCC

It is also possible that some of the RCC may have been affected by seepage. As discussed above, the first crack noted was situated in the vicinity of a gully down the abutment, which coincided with a Set 2 defect. The gully naturally accumulated seepage emerging from the abutment, which would emerge following rain events.

Larger seeps are generally diverted, but given that the seepage into this area was only intermittent, inflows were typically being managed during placement. In this area when seepage was a concern, the placement area was kept low. The RCC/GERCC would then be placed in the low spot in a concentrated effort once the water had been removed and inflows were being directly managed using the sucker truck. This process was, however, not always followed and on multiple occasions RCC had to be removed as it had been compromised by the inflows.

It is possible that the RCC may have been compromised on other occasions without being detected and removed. Should this have occurred, the RCC strength and drying shrinkage would have been affected, which would increase its risk of cracking.

## 3.4 Temperatures

### 3.4.1 Within the Dam

The temperature readings from the thermocouples in the dam in late February showed the peak temperature within the dam to be around 36°C degrees and about 24°C at the extremities (0.75m from the dam face). These readings were reasonably consistent with modelled results. Since re-establishing the data logger in the dam, the temperature readings show the peak temperature to remain at around 36°C in the middle of the dam. The temperature approximately 1m and 3m in from the upstream face of the dam is around 15°C.

During the clean up period and prior to RCC placement recommencing, thermocouples were installed in holes drilled up to 300mm into the crest level (RL511.3) to monitor the temperature of the RCC near the surface. The temperatures ranged from around 10-14°, showing the RCC surface had undergone considerable cooling.

### 3.4.2 Ambient

In the days prior to when the first cracks were observed in April, the ambient temperature had dropped considerably (close to 0°C). This is illustrated in the temperature plot in Appendix B.

### 3.4.3 Curing

Immediately following the floods curing of the dam could not continue as the water delivery infrastructure was destroyed and works were underway on the downstream steps reinstating power to the tower cranes. The curing system was re-initiated before the Easter weekend. The water from the curing would have contributed to the cooling of the RCC, with wet bulb temperatures being considerably below dry bulb temperatures.

## 3.5 Preventative Measures

Although a procedure for protecting the concrete during cold weather has been established and has been used previously on the project, no such measures had been implemented at the time when cracking was noted on the dam placement. This was due to distractions of the post flood remedial measures and being caught out by the first cold nights of the 2012. Following the onset of the cool weather and detection of the first crack, the abutment monoliths were insulated using plastic and geofabric. This system was found to be suitable for the foundation concrete construction last winter. A temperature plot from one of the foundation pours, constructed of GERCC-m-25, which was insulated in this manner, is included in Appendix C.

Consideration was given to insulating the remainder of the dam although significant access to the dam to prepare the surface for RCC placement was required. The abutment monoliths were protected as these were the shallowest areas of RCC and were considered to be at the greatest risk of cracking. These could also be protected without interruption to the remaining clean up works required on the surface of the dam.

# 4 Potential Issues

## 4.1 Crack Propagation

If the cross valley cracks were to extend vertically through to the downstream face of the dam, significant pressures could generate in the crack from velocity head and associated pressure pulses which could compromise the stability of the part of the monolith downstream of the cross valley crack. If the downstream part of the monolith were to fail, the stability of the upstream part could also be compromised on account of the reduced mass and restoring moment resulting from the truncated cross section.

It is therefore important that the propagation of the cross valley crack, through to the downstream face, is prevented.

## 4.2 Thermal Analysis

The thermal analysis of the Enlarged Cotter Dam (BWA, February 2011) highlighted the potential for cross valley cracking in the long term. It was however concluded that the stresses would be within the tensile capacity of the concrete.

Provided the cracks remain within the body of the dam (i.e. do not propagate to a free surface), and the resulting stress redistribution does not exceed the capacity of the concrete, the global stability of the dam is unlikely to be affected (to be confirmed with further modelling, refer to Section 8). On account of the identified crack potential, thermal modelling of a cracked model was undertaken to investigate this.

The cracked analysis of the Enlarged Cotter Dam demonstrated that if cracking were to occur, it would reduce the stresses in the concrete near the foundation and the vertical extent of cracking is unlikely to be the full height of the dam. For the model that assumed the full tensile capacity of the RCC (2MPa), the strength of the concrete itself was sufficient to keep the cracks below top of gallery level. The stress redistribution arising from the cracking did not exceed the capacity of the concrete and the cracking remained within the body of the dam, for the load case examined (reservoir at full supply level). The stability of the dam was therefore found not to be affected.

Notwithstanding the outcome of the analysis, having identified a number of cracks there was potential for them to propagate up through the dam. Adding to this, the load case giving rise to the cracking is different to that analysed. Having already gained considerable strength and stiffness and having already undergone some of its cooling, the RCC already placed will serve to provide some restraint to the thermal movement of the RCC above, similar to that typically exerted by the foundation. With a predetermined plane of weakness (i.e. the cross valley cracks) stresses may concentrate at this point and initiate further cracking in the RCC above. Treatment was therefore required to address this risk.

# 5 Treatment

The treatments implemented on the cracks found are outlined in the sketches in Appendix D.

The cross valley cracks, the crack parallel to the left abutment (near the groin) and the cracks on the left and right abutment towards the inclined gallery blockouts were covered with a strip of sand and a strip drain. The sand serves as a crack stopper (i.e. to distribute any strain associated with movement of the joint below over a larger area, thereby reducing the stress in the RCC at the crack tip) and also as a drain should any pressures develop in the crack. A PVC pipe connects from the sand and strip drain to the gallery to facilitate drainage and alleviate excess pressures should they exist. The crack may also be able to drain into the transverse joint.

Reinforcement was also provided over the cracks as a second line of defence should they continue beyond the sand layer. A row of 4m long N28 reinforcement bars were placed at 200mm centres on the bottom of the second layer above the cross valley cracks (RL511.7). Also 4m long cogged N24 bars at 150 centres were placed over the cracks which tended upstream/downstream, adjacent to the left abutment. .

A second line of N28 bars were placed over the cross valley cracks on the bottom of the fifth layer above the cracks (RL512.6). These bars were 6m long and were extended all the way to the right abutment, to ensure protection for any potential cracks in this area.

To ensure full encasement of the reinforcement bars, bedding mortar was placed on the lift joint prior to placing the bars, regardless of whether the joint was warm or not

TAMs grout tubes were installed directly on the upstream/downstream crack located on the upstream left abutment. The grout tubes were placed in a circuit to allow grout work to be undertaken from the gallery at a later date. Furthermore a 100mm diameter PVC riser pipe has been installed over the crack at RL512. This pipe is connected to the gallery on the same level through a T-junction and 100mm diameter pipe that extends to the gallery similar to the waterstop drains. Should a seepage problem be found in the area of this upstream/downstream crack on the left abutment after the dam fills, an attempt to close the leak will be first made with the TAMS grout tubes. If this is not successful in plugging any leakage, the riser pipe can be used to drill back down into the crack. Any seepage or pressure build up in the crack will then be drained into the riser pipe, through the T-junction into the gallery.

Photographs of the works described above can be found in Appendix D.

To further ensure that the cross valley cracks do not become pressurised at a later date, horizontal drains will be drilled from the gallery into the cracks. The drains will be at approximately 3m spacing, 100mm in diameter and orientated such that they will not block due to calcite build up. The drains will be drilled from the horizontal gallery and up the inclined galleries to RL511.3. The detail of this work is yet to be confirmed, however a concept arrangement for the horizontal drains into the cracks can be found in Appendix D.

The crack treatment measures were resolved by the ECD design team, including input from [redacted] and discussed with [redacted] both of whom are on the ECD Technical Review Panel. They have endorsed the treatment approach in their Technical Review Panel Report (April 2012).

# 6 Future Monitoring

The options for installation of monitoring instrumentation on the cross valley cracks are being assessed. Piezometers and extensometers could be installed in horizontal boreholes drilled from the gallery to the crack location. As the exact location of the cracks, and the depth to which they extend below RL511.3, is unknown, the instrumentation design would have to allow for this uncertainty.

With regards to the piezometers, the permeable sand zone around the piezometer tip would extend some distance either side of the anticipated crack location. If the crack was to become pressurised, it should be detected by the piezometer. Furthermore if the piezometers were located approximately in line with the dam foundation piezometers, then any pressure found in the crack could be compared with the general internal pressure of the dam.

Rod extensometers can be installed with up to six anchors per unit. These anchors could be positioned at varying lengths across the borehole, ensuring that any movement due to the crack opening up is monitored.

The final arrangement for any instrumentation (i.e. number of instruments, location and spacing) will depend on the results of the finite element analysis currently being undertaken. The analysis will assist in understanding the likelihood of the cracks opening or propagating.

# 7 Resumption of RCC

On account of the surface cooling the existing RCC will provide restraint to any fresh RCC placed above, similar to the restraint typically provided by the foundation, as per the thermal analysis. The differences are:

- The RCC is stiffer (currently approximately 20GPa) than the upper 5m of the foundation (assumed to be 8.5GPa in the thermal analysis), but more flexible than the foundation at depth (assumed to be 28GPa over 5m depth);
- Heat still radiates from the body of the dam below. When subsequent layers of RCC are placed above, it will serve as insulation to the layers below. The existing surface would therefore heat up again; both from heat trapped within the RCC below and from heat generated from hydration of newly placed RCC above;
- The RCC surface is generally planar, compared to the foundation which is quite irregular, which can lead to differential restraint, giving rise to possible stress concentrations.

Whilst the first of the points above would serve to increase the stresses encountered in the RCC above, the latter two would give rise to a reduction in the stresses. It was considered that the net effect is a stress regime that is less severe than analysed for the dam foundation. As the thermal analysis for the foundation was found to be satisfactory, the risks associated with resuming RCC were therefore also deduced to be acceptable. This will be confirmed through further thermal modelling.

It was decided that resuming placement as soon as possible would serve to minimise the delay and RCC surface exposure to the coming cooler winter temperatures, thereby keeping the risks associated with this scenario to a minimum.

# 8 Further Analysis

Further Finite Element Analysis (FEA) of the Enlarged Cotter Dam is currently being undertaken. The purpose of the analysis is to show that the safety of the dam is not compromised by the cross valley cracking, which for the purposes of the analysis is assumed to extend from RL511.3 all the way to the dam foundation.

The analysis to date has found that the cross valley cracks will not propagate upwards through the dam due to thermal stresses [1]. Due to the location of the aeration step approximately 10m above the known location of the cross valley cracks, there was a concern that the cracking may extend to the edges of the aeration step. However the analysis has shown no tensile stress concentrations around the edges of the aeration step blockout. With this information, it was decided that no additional reinforcing bars were required below the aeration step.

The analysis still be to undertaken will assess the safety of the dam with cross valley cracking against all other load cases. These are summarised in Table 1.

**Table 1 Load Cases to be Examined in Further Analysis**

| Load Case | Load Description [1] |
|---|---|
| 1. Usual<br>(Analysis Completed) | (a) FSL<br>Dam at full supply level (FSL) – drains functioning |
| 2. Unusual | (a) FSL<br>Dam at full supply level (FSL) – drains not functioning<br>(b) Earthquake - OBE<br>Post-earthquake static analysis with reservoir at FSL |
| 3. Extreme | (a) Flood<br>Probable Maximum Flood (PMF) – drains functioning<br>(b) Flood<br>Probable Maximum Flood (PMF) – drains not functioning (this is considered to be excessive, however it will be undertaken to determine the impact of failed drains)<br>(c) Earthquake - MDE<br>Post-earthquake static analysis with reservoir at FSL |

[1] Load combinations also include loads due to uplift, tailwater and crest pressures.

The above load combinations are considered to be those critical to the safety of the dam. Two sections of the dam will be analysed: the maximum cross section and also an abutment section. Further details on the further analysis can be found in *GHD-ECD-GEN-DAM-TMM-0100-0-Finite Element Modelling of Cracked Section* [2].

# 9 Conclusion

The cracking found on the dam placement is understood to be a result of thermal cracking, arising as a result of extended delays to RCC production due to the flooding, and exacerbated by the cold weather that followed. There are also several other local factors that could have contributed to the initiation of the cracks.

Further finite element analysis undertaken to date has shown that the cross valley cracks will not propagate upwards through the dam due to thermal stresses. Notwithstanding this, robust treatment involving both a "crack stopping" sand layer, which also serves to alleviate excess pressures (should they exist), and reinforcement has been provided to address any risk of crack propagation. A PVC pipe connects from the sand drain to the gallery to facilitate drainage and alleviate excess pressures should they exist.

A transverse crack located on the left abutment upstream face has been fitted with grout tubes and also had a riser pipe located over it. Should any leakage problems be found here after the dam fills, the possibility of grouting the crack or draining it with a hole drilled through it are available.

Future drilling into the cross valley cracks from the gallery will be undertaken to ensure the cracks do not become pressurised. Furthermore consideration has been given to installing monitoring instrumentation devices in the cross valley cracks.

More general thermal issues associated with resuming RCC placement after an extended delay was considered. This scenario is likely to be less severe than analysed for the full height dam on the rock foundation. As the thermal analysis for the foundation was found to be satisfactory, the risks associated with resuming RCC were therefore also deduced to be acceptable. This will be confirmed through further thermal modelling.

RCC placement was resumed on 5th May to minimise the delay and exposure to the coming cooler winter temperatures, thereby keeping the risks associated with this scenario to a minimum.

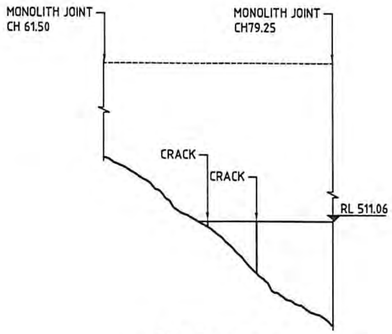
Additional finite element analysis of the dam is being undertaken to analyse the stability of the cracked dam section under the unusual and extreme load cases.

# 10 References

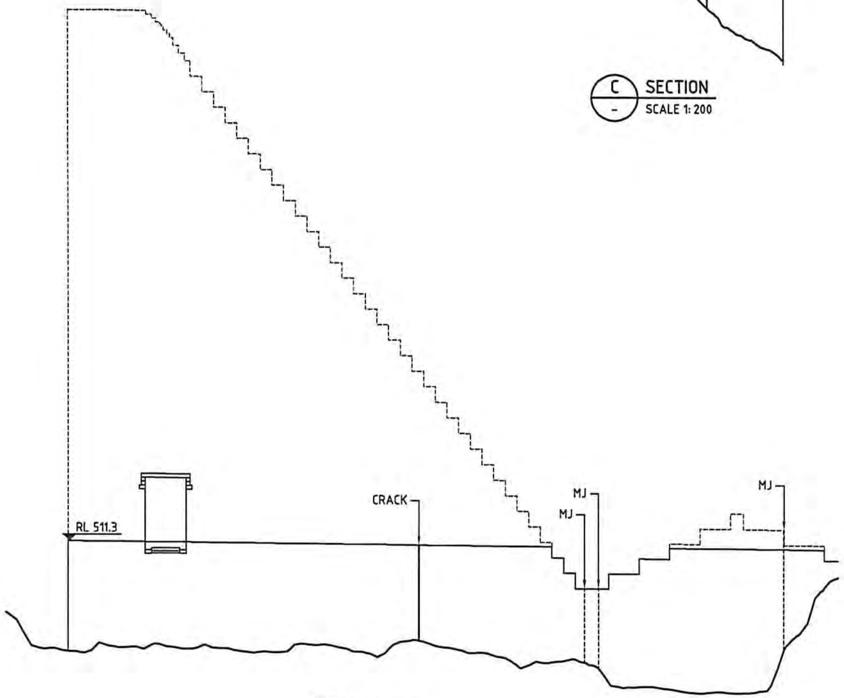
[1] Bulk Water Alliance, 2012. Memorandum: *ECD – Thermal Analysis – Cracked Section*. May 2012.

[2] Bulk Water Alliance, 2012. Memorandum: *ECD – Finite Element Modelling of Cracked Section*. June 2012.

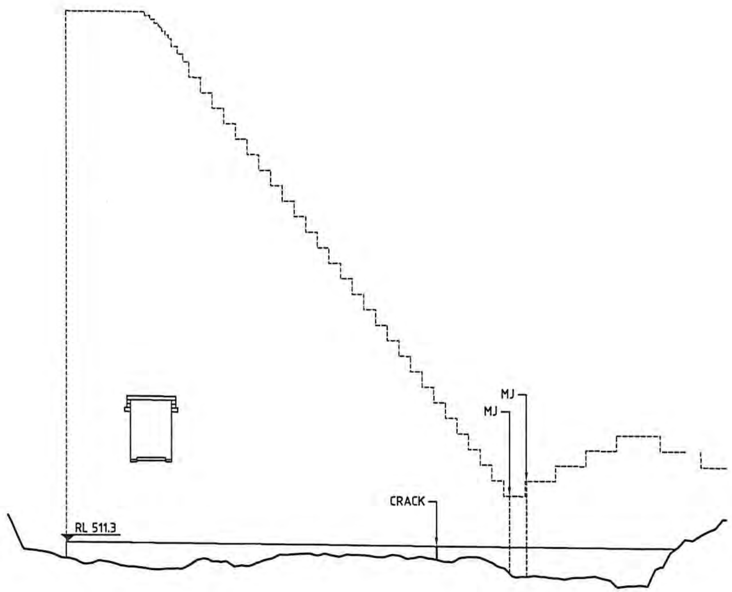
# Appendix A **Plans, Sections and Photographs**



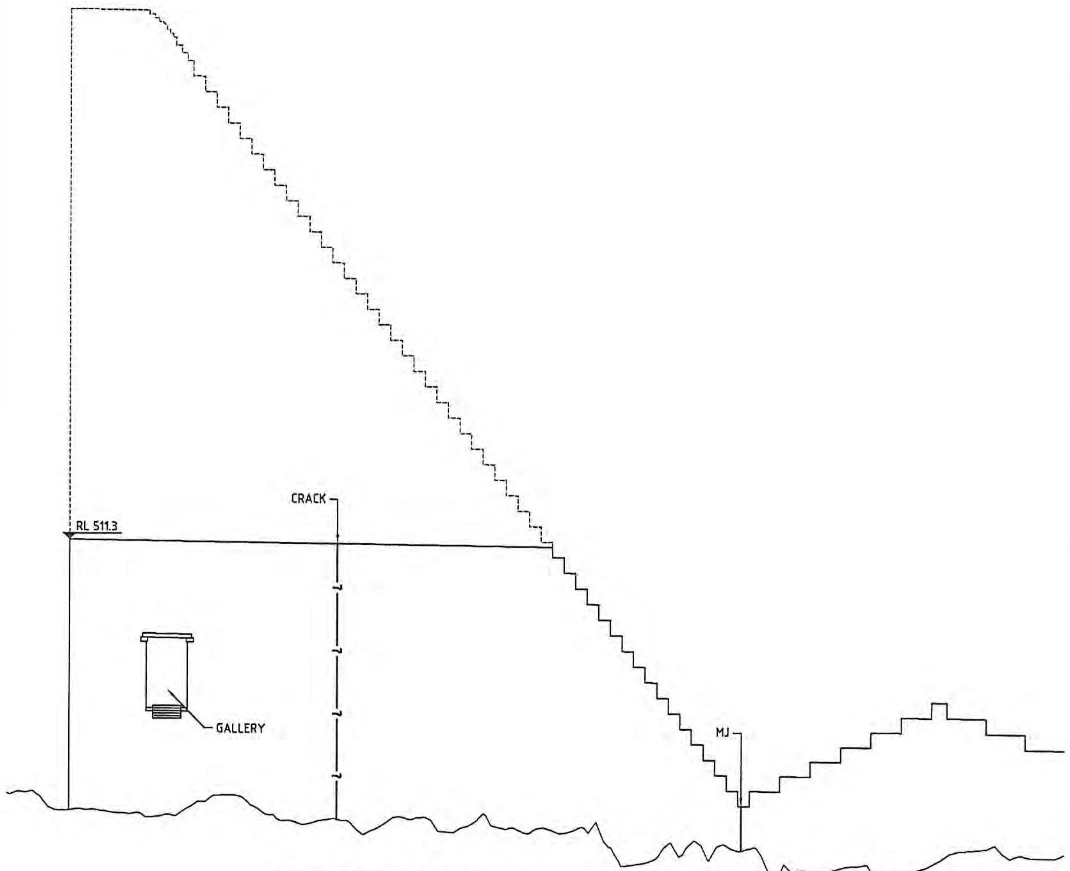

C SECTION
SCALE 1: 200




A SECTION
SCALE 1: 200

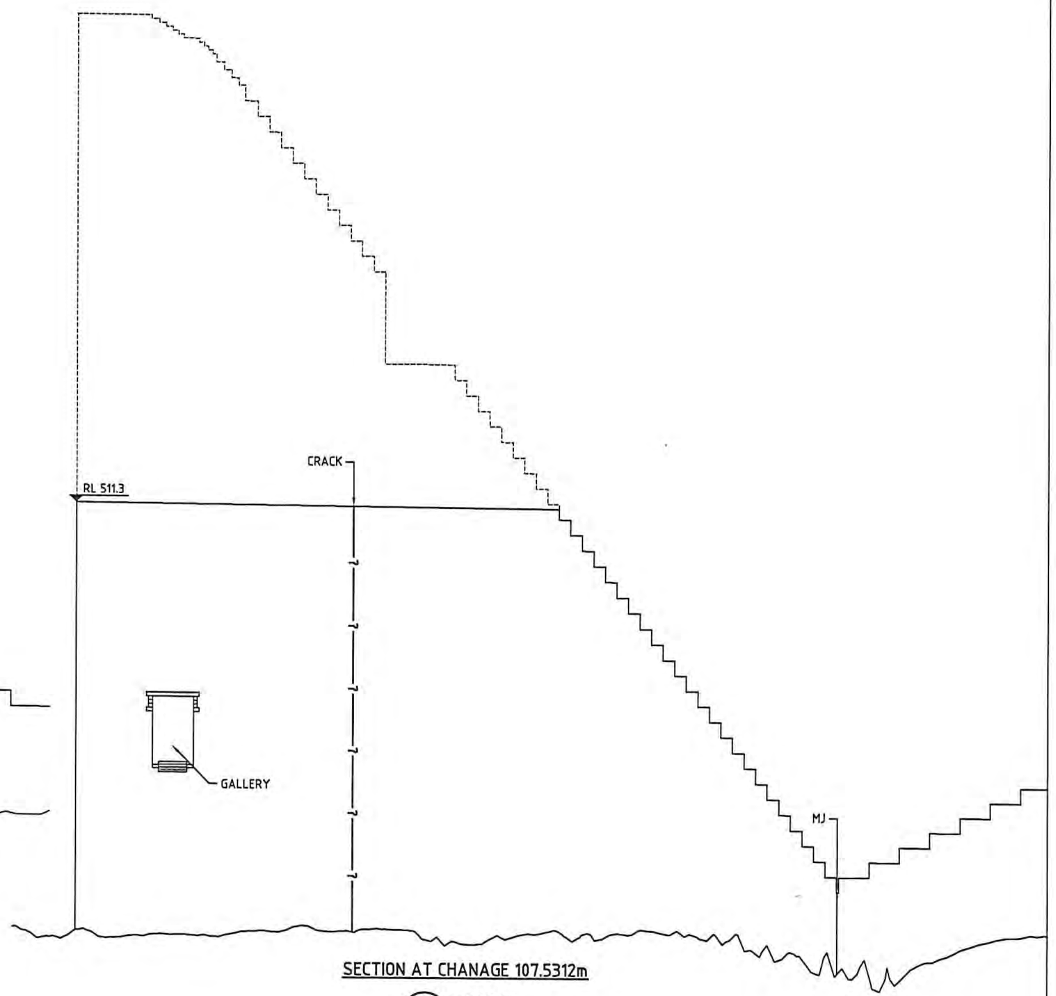



B SECTION
SCALE 1: 200



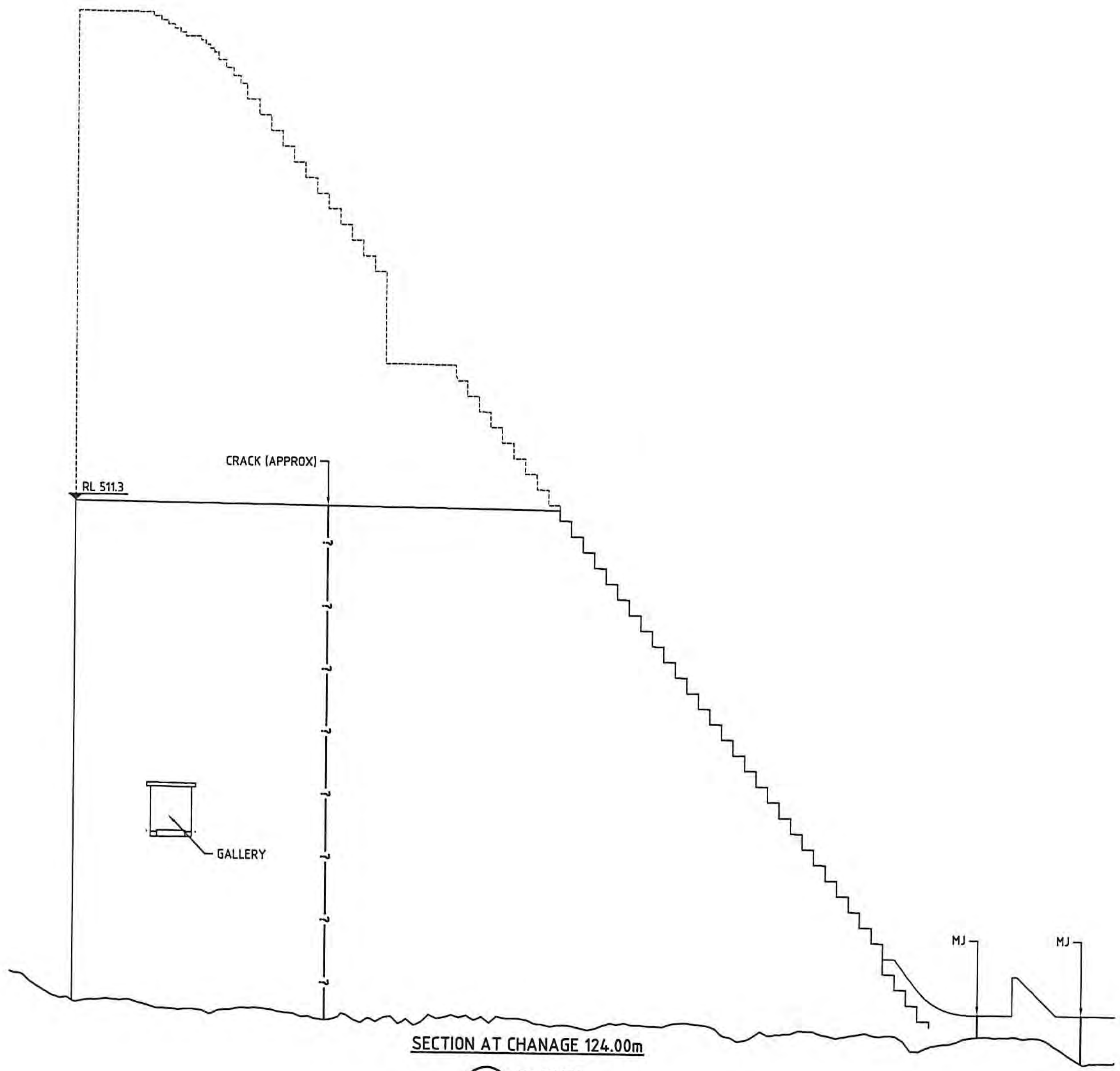

SECTION AT CHANAGE 97.00m

E SECTION
- SCALE 1: 200




SECTION AT CHANAGE 107.5312m

F SECTION
- SCALE 1: 200




SECTION AT CHANAGE 124.00m

G SECTION
SCALE 1: 200

**Photo A.1** - Cross valley crack in Monolith D. Taken looking towards left abutment.

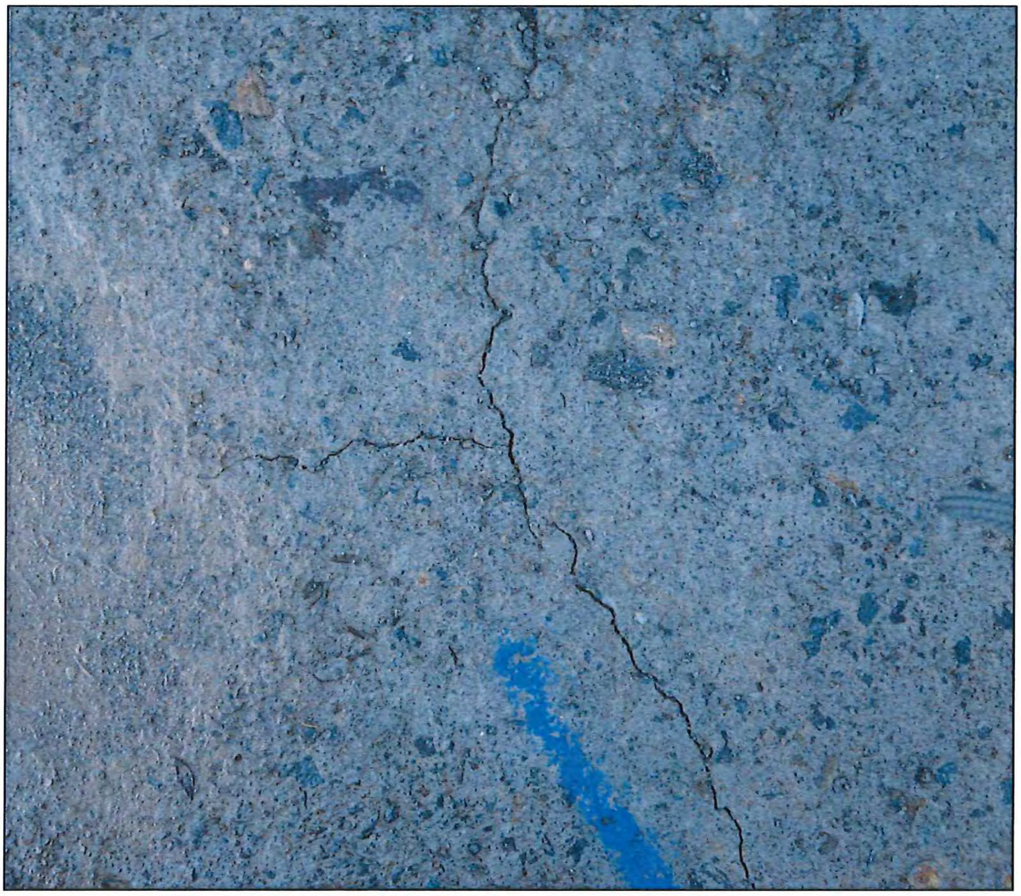


**Photo A.2** – Bifurcation of upstream downstream crack with cross valley crack.

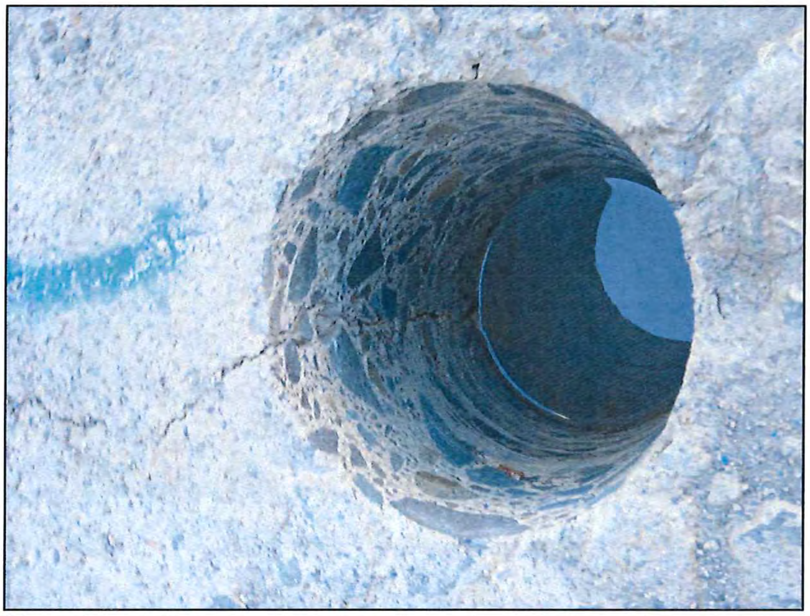


**Photo A.3** – 150mm core through upstream-downstream crack.

**Photo A.4 –** Cracking on upstream left abutment (cracking outlined with blue paint).

**Photo A.5 –** Cracking from right abutment to gallery blockout on RL510.9 (cracking outlined with white paint).

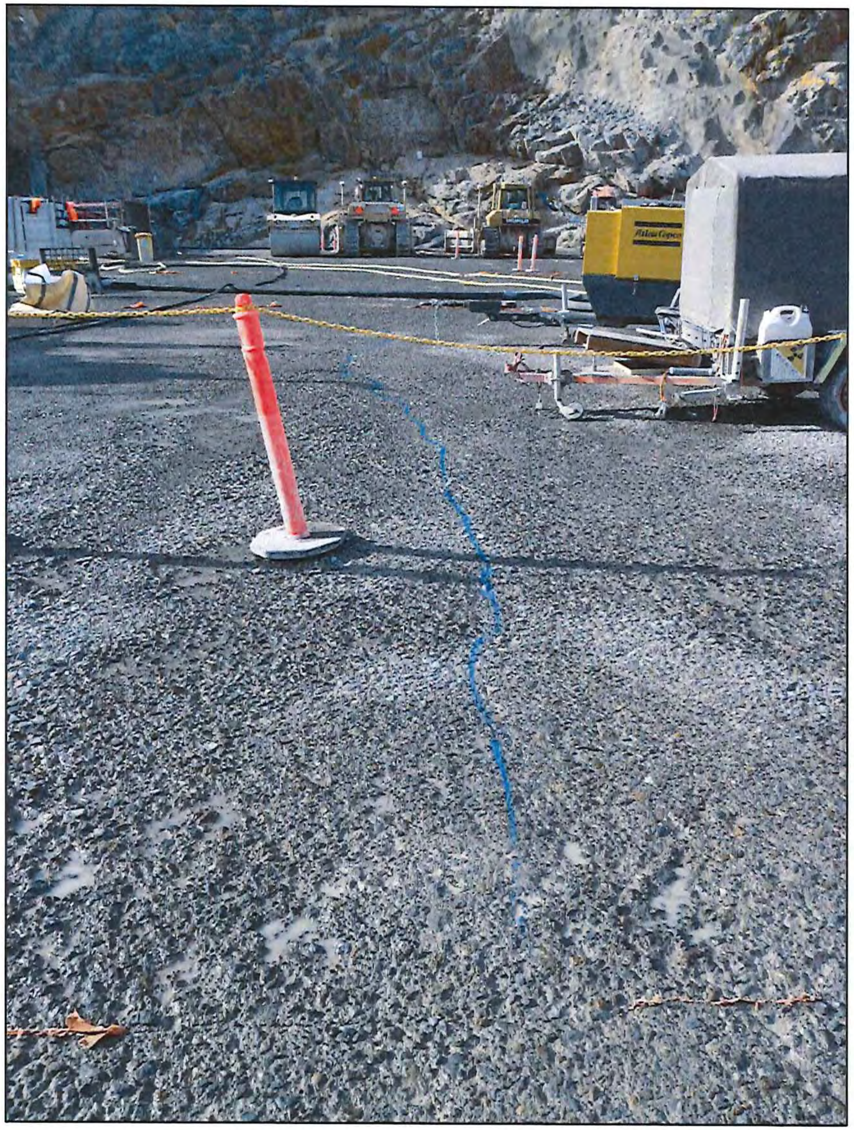


**Photo A.6 –** Cracking in Monolith F, looking towards left abutment (cracking outlined with bue paint).

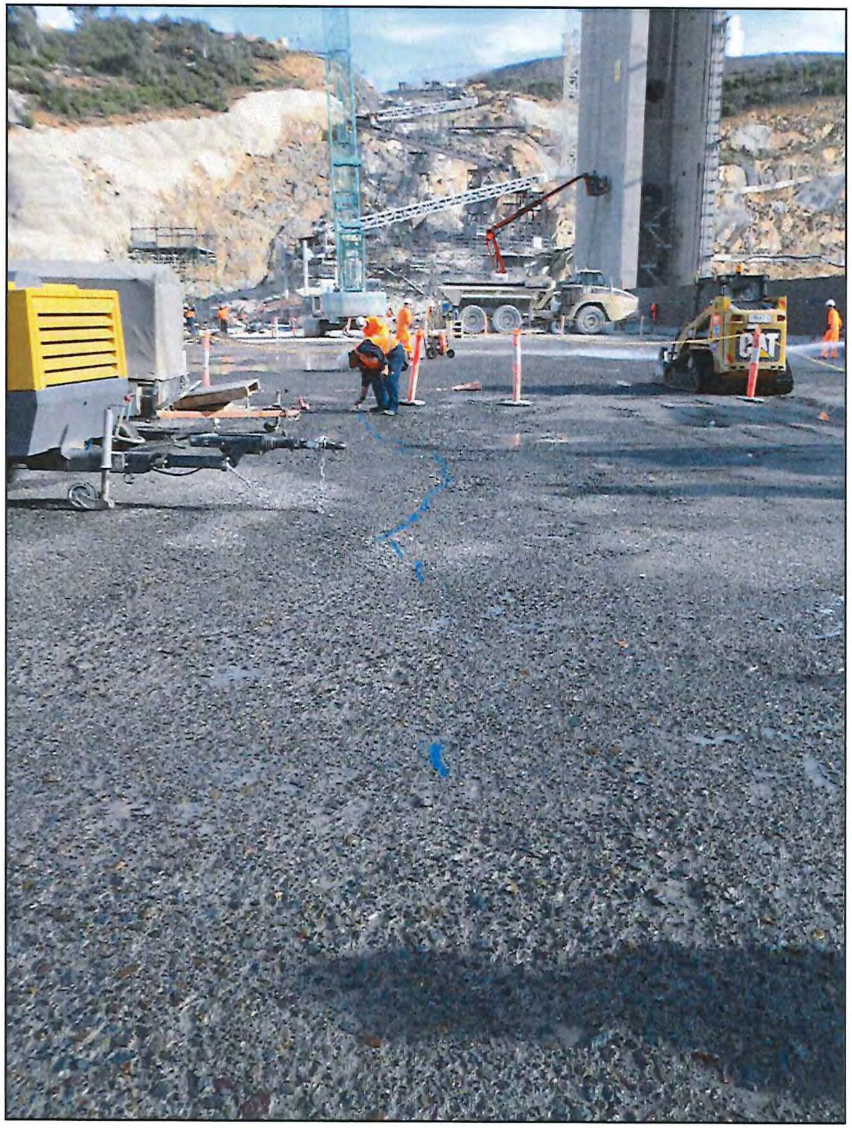
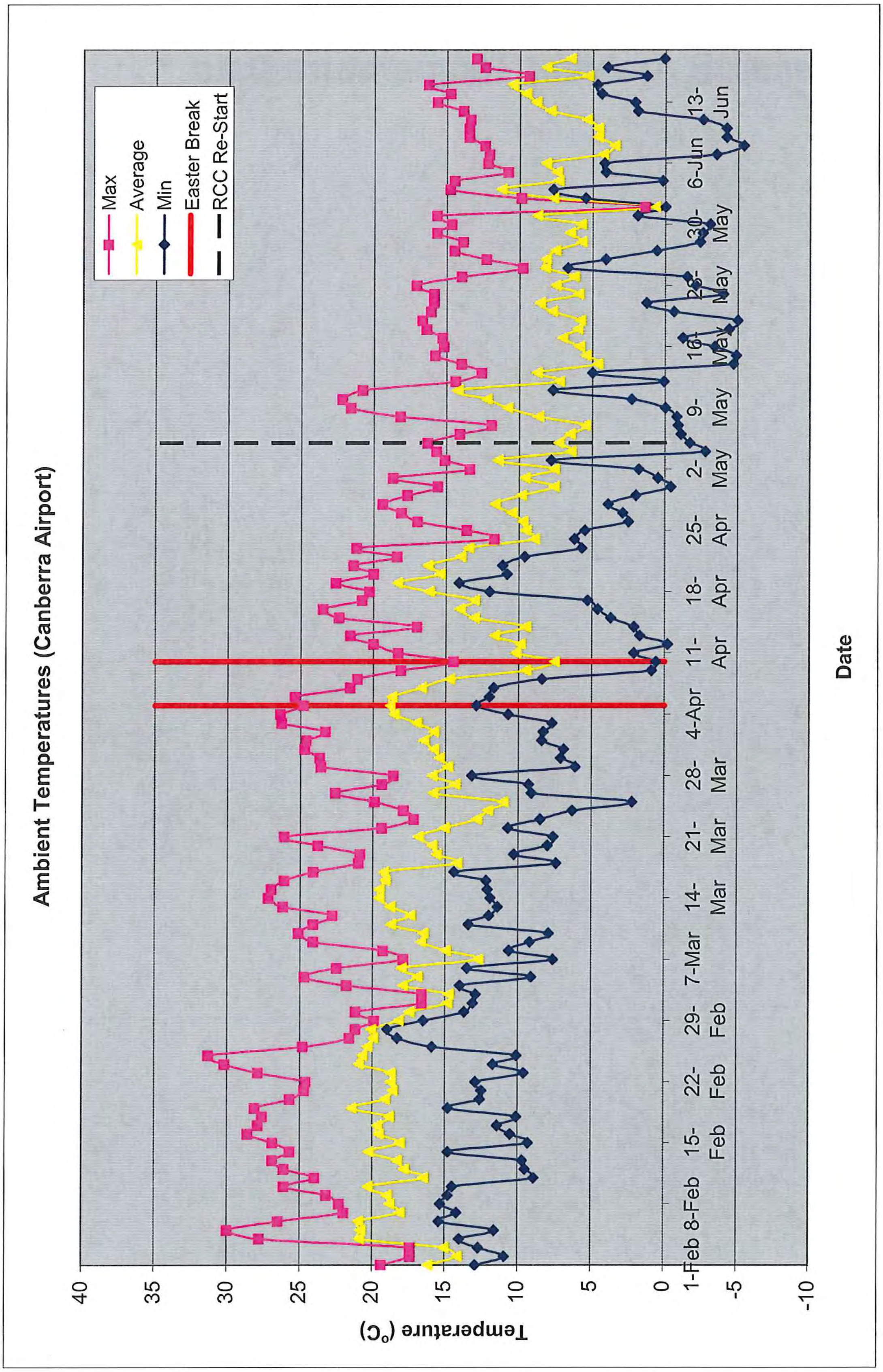


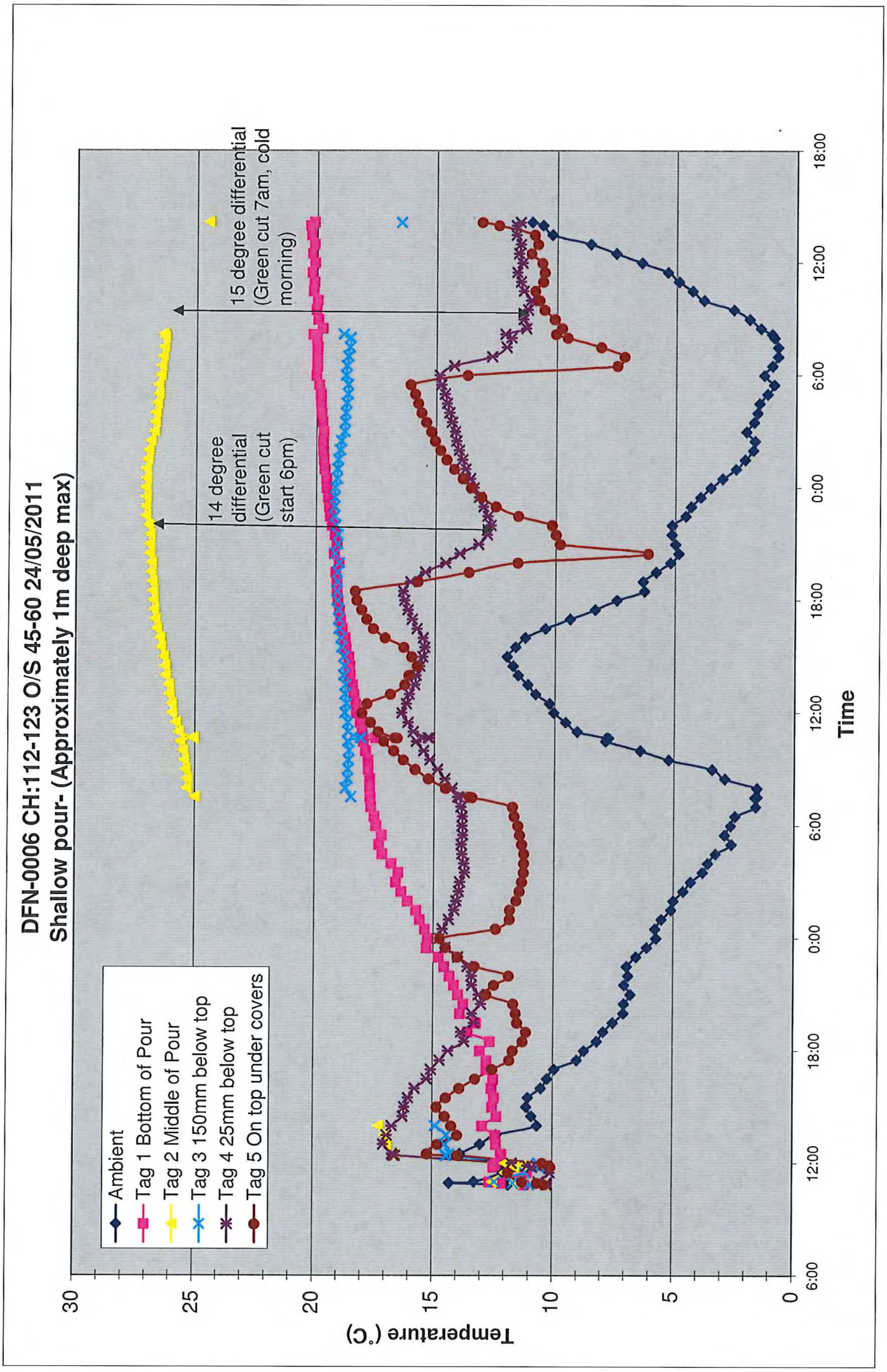
**Photo A.7 –** Cracking in Monolith G, looking towards right abutment.

# Appendix B **Ambient Temperature Data**

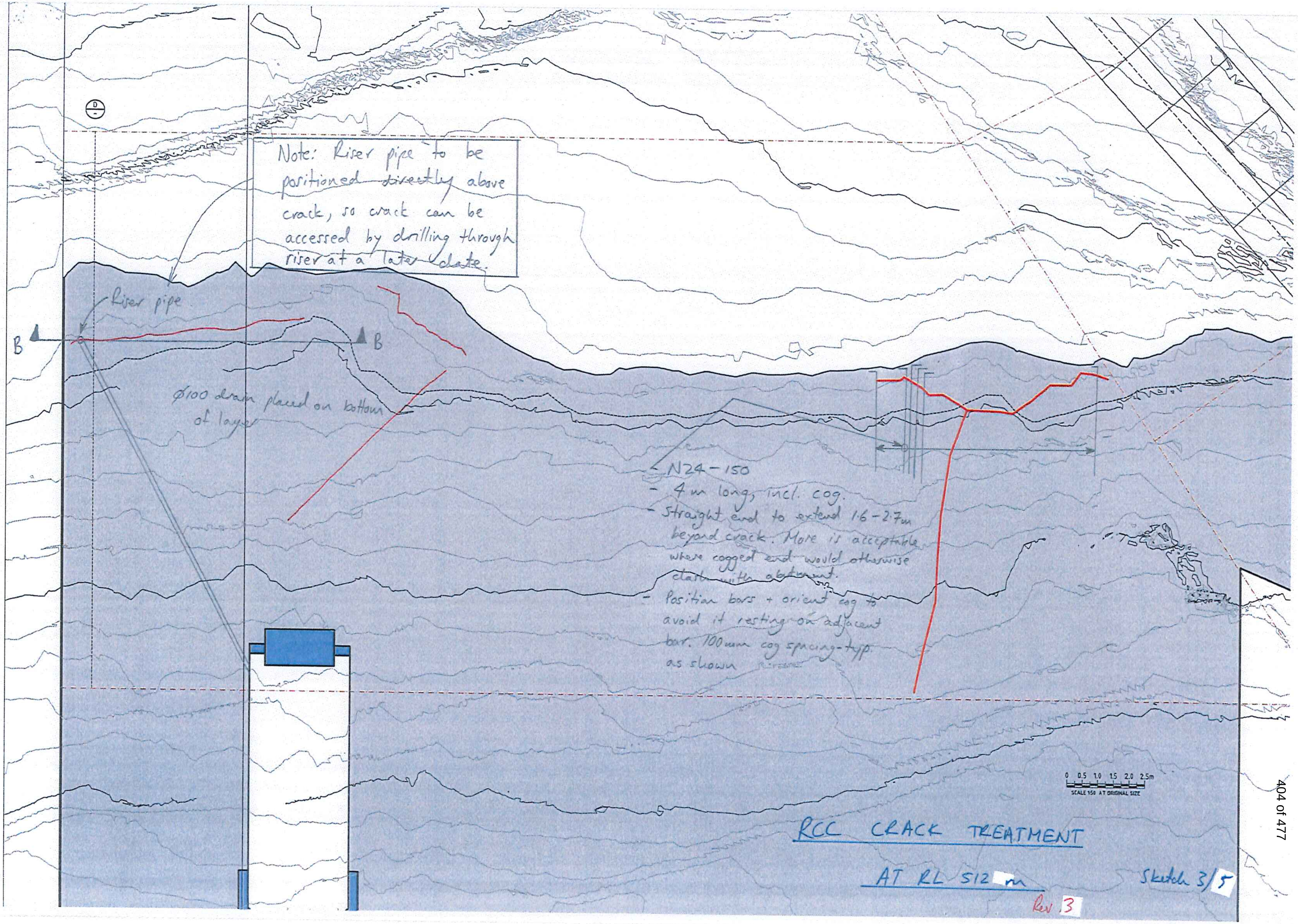


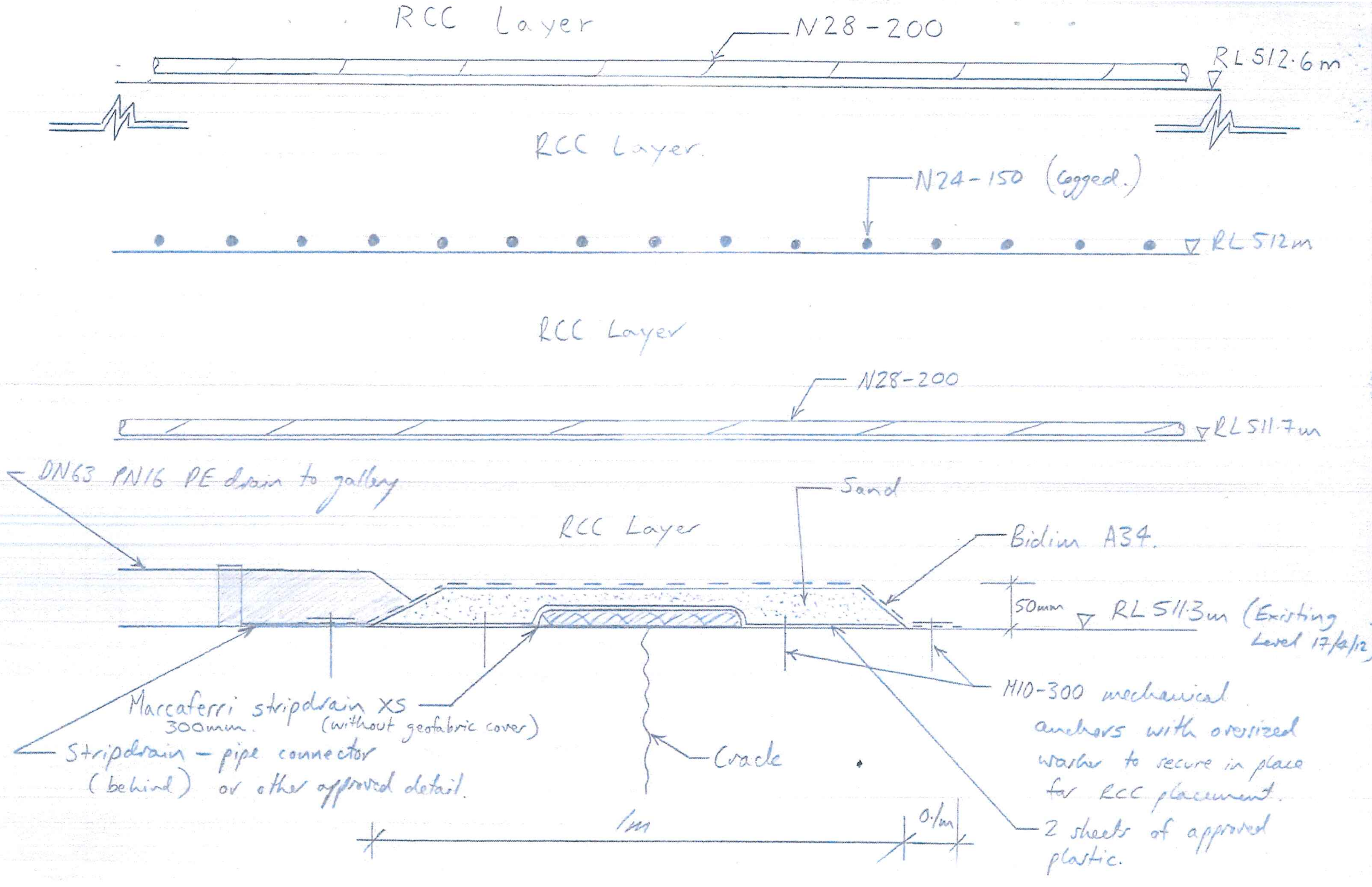
Ambient Temperatures (Canberra Airport)
Temperature (°C)
40
35
30
25
20
15
10
5
0
-5
-10
1-Feb
8-Feb
15-Feb
22-Feb
29-Feb
7-Mar
14-Mar
21-Mar
28-Mar
4-Apr
11-Apr
18-Apr
25-Apr
2-May
9-May
16-May
23-May
30-May
6-Jun
13-Jun
Date
Max
Average
Min
Easter Break
RCC Re-Start

# Appendix C Thermal Monitoring of Dam Foundation Concrete Pour


DFN-0006 CH:112-123 O/S 45-60 24/05/2011
Shallow pour- (Approximately 1m deep max)
Temperature (°C)
Time
30
25
20
15
10
5
0
6:00
12:00
18:00
0:00
6:00
12:00
18:00
0:00
6:00
12:00
18:00
Ambient
Tag 1 Bottom of Pour
Tag 2 Middle of Pour
Tag 3 150mm below top
Tag 4 25mm below top
Tag 5 On top under covers
14 degree differential (Green cut start 6pm)
15 degree differential (Green cut 7am, cold morning)

# Appendix D **Crack Treatment**

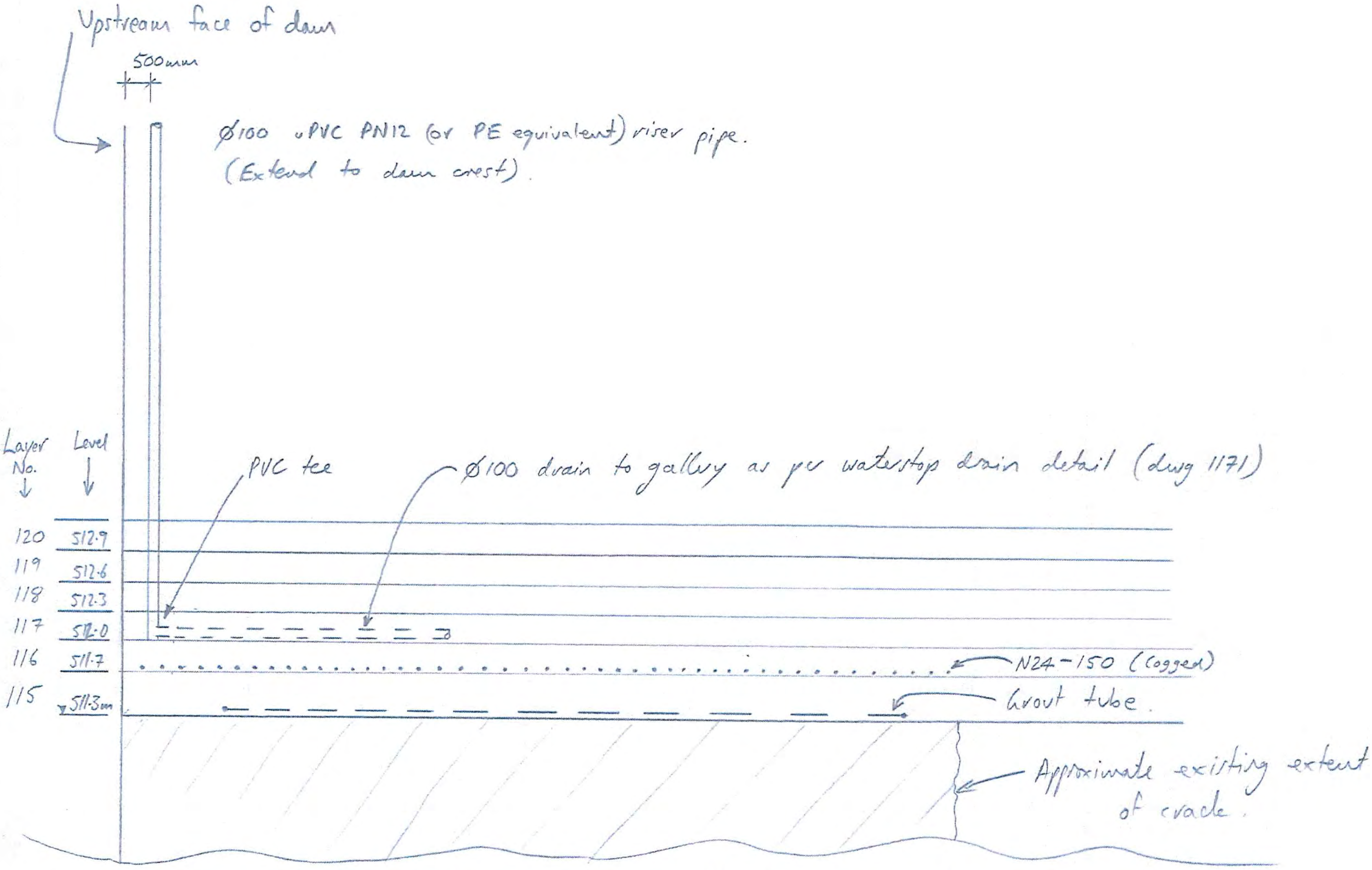

Note: Riser pipe to be positioned directly above crack, so crack can be accessed by drilling through riser at a later date.
Riser pipe
B
B
Ø100 drain placed on bottom of layer
N24-150
- 4m long, incl. cog.
- Straight end to extend 1.6-2.7m beyond crack. More is acceptable where cogged end would otherwise clash with abutment.
- Position bars + orient cog to avoid it resting on adjacent bar. 100mm cog spacing-typ. as shown
0 0.5 1.0 1.5 2.0 2.5m
SCALE 1:50 AT ORIGINAL SIZE
RCC CRACK TREATMENT
AT RL 512 m
Sketch 3/5
Rev 3




Section A-A

Rev 3

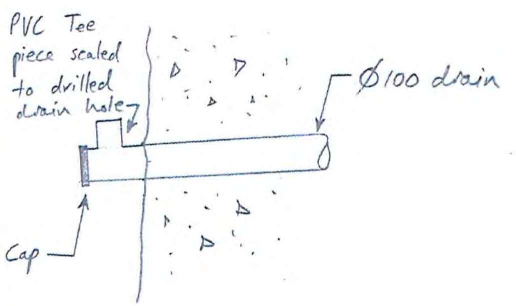
Sketch 4/5



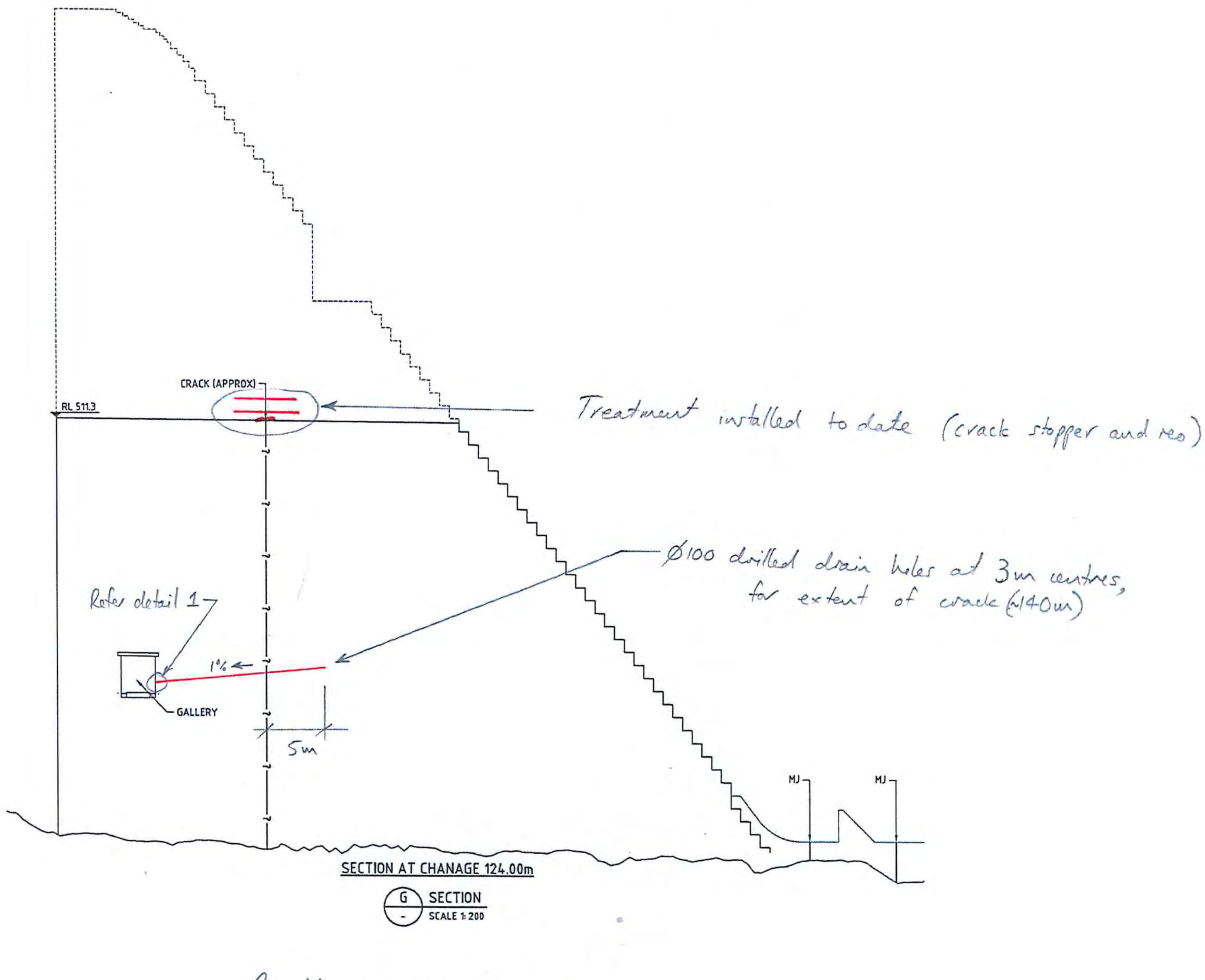

Section B-B

Treatment of upstream-downstream crack
At ch 68m, Offset chainage 0-8m.

Rev 3 Sketch 5/5




Detail 1




SECTION AT CHANAGE 124.00m

G SECTION
SCALE 1:200

Possible Crack Treatment

DRAFT

RL511.3

**Photo D.1 –** Sand crack stopper and strip drain being installed in Monolith D.

**Photo D.2 –** Sand crack stopper and strip drain being installed in Monolith E.

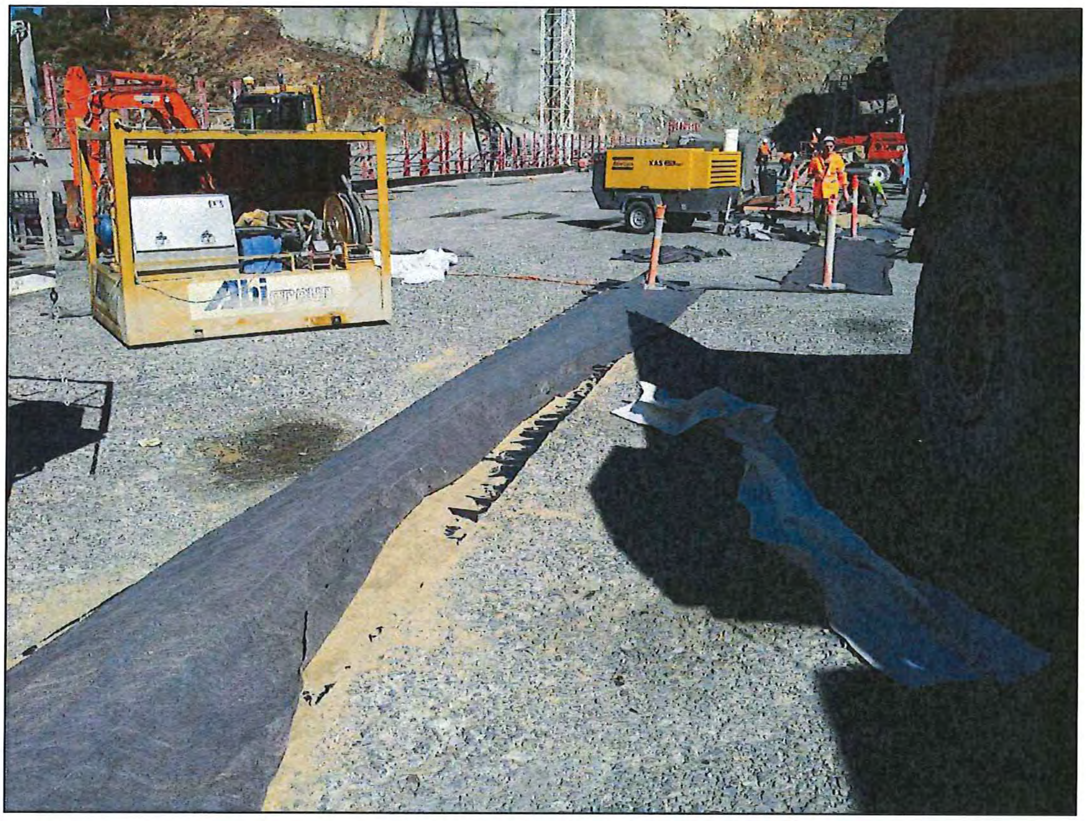


**Photo D.3 –** Sand crack stopper and strip drain being installed in Monoliths F and G

**Photo D.4 –** Drain pipes connecting strip drains to left hand gallery.

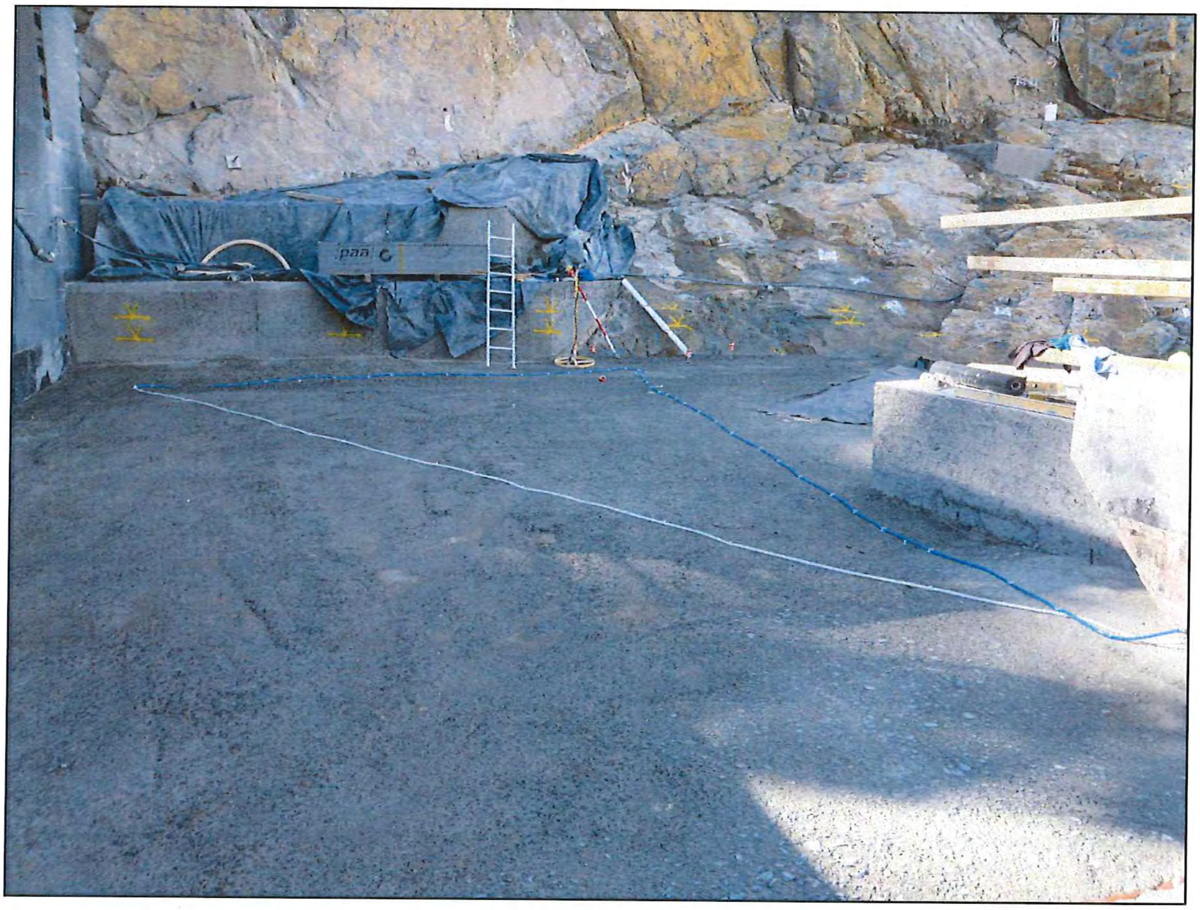



**Photo D.5 –** TAMs injection and non-injection grout tubes installed on transverse crack on upstream left abutment.

RL511.7

**Photo D.6 –** N28 reinforcement bars being installed on top of the cross valley cracks in Monolith D.

**Photo D.7 –** N28 reinforcement bars being installed on top of the cross valley cracks in Monolith G.

RL512

**Photo D.8 –** N24 cogged reinforcement bars installed across transverse crack on left hand abutment groin.

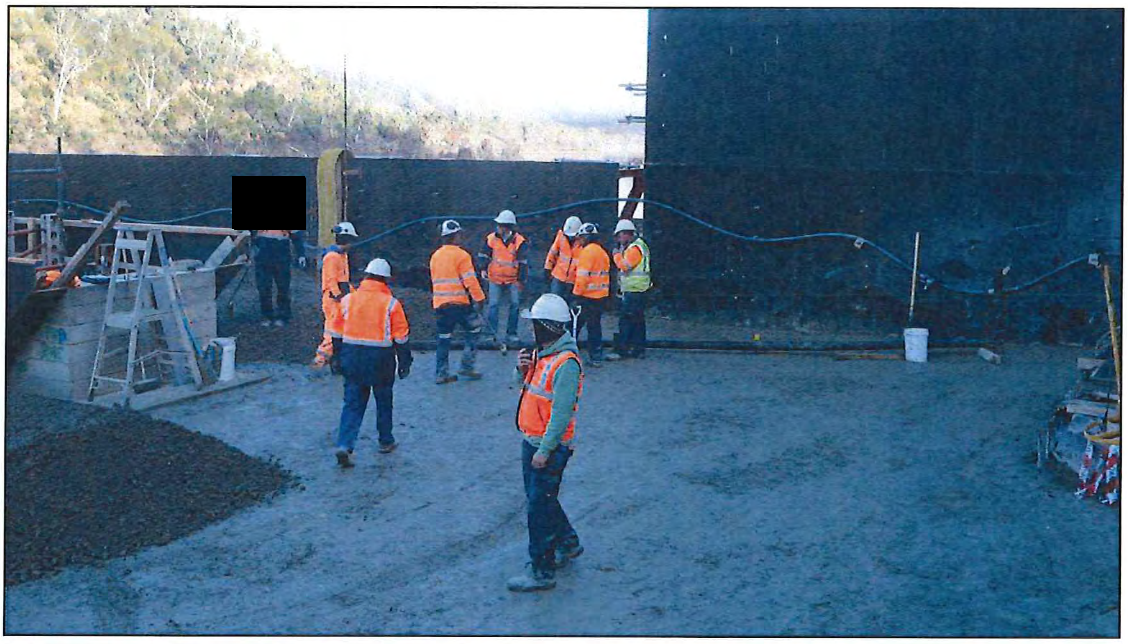


**Photo D.9 –** Installation of 100mm diameter riser pipe and drain connecting to gallery.

RL512.6

**Photo D.10** N28 reinforcement placed abutment to abutment on cross valley cracks, shown here in Monolith G.

**Photo D.11 –** N28 reinforcement placed abutment to abutment on cross valley cracks, shown here in Monolith M.