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THE USE OF 400 MM RCC LIFTS IN THE ENLARGED COTTER DAM

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SUMMARY

This paper discusses the process adopted to identify the benefits of 400 mm thick RCC lifts compared to the usual industry standard of 300 mm. The discussions include those aspects where the greater lift thickness proved beneficial or a detriment to the overall process of placing RCC. Other topics discussed include, trial embankment results, trial placement within the dam, construction productivity, quality control for layer thickness and compaction, performance of the GERCC facing and performance of lift joints within the dam. Finally, as the dam was constructed using both 300 mm and 400 mm lifts a direct comparison of both has been possible.

1. INTRODUCTION

1.1. THE PROJECT

The south eastern corner of Australia suffered a major drought from 1998 to 2010, which severely impacted on the water supply of urban communities in the region. Canberra, the capital city of Australia, reacted to this situation by initiating a number of water supply projects to reduce the long term risk of significant impacts of future droughts. One of these projects is the Enlarged Cotter Dam (ECD), consisting of an 85 m high RCC dam on the Cotter River and two auxiliary saddle dams on the right bank to the south west of the main dam spanning neighbouring low lying valleys.

The dam replaces an existing 30 m high concrete gravity dam and in so doing increases the reservoir capacity from 4 GL to 78 GL, increasing the total storage capacity of the Canberra supply system by about 25%.

1.2. DESCRIPTION OF THE DAM

The Enlarged Cotter Dam is the largest RCC dam built to date in Australia. At a height of 85 m and with a volume of almost 380,000 m^3 of RCC, it exceeds the previous highest RCC dam by 30 m. The total crest length is 335 m. The dam has a typical cross section with a vertical upstream face and a downstream face with 1.2 m high steps at a nominal 0.75 H to 1 V slope. The majority of the crest and downstream face are utilised as the spillway, with the central 70 m containing the primary spillway, for floods up to the 1 in 1000 AEP event and the flanking 140 m coming into operation for floods up to the probable maximum flood. A plan and section of the dam are shown in Figure 1. Spillway discharges outside the primary spillway are returned to the river by abutment channels along the groins at the toe of the dam. The abutment channels were constructed from RCC simultaneously with the main dam.

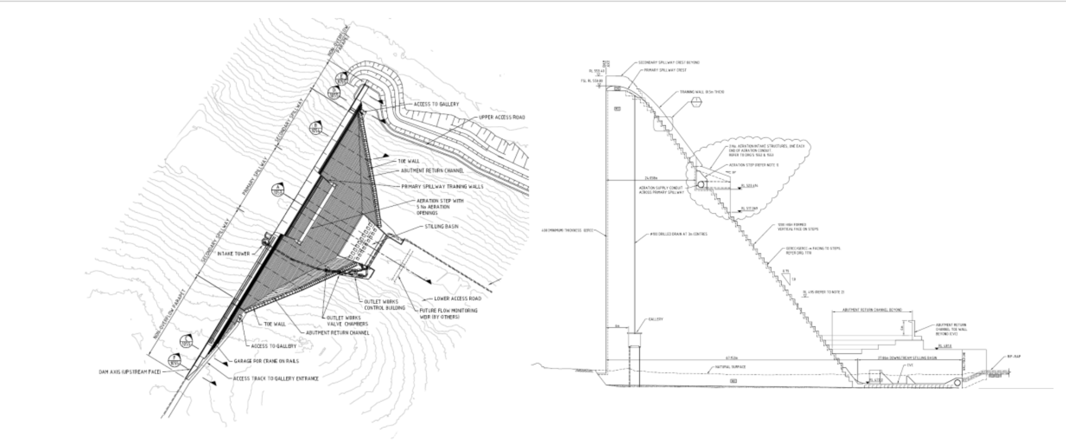

Fig. 1
Plan and Cross Section of the Dam

The RCC mix contained 75 kg of cement and 120 kg of flyash per cubic metre. All of the aggregate including the sand was crushed from rock won on site [4]. The mix contained a water reducer/retarder to produce an initial set time of 18 to 24 hours. The design characteristic compressive strength was 15 MPa at 180 days.

1.3. BACKGROUND TO ADOPTING 400 MM LIFTS

As a means of potentially increasing the rate of placement of the RCC, the option of placing the RCC in 400 mm thick lifts was investigated and adopted for a portion of the dam above the gallery level. The construction team undertook a review of the construction methodology and considering placement and compaction times, compaction of the GERCC facing, formwork relocation, availability of cranes and potential delays concluded that it would be more efficient to place in 400 mm lifts than the traditional 300 mm lifts, with a reduction in placement time of the RCC of approximately 50 shifts. The 400 mm lifts allowed for an average daily placement of about 2200 m^3 and monthly placement of about 100,000 m^3, compared to 1800 m^3 and 80,000 m^3 respectively for the 300 mm lifts. Key areas where it was considered that the overall placement time could be improved were:

- Better utilization of the batch plant; as there were fewer lifts and therefore a reduced number of delays at the start to start and finish each lift;
- Reduce the formwork delays on the downstream forms; as the placement of the larger lift volume provided more time to jump the forms;
- Reduced number of lift joints therefore less cleaning and layer preparation;
- Less linear meters of GERCC; and
- Less exposure to the weather conditions as the construction program was shortened.

1.4. EXPERIENCE OF PREVIOUS PROJECTS

Historically RCC dams have been constructed using a lift thickness of 300 mm or less. Review of available data [1,2] on the construction of RCC dams indicates that by 2010 a total of approximately 470 RCC dams have been constructed globally. Of these only 32 dams (7%) have used a lift thickness of greater than 300 mm (including dams where parts where constructed in 300 mm thicknesses and parts constructed in thicknesses greater than this). Only 19 dams used a lift thickness of 400 mm or greater, which corresponds to 4% of the global total.

This weight of numbers would suggest that 300 mm lifts provide the better combination of production and quality than 400 mm for most projects. There is little published information on the use of 400 mm lifts; therefore the authors approached five practitioners to seek specific advice with their experience in 400 mm lifts. All five practitioners preferred 300 mm lifts as the 400 mm lifts introduced additional quality control issues (segregation, lack of bond with previous lift, lack of compaction and reduced the number of hot joints) and did not necessarily increase the rate of RCC production.

2. ECD 400 MM LIFT TRIALS

2.1. TRIAL LOCATIONS

Two trials were undertaken to test that 400 mm lifts could be placed without compromising the required quality. This was done in a staged process, initially as a trial embankment followed by an in-situ trial in the dam at gallery level.

The trial embankment was nominally 25 m long by 10 m wide by 2.5 m high (six layers). It had a stepped downstream face, an embedded waterstop and associated transverse joint and contained all lift joint types (hot, warm and cold joints). All lifts were 400 mm thick other than the last, which was placed 500 mm thick to test the above should the intended level control not be obtained.

The full scale trial was undertaken at the gallery level of the dam. The gallery was constructed by placing RCC to the top of the gallery and then trenching back through the placed RCC to form the gallery [1]. This provided a face of RCC cut through the trialled lifts allowing for an extensive inspection and access for sampling. It also provided easy access for repair, should the lifts have been of poor quality and the gallery would act as a point of drainage should the layers not be water tight. Six 400 mm lifts and five 300 mm lifts were placed in total for the gallery.

2.2. OBJECTIVES OF THE TRIALS

A set of predetermined criteria was established for assessment of the trial embankment. The following issues were to be investigated:

- RCC density across the full depth of the layer;
- Lift joint bond strength;
- Segregation and its effect on the two points above;
- GERCC quality (surface finish and density throughout the zone);
- GERCC/RCC interface (density throughout); and
- Waterstop embedment.

On the successful completion and testing of the of the trial embankment the in-situ trial in the dam was approved. Successful placement of 400 mm lifts in the dam was measured against the following criteria:

- Field density test results;
- Layer thickness control;
- Field observations of the gallery cut; and
- Visual observation and density testing of horizontal cores from the downstream face of the gallery.

2.3. DISCUSSION OF ACCEPTANCE CRITERIA

2.3.1. Trial Embankment

The RCC mix itself was of good consistency was cohesive and showed little tendency to segregate. Vebe times were around 15 seconds. RCC and GERCC strengths were consistently achieved. These properties were imperative for the 400 mm layers to be considered.

Following the refinement of the compaction methodology, all compaction results (from Layer 4 to Layer 6) met or exceeded the target density (98% TAFD), including the top 500 mm thick layer. This indicated that the required density could consistently be obtained across the full depth of the later.

A wire saw cut was made through the trial embankment, shown in Figure 2. Inspection of the cut face provided a visual confirmation that the RCC was generally well compacted, with only a few minor areas of honeycombing and voids. The overall appearance was equally as good as the cut face on the 300 mm trial. In addition to the cut face further confirmation of the compaction was obtained from a number of cores taken from the embankment.

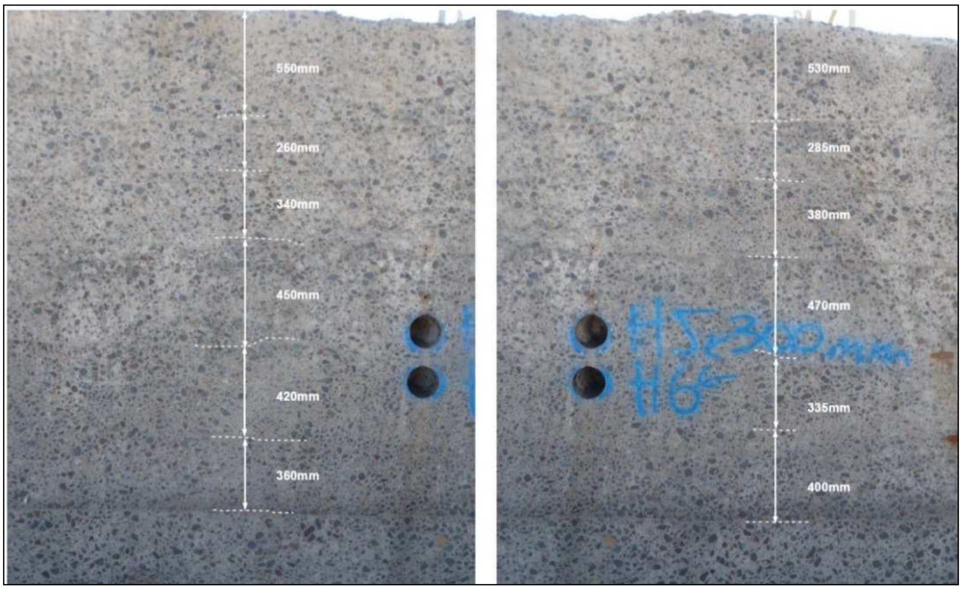

Fig. 2
Saw Cut Face of Trial Embankment

Quantitate assessment of the degree of compaction was achieved by cutting a number of the cores into thin (30 mm) slices and checking the density through the depth of a lift. As seen in Figure 3, the results showed reasonably consistent density across a lift with variation between the density of the slices generally being attributed to the amount of coarse aggregate within each slice.

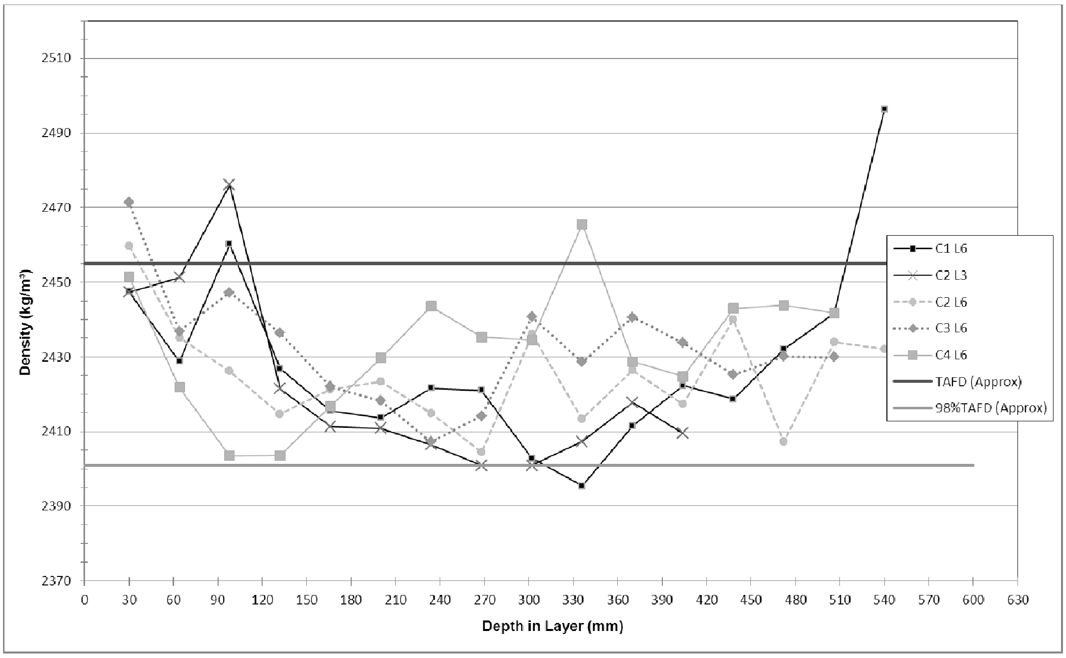

Fig. 3
Comparison of densities for 30 mm slices through layers

Core samples from lift joint locations were tested for direct tensile strength (DT). Samples of the hot, warm and cold joints were tested at 56 days and 110 days concrete maturity. The results are shown in Table 1. The 110 day direct tensile strength results were equivalent to those for the corresponding lift joints in the 300 mm lift trial. All results exceed the ultimate direct tensile strength required across lift joints (0.45 MPa at 360 days).

Table 1
Lift Joint Direct Tensile Result Comparison

Joint type	300 mm Lift Trial	400 mm Lift Trial	
	DT Ave Strength 90 d (MPa)	DT Ave Strength 56 d (MPa)	DT Ave Strength 110 d (MPa)
Hot	0.49	0.26	0.72
Warm	0.57	0.48	0.59
Cold	0.65	0.51	0.92

To investigate the degree of aggregate penetration through lift joints, pieces of paper were placed on the lift surface in some locations for later coring. The experiment was small scale, but it did indicate that the coarse aggregate from the upper lift was penetrating into the top of the preceding hot and warm lift surfaces. This is shown in Figure 4.

Fig. 4
Core through Laminating Paper Placed on a Warm Joint during Construction

2.3.2. Construction Equipment

The initial lifts were used to investigate different compaction methods. This included variation of the vibratory frequency and amplitude of the rollers. However after a number of incidents of lifts with low densities the compaction method utilised for the 300 mm trial was found to also be suitable for the 400 mm layers comprising of one static and three dynamic passes with a 12 t Caterpillar CB-534D XW Vibratory Asphalt Compactor double drum roller.

2.3.3. Trial in the Dam

During placement measurements of density were taken at five randomly selected locations on each RCC lift. At each location the density was measured at 100 mm, 200 mm and 300 mm and 400 mm depths through a lift. All but two of the density test results from the 400 mm lifts met the required density.

Lift thickness was generally controlled to within Specification limits of +/-50 mm. No significant difference in the occurrence of out of tolerance layer thickness was observed between the 300 mm and 400 mm lift.

Visual inspection of the gallery excavation through both the 300 mm and

400 mm RCC lifts found overall the RCC to be consistent in terms of the concrete matrix. Some minor, isolated pockets of segregation were noted; however the overall appearance is consistent with that observed in the trial embankments. With the exception of the cold joint, the 400 mm lift joints are difficult to distinguish and the RCC is overall homogeneous and monolithic in appearance.

Thirteen horizontal cores were taken from the downstream side of the gallery. Those cores targeted lift joints and the top and bottom of lifts. From these cores there were no significant voids or defects identified. Cored lift joints remained intact indicating good bond. Typically it was difficult to determine the actual location of the hot joints within the cores indicating good penetration of aggregates across the lift surface.

3. CONSTRUCTION OF THE DAM

3.1. OVERALL PRODUCTION

Overall production rates never achieved those planned due to a number of constraints which were never adequately addressed in the initial planning. This was mainly due to three constraints:

- Above average rainfall (60-year rainfall season) delaying works and resulting in numerous cold joints;
- Geometry of the abutment return channels proved to be significant constrictions to completion of each lift; and
- Australia's high level of safety requirements which required delineation between personnel and moving plant which delayed the compaction of the GERCC with resulting delays to the RCC.

It is not known if the impact of these constraints would have impacted more on placement rate of the 300 mm or 400 mm lifts, as each had a varying influence in different parts of the dam.

At the time of writing about 70% or 275,000 m^3 of the RCC had been placed. Of this 100,000 m^3 had been placed in 400 mm lifts. Figure 5 shows the rates of placement of the RCC.

To assess the impact on production of using 400 mm lifts compared to the 300 mm lifts, the RCC production rates considered and lost time rates were reviewed for all RCC placed to date. Three rates were considered:

1. The overall production rate, which includes all hours were RCC was intended to be placed,
2. The effective production rate, which includes only the time where RCC

was actually placed

3. The lift dependent production rate, which includes, lost time where that time was considered to be lift thickness dependent. These include such delays as incidental joint surface cleanup due to inability to place next layer as a hot joint, some delays in jumping formwork, preparation of GERCC and downstream step surface.

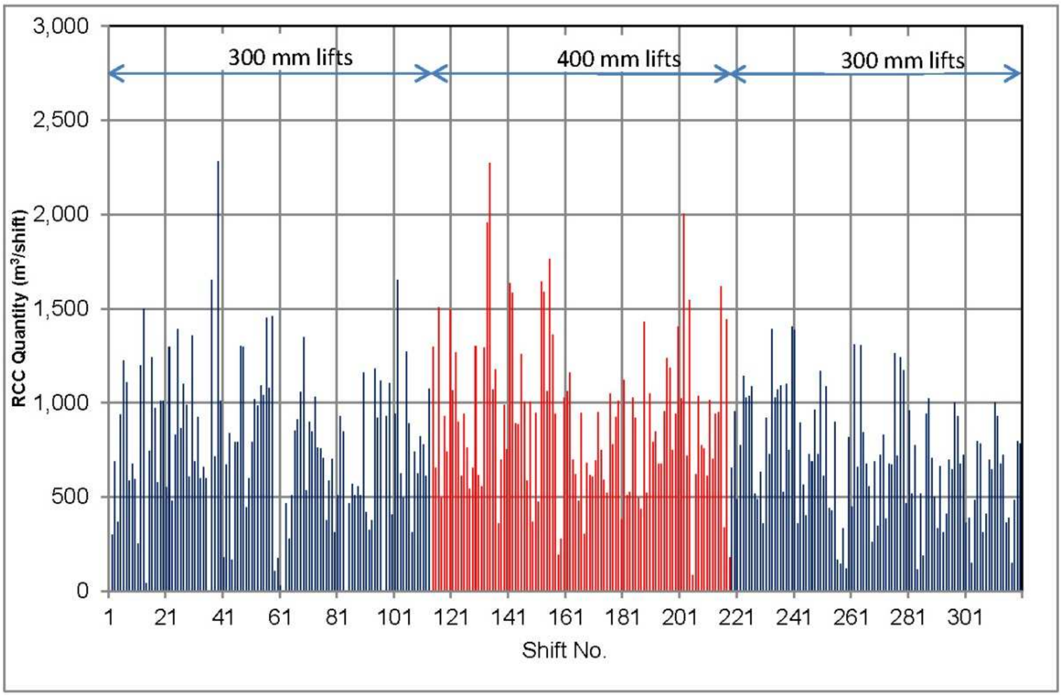

Fig. 5
Effective RCC Production Rates

Table 2 provides a summary of the placement rates achieved to date.

Table 2
Summary of RCC Placement Rates

	Average (m^3hr)	300 mm lifts (m^3hr)	400 mm lifts (m^3hr)
Overall Production Rate	45	41	51
Effective Production	100	105	92
Lift Dependent Production	83	83	82

Whilst the rates are indicative, the large number of variables means that a true ‘like for like’ comparison has not been achieved. The location of the tower cranes within the dam footprint, for example, provided a particular constraint to production which primarily affected the 400 mm lifts. The overall geometry of the placement area was however better for the 400 mm lifts than for the 300 mm lifts. These variables and many others have influenced the results, but the information is indicative none the less.

As can be clearly seen in Table 2 once lift thickness dependent delays had been considered there was no significant difference in the production rates achieved.

3.2. QUALITY

The quality of the 300 mm lifts compared to the 400 mm lifts has been compared in three critical areas, namely:

- Density (noting that if density is achieved then strength and impermeability will also be achieved)
- Lift joint quality
- Compaction of the GERCC

3.2.1. Density

Within the specification limits, density was always achieved as any areas that could not be compacted to achieve the required 98% TAFD were removed from the dam. Although some RCC had to be removed, the occurrences of this were few enough for both the 300 mm and 400 mm lifts, they are therefore not considered statistically significant.

However the specification required re-rolling of an area if the initial density did not meet the required 98% TAFD. Approximately 2% of all field densities failed this requirement for the 400 mm lift, whereas only about 1% of the test failed for the 300 mm lift. This indicates that the 400 mm lifts were closer to the limit of the compaction equipment and methodology.

3.2.2. Lift Joint Quality

Some initial cores of the dam were taken using a 100 mm diameter core (producing 80 mm diameter samples). The first of these cores had been taken just prior to the writing of this paper. Initial review shows very good density throughout both 300 mm and 400 mm lifts. Broken lift joints were encountered on approximately 25% of the joints (the same for both the 300 mm and 400 mm lifts). Detailed review of this core showed that the actual number of unbonded lift joints is as shown in Table 3. The results suggest some reduction in lift joint quality with 400mm layers, although the sample size is limited. The other broken joints were deemed to be coring related, possibly indicating lower bond strengths. An angled core is to be undertaken to further investigate these broken lift joints encountered on hot, warm and cold joints.

Table 3
Summary of Lift Joint Quality

Joint Type	300 mm Lifts		400 mm Lifts		All Lifts
	No	% of Total	No	% of Total	
Total No Joints	68		51		119
Total Bonded	67	98.5%	46	90.2%	113
Total Unbonded	1	1.5%	5	9.8%	6
Total Hot	38	55.9%	16	31.4%	54
Total Warm	23	33.8%	24	47.1%	47
Total Cold	7	10.3%	11	21.6%	18
Unbonded Hot	0	0.0%	2	3.9%	2
Unbonded Warm	1	1.5%	3	5.9%	4
Unbonded Cold	0	0.0%	0	0.0%	0

3.2.3. Quality of the GERRC Facing

The specification required both the upstream and downstream faces of the dam to have a high quality aesthetic finish to the GERCC to achieve both a durable and water tight surface. This required the RCC to have the correct proportion of grout added and for it to be adequately vibrated to ensure both full distribution of the grout and proper compaction of the GERRC. There were frequent failures to achieve a suitable standard of compaction of the GERCC for both the 300 mm and 400 mm lifts. However the incidents of the poor compaction were higher in the 400 mm lifts. This was judged to be the greater likelihood of not achieving full penetration of the grout and vibrators with the greater lift depth.

300 mm lifts were ultimately adopted in the upper part of the dam. At the same time greater control over the lapsed time from placement of RCC to grout enrichment was achieved in construction, this improved the quality of the GERCC for the 300 mm lifts higher in the dam. It is probable that if these improved construction processes had been adopted for the 400 mm lifts a similar improvement in quality would have been achieved.

4. CONCLUSIONS

This paper discusses the process adopted by the Enlarged Cotter Dam project team in electing to construct part of the dam using 400 mm lifts. The outcome of the 300 mm and 400 mm lifts placed in the dam are also discussed both from a quality and construction perspectives.

The industry experience suggests that quality and construction issues encountered with the thicker lifts, compared with the 300 mm lifts does not justify any improvement in production the thicker lifts may achieve. The ECD project undertook a rigorous trial program to demonstrate that the quality of the compacted RCC, the bond between layers and the GERCC would not be compromised if 400 mm lifts were adopted. These trials, initially as a trial embankment, and then in-situ within the dam, indicated that with appropriate procedures 400 mm lifts could be placed with no compromise to the quality of the RCC.

Encouraged by the results of the trials, 400 mm lifts were adopted for the middle portion of the dam, (21% of the total (245) layers placed). The production rates were restricted by unusually wet weather, the geometry of the dam and safety requirements. The estimated rates of placement were therefore only achieved for short periods of time and it is difficult to confirm the extent to which production was genuinely improved.

The construction procedures remained effectively unchanged between the 300 mm and 400 lifts. The same plant was utilised and the same mandatory number of roller passes were applied.

Where it has been possible to compare, there did not appear to be any significant compromise in quality of the RCC by using the greater lift thickness. It did however increase the likelihood of a lift being below density after the mandatory number of passes and for addition rolling to be required. Furthermore there is some evidence that the quality of the lift joints may be slightly reduced although this is not conclusive.

The quality of the GERCC was below the required standard for both the 300 mm and 400 mm lifts although the frequency of below standard areas was higher for the 400 mm lifts. This was judged to be due to the greater depth and the higher probability of not achieving full grout penetration and distribution and compaction if the construction process is not carefully controlled. Tighter control over the GERCC construction process was achieved later in the project and very few issues were encountered thereafter. However this was only applied following the recommencement of the 300 mm layers. Although not tested on the 400 mm lifts, it is expected that the quality of the GERCC would have also improved if this procedure had been adopted for the 400 mm lifts.

Although there was ultimately little advantage to the project in adopting greater lift thickness, based on this experience, construction of RCC dams utilising 400 mm lift can be achieved without compromising the quality and is therefore worthwhile to be considered in future RCC projects. A very reliable RCC mix with good consistency and little tendency for segregation is however imperative. The construction process also needs to be tightly controlled as the margin for error is reduced with thicker lifts.

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Dams: Cotter Dam.

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