INNOVATIONS OF SIGNIFICANCE AND THEIR DEVELOPMENT ON SOME RECENT RCC DAMS

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SUMMARY

This paper deals with what the author believes are some of the more significant innovations that have been adopted on RCC dams in recent times which provide for improved quality, more efficient construction and reduced costs. These include the sloped layer construction procedure and use of grout enriched RCC in place of conventional vibrated concrete and some recent new approaches to their use. It also includes some other interesting procedures used recently, such as slip forming GERCC for the top step on stepped downstream faces and spillways, the construction of galleries by excavation using a rock trenching machine, and the use of precast concrete elements for the spillway ogee crest structure.

1. INTRODUCTION

Over 500 large RCC dams have been developed in the world\(^1\) since the advent of RCC to the dam design and construction industry with the completion of Willow Creek dam in the USA in 1982. As with any dam, each RCC dam is unique in its setting and consequent design. It is with respect to this uniqueness that RCC technology has developed through innovation to its current state of the art.

In the evolution of RCC design and its construction process, a huge number of different approaches have been trialed, with varying degrees of success, involving both the very basics of RCC including design concepts, methods of transporting and placing RCC, construction of upstream and downstream faces etc, as well as many of the minor details.

It is this through this process of innovative trialing and regular reporting at international symposia, such as this one, that we are now reaching some consensus, particularly on the basic aspects, as is evident in the Chinese approach to RCC design and construction. However it is important that there always remains the opportunity for innovative thinking and trialing, as this is what drives us as engineers, makes the subject of RCC as stimulating as it is and will
continue to deliver improvements in quality and reductions in construction time and project costs.

The principle ‘concern’ that RCC dam owners, designers and regulators have with regard to RCC relates primarily to the high number of lift joints and their potential for leakage and reduced strength when compared to CVC construction. Generally an RCC dam placed with 300mm thick lifts will have 5-8 times the number of lifts than an equivalent CVC dam. The need to achieve monolithic construction across lift joints is particularly critical with higher dams and those in high seismic regions. The method of placing RCC lifts using sloping layers is an innovative and effective solution which also delivers many other benefits to the RCC construction procedure. A very simple in-situ transformation of RCC by the addition of a cement grout will achieve an impermeable, durable outer facing of GERCC to the upstream and downstream faces of the dam and spillway, as well as for use in other parts of the dam, thereby eliminating the need for a separate CVC mixing and delivery system. Both of these innovative developments are discussed in detail in the paper as well as some recent new approaches to their use.

Selection of other innovations for inclusion in this paper has been on the basis of some recent Australian RCC projects which have been developed under Alliance Contracts\(^2\), which tend to drive innovative thinking and ideas and their adoption for the benefit of the project and the Alliance partners (Owner, Engineer, Contractor). These include the use of a slip form paver to finish the GERCC on the wide top of downstream face steps to reduce hand labour and improve surface tolerances; excavating horizontal galleries through hardened RCC using rock trenchers, and; pre-casting concrete spillway ogee crest elements to accelerate the completion of the crest works and reservoir impoundment.

1. THE SLOPED LAYER METHOD

A significant difference between a CVC dam and a RCC dam is the number of horizontal construction lift joints. Formed conventional concrete is generally placed in 1.5-2.5m lifts, whereas RCC is generally placed in 0.3m lifts, i.e. with RCC there are 5-8 times more lift joints and potential planes of weakness along which seepage, sliding or overturning failures could occur.

Various approaches have been adopted in earlier RCC dams to achieve bond between lift joints, including minimizing RCC segregation and damage to the compacted lift surface by construction plant, maintaining curing, pre-preparation of the surface, final surface clean up and use of a bonding concrete, mortar bedding, or grout applied over all or part of the lift. Another approach is the use of RCC mixes containing a high fly ash or pozzolan content, relying on the delayed hydration and cementation process of the fly ash or pozzolan to assist in the bonding process with the overlying lift, or/and use or set retarding admixtures.
The ‘maturity index’, which is a function of lift surface age and ambient temperature to which it has been exposed, has been used to define the difference between ‘hot’, ‘warm’ and ‘cold’ joints and the degree of treatment required to the lift joint surface. However since it is unusual to be able to place more than one or two RCC lifts per day over the full area of the dam, the initial and final set of the cement will have well and truly occurred before the next lift is placed, especially with un-retarded RCC mixes. As a consequence, the ability of the surface of the lower lift to develop full bond with the under surface of the overlying lift, is largely lost.

Vertical cores taken through RCC lift joints commonly show one in every two joints recovered broken, i.e. the bond was insufficient to overcome the torque applied by the coring bit. Direct tensile strengths of bonded joints have been shown to vary considerably, seldom are joints more than 1/3rd of the parent RCC tensile strength, those using a bedding mortar may reach 2/3rd, but it is very unlikely that aggregate particles from the overlying lift will penetrate the stiffened surface of a lower lift. Cores across lifts where waterproof paper was placed confirm this.

With this background experience it is now generally accepted that unless the overlying lift can be placed within the initial set time of the RCC then lift joint strengths must dominate the design and will determine the potential failure plane. Hence the parent RCC strength itself is, in fact, of lesser importance.

Two basic approaches have evolved. One is to heavily retard the hydration process by use of a commercial chemical admixture, the other being to significantly reduce the surface area of the placed lift by constructing the dam in ‘blocks’ or by using the method of ‘sloping layers’.

Chemical retarders were first used in RCC in China in the mid 1990’s; an inexpensive product of the sugar industry developed for the purpose. Retardation extended initial set from 1.5-2.0 hours (unretarded) to 6-8 hours depending on summer/winter temperatures. The placing process involved forming up for a 3m thick lift with the form aligned on a transverse contraction joint, such that the area enclosed resulted in a 300mm thick RCC layer with a volume equal to or less than the volume of RCC that could be produced and delivered in the retarded initial set time, as was adopted initially for Jiangya Dam in 1997\[3\], Fig 1.

In this way 10 layers of RCC would be placed all within the retarded initial set time of the RCC. A gap in the form and a sloped RCC ramp allowed access into the placement area. On completion of the lift the transverse form would be re-erected and the adjoining 3m lift placed. The surface of the cold lift joint would be ‘greencut’ and a bedding mortar applied with the first RCC layer. The process was encumbered with the cost and time of setting up the transverse form and the cost of the retarding admixture, but this was offset to some degree by the time and costs saved in lift joint preparation.
Jiangya Dam, 131m high, 1.1 mill m$^3$ China 1997, placing 10 layers of RCC in a formed up 3.0m block.

The block process was developed on more recent projects to one of placing fewer layers, generally four, to form a 1.2m thick lift. By using pre-cast concrete blocks as the tranverse ‘form’, time and costs were reduced, but it involved more cold joints for preparation, e.g. at Koudiat Acerdoune Dam in Algeria, Fig 2.

Koudiat Acerdoune Dam, 121m high, 1.65mill m$^3$ Algeria 2007, placing four RCC layers with pre-cast concrete side forms and steel access ramp for a 1.2m lift.
The main advantage of this method is that it simplifies the forming up of the downstream stepped face of the dam, which is complex when lifts heights exceed the step height adopted for the steps.

On some projects that are set up for very high RCC placement rates, often using a high pozzolan or fly ash content in the RCC mix which, together with a retarding admixture, can achieve delayed initial set times of 18-24 hours, it is possible to place a single 300mm lift over the full area of the dam within the delayed initial set time of the previously placed lift and there is no need to divide the dam into blocks. In which case, the placing rate, selection of plant and retarder dose rate is based on the maximum lift volume of the dam – which typically occurs at about 1/3rd height for dams with uniformly sloping abutments. For this method placing rates for large dams of up to 8-10,000m³/day are usually necessary, e.g. at Yeywa Dam in Myanmar.

The sloped layer method (SLM) of placing RCC was conceived during the construction of Jiangya Dam in late 1997\[3\] and adopted from about mid height onwards. Placing rates increased considerably and the project was thus competed on target as a direct result of changing to the sloped layer method. Since then the method has been used with similar success on many other RCC dams in China and others internationally.

The procedure initially adopted on Jiangya had been to place the RCC in 3m high blocks using a transverse form as described above. By removing the transverse form and placing the 300mm thick layers of RCC on a slope, in a direction parallel to the axis of the dam, from one abutment to the other between the formed upstream and downstream faces, as shown in Fig. 3 below, the same 3m lift could be built up as a continuous process across the entire dam without the need for the transverse form.

![Fig. 3](image)

**Fig. 3**
Explanation of the Sloped Layer Method.
Simply changing the slope selected for the layers alters the volume of RCC placed in the 300mm thick sloping layer. For example, using a 3m high SLM, as adopted at Jiangya, with an RCC mixer output of 500m³/hr, an initial set time of the un-retarded RCC of 2 hours and a width between upstream and downstream faces of 'W', then the slope 'S' of the layer, as shown in the Figure 3 below, can be found from:

\[ S < \frac{2 \times 500}{W \times 3 \times 0.3} \quad \text{i.e. } S < \frac{1000}{W} \text{ approx} \]

Hence, for the example above, at lower elevations, where the width W is say 100m, then a slope of 1 on 10 is required. Later, when the width has reduced to say 25m at upper elevations nearer the crest, then a flatter slope of 1 on 40 could be adopted, if the time between placing RCC layers of only 0.5 hour with a slope of 1 on 10 is considered too short. Trials have shown that slopes should not be steeper than 1 on 10 as the vibrating roller will tend to shear the RCC surface.

When using SLM the final clean up and preparation of the lower lift surface, including application of bedding mortar, is restricted to a narrow strip along the toe of the sloped layer where it contacts the previous lift surface. For slopes of 1 on 10 the width of the strip is about 3m and for slopes of 1 on 40 it is about 13m. The newly completed horizontal lift surface behind can be green-cut whilst the RCC is still young and the upstream (and downstream) face forms can be lifted, between 5-10 days would be available to prepare for the start of the next 3m lift. Lift surface preparation and form lifting are thus effectively removed from the ‘critical path’.

If the 300mm thick sloping layers are placed within the initial set time of the RCC no surface preparation, clean up or bedding mortar is required prior to placing the next sloped layer. For 3m high lifts this reduces the surface preparation required by 90%. It also reduces the number of lift joints (and potential failure surfaces through the RCC dam) by 90%. Using sloped layers to build up 3m high lifts therefore results in half the number of lifts which would occur in a conventional concrete dam constructed using 1.5m high concrete pours.

To overcome the existence of a series of ‘feather edges’ at the toe of each sloping layer, as the layers run out onto the lower 3m lift surface, the solution derived at Jiangya Dam, Fig 4, was to first place and compact a 4-5m wide horizontal layer 150-300mm thick on the top of the previous lift as a strip or ‘foot’ along the toe of the sloping layer over the prepared lift surface. The sloping portion of the layer then commences from about the centre of the foot. If necessary the front of the foot can later be trimmed back by 100-200mm to firm RCC as part of the surface preparation work that is progressing ahead of the advancing sloped layer construction, being covered with bedding mortar just prior to placing the adjoining foot for the start of the next sloping layer.
Fig. 4
Jiangya Dam showing the SLM using 3m high lifts.

Similar ‘feather edges’ will also occur at the top of the sloping layers, as they run out at the top of the 3m high lift, these may also need to be cut back to 50-70mm thick as part of the lift joint preparation process. This is easily achieved using high pressure air-water jetting to break away any poorly bonded ‘feather edge’ material during the preparation of the hardened lift surface.

Besides ensuring improved lift joint quality, the sloped layer method removes most of the ancillary items of work from the critical path; surface preparation, curing and lifting of formwork can all be carried out independent of the RCC placing. In addition, the amount of time available for lift surface clean up and preparation will be increased up to ten fold when 3m high lifts are adopted.

The slope of the layers is controlled during placing by lines painted on the upstream and downstream forms and by survey methods. Trucks have been used on most of the projects but the ‘all conveyor’ system using a ‘crawler placer’ has been successfully used on the Koudiat Acerdoune Dam in Algeria when the sloped layer method was adopted for the 1.2m high lifts, Fig.5.

Since the 300mm thick layers of RCC are placed within the initial set time of the previously placed layer, a greater RCC loading on the formwork will be experienced before the lower layers reach final set condition. The design of the upstream and downstream formwork and its anchorage back into the RCC needs to take account of this increased loading when using SLM.
Koudiat Acerdoune Dam, using a crawler placer for SLM in 1.2m high lifts.

For inclined downstream faces, one of the approaches until recently was to use vertical steps. If formwork is used then, for simplicity, the SLM lift height would be made equal to the step height. At Jiangya Dam and also Kinta Dam (90m high 0.9mill m³, Malaysia 2006) where 3m high SLM lifts were used, precast concrete blocks were used to form the 1m and 0.6m high steps on the downstream face respectively[4]. Blocks were simply recovered from behind and added ahead of the advancing layers as the horizontal RCC steps were constructed and a base for the blocks to form the next step above became available. This stepped precast block ‘formwork’ system would appear to be an ideal method where more than one step is required to match the selected SLM lift height, see Fig.6.
More recently at the Bui Dam (108m high, 1.0mill m$^3$, Ghana, 2011) the downstream face was formed using a full 3m high inclined form with SLM used to place 3m high lifts. In the overhang, or ‘shadow’, zone where it was not possible to get the large roller in to compact the RCC, the zone was constructed using grout enriched RCC as described later in the paper, see Fig. 7.

![Bui Dam, inclined downstream formed face using 3m SLM lifts and GERCC under the shadow areas inaccessible to the roller.](image)

Fig. 7

Placing a sloped layer generally involves commencing at the downstream face and moving across to the upstream face (or visa versa), placing over the full height of the lift and compacting in the up-down slope direction. The cross fall of 2-3% generally adopted in placing the traditional ‘horizontal’ RCC layers for drainage purposes during construction, can be retained when using SLM, i.e. sloped layers will have a true slope directed slightly upstream (or downstream) of the dam axis.

When commencing RCC placement and coming up off the foundations it is appropriate to use the horizontal layer method. Once a width of about 20-25m between abutments is reached the sloped layer method can be initiated with the layers being sloped from downstream to upstream, i.e. parallel to the dam axis. For the larger dams, the placement area can be divided into two or more blocks and the sloping layers placed from downstream to upstream, as was done at Murum Dam in Sarawak, Malaysia (141m high, 1.6mill m$^3$, Sarawak Malaysia 2011), see Fig. 8.

![Murum Dam placement](image)

Later, when sufficient height of dam has been reached, such that the distance between the upstream and downstream faces on the placement area equals the distance between the abutments, i.e. the placement surface is essentially ‘square’, then the direction of the slope of the layers should be changed to slope from abutment to abutment, i.e. in a direction normal to the dam axis. Placement would continue in this manner until such a height were reached that the width of the placement area had reduced to 10-15m, i.e. near the crest of the dam, at which point placing would revert back to horizontal layers.
Murum Dam using SLM with a 3m thick lift to place RCC in a block from downstream to upstream in the river channel area, note the inclined, formed upstream face adopted for the lower elevation of the dam (right).

Cores of RCC extracted from Jiangya, and more recent dams using the sloped layer method, where a thin layer of bedding mortar has been applied on any layer or lift joints older than the initial set time of the RCC, are at times being recovered in single, un-broken lengths up to 15m long, see Fig. 9 and 10.

RCC core up to 5m long from Jiangya Dam by SLM (left) and 15.1m long from Longtan Dam (right) using horizontal lifts placed within the retarded initial set time.
RCC core from Murum Dam 14.7m long 150 mm diameter with one broken lift joint near the top and the rig used to drill it using a single tube barrel

Typically more than 9 joints out of 10 are being recovered intact compared with 1 out of 2 for joints where the initial set time has been exceeded.

Advantages of the SLM include:

• Achieves homogenous, monolithic RCC across layer joints,
• Reduces the horizontal construction lift joints by up to 90%,
• Importantly, reduces the area of young RCC exposed to rainfall or subject to freezing and requiring protection works and also reduces the potential for pre-cooled RCC to gain heat in warm ambient conditions,
• Provides a low ‘notch’ or channel over the RCC placement area allowing the works to be safely overtopped by floods with plant parked up above the flood, thereby reducing subsequent clean up work,
• Initial and final lift joint preparation and form lifting taken off the critical path,
• Proven increases in RCC placement rates of + 30 to 50%.

Apparent disadvantages of the SLM are:

• Use of bedding mortar on each cold lift, i.e. every 1.2 to 3.0m, depending on the lift height selected,
• Increased loading on the vertical forms,
• ‘Feather edges’ running in an upstream-downstream direction at the top and bottom of the sloping layer need to be properly dealt with,
• Survey control of the RCC layer thickness is a little more complex.
2. GROUT ENRICHED RCC

The difference in the proportions of the ingredient materials of conventional internally vibratable concrete (CVC) and RCC is that CVC has a greater quantity of cement and water than RCC. By simply adding additional cement and water to unconsolidated, freshly spread RCC in the form of grout, such that it is reasonably distributed throughout the RCC, the RCC can be mobilized and the grout uniformly worked through the RCC during consolidation by a poker vibrator. This is the basic concept of grout enriched RCC (GERCC).

For the GERCC process to ‘work’, the applied grout needs to fully drain down into the spread RCC lift, to do this it is essential that the RCC is in a loose, ‘as spread’ condition. Usually it is necessary to trim back by hand the low windrow left by the dozer blade that develops along the forms and to roughly level off the surface of the RCC to that expected of the ‘final’ GERCC surface before applying the grout.

Fig.11
Some examples of GERCC used for upstream facing, left Ralco Dam (155m high) in Chile and right Kinta Dam (90m high) in Malaysia.

Grout penetration and distribution can be assisted if the RCC is hand ‘rodded’ using a length of 12 mm diameter reinforcing rod, say at regular 200-250mm intervals, to full depth of the lift.

During these activities, and at all stages up until the poker vibrator is inserted into the RCC, it is essential that the RCC remain in its loose state and no pre-compaction occurs, either by workers feet, or by the vibratory drum roller getting any closer than about 1.5m to the GERCC zone. The adjoining zone of RCC should only be compacted after the GERCC has been compacted.

Exposed final GERCC top surfaces can be finished to a smooth level surface by first tamping with a long timber plank on edge, to level up the surface, after which it can then be wood-floated to final surface. GERCC lift surfaces may need
to have any residual grout/laitance removed, according to the specification requirements for the lift surface of the RCC. If the next lift is to be placed within a few hours the poker vibrator will re-penetrates the lower GERCC lift and the lift joint will ‘disappear’, in which case there is no need to remove any laitance.

The quantity of grout required can be determined by laboratory or field trials. About 8 litres/m/400mm facing width for a 300mm thick RCC lift has been found to be adequate where the parent RCC has a VeBe of 15-20 seconds. At La Miel I Dam (190m high 1.7mill m³, Colombia, 2002) the dryer 125kg/m³ cemetitious content RCC mix, which had a VeBe time in excess of 40 seconds, required about 10-12 litres/m/400mm width. By making the water cement ratio of the grout equal to that of the RCC, similar compressive strengths will be achieved for the GERCC. Admixtures such as water reducers, set retarders and plasticisers can be added to the grout if necessary. At both La Miel I and the Ralco Dam (155m high 1.6mill m³, Chile 2003) a superplasticiser was used to enable thicker grouts to be used than the usual 1:1 water cement ratio mix, which had previously been found just capable of percolating down into the spread parent RCC. The increased cement content grout gave a slightly higher strength to the GE-RCC. Marsh cone viscosity testing was used to determine the quantity of superplasticiser required to obtain a viscosity of about 34-36 seconds, similar to that of the 1:1 grout mix. The viscosity of the grout must be such that it will flow into the voids of the unconsolidated RCC lift, not pool on the surface.

During compaction the surface of the GE-REC will become mobile underfoot with air bubbles coming to the surface - indicating that compaction is taking place effectively, just as seen during the consolidation of CVC. If this is not evident then more grout is necessary and dose rates need to be adjusted. On removal of the vibrator, any holes left by the poker should be ‘tramped’ to close them up, or if this is not able to be properly done grout dose rates should be further increased.

Fig.12
Application of grout and poker vibration of GERCC at Kinta Dam.
The ultimate objective is too keep grout dose rates to a minimum if strength and full compaction of the RCC/GERCC interface, is to be achieved. Slump cone testing of freshly consolidated GERCC sampled from the facing should have a slump between 5-20mm to avoid drying shrinkage cracking and to ensure proper compaction along the GERCC - RCC interface. In some instances it may be found that in fact no grout is needed to enable consolidation by poker vibration, as experienced at Cadiangullong Dam (43m high 0.12mill m³, Australia 1997) when the parent RCC was fresh and highly workable with a low VeBe time (<12 seconds).

For the earlier projects grout was simply hand mixed in a front end loader bucket or in wheel barrows. Nowadays grout is usually proportioned and mixed in a high shear colloidal mixer. The mixer can be located on one abutment of the dam or on a flatbed truck on the dam that also carries sacks of cement. The grout may then be pumped to the placement area or simply carried in buckets to the dam face by labourers.

An outline frame made from light reinforcing bar, bent to a rectangle and laid on the RCC surface, helps define the area for the contents of the bucket or discharge of the grout delivery hose. The mixing, pouring and compaction required a team of only 3 labourers to keep up with initial RCC placing at Cadiangullong Dam, and as the dam rose and the length of facing increased for each lift, additional teams were assembled to assist. The process can be made very simple and flexible.

Fig. 13
RCC compaction at Kinta Dam of a sloping RCC layer alongside the GERCC facing, followed by hand tamping the raised edge of GERCC.
The size of poker vibrator is dependent on the maximum aggregate size, workability of the original RCC, quantity of grout etc. At Jiangya dam a set of 4 x 150mm diameter poker units mounted on a transom attached to a mobile rig were used. This was originally provided for large conventional concrete pours; it was more than was necessary for the 300mm thick GERCC lifts. Elsewhere, such as Cadiangullong and Kinta dams, poker vibrators as small as 50mm diameter were used successfully. Two pokers side by side are often more effective than each operating independently.

Following consolidation of a reasonable length of GERCC, about 10-15m, roller compaction of the adjoining RCC, using the usual large vibrating rollers, should take place right up to and overlap the first 50-75mm of the GERCC so that the contact between the two is fully compacted. The GE-RCC will be displaced upwards by the roller, but this is of no concern if it is less than 20-30mm, otherwise the grout dose rates should be reduced, Fig. 13.

At the Cadiangullong Dam in Australia the lower 0.3m lift of the 0.6m high spillway steps were done in GE-RCC and the top lift in CVC, as it was perceived by the contractor to be more easily finished to the required tolerances. Later at the Tannur (60m high 0.25mill m$^3$, Jordan 2000)$^{[4]}$ and Kinta dams the full 1.2m and 0.6m high spillway steps (respectively) were constructed using GERCC, initially using the usual horizontal RCC placing method with a later change made to the sloped layer method, see Fig. 14.

![Fig. 14](image)
GERCC spillway steps, left Kinta Dam 0.6m high after 6months of spillage, right Tannur Dam 1.2m high, no spillage yet.

At Ralco dam the 0.6m high downstream face steps were constructed in GERCC to provide a superior and more durable quality than plain RCC so as to better resist the colder temperatures and potential freeze-thaw problems, Fig.15. During construction the dam was overtopped on two occasions for nearly a week, flows of up to 500m$^3$/s, 1m deep were experienced with absolutely no damage to the young GERCC facing.
At Wadi Dayqah dam (75m high, 0.6 mill m$^3$. Oman 2009) the 1.2m high unreinforced GERCC spillway steps were overtopped by 6m with no damage other than the removal of the thin surfacing of mortar from the top of the steps and a few small chips from the edge of the step, most likely due to debris impact. The top step was constructed out of “GERCC-M” (discussed later) to facilitate placing the wide top of the step to achieve a smooth uniform finish, Fig 16. The average GERCC-M cylinder strength was 25.7MPa at 270 days, 30% higher than the parent RCC.

At the Enlarged Cotter Dam (85m high, 0.4 mill m$^3$, Australia 2012) the dam discharged up to 2m over a 9 day flood during construction when it had reached a height of 40m. The top surface of the 1.2m high GERCC faced steps were
undamaged, other than the top few, younger step surfaces, where the surface mortar was removed and some corners eroded/chipped by debris, Fig 17.

![Fig.17](image)

Enlarged Cotter Dam flooding over the GERCC steps without significant damage.

GE-RCC, instead of conventional concrete, has also been used on many dams to provide the interface between the abutment rock and the RCC. It is vital to achieve a good intimate bond with the abutment rock for both structural and impermeability reasons. This can be achieved with conventional concrete, however the contact between RCC and the concrete is equally important and, as mentioned earlier, the RCC adjoining the conventional concrete has often been found voided and poorly compacted. GE-RCC overcomes this concern.

GERCC has also been used on many dams for encasing the waterstops and drains placed across the vertical transverse contraction joints. As with CVC, extreme care is required to ensure the GERCC is fully consolidated and no tracts left which bypass the waterstop installation if leakage is to be avoided, Fig. 18. It is worthwhile pre-testing the waterstop embedment by filling the drain void often placed downstream of the waterstop, to check for leakage to the upstream face so any repairs can be made at the upstream face before impoundment.

![Fig.18](image)

PVC waterstop embedded horizontally in GERCC facing at Tannur Dam and as cored through the GERCC encasement in the trial at the Enlarged Cotter Dam.
The embedment of horizontal PVC waterstops in GERCC facing was very successfully undertaken at Tannur Dam\(^5\) along the connection of the RCC dam to the CVC spillway apron, Fig.18.

Where reinforcing steel has been incorporated in GERCC, such as around galleries as at Murum dam and in the upstream face as at Wadi Dayqah dam, the steel appears to be just as well encased in the GERCC as in CVC. The feasibility of incorporating reinforcing into GERCC in such locations, as well as in other areas, has proven to be simple, straightforward and effective.

Cores taken horizontally through the facing and into the parent RCC behind, consistently show fully compacted GERCC, often with no clear indication of the transition to the RCC, which appears monolithic with the GERCC. Likewise horizontal cores taken across lift joints have consistently shown excellent bond between GERCC lifts, Fig. 19.

![Fig.19](image)

Horizontal 150mm diameter cores from Kinta Dam spillway through 400mm of GERCC and into RCC, core on left is taken along a lift joint.

Quality assurance for GERCC comprises sampling of the GE-RCC after compaction for slump testing and manufacturing of test samples for strength testing. Grout density by density balance will confirm the cement content and if the grout is not continually agitated then a test for grout stability can also be done by simply observing the quantity of cement settling out of the grout mixture, between time of mixing and using, from a sample stored in a clear plastic bottle. Horizontal coring through the face, either within the body of the lift or along the lift joint itself,
into the parent RCC behind will confirm homogeneity and density of the GERCC, its lift joint strengths and the quality of the transition between GERCC and the RCC.

On some recent projects, in order to significantly increase GERCC strengths for additional durability, or to be able to effectively add freeze-thaw admixtures to GERCC, both of which are not able to be effectively incorporated into GERCC via the added grout, the GERCC has been specially pre-mixed, either with all the proportioned materials and additives mixed together at the CVC mixing plant, or by feeding mixed RCC into a truck mixer on the dam and adding the additional materials into the mixer drum and mixing them in with the RCC. The latter has the advantage in that it overcomes special additional mixing and transportation plant.

This pre-mixed GERCC is being referred to as “GERCC-M”. Test results show it is a superior material displaying a higher strength (without additional cement) and as it can be superplasticised to achieve a higher slump, it is more easily placed and the surface finished off for the wider top steps associated with higher downstream steps. It has been used for the latter reason at the Wadi Dayqah and Al Wehdah dams. At the Enlarged Cotter dam GERCC-M was used an economical foundation leveling concrete, being superplasticised so it could be pumped into position, but yet displayed set elastic properties similar to the parent RCC and, like the GERCC, had minimal potential for drying shrinkage cracking.

Advantages of GE-RCC include:

- Provides a durable, impervious, high quality off-form finish for upstream and downstream facing to the body of the RCC dam,
- Forms a homogeneous and monolithic mass with its adjacent parent RCC,
- The entire procedure is simple, easily controlled and does not control the progress of RCC placing,
- A separate batching, mixing, transportation system is not required, unlike with CVC,
- Grout can be mixed by hand or by grout plant; tests on projects to date confirm the uniformity of GERCC is similar to the parent RCC. Coefficients of Variation below 10% have been achieved for compressive strengths,
- Ability to incorporate reinforcing steel, waterstops, pipe encasements etc.,
- Can be used between abutment rock and the RCC body to achieve good bond and the filling of all rock cavities, irregularities etc.,
- Pre-mixing in a truck or CVC mixer enables freeze-thaw and other admixtures and extra cement etc to be added (i.e. ‘GERCC-M’) as required.
- Low cost.
Requirements and Limitations of GE-RCC include:

- Quality control relies on inspection, an understanding of the requirements by those applying the grout and doing the vibration, the inspection and repair of any defective zones when evident on stripping of the forms and controlling grout dose rates,

- Lift joint treatment is necessary, as with any conventional concrete lift surface,

- Achieving a toweled, level surface, say for exposed step surfaces, is not as easily achieved as with conventional concrete since it is less workable, using GERCC-M assists in this regard,

- Where transverse joint waterstops are incorporated it may be necessary to locally widen/transition the adjacent facing width to facilitate the large RCC drum rollers negotiating around the waterstop installation.

3. SLIP FORM PAVING THE TOP OF GERCC STEPS

Using GERCC for constructing downstream stepped facings, including unreinforced spillway steps, has been successfully adopted on many RCC dams, as described above. However with higher steps heights (1.2m or more) it has been found that the width of the top step becomes too wide (1.4m or more) to be readily compacted, leveled and surface finished by hand. Also, a common problem found with most horizontal downstream steps is that any seepage or light rainfall tends to collect in the low spots along the top of the steps rather than drain off uniformly, which then results in an unsightly aspect, including vegetation growth, to an otherwise pleasing downstream face.

On the Enlarged Cotter Dam, presently under construction in Australia, the 1.2m high GERCC faced downstream steps were detailed to be finished with the top step having a drainage cross fall of 1% and the outer corner finished with a 50mm 45° chamfer. The contractor proposed the use of a small slip form paver (Gomaco Commander III) that was available off a recent pedestrian pavement job. The paver used a gang of 5 poker vibrators to compact the in place GERCC, after the RCC had been pre-dosed with grout in the usual manner, and a surface screed plate to finish the top surface according to the designed cross fall. The final surface was then given a light hand trowel finish and dam’s transverse contraction joints notched into the surface as required, Figs. 20 and 21.

The paver tracked along the adjacent leveled of and lightly pre-compact ed RCC placed just ahead or the advancing paver. The GERCC along the vertical step form was pre-compact ed with a hand held poker vibrator to ensure that a good off form surface was always achieved.
Slipform paver, shown compacting GERCC for the top lift of the step using poker vibrators; the paver is moving towards the camera.

Fig. 20

Fig. 21

Finishing off the slipformed surface of the top lift and the final aspect of the stepped downstream face of the Enlarged Cotter Dam (see also Fig 17).

The slump achieved in the GERCC was less than 20mm, the same workability as that specified for all the other GERCC on the project.

Despite some initial (albeit misplaced) concerns, mainly being that slip paving would be an impediment to overall RCC placing rates and just result in ‘another item of plant on the dam’ etc, the paver has proved to be a success. The result is a uniformly, fully compacted 300mm (or 400mm\textsuperscript{6}) thick layer of GERCC in the top step, finished with a 1% drainage cross fall and chamfer as per design, and, importantly, it has reduced the time involved and number of (high cost) labourers otherwise necessary to finish the GERCC step surface by hand.

4. GALLERY CONSTRUCTION BY ROCK TRENCHER

In two recent Australian dams (Enlarged Cotter Dam and Wyaralong Dam\textsuperscript{7}) a rock trenching machine (400HP T955 Vermeer Commander and a 340HP 960
Trencor respectively) with an extended boom, capable of cutting slots 460mm wide and up to 3.9m and 3.6m deep respectively in hardened RCC, has been used in constructing the main horizontal drainage/grouting galleries. The process of constructing galleries by excavation is not ‘new’ in the sense that some earlier projects have excavated pre-placed non cemented sand, aggregates etc placed as a temporary fill during RCC placement, or simply trenched through the RCC while it still has a low strength using a backhoe or excavator. Using the rock trencher has simplified the process and allowed deeper, harder (i.e. older) RCC to be neatly excavated and achieve design gallery height without concern.

The process involves cutting a continuous slot along each side wall and, for wider galleries, one or more through the central zone with the narrow uncut central portions left to be broken out and removed by excavator. Precast reinforced concrete slabs form the roof. At Wyaralong dam the side drain along the floor was cut by the trencher at the same time, with a high degree of accuracy being achieved. The length of the cut gallery at the Enlarged Cotter dam was only about 40m with a cross section 3.2m wide x 3.9m high, whilst that at Wyaralong dam was about 150m but with a far smaller section. It was found that the Enlarged Cotter dam gallery was too short to fully achieve the anticipated benefits in terms of time saving that would be obtained trenching a longer, smaller sectioned gallery; the actual trench cutting operation itself took 3 shifts whilst the process of excavating, floor trimming etc took a further 10 shifts.

At the Enlarged Cotter dam the rock trencher was trialed in the earlier constructed full scale trial RCC placement where the RCC had already attained a cylinder compressive strength of 20MPa, which it cut through with ease, Fig. 22.

In the dam gallery itself, the RCC strength varied from about 5-12MPa (top to bottom) and the rock trencher achieved a neat intact RCC top edge, despite the lower strength RCC near the top of the gallery walls. Unfortunately the top corners were subsequently damaged by the excavator and required repair before the roof

Fig. 22
Trialing the rock trencher at the Enlarged Cotter Dam RCC trial placement in 20MPa RCC.
slabs could be placed. The final as-trenched wall surface is uniform but with a rough texture; it allows direct inspection of the RCC, its lift joints and, in the future, any areas of seepage should such occur, see Fig. 23.

![Fig. 23](image)

The three trenched slots and two remaining upstands in the lower gallery of the Enlarged Cotter Dam, prior to their breakout and removal of spoil by excavator and the completed gallery.

5. PRE-CASTING SPILLWAY Ogee CRESTS

At the Meander Dam (50m high, 85,000m³, Tasmania Australia, 2007), the

![Fig. 24](image)

The precast concrete elements forming the crest spillway at the Meander Dam in Tasmania, the void under them was backfilled with mass concrete[8-Fig 5].
designers (Hydro Tasmania Consulting) maximized the use of pre-cast concrete in the construction of this RCC dam, including using pre-cast concrete elements/profiles to form the 50m long simplified ‘ogee’ spillway crest\cite{8,9}, as seen in Fig. 24.

The design worked well in that it reduced the time and complexity usually associated with the normal formed-in-place concrete construction of such spillway crests and the associated placement of its surface anti cracking reinforcement.

The pre-cast elements were 1m wide, 0.3m thick, had a span of 8m, height of 2.7m and weight of 7.5t (approx.). Anchor bars were cast into the underside of the elements and grouted into the upper lifts of the RCC to connect the elements through the mass concrete backfill to the RCC dam.

For dams with longer crest lengths, future designs might consider a similar pre-cast concrete outer surface but seek to reduce the infill mass concrete requirements and develop a means of providing a watertight seal along the butt joints of adjacent elements.

6. CONCLUSIONS

The use of the sloped layer method (SLM) of placing RCC and the use of grout enriched RCC (GERCC) continues to gain favour worldwide since the procedures were first developed towards the end of the 1990’s. With their use other techniques have been developed which enable inclined forms to be adopted instead of the traditional step-formed downstream face and thus gain further advantages and efficiencies from SLM.

By pre-mixing the materials in GERCC either on site or at the point of RCC delivery, it is now possible to effectively include admixtures for freeze-thaw resistance of GERCC facing, to obtain additional workability using superplasticizers and so provide a GERCC which can be pumped, or used in mass pours for dental/backfill concrete, yet still retain the cost benefits from the ‘parent’ RCC and the low cracking potential from low slump GERCC, or to be able to add additional cementitious materials for enhancing the strength and durability of GERCC. This pre-mixed GERCC has been termed ‘GERCC-M’

Slip form pavers have proved capable of easily and effectively compacting GERCC to give an accurately placed and quality finish to the wide top step surface of stepped downstream faces and spillways. Use of rock trenchers have been used to accurately cut 20MPa RCC to depths of up to 3.9m for galleries, thus simplifying their construction and reducing their negative influence on RCC placing rates. A new use of pre-cast concrete elements for an ogee type spillway crest profile has been developed on a recent RCC dam in Tasmania which promises to significantly
reduce the usual lengthy time often taken to construct these final works prior to reservoir impoundment.

It is pleasing to see that innovation and engineering imagination is still thriving in the RCC industry, and that new ways of meeting quality, time and cost challenges are continuing to be explored, trialed and successfully developed.

REFERENCES


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