



**Anais do 50º Congresso Brasileiro do Concreto
CBC2008 - RCC Symposium**
Setembro / 2008
ISBN
@ 2008 - IBRACON



RCC – New Developments and Innovations

Brian A. Forbes, Manager-Major Dams Projects, GHD Pty Ltd, Brisbane, Australia.
(e-mail bforbes@ghd.com.au)

Abstract

In the last 25 years, following the completion of the Willow Creek 'all' RCC dam, the experience and knowledge gained through the completion of over 350 RCC dams has been considerable. Many new ideas and innovations have been tested and adopted so that today 300m high RCC dams are almost a 'reality' with Pakistan soon to embark on the construction of a 272m high RCC dam on the Indus River. The paper looks in detail at what the author considers to be two of the most important developments in the history of RCC. One being solving the issue of bonding by placing the RCC lifts within the initial set time of the RCC the other, achieving a durable, impervious and aesthetic facing to the RCC by altering in-situ the proportions of the RCC with the addition of grout to the uncompacted, as spread RCC so it will behave as conventional concrete when internally vibrated.

Keywords: Roller compacted concrete, initial set time, sloped layer method (SLM), grout enriched RCC (GERCC)

1 Introduction

Although the compaction of concrete using vibrating rollers occurred well before the early 1980's, it is generally recognized that Willow Creek dam in Oregon, USA was the first dam to be constructed almost entirely out of RCC. Over the following 25 years over 350 dams, large and small, as well as a significant number of rehabilitation works to dams, have made use of the RCC procedure. Many new ideas and methods have been tried in the evolution of the RCC to get it to where the technology stands today, with dams well over 200m high, such as the 272m Daimer Basha dam on the Indus River in Pakistan, for which construction bids for placing the 16 million m³ are soon to be invited, and the 190m high Miel 1 and 192m high Longtan dams in Colombia and China are already complete and successfully storing water.

Of the many developments and innovations that characterize the evolution of RCC, the author considers the 2 most significant are bonding of the horizontal construction lift joints and facing of the RCC dam body.

It is almost universally accepted practice that RCC be placed and compacted in lifts 300mm thick. Bonding the next lift to that below has been an ongoing difficulty. However, with the high dams we are now constructing, many in regions of high seismicity, effective bond has become a vital issue, both in terms of dam stability and prevention of seepage.

Many different facing systems have been used over the last 25 years, such as pre-cast concrete panels, cast-in-situ conventional concrete and PVC membranes, all with the aim of achieving a durable, aesthetic, impervious protective facing to the RCC.

The paper describes the methods now used to *bond RCC lifts by placing lifts within the initial set time of the RCC placed in the lift below*, such that the direct tensile strength across lift joints is similar to that of the parent RCC and, thereby, achieving a monolithic mass of RCC. One of the methods described being that termed the 'sloped layer method' (SLM).

The paper also explains the method of a *adding cement grout* to RCC spread along the faces of the dam, abutments and galleries etc, and by this means modifying the RCC to enable it to be compacted by internal vibration so as *to achieve an economical, high quality facing concrete, now termed 'grout enriched RCC' (GE-RCC)*.

2 Lift Joint Bond and the Sloped Layer Method

One of the significant differences between a CVC dam and a RCC dam is the number of horizontal construction lift joints. Formed conventional concrete is placed in 1.5-2.0m lifts, whereas RCC is placed in 0.3m lifts, i.e. with RCC there are 5-7 times more joints and potential planes of weakness for sliding or overturning failures to occur along.

Various approaches have been adopted in earlier RCC dams to achieve bond between lift joints, these include minimizing deterioration by plant of the compacted lift surface, maintaining curing, preparation of the surface, final clean up and use of a bonding concrete, mortar bedding, or grout over all or part of the width 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.

The 'maturity index', which is a function of lift surface age and ambient conditions 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 1 or 2 RCC lifts per day, 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 1 in 2 joints recovered broken, i.e. the bond was insufficient to overcome the torque applied by the coring bit. Direct tensile strengths of bonded joints has been shown to vary considerably, seldom are joints more than $1/3^{\text{rd}}$ of the parent RCC tensile strength, those using a bedding mortar may reach $2/3^{\text{rds}}$, but it is very unlikely that penetration of aggregate particles for the overlying lift will be seen to have penetrated the surface of the lower lift.

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 RCC strength itself is 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 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 was developed for the purpose. Retardation extended initial set from 1.5-2.0 hours (unretarded) to 6-8 hours depending on summer/winter temperature. The placing process involved forming up a 3m thick block using a form aligned on a transverse contraction joint, such that the area enclosed resulted in a 300mm thick RCC layer with a volume equal or less than the volume of RCC that could be produced by the mixing plant in the retarded initial set time, as adopted initially for Jiangya Dam in 1997

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 offset by the time and cost saved in lift joint preparation.



Photo1 - Jiangya Dam, 131m high, 1.1 mill m3 China 1997, placing 10 layers of RCC in a formed 3.0m block

The process has developed on some recent projects to one placing fewer layers, generally four, so as to form a 1.2m thick lift. By using pre-cast concrete blocks as the transverse 'form', time and cost is reduced, but it involves more cold joints for preparation. A steel ramp, or sloped zone of RCC, allows plant access into the formed placement area, e.g. at Koudiat Acerdoune Dam

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 lift heights exceed the step height.



Photo 2 - Koudiat Acerdoune Dam, 121m high, 1.65mill m3 Algeria 2007, placing 4 RCC layers with end form and access ramp for a 1.2m lift

A further development of the procedure, still using lift heights of 1.2m being equal to the downstream face step height, has been to eliminate the transverse form entirely, i.e. extending the access ramp of RCC to full width of the block between upstream and downstream faces. Ideally the ramp is located over the transverse contraction joints, wherever possible. The 4 layers of RCC are ramped down to the previous cold lift surface so as to finish off with a ramp slope of 4H:1V. The 'feather edge' of the ramp is cut back during the preparation of the lower lift surface to a minimum thickness of 100mm, then covered entirely with bedding mortar at the start of placing the first layer in the adjoining lift.

A disadvantage of this method is that the lift surface preparation in the adjoining block cannot be effectively undertaken until the lift has been completed, i.e. it is more suited to RCC placing every second shift in a two-shift day.



Photo 3 - Wadi Dayqah Dam 80m high, 0.6 mill m³ Oman 2008 placing 4 RCC layers in a 1.2m lift rolled down without end form

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.

The placing rate, selection of plant and retarder dose rate is based on the maximum lift volume of the dam – which typically occurs about 1/3rd height for 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

The sloped layer method (SLM) of placing RCC was conceived during the construction of Jiangya Dam in late 1997 and adopted from about mid height onwards. Placing rates increased considerably and the project was thus completed 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 Chinese RCC dams and others internationally.

The procedure initially adopted on Jiangya had been to place the RCC in blocks 3m high 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 the figure below, the same 3m lift could be built up as a continuous process across the entire dam without the need for the transverse form.



Photo 4 - Yeywa Dam 134m high, 2.4mill m3 Myanmar 2008, placing 1 lift/day over full dam area using high RCC placing rate

Simply changing the slope selected for the layers alters the volume of RCC placed in the 300mm thick sloping layer. For example, using say 3m high forms, as were adopted at Jianguya, with an RCC mixer output of 500m³/hr and initial set time of the un-retarded RCC of 2 hours, and a width between upstream and downstream faces of 'W', then 'S', denoting the slope shown in the Figure 1 below, will need to be:

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

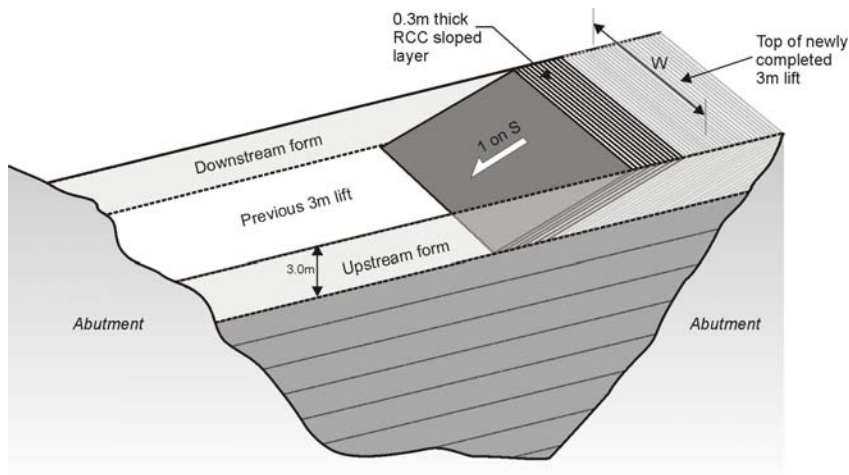


Figure 1 - Explanation of the Sloped Layer Method

Hence, for this example, 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 might be adopted if the time between placing RCC layers of only 0.5 hours with a 1 on 10 slope is, for some reason, considered to be too short.



Photo 5 - Jiangya Dam showing the SLM using 3m high lifts

When using the sloped layer method 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. Form lifting and lift surface preparation 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 was to first place 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. This portion of the layer is placed and rolled in an upstream-downstream direction. 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.

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 later easily achieved using high pressure air-water jetting to break away any poorly bonded 'feather edge' material.

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 paint lines marked 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 recent Koudiat Acerdoune Dam in Algeria when the sloped layer method was adopted for the 1.2m high lifts.

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 the sloped layer method.



Photo 6 - Koudiat Acerdoune Dam, crawler placer for SLM in 1.2m high lifts

For inclined downstream faces the best arrangement appears to be to use vertical steps. If formwork is used then the step height would be equal to the lift height. At Jiangya Dam and also Kinta Dam (90m high 0.9mill m3, Malaysia 2006) where 3m high lifts were used, precast concrete blocks were provided to form the 1m and 0.6m high steps on the downstream face respectively. Blocks are 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 lift height.



Photo 7 - Kinta Dam, pre-cast block forms for 0.6m d/s steps for SLM in 3m lifts

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 an up-down slope direction. The crossfall of 2-3% generally adopted in placing the traditional 'horizontal' RCC layers for construction drainage purposes can be retained for the sloped layer method, 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. 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 would be changed to slope from abutment to abutment, 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.

Cores of RCC extracted from Jiangya, and more recent Chinese 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, unbroken lengths up to 15m long equal to the length of the core 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.



Photo 8 - Left, lengths of core up to 5m long from Jiangya Dam, right, 15.1m from Longtan Dam where horizontal lifts were placed within a retarded initial set time

Advantages of the SLM include:

- Achieves homogenous, monolithic RCC across lift joints.
- Reduces the horizontal construction lift joints by up to 90%
- Initial and final lift joint preparation and form lifting taken off the critical path.
- Reduces the area of young RCC exposed to rainfall or subject to freezing, reduces the potential for RCC to heat gain in hot 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 reduces subsequent clean up work.
- Proven increases in RCC placement rates of 30-50%

Possible disadvantages of the SLM are:

Downstream face requires either the use of high steps equal to the lift height or use of temporary pre-cast concrete blocks to form up the steps.

Increased loading on the vertical forms

'Feather edges' running in an up-downstream direction at the top and bottom of the slope need to be properly dealt with.

Survey control of the RCC placing is a little more complex.

3 Grout Enriched RCC for Facing Concrete

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 premise of grout enriched RCC (GERCC).



Photo 9 – GERCC upstream facing, left Kinta Dam 90m high, right Ralco Dam 155m high

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. Also it can assist grout penetration and distribution 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 till 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 lift surface of the RCC. If the next lift is to be placed within a few hours the poker vibrator will re-penetrate 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 Miel I Dam the dryer 125kg/m³ cementitious content RCC mix, which had a VeBe time in excess of 40 seconds, required about 10-12 litres/m/400mm width. By having 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, air entrainers and plasticisers can be added to the grout if necessary. At both Miel I and 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 conventional concrete. 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 the grout dose rates further increased.

The ultimate objective is to keep grout dose rates to a minimum if strength and full compaction of the RCC/GERCC interface is to be achieved.



Photo 10 - Applying grout and poker vibration of GERCC at Kinta Dam

In some instances it may be found that in fact *no* grout is needed to enable consolidation by poker vibration, such as at Cadiangullong Dam (43m high 0.12mill m³, Australia 1997) where the RCC mix was highly sanded and very workable when the RCC at time of delivery had a lower than usual Vebe time (<12-15 seconds). Slump cone testing of freshly consolidated GERCC sampled from the facing should have a slump between 5-20mm if drying shrinkage cracking is to be avoided.

While the grout was hand mixed in a front end loader bucket or hand pushed wheel barrows for the earlier projects, grout is now 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. A supply of water is also needed. The grout may then be pumped to the placement area, or simply hauled to the dam face in buckets by laborers.

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

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 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.

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 over the first 50-75mm of the GERCC if the formwork will permit, so that the contact between the two is fully compacted.

The GE-RCC will be displaced upwards by the roller, this is not of concern as long as it is no more than 10-20mm, otherwise grout dose rates should be reduced.



Photo 11 - RCC compaction of the sloping layer alongside the GERCC facing, followed by hand tamping the raised edge of GERCC

Quality assurance comprises sampling of the GE-RCC after compaction for slump testing and manufacturing of test samples for compressive strength testing. 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 jar. Horizontal coring through the face, either through the body of the lift or along the lift joint itself, into the parent RCC behind will confirm homogeneity and density of the GERCC and its lift joint strengths and the continuity of the transition between GERCC and the RCC.

At the Dachaoshan Dam (111m high 0.76mill m³, China 2001) the downstream stepped portion of the spillway chute has been constructed in 0.9 m high steps using GERCC.

Velocities down the spillway chute are high and finished surface quality and alignment were important issues to the designer. At Cadiangullong dam the lower 0.3m lift of the 0.6m high spillway steps were done in GE-RCC and the top lift in conventional concrete, as it was perceived by the contractor to be more easily finished to the required tolerances. Later at Tannur (60m high 0.25mill m³, Jordan 2000) and Kinta dams the full 1.2m and 0.6m high 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. 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. During construction the dam was overtopped on two occasions for nearly a week, flows of up to 500m³/s, 1m deep were experienced with absolutely no damage to the young GERCC facing.



Photo 12 - GERCC spillway steps, left Kinta Dam 0.6m high after 6months of spillage, right Tannur Dam 1.2m high 7 years no spillage yet

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. The embedment of horizontal PVC waterstops in GERCC facing was very successfully undertaken at Tannur Dam along the connection of the RCC dam to the CVC spillway apron.

Where reinforcing steel has been incorporated, such as around gallery openings, GERCC has replaced CVC, the steel appears to be just as well encased in the GERCC as in CVC. The feasibility of incorporating reinforcing into RCC in these locations, as well as in other areas, such as along the upstream faces of the higher dams to distribute any cracking potential evenly between transverse joints, is now greatly simplified with GE-RCC.



Photo 13 - Horizontal waterstops at Tannur dam embedded in GERCC facing

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.



Photo 14 - Horizontal 150mm dia cores from Kinta Dam spillway through 400mm of GERCC and into RCC, core on left is through a lift joint



Photo 15 - Horizontal 150mm cores from Wadi Dayqah Dam through 400mm of GERCC and into RCC beyond line marked on right, fracture to the left is deliberate drilling break, top core through a bonded cold lift joint using bedding mortar.

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.
- No separate batching, mixing, transportation system is 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 as low as 10% have been achieved
- Ability to incorporate reinforcing steel, waterstops, pipe encasements etc
- Can be used between abutment rock and the RCC body to achieve good bond and filling of all rock cavities, irregularities etc.
- Low cost, in the region of US\$15/m² for a 400mm thick facing.

Requirements and Limitations of GE-RCC include

- Quality control relies on inspection, an understanding of the requirements by those applying the grout and carrying out vibration, inspection and repair of any defective

zones where evident on stripping of the forms, and with simple procedures in place to regulate grout dose rates.

- Lift joint treatment is necessary, as with any conventional concrete lift surface.
- Achieving a troweled, level surface, say for exposed step surfaces, is not as easily achieved as with conventional concrete since it is less workable.
- 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.

4 Conclusions

The realisation that homogeneity across RCC lift joints and the development of lift joint bond, tensile resistance and shear strength approaching that of the RCC itself will only be achieved with joint surfaces if they are covered by the next lift within the initial set time of the RCC, has been instrumental in giving designers confidence to develop RCC gravity dams to heights now approaching 300m. Where cold joints do occur they are treated in the same manner as with CVC, green cut to expose aggregate surfaces and treated with a bedding mortar.

Various RCC placement procedures to achieve this have been used. These include, dividing the placement area into blocks, 1.2-3.0m high to reduce the volume of each 300mm thick layer, adopting very high plant output rates and heavily retarded RCC mixes so a single 300mm thick lift can be placed over the full area of the dam within the initial set time, and the 'sloped layer method' which reduces the area to that which does not require the use of retarding admixtures or block forms. The success of the process is demonstrated by the lengths of intact, homogeneous vertical RCC cores of up to 15m in one complete length being recovered from the placed RCC.

The ability to modify the in-place RCC after spreading, by the simple addition of a cement grout to change the consistency of the RCC, so it can be internally vibrated as a CVC, has led to a high quality, impervious concrete facing which, as consistently shown by cores, is totally monolithic with the RCC behind. The process is easily undertaken, does not impact on the rate of RCC placement and can be applied to wherever CVC would in the past have had to be separately produced and placed.

Besides upstream facings it has also been applied with success to stepped spillway facings, gallery walls, waterstop encasement and incorporation of reinforcing steel. It's cost is minimal and quality and uniformity has been shown to be similar to the parent RCC. It has been used as the upstream facing to some of the worlds highest completed RCC dams.

These two developments in the technology of RCC are considered to be the most important innovations amongst the many innovations developed by proponents of RCC in the last 25 years.

2 References

FORBES BRIAN., YANG LICHEN., TANG GUOJIN., YANG KANGNING. **Jiangya Dam, China. Some Interesting Techniques Developed for High Quality RCC Construction.**

Proc. of the International Symposium on Roller Compacted Concrete Dams, Chengdu, April 1999.

JIANG CHANGING., DU ZHIDA., YANG KANGNING. **Horizontally Advancing Sloped Layer Construction of RCC.** Proc of the International Symposium on Roller Compacted Concrete Dams, Chengdu, April 1999.

FORBES, B.A., **Grout enriched RCC: A History and Future.** International Water Power and Dam Construction Journal, June 1999.

FORBES, B.A., **Solving Some Long-standing RCC Concerns.** International Journal on Hydropower and Dams, Volume 7, Issue 3, June 2000.

FORBES, B.A., ISKANDER, M, M., MALKAWI, A. I. H. **High RCC Standards Achieved at Jordan's Tannur Dam.** International Journal on Hydropower and Dams, Volume 8, Issue 3, June 2001.

FORBES, BRIAN, A. **Using Sloped Layers to Improve RCC Dam Construction.** Hydro Review Worldwide (HRW), Vol 11, Number 3, July 2003.

FORBES, B.A. **Some Recent Innovative Methods and Techniques in the Design and Construction of RCC Dams.** 4th International Symposium on Roller Compacted Concrete (RCC) Dams, Madrid November 2003.

FORBES, BRIAN, A., HANSEN, KENNETH, D., KITZGERALD, THOMAS, J. **State of the Practice – Grout Enriched RCC in Dams.** United States Society on Dams Annual Conference, Portland Oregon, April/May 2008