STATE OF THE PRACTICE – GROUT ENRICHED RCC IN DAMS

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ABSTRACT

Grout Enriched Roller-Compacted Concrete (GERCC) is a relatively new development in the design and construction of RCC dams. GERCC is basically a method for producing a mixed-in-place conventional concrete by adding grout to uncompacted RCC and vibrating the two materials together. It was initially developed in China and has seen considerable acceptance in other countries. However, acceptance in the United States has been slow.

This paper presents the history and development of GERCC worldwide to include its limited use on RCC dams in the US. Three case studies are presented to illustrate the construction method and results. The current state of the practice with respect to RCC and grout mixture proportions, equipment used, production methods, and quality control are discussed and evaluated. Performance and properties of RCC faces as well as concerns with freeze-thaw durability and waterstop embedment are presented. Research needs and future developments are also discussed.

INTRODUCTION

Grout Enriched Roller Compacted Concrete (GERCC) refers to the final product produced by adding grout to the surface of uncompacted roller-compacted concrete (RCC) and when combined with internal vibration, produces a homogeneous mass similar to that of conventional slump concrete. It may be described as in-place mixed concrete in an RCC dam.

The process has typically been used to produce upstream and downstream faces for RCC dams. The GERCC method has also be used for consolidation at the rock/abutment contact area and around conduits or galleries within the dam body.

A similar process is referred to as grout enriched vibratable RCC (GEVR). For GEVR, the grout is placed directly on the previously compacted RCC lift. Then loose RCC is placed over the grout and internal vibration is used to draw the grout up into the RCC to

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produce the facing. The GEVR method is only used with very workable (low Vebe time) RCC mixes, which can possibly be consolidated by vibrators without the addition of grout to produce acceptable results. This paper will primarily deal with GERCC as defined and noted above.

Advantages of GERCC

The advantages of GERCC are well documented in the literature (see references) and include:

- Production of a durable, relatively impermeable, smooth and attractive upstream face
- A seamless transition between the GERCC facing and the adjacent RCC mass, as well as producing a positive adhesion to foundation or abutment rock
- A simplified construction procedure that requires little training
- Elimination of separate batching, mixing, and transporting equipment needed to produce an upstream face using conventional concrete
- Production concurrent with RCC placement with little or no impact on RCC placement rates
- GERCC is invariably less costly than alternative facing systems for RCC dams.

HISTORY

Worldwide Overview

The use of GERCC to produce a finished upstream face was initially used in the cofferdam for Puding Dam in China in 1994. The 430 foot high Jiangya Dam, also in China, was the first major dam to incorporate the GERCC method for its upstream face. (See Figure 1) More information on the use of GERCC in Jiangya Dam (1996-1999) is presented in the next section of this paper as a case study.

Since these early developments, GERCC continues to be used extensively in China and on a significant number of RCC dams throughout the world. According to a listing of RCC Dams worldwide published in Hydropower and Dams World Atlas 2007 (Dunstan 2007), a total of 384 RCC dams have been completed, were under construction, or scheduled to start construction in 2007.

GERCC and GEVR have been, or will be used in 59 of the dams. Kinta Dam, a 295 foot high dam in Malaysia (2004-2006) is further discussed in this paper as an example of a more recent GERCC project. All but three of the dams utilizing GERCC will have an exposed GERCC upstream face. Two dams, Miel 1 (617 feet) in Colombia and Olivenhain (308.5 feet) in southern California used GERCC and GEVR respectively to produce a smooth backing for an exposed membrane liner on the upstream face. For Hickory Log Creek Dam (188 feet) in the state of Georgia, the GERCC was only applied to portions of the downstream face.

Figure 1. Jiangya dam, overall view

China continues to lead in the use of GERCC upstream faces for its dams with 36 such applications. The other 23 GERCC faced dams are located in 17 different countries. GERCC faces are being used on some of the highest RCC dams in the world as 26 of the dams are more than 100 m (328 ft) high. Longtan Dam in China at 630 feet heads the list of the high dams with an upstream face of GERCC, followed by Ralco in Chile at 508 feet high.

GERCC Applications in the United States

GERCC has not been used much to date on RCC dams in the United States. A small trial was accomplished at the 23 foot high Atlanta Road Dam in 1999. It was a joint effort between the contractor (Thalle Construction Co.), the design engineer (Schnabel Engineering), the Portland Cement Association (PCA) and the US Army Corps of Engineers (Corps).

Then in 2001, the Corps in conjunction with Barnard Construction Co. and representatives from a number of other governmental agencies and private consulting firms constructed a full scale test section at the North Fork Hughes River RCC Dam, then under construction in West Virginia. This test section was supplemented by evaluating various grout mixtures in the laboratory and testing of cores obtained from the test section (McDonald, 2002).

During the 2002 construction of the 309 foot high Olivenhain Dam in southern California, a value engineering (VE) proposal initiated by the contractor, Kiewit Pacific was accepted. Their VE proposal revised the original RCC mixture proportions to that of one with “excess paste”. The new mix allowed GEVR to be produced as a smooth backing for the dam’s exposed membrane upstream face. However this was only partly successful, as considerable work was necessary to remove and patch relatively large areas of honeycombed surface before the membrane could be installed. GEVR was also used for the RCC rock interface at each abutment. More information on these early projects can be found in "Grout Enriched RCC: the Past and Future in the USA" by Fitzgerald, Hansen & Bowen (2007). The use of GERCC at the 188 foot high Hickory Log Creek Dam (2007) located north of Atlanta is further discussed in this paper.

According to Fitzgerald, et al (2007) the reasons for GERCC having not been used to any great degree in the United States is related to:

- An inadequate understanding of the consistency of the grout.
- Previous RCC mixes in the US have either tended to be too dry (high or no Vebe time) and/or grouts too stiff (too low a water cement ratio w/c) together with the incorrect quantity of grout applied.
- Concern with freeze-thaw durability of GERCC. Trials at introducing adequate air entrainment have not proved successful to date.

CASE STUDIES

<u>Jiangya Dam – China</u>

The most important development in the use of GERCC in a major dam occurred at Jiangya Dam in Hunan Province, China. The original design for the upstream face for this 430 foot high RCC dam called for 2 meters (6.6 feet) of conventional concrete. An alternate design which turned out to be called GERCC was proposed and tested by the contractor and subsequently approved by the design engineers. Placement of the 1,439,000 cu. yd. of RCC was completed in 1996.

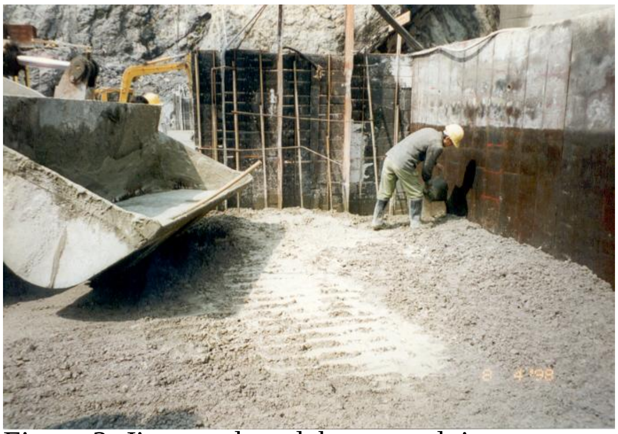


Figure 2. Jiangya dam, laborer applying grout

This new method of producing an in-place mixed conventional concrete face consisted of adding a water-cement grout adjacent to forms or rock abutments atop the uncompacted RCC. The grout was hand mixed in the bucket of a front-end loader and then carried to the face by laborers in a pail. It was deposited at a rate of 0.64 gallons per foot for a thickness of 15.8 inches from the upstream face. (See Figure 2)

Then, four 6 inch diameter immersion vibrators gang mounted on a rig attached to an excavator, which was available on site for large conventional concrete pours, internally consolidated the grout enriched zone. (See Figure 3) A wider zone of GERCC was produced at the RCC rock abutment interface. Finally, the edge of the GERCC zone and adjacent RCC were compacted with a dual drum vibratory roller. (See Figure 4)

Figure 3. Jiangya dam – Gang mounted vibrators consolidating GERCC

Figure 4. Jiangya dam - Compaction of GERCC / RCC interface

At Jiangya, two RCC mixes were used. For the upstream and downstream portions of the gravity section a richer A1 mix was used. The A2 mix was used for the remainder of the mass. The Vebe consistency of the A1 mix was 6 to 8 seconds with a 22 pound surcharge. See Table 1 for RCC mixture proportions.

Table 1. RCC Mixture Proportions per Cubic Meter (Cubic Yard)

RCC Mix	**Maximum Aggregate mm (inches)**	**Water Kg (lbs)**	**Cement Kg (lbs)**	**Fly Ash Kg (lbs)**	**Design Strength MPa 90 days (Psi 90 days)**
A1	40 (1.6)	103 (174)	87 (147)	107 (180)	28 (4060)
A2	80 (3)	93 (157)	68 (115)	101 (70)	25 (3620)

A low range water reducing admixture was used with both RCC mixes.

The overall quality of the face was termed excellent by consultants working on the project. Very little defect patching was necessary.

<u>Kinta Dam – Malaysia</u>

The use of GERCC at Kinta Dam in Malaysia represents a recently completed project where GERCC was used just about anywhere conventional concrete would have been required in past designs. This included the entire upstream and downstream faces (including the stepped spillway), the transition zone between RCC and rock abutments, drainage gallery walls, as well as encasement of waterstops, drains, and reinforcing steel.

Figure 5. Kinta dam – Overview

Kinta is a 295 foot high RCC water supply dam (See Figure 5) located near the city of Ipoh, northwest of Kuala Lumpur. It is Malaysia's first RCC dam. The 1,273,000 cu. yd. of RCC was placed in the 3,190 ft long dam between 2004 and 2006. The RCC mixture contained 169 lbs/ cu. yd of both portland cement and a Class F fly ash. It had a Vebe consistency of 18-22 seconds using a 22 lb. surcharge.

A further discussion on the efforts to produce a higher strength GERCC for the spillway as well as a seepage problem that occurred around the waterstops is presented in later sections of this paper.

The RCC aggregate was a crushed granite with a maximum size of 2 inches, sand content was about 35% and 4-5% of the combined materials was finer than the #200 mesh. The majority of the RCC was placed using the Sloped Layer Method using 10 one foot layers per lift.

Grout was mixed in a high speed grout mixer drum mounted on a truck and decanted through a hose to pails which were carted by hand to the face. An open frame made of reinforcing steel laid on the RCC marked the area to be dosed with grout from each full pail, thus controlling the application rate. The RCC was 'rodded' using a length of a #4 rebar, say at regular 8 to 10 inch intervals, to assist the grout in penetrating the RCC to the full depth of the lift. Consolidation of the GERCC was accomplished using two 2-1/2 inch poker vibrators held about 1 foot apart. Figure 6 shows the process, the consolidated GERCC in the background, the dosed RCC in the mid-ground and the spread RCC in the foreground.The average RCC 180-day sample strength was 4,060 psi and the corresponding GERCC strength was 3,480 psi based on 800 and 300 samples respectively, corresponding coefficients of variation were 19% and 24%, being high largely as a result of uncontrollable varying fly ash quality.

The GERCC facing for the 328 foot stepped spillway was unreinforced but the strength of the GERCC was increased by the addition of silica fume to the grout, with the intention of trying to achieve a strength of 4,350 psi at 1-year. This is further described later in the paper. Average strength from 24 samples was 4,640 psi and coefficient of variation was 20%. The GERCC facing at no stage caused any delays in the placing of RCC, either in the initial stages when the RCC was placed using the typical horizontal method and later in combination with the Sloped Layer Method. The surface finish on form stripping was excellent, some patching was required to an occasional honeycombed area but no more than is usually found with conventional concrete. Cores drilled horizontally into the face through the GERCC and into the RCC were very consistent and showed a monolithic homogeneous interfacing.

Figure 6. Kinta dam – GERCC production

Hickory Log Creek Dam – USA

The most recent example of the use of GERCC in the United States was for the 188 foot high Hickory Log Creek Dam completed in 2007 north of Atlanta, Georgia. The dam was completed to provide an additional water supply source for Cobb County and the nearby City of Canton, Georgia. (See Figure 7)

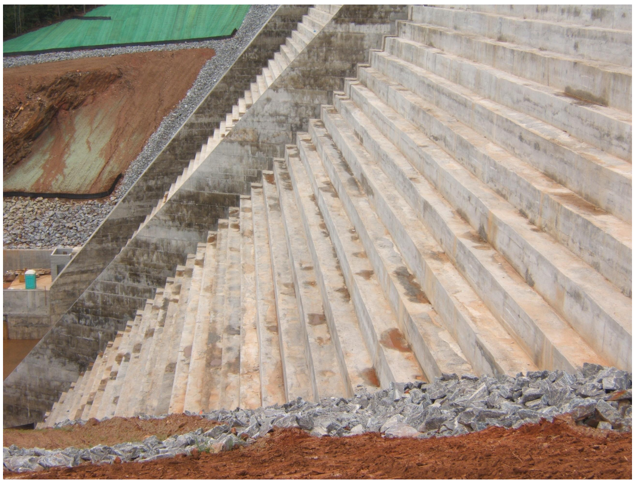
Figure 7. Hickory Log Creek dam – Overview

GERCC was used for facing the 3 foot high formed steps in the non-overflow portions of the downstream face on either side of the converging spillway. The entire dam required 220,000 cubic yards of RCC with a total cementitious content of 300 pounds per cubic yard. At the onset, the RCC mix contained 150 pounds of cement and 150 pounds of Class F fly ash per cubic yard. As the dam rose from its rock foundation, actual compressive strengths exceeded laboratory mixture proportioning study results. This caused Schnabel Engineering to revise the RCC mixture to contain 135 pounds of cement and 165 pounds of fly ash per cubic yard to save cost and still attain desired in place strength properties.

The grout used to produce the GERCC was a mixture containing equal parts of cement and water by weight (a 1:1 mix). Vebe consistency of the RCC mixture was usually in the 22 to 25 second range using the US surcharge of 50 lbs (ASTM C1170). The aggregate used was a blend of 85% Georgia DOT aggregate base course (GAB) and 15% #4 stone. Large quantities of coarse aggregate (#57 stone) were generally unavailable at the time of construction due to heavy demands for aggregate from highway projects and a vibrant housing market.

The GERCC was produced by ASI Constructors who were the RCC placing subcontractor to the prime dam contractor, Thalle Construction. ASI's GERCC placing crew consisted of five workers. This included an overall foreman and four laborers. Two laborers were used to produce the grout mixture in a colloidal mixer located on one abutment of the dam. The grout was then pumped to the downstream face and spread atop the uncompacted RCC in the steps.

The two other laborers were used to internally consolidate the grout into the RCC using 2-1/2 to 3 inch diameter hand held vibrators. GERCC was used for a 9-inch thick vertical facing for the 3 foot high step. For the horizontal portion of the steps, grout was only introduced into the top 1-foot thick RCC lift. Production of the GERCC so described averaged about 200 feet of step per hour. In no case did the GERCC production hold up placement of the next lifts of RCC.



From a distance, the resulting GERCC face looks very good and is basically indistinguishable from the conventional concrete facing used in the spillway portion of the downstream face. (See Figure 8) Up close, there were some areas of honeycombed GERCC which required repair. The first major application of exposed GERCC on the face of a dam in the US was thus produced successfully. (Fitzgerald, et al, 2007).

Figure 8 Hickory Log Creek dam – Completed GERCC downstream steps

STATE OF THE PRACTICE

This section summarizes the present state of the practice with respect to the use of GERCC in dams. It presents not only the main requirements for GERCC, but also limitations to its proper use.

RCC Mixture Proportions

There has been basically no experience with grout enrichment of RCC mixes containing less than 200 lbs/cu. yd. of cementitious materials (Portland cement plus a pozzolan – usually a Class F fly ash). At Miel I dam in Colombia the upper half of the upstream face of this 617 foot high dam used 210 lbs/cu.yd. of portland cement. Most RCC mixes to which grout has been introduced have contained at least 300 lbs/cu. yd. of cementitious materials.

Grout has been introduced into RCC mixes with a Vebe time as high as 30 seconds. ASTM C1170 requires a 50 pound surcharge on the RCC, while overseas a 10 kilogram (22 lb) surcharge is typically used. Thus Vebe times quoted in the US are a few seconds less for the same mixture than on international projects. The less workable the RCC mix the more grout is required to achieve a 'slumpable' GERCC which will respond to internal vibration.

Typically the parent RCC is a well-graded mix, which, after compaction, has a void content of only 1-2% and is highly impervious. Prior to compaction, the parent RCC will have a void content of about 10-15% and is therefore 'pervious'. RCC with minus #4 sieve sand contents ranging from 33 to 55 percent have been successfully used to produce GERCC. However, minus #200 sieve fines should be limited to 8% and preferably less to keep the mix from being too impermeable to allow for proper introduction of the grout. A maximum size aggregate in the 1-1/2 to 2 inch range has been used for most RCC mixes used to produce GERCC.

There is a trend toward use of a water-reducing set retarding admixture (ASTM C 494, type D) in the RCC. Methods for introducing air-entraining admixtures into the RCC or the grout have been unsuccessful in actual field operations to date.

Grout Proportions and Use of Chemical Superplasticiser Additives

The grout used in GERCC consists of mixture of water, portland cement and, at times, a high range water reducing admixture (ASTM C 1017) known as a superplasticizer. Without the admixture the water to cement proportions have been usually 1.0:1.0 by weight (w/c = 1.0). Grout mixtures with a w/c ratio less than 1.0 have been found to be too viscous (stiff) to properly seep into the uncompacted RCC. A simple trial will show that at about 1.0:1.0 the grout, which would have a Marsh Cone viscosity of about 34 seconds, will drain down completely into the loose RCC within a few minutes.

In order to use a lower w/c ratio grout, closer to that of the RCC of say 0.8W:1.0C with the intention of increasing the GERCC strength, e.g.to have a facing concrete with slightly greater durability than the parent RCC, the viscosity of the grout has to be reduced. To achieve the same viscosity of about 34 seconds it would be necessary to use a chemical additive in the grout, such as a superplasticiser typically used in concrete to increase the slump. At Ralco dam in Chile this was attempted and found that it was possible to use a 0.8:1.0 superplasticsed grout which was fluid enough to penetrate the loosely spread RCC. Compressive strength test results at Ralco showed that the average GERCC strength achieved was about 70 to 145 psi higher than the parent RCC.

Construction Procedure

Grout Mixing and Transport: While the grout was hand mixed in a front end loader bucket or hand pushed wheel barrows for early 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, rather than hauled to the dam face in buckets by laborers. Mixing equipment and hoses need to be cleaned daily to prevent grout buildup.

Preparation of RCC Lift Surfaces: For the GERCC process to work properly, the applied grout needs to fully drain down into the spread RCC lift. Commencing poker vibration prematurely will stop this draining process. It is essential that the RCC is at a loose, 'as spread' condition. Usually it is necessary to trim back by hand the low windrow left by the dozer blade along the form and to roughly level off the surface of the RCC before applying the grout. Also it can assist grout penetration and distribution if the RCC is hand 'rodded' using a length of a #4 rebar, say at regular 8 to 10 inch intervals, to the full depth of the lift.

During these activities, and at all stages prior to consolidation with a poker vibrator, 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 5 feet to the GERCC zone. Once the GERCC has been vibrated, the adjoining RCC should be compacted with a roller. In order to get complete compaction coverage and full compaction of the RCC-GERCC interface, the vibrating roller should overlap the GERCC by about 2 inches. After compaction of the RCC, the surface of the GERCC will be about 1-2 inches higher than the adjacent rolled RCC lift surface.

Achieving a troweled, level horizontal GERCC surface for exposed steps is not as easily achieved as with conventional concrete as the GERCC is less workable (lower slump). Exposed final GERCC top surfaces can be finished to a relatively 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 produce the 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.

Application of Grout and Dosage: The grout needs to be spread uniformly over the designated area in the predetermined amount. For a 16 inch thick facing, 12 inches deep, this amounts to about 1/2 to 2/3 of a gallon of grout per running foot as recommended by Forbes (1999) for an RCC with a Vebe time of about 20 seconds. The grout should be applied soon after the RCC is placed as RCC tends to stiffen with increased time and temperature as evidenced by an increase in Vebe consistency time. If the grout does not flow into the voids of the RCC surface in a few minutes, the grout is either too thick or the RCC too stiff. For this case, the proportion of the materials (mainly the grout) should be revised. For stiff RCC (higher Vebe time mixes) a greater dosage of grout may be necessary for proper consolidation by poker vibration.

Where waterstops are incorporated near the upstream face, it is usually necessary to locally widen the grout treated facing area. This will aid the large RCC vibratory drum rollers used for final compaction in negotiating around the waterstop installation which could also include a drain hole downstream of the waterstop(s).

Internal Vibration Equipment: While 6 inch diameter immersion vibrators were used initially, they are not readily available in the United States. Recently, most projects have used hand held vibrators in the 2 to 3 inch diameter range. For very large RCC volume project, gang mounting of the vibrators on an excavator may prove feasible.

Quality Control

Test Section: In the view of nearly all design engineers, it is imperative that the contractor be required to include a demonstration of GERCC production in the RCC test section. In this manner, the designer can ascertain if the contractor has the proper mixture proportions, equipment and construction procedures to produce an acceptable GERCC face. The surface texture produced in the test section, if acceptable, can be used as a “paint chip” for evaluating the quality of the work to be done under more rapid construction conditions in the dam. The final surface texture of the exposed GERCC face in the dam should be equal to or better than that produced in the test section.

RCC Consistency: As noted previously, a Vebe consistency test should be used to determine the Vebe time of the RCC placed in the dam just prior to grout application. The Vebe time taken at the mixing plant should not be used unless it has been determined how much increase in Vebe time occurs due to time and temperature effects between the plant and the placement area. The Vebe consistency needs to be within the range specified in the specifications and proven to work properly to produce RCC in the trial placement at the test section.

Grout Consistency: Grout of the specified proportions and viscosity needs to be produced in the mixer which after transport to the placing area, seeps into the uncompacted RCC in about one minute or less. A Marsh cone (also called a funnel) is used to determine the viscosity of the grout to determine if the grout is thin enough for proper GERCC production.

Slump Testing: In order to keep the quantity of grout applied to a minimum, i.e. just sufficient to achieve poker vibration (so as to thus minimize potential for drying shrinkage cracks, excess laitance formation on the compacted lift surface and reduce the mobility of the GERCC when the RCC alongside is roller compacted), regular slump testing is useful.

Typical target for the slump of the resulting GERCC will depend on the size and imparted energy of the poker vibrator. For a typical hand held 2 to 2-1/2 inch diameter poker, the slump targeted would be 0.6 to 1.0 inches and less with larger diameter vibrators.

Samples for slump testing are taken immediately after the GERCC has been consolidated, from top to bottom of the lift. After measuring the slump the material can either be replaced and re-consolidated or used to make strength test samples. In this case the sampled area would be repaired with RCC/GERCC.

PERFORMANCE AND PROPERTIES OF GERCC

Strength Properties

Compressive Strength: The compressive strength of GERCC is dependent on the w/c ratio of the added grout compared to the RCC itself and the quantity added. Typically RCC has a w/c ratio of about 0.8 for a mix consisting of 250 pounds of cement plus 200 pounds of water per cubic yard (250C+200W), and 0.5 for the high fly ash mixes (370C+185W). Thus, simply on the basis of w/c ratios, use of a 1:1 grout would be expected to lower the strength of the GERCC below that of the parent RCC, not withstanding the additional 65 to 100 pounds per cubic yard of cement in the GERCC mix. This was clearly demonstrated at Tannur dam in Jordan where the 90 day average strength was about 3,480 psi compared to the 3,620 psi parent RCC. It should be noted that in the United States, it has been difficult to achieve the low water contents in the RCC noted above, due mainly to non-optimum aggregate grading.

Shear and Tension at Lift Lines: The shear and tensile strength at lift lines will depend on the time between placement of consecutive lifts and the extent of lift surface preparation together with the time allowed to exceed the initial set time of the lower lift. If lifts are placed within the initial set time, as is possible with the Sloped Layer Method of RCC placing, then the lift line is non-existent as the poker will penetrate through into the lower lift (Forbes 2003). For example, at Tannur dam it was possible at times to penetrate through to the second lift below and lift lines were not visible. In these circumstances the shear and tension strengths will be those of the GERCC itself. To improve the strengths on aged lift lines it is necessary to green cut the surface to remove any excess set grout (‘laitance’) and expose the surfaces of the aggregate. Use of bedding mortar will be necessary, as with the adjoining parent RCC surface.

Seepage: Seepage through properly compacted GERCC will be minimal, as with conventional vibrated concrete (CVC). Seepage where it occurs will be across lift joints, which have been inadequately prepared, or did not have bedding mortar applied to them. After first filling of the 295 foot high Kinta dam in Malaysia, there were only a few damp spots evident on the upstream wall of the lower and upper drainage galleries. In general, these were located at lift joints. See discussion in Waterstop Enhancement section.

Durability

Freeze-thaw Durability: One known experience to date with trying to achieve a freeze-thaw resistant GERCC facing relates to a small hydro RCC weir, the 43 foot high Horseshoe Bend dam in the south of the South Island of New Zealand in 1998. To achieve 4% air the grout used for the GERCC facing was dosed with an air-entraining additive, sufficient to result in 4% residual air in the 16 inch wide GERCC facing. However the mixed grout was so highly aerated that it resembled more of a foam then a fluid. Thus, it would not soak down into the loosely spread parent RCC. Different approaches were tried, including placing the grout in the mid zone of the lift. None were really successful. Generally, after poker vibration most of the air from the additive had been lost, vibrated out of the GERCC.

Studies by the U.S. Army Corps of Engineers in the laboratory and the test section at the North Fork Hughes River Dam were not successful in their attempts to add proper air entrainment either. A total of eight placements were made in the test section using non-air entrained RCC. In these placements an air entraining admixture was added to the grout. Measured air contents ranged from 0.8 to 2.8 percent. Freeze-thaw testing performed revealed that the number of freeze-thaw cycles resulting in a loss of mass of 25 percent ranged from 38 to 105 with an average of only 75 cycles (McDonald, 2002). A minimum of 300 cycles is considered necessary to produce acceptable freeze-thaw resistance.

Erosion Durability: The durability of GERCC to erosion from flow over a stepped spillway will essentially depend on the compressive strength of the GERCC and quality of the aggregates. As described previously, the surface of the stepped spillway of Kinta dam is entirely GERCC. It has a 180-day characteristic compressive strength of 2,900 psi and at 1 yr of about 3,625 psi.


Figure 9. Kinta dam – GERCC faced stepped spillway (about to spill)

After some 6 months of spillway flow to depths of nearly 8 inches over the ogee crest, the surface of the 2 foot high steps are still in good shape. (See Figure 9) Some of the excess grout left behind on the surface of the steps and cement mortar has of course been plucked off and the aggregate exposed, however no noticeable concrete erosion has occurred.

Appearance

In essence, GERCC is a low slump vibratable conventional concrete. Being low slump it is subject to surface defects such as voids or honeycombing from insufficient consolidation as well as loss of paste from gaps in the formwork with consequent surface voids/honeycombing, just as is the case with a normal concrete facing. As with conventional low slump concrete, when such occurs, surface patching is necessary soon after removal of the formwork. The depth of poorly compacted GERCC is seldom more than 3/4 to 1 inch and can be repaired. A surface with a minimum of voids can be assured by applying grout immediately along the form as well as having it well distributed over the width of GERCC desired and ensuring complete coverage by the poker vibrator

Based on experience with many successful GERCC faced dams the need for surface patching is minimal and no more than would be expected with conventional concrete having a similar slump. An important aspect of the construction process is that operators of the poker vibrators are trained to know when sufficient compaction has been achieved and not to move on to the adjacent zone too soon.

Waterstop Embedment

Generally the upstream waterstops through the transverse contraction joints are encased in conventional concrete. However some projects have used GERCC with generally good results, such as at Tannur dam. (See Figure 10) In this case, a PVC waterstop was placed between the RCC dam and the later constructed downstream concrete stepped spillway section. Both vertical and horizontally placed sections were required to conform with the four foot high stepped spillway section. The waterstop was incorporated into the GERCC facing of the spillway, and on inspection after stripping the formwork, it was clear that the waterstop had been successfully embedded without any sign of voiding on the underside of the horizontal sections, or under the bends where it changed to vertical.

Figure 10. Tannur Dam – Embedded waterstop between GERCC and concrete spillway

In any construction process, proper embedment and elimination of bypassing seepage is essential. The justification for use of GERCC instead of conventional concrete was on the basis of the difficulty of achieving a monolithic connection between concrete and adjoining RCC, as with the facing. Any inadequately compacted RCC along this interface will provide a pathway for seepage bypass.

At Kinta dam the transverse contraction joints have two vertical waterstops, a copper one with rubber waterstop as a back up, both located upstream of a cast drain hole. GERCC was used entirely for their embedment, placed at the same time as the facing GERCC. On reservoir filling, when the level got to about mid-height many of the drains behind the waterstops started to discharge seepage into the gallery. This was evidence that both of the waterstops were being bypassed. Clearly some event common to the encasement of the affected waterstops at this elevation had occurred in the construction process. In view of this experience it may be prudent on future RCC dams to use a higher slump conventional concrete (2 to 3inches) to surround the actual waterstops, then to transition out to the RCC body with a zone of GERCC. In this way it would be less likely to have any zones of encasement under compacted, resulting in a seepage bypass path.

RESEARCH NEEDS AND FUTURE DEVELOPEMENTS

Strength Enhancement

As mentioned previously the strength of GERCC is close, but slightly less than that of its parent RCC if no superplasticizer is used in the grout. At Kinta Dam the 328 foot wide, spillway with 2 foot high steps leads to a roller bucket spillway at the toe of the dam. (See Figure 9) The spillway, designed for a unit flow of 320 cfs/ft, was constructed with a facing of GERCC. The design required the stepped facing be constructed of GERCC with strength being enhanced from the parent RCC strength of 2,900 psi to 4,350 psi. If the contractor was unable to achieve this, conventional concrete would be required for facing the steps in the spillway area.

In order to achieve this it was anticipated that use of silica fume in the grout would impart the required strength gain to a superplasticised grout with a w/c ratio of about 0.8:1.0, as used for the remainder of the dam facing.

The results were only partially successful. Compared to the plain GERCC the silica fume dosed GERCC was only approximately 220 psi higher at 180-days and 310 psi higher at 365 days (based on characteristic compressive strengths). The silica fume was supplied as a fluid and the dose rate was 10% of the cement in the grout, or about 4% of the total GERCC cement content. The silica fume increased the viscosity of the grout according to the ambient temperature which consequently created difficulties with grout penetration into the RCC.

There is a definite need to carry out further investigations into strength enhancement, especially for use in spillway facings. Silica fume needs to be more closely investigated, especially when used with a high fly ash content RCC (50% fly ash was used at Kinta dam) and in conjunction with a superplasticiser.

Construction Procedure

Assuming the immersion vibrators have been determined to be acceptable for producing a homogenous GERCC mass, quality control of the final product relies to a great extent on the diligence of workmen operating the vibrators. The limits of grout incorporated into the RCC cannot be verified, except at the horizontal surface.

Once forms are stripped, it will provide the inspector or engineer with a good idea of the appearance of the GERCC face and to what extent repairs are required. If the resulting face is unacceptable, mixture proportions and the construction procedure needs to be evaluated and revised until the specified and desired results are obtained.

Air Entrainment

While all efforts to produce a GERCC with sufficient entrained air for increased freeze-thaw resistance have not been successful to date, future investigations may produce better results.

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