Blalock Dam and Reservoir Improvement Works

R A N HUGHES, MWH, UK
R D BOYCE, Black & Veatch Corporation, USA
R R OSBORNE, Black & Veatch Corporation, USA
C E JACKSON, Spartanburg Water System, USA
R RHODES, Spartanburg Water System, USA

SYNOPSIS. The H. Taylor Blalock Reservoir is a water supply reservoir in South Carolina, USA. The reservoir is owned and operated by Spartanburg Water System (SWS) and provides vital storage to their water network which supplies over 180,000 people in Spartanburg County.

Shortly after construction was completed in 1983, the Dams and Reservoir Safety Division of the South Carolina Department of Health and Environmental Control (SCDHEC) reclassified the dam's hazard potential from 'significant' to 'high' hazard. The reclassification increased the design flood from half the Probable Maximum Flood (PMF) to the full PMF.

In addition to upgrading the dam and spillway to pass the design flood, SWS carried out construction works to raise the reservoir full supply level (FSL) by 3m to meet future water supply requirements. This paper describes the project and provides information on the Roller Compacted Concrete (RCC) used in the works.

BACKGROUND

Blalock Reservoir is one of three water supply reservoirs owned and operated by SWS. The reservoir was formed in 1983 by the construction of a homogenous earthfill dam across the Pacolet River near Spartanburg, South Carolina. The dam is 216m long and about 21m high with an 82.3m long spillway at its western end. An aerial view of the original dam is shown in Figure 1.

The original reservoir design was for a FSL of EL 216.41m but during construction of the dam SWS decided to carry out a phased approach. The dam was constructed to the original design levels apart from the spillway crest. In order to defer the cost of installing permanent spillway gates to

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maintain the design operating pool at the design FSL, a fixed ogee spillway crest was constructed to EL 210.92m and 2.44m high flashboards installed to raise the FSL to an interim level at EL 213.36m.

Figure 1. Blalock Dam prior to the Improvement Project

SWS contracted Black & Veatch Corporation in 1995 to design and oversee construction of improvement works to the dam and reservoir. The project brief comprised:

- Raise the FSL by 3.05m to the original design level to meet future water supply needs.
- Satisfy the SCDHEC requirements following reclassification of the dam.
- Provide long-term, reliable spillway chute operation.
- Provide positive outlet control.
- Provide vehicular access across the dam.

Raising the FSL by 3.05m increased the reservoir volume by 70% to 27.4 Mm^3 and its surface area by 28% to 395 ha.

IMPROVEMENT WORKS

Raise the FSL

Raising the FSL involved the reconstruction of the spillway crest. The original weir and flashboards were demolished and the formation excavated to bedrock. The maximum excavation depth below the original crest level was 6.8m which was at the left abutment of the spillway.

Figure 2 shows a section through the raised spillway crest. The new weir consists of a RCC core with a reinforced concrete overlay on its crest and downstream face.

Precast concrete panels define the upstream face and incorporate an integral high-density polyethylene (HDPE) membrane on their downstream face. After the panels were placed in their final location the continuity of the watertight barrier was achieved by welding HDPE strips onto the membrane which spanned the joints.

The panels are tied to the RCC core by 1.2 m long rods connected to the panel by threaded inserts. The rods were encapsulated in RCC as placement progressed to create the connection between the panels and the RCC. The panels were cast at a specialist precast yard in Spartanburg and delivered to site once they had achieved sufficient strength for handling.

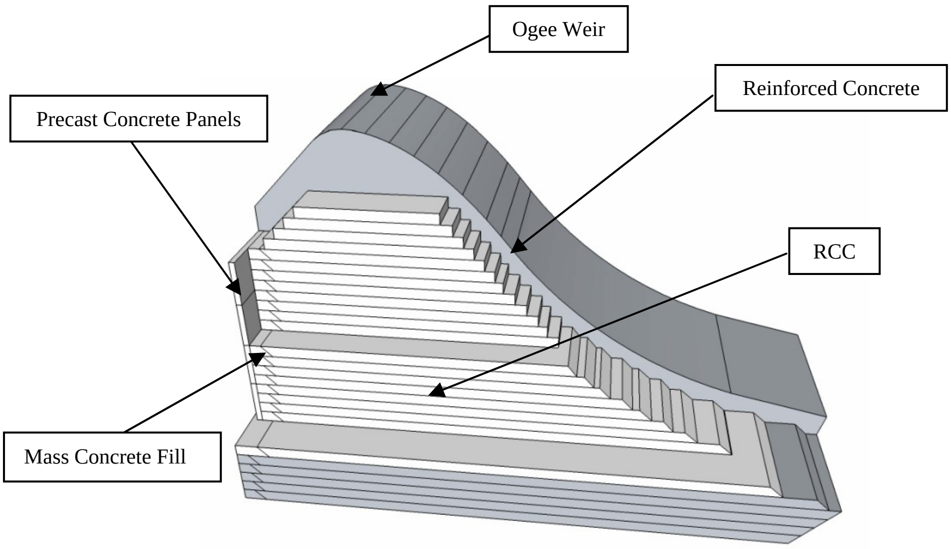

Figure 2. Cross section of raised spillway crest

Due to the irregular profile of the bedrock excavation mass concrete was used to fill the deepest sections until there was sufficient working space for the RCC placement equipment. RCC was placed and compacted in 300mm thick layers and mass concrete used to fill between the RCC and the precast panels and existing spillway walls.

Steel forms were used to create the profile of the ogee crest and downstream face. The complex shape and limited space beneath the forms would have made it difficult to achieve a satisfactory finish to the surface using conventional concrete. This was overcome by the use of self-consolidating concrete (SCC) which eliminated the need for compaction and vibration of the concrete during placement. Prior to its use in the permanent works, on-site trials were carried out to demonstrate its suitability. Concrete cylinders were also taken to determine the strength gain properties of the SCC.

Satisfy SCDHEC requirements

The reclassification of the dam increased the design flood inflow to 8,700m³/s. The PMF outflow is approximately 5,900m³/s.

During the design stage it was determined that modifying the existing spillway to safely pass the PMF was uneconomical. SCDHEC required that the spillway was designed to safely convey the outflow from a 500-year return period flood without overtopping the embankment. The outflow from a 500-year flood was calculated to be about 860m³/s.

The new spillway crest is split into seven bays by bridge support piers. Four of the bays are fixed crest ogee weirs at EL 216.56m. The remaining three bays contain hydraulically operated pelican type hinged crest gates which are used for low flow control, trash sluicing, and additional flow capacity for passage of the 500-year event. Each gate is 10.7m long and 1.67m tall and is designed to be automatically adjusted to maintain the reservoir surface at FSL at low and normal flow conditions. During periods of higher flows the gates are designed to be gradually lowered to a sill level of EL 214.73m.

During the PMF event, the flood level peaks at EL 224.94m which is about 4.6m above the embankment crest. To enable the embankment dam to withstand overtopping the dam was armoured with RCC. Figure 3 is a cross section through the armoured embankment.

The RCC has a nominal thickness of 900mm on the embankment crest and downstream face and has a stepped profile to aid energy dissipation. At the downstream toe, a stilling basin dissipates energy before the flow re-enters the Pacolet River.

On the downstream face there are 300mm thick layers of coarse and fine filter stone beneath the RCC armouring. Perforated longitudinal drains within the coarse filter at the toe and at the mid-height of the dam direct any water into the stilling basin.

The upstream face of the dam is also armoured with RCC above EL 215.2m. This was placed with a nominal thickness of 600mm onto the embankment and the existing upstream riprap armament extended to overlap the RCC.

At the left abutment, an earth embankment was constructed with a crest level 300mm above the PMF stillwater flood level. The embankment will ensure that water overtopping the embankment will only occur on the RCC armoured portions. The embankment is approximately 100m long and was constructed of material removed from the upstream face of the dam for placement of RCC.

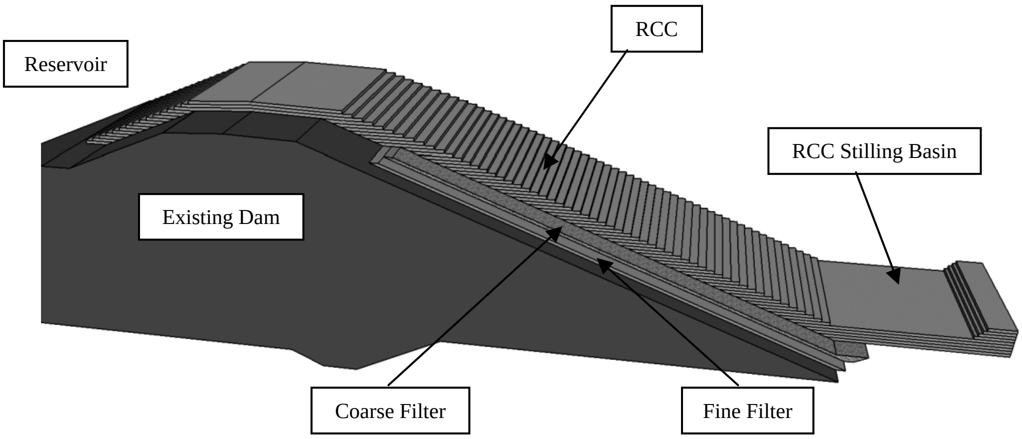

Figure 3. Cross section of armoured embankment

Provide long-term, reliable spillway chute operation

The spillway chute is about 82.3m wide and 40m long and consists of 55 reinforced concrete panels, nominally 150mm thick. The chute has a slope of about 1V:2H with a 300mm thick underdrainage layer that incorporates a vitrified clay pipe drain system. The chute is connected to a USBR Type III stilling basin which is submerged by the water retained in the turning pool immediately downstream. The turning pool outlet returns the flow back to the Pacolet River.

A section of the spillway chute was undermined and damaged during a high river flow event in 1995. A review of the spillway chute design identified pressure fluctuations caused by a hydraulic jump occurring where the spillway chute flow enters the stilling basin as the cause of the damage.

The damage raised concerns about the ability of the chute to withstand future high river flows. It was determined that the most economical way to repair the damage and to ensure long-term, reliable spillway operation was to overlay the existing chute with a reinforced concrete slab anchored into the underlying rock.

The spillway chute overlay works consists of a 380mm thick reinforced concrete slab, constructed in panels to the same dimensions as the original chute. The overlay is designed to withstand differential hydrostatic pressures for flows up to the PMF flood. Uplift forces are resisted by anchors grouted into sound rock. Damaged baffle blocks at the bottom of the spillway chute were repaired and all chute blocks are integrated into the new overlay system.

The anchor arrangement consists of: (1) a 250mm diameter steel casing from the original slab level that was driven into the underlying bedrock, and (2) a 25mm diameter rock anchor grouted in a 100mm diameter hole drilled a minimum 5.5m into sound rock. Over 750 rock anchors were installed into the bedrock, with an average anchor length 7.9m.

The casings serve two purposes: (1) they contain the grout preventing contamination of the underdrainage layer, and (2) they act as mini piles to support the overlay slab in the event of loss of material from beneath the existing chute floor.

During the drilling of the rock anchor holes, voids were discovered beneath the existing chute slabs. Where the cores for the steel casings indicated the presence of voids, additional 100mm cores were drilled to determine the size of the void. The voids varied in depth to a maximum of 760mm.

Although the design of the new chute overlay panels could accommodate voids, it was decided that any voids discovered were to be filled with flowable fill. The flowable fill mixture was pumped into the void at low pressure to minimize infiltration into the underdrains.

<u>Positive outlet control</u>

The provision of positive outlet control was accomplished in two phases. In the first phase, carried out between 1998 and 2000, the requirements for providing positive outlet control were addressed. The second phase provided a means to isolate the outlet for maintenance.

The original outlet works was a 141m long, 3.65m by 3.65m concrete conduit under the dam. Flow control was achieved by a 2.74m butterfly valve at its upstream end and by a 1.52m butterfly valve within a wet well that supplied the raw water to the treatment works

Phase 1

Positive outlet control was required because of concerns with the reliability of using the control valve to provide minimum flow releases and bypass flows during construction of the new spillway.

The works involved the installation of a 3.05m diameter steel pipe within the conduit and encased in cellular concrete. The wet well bypass was connected to the pipe by means of a Y connection. A 2.0m diameter fixedcone valve (Howell-Bunger) was installed at the downstream end for flow control.

Phase 2
Following completion of the Phase 1 works, the 2.74m isolation butterfly valve became inoperable. To regain the full hydraulic capacity of the outlet tunnel a 2.75m by 2.75m sluice gate was installed at the entrance to the tunnel. The works involved the removal of the existing thimble and section of original liner and its replacement with a new section of liner and thimble.

The sluice gate is operated by an actuator located on a platform about 17m above the tunnel centreline. A 115mm diameter spindle made up of four lengths connects the sluice gate to the actuator. Figure 4 shows the installation of the sluice gate and thimble.

Figure 4. Thimble and Sluice Gate Installation

Installation of the sluice gate required the dewatering of the approach channel to the intake structure. The channel is approximately 8m wide and about 12.8m deep. A temporary cofferdam comprising a sheet pile wall supported by rock and gravel shoulders was installed at the upstream end of the channel. Continuous dewatering by two 300mm diameter pumps was required to remove water that entered the working area through the cofferdam. Upon completion of the work the sheet pile wall was extracted and the shoulder material dredged out of the channel.

<u>Provide vehicular access across the dam.</u>
The existing dam did not have provision for vehicular access onto the embankment from the right (west) abutment. In order to access the embankment a 10km journey was needed along the busy US Route 221 highway, a narrow access track and a railway crossing.

The new spillway crest includes a seven span precast concrete beam bridge above the crest supported on reinforced concrete piers. In addition to providing access to the embankment, the bridge also serves as access to the crest gates for maintenance and for raising and lowering stoplogs upstream of the gates.

The bridge is 3.66m wide above the fixed crest spillway and increases to 7.32m wide above the three bays incorporating gates. This provides access for a mobile crane for gate maintenance and handling of stoplogs.

Figure 5. Finished Bridge and Spillway

Clearing

Raising the reservoir water level 3.05m resulted in the inundation of an additional 88 hectares. The reservoir perimeter is densely wooded and a significant clearing operation was carried out as part of the project.

The majority of the clearing operation was carried out manually due to the topography. Removing the trunks of the felled trees was carried out mechanically and the remaining debris collected and burned in a controlled and managed manner within the reservoir basin.

ROLLER COMPACTED CONCRETE

Mix designs

In advance of the tender process several mix designs were prepared to provide guidance on likely mix proportions for the project. Experience on another nearby RCC dam had provided useful information on suitable mix proportions. The mix designs used crusher-run aggregates produced from two local quarries which were blended with other aggregates in order to establish the optimum content of cementitious material.

Two mix designs were specified for the project. The Gravity mix was used for the new spillway crest and the Armouring mix was used to overlay the embankment dam. The final mix proportions are summarized in Table 1.

Table 1 - RCC mix proportions

	Gravity	Armouring
Design strength @ 28 days (N/mm^2)	10	17
Water cement ratio	0.70	0.56
Aggregate (kg/m^3)	2028	1854
Cement (kg/m^3)	182	295
Fly ash (kg/m^3)	60	59
Practical max density (kg/m^3)	2500	2510

The final proportions for the Gravity mix were designed and verified in a materials laboratory. To maintain progress on the project, the contractor decided to forego the laboratory testing stage for the Armouring mix at his own risk. Based on the results of the Gravity mix tests the contractor prepared a mix which was tested as part of the RCC test pad.

<u>Production</u>

A continuous flow pugmill was used to produce the RCC on site. The manufacturers quoted maximum production rate was 150m^3/hr but due to restrictions with water supply to the site, actual production was about 75m^3/hr. The integral 50t silo was used to store cement and an auxiliary 50t silo was used for fly ash storage. Two pneumatic bulk storage trailers each with a capacity of about 80t provided additional fly ash and cement storage.

All aggregate was imported from the Vulcan Materials Blacksburg Quarry about 56km from the site. Aggregate was stockpiled adjacent to the pugmill which commenced during the cooler months in order to keep the stockpile temperature low and thus the temperature of the RCC. During the hotter months, the surface of the stockpile was moved at the start of RCC production allowing the cooler material from inside the stockpile to be used.

A total of 30,000m^3 of the armouring mix was placed in the permanent works and about 4,300m^3 of RCC was placed in the new spillway crest. This required over 3,300 deliveries of aggregate.

Transportation and placement

Placement of the RCC was predominantly by a Rotec Creter Crane; a smaller unit was used to place material where the Creter Crane could not navigate. Figure 6 shows the Creter Crane in operation.

When RCC placement was near to the pugmill, a conveyor system was used to transport the RCC to the Creter Crane. Elsewhere dump trucks were used to transport the RCC to a feed conveyor which supplied the Creter Crane.

Figure 6. Placement of RCC armouring to embankment dam

Spreading the RCC to the required thickness was carried out by a bulldozer and then compacted using a vibratory roller. A smaller double drum vibratory roller was used in tighter spaces for compaction. On the embankment crest the final layer was placed by a paver in order to achieve tighter tolerances on the finished surface.

The vertical faces of the RCC steps were created using 300mm high steel forms that were held in place by steel pins driven into the RCC below. The forms were removed upon completion of a layer and reused.

Adequate compaction of the RCC against the forms was vital in ensuring a high quality appearance. Initially the contractor placed a 300mm layer against the form which was compacted using a vibrating plate compactor. Removal of the forms showed that the face had received minimal compaction resulting in a poor surface finish. The placement and compaction process was subsequently refined by using a trench rammer to compact the RCC which was placed against the forms in two 150mm thick layers.

Specification requirements

Temperature
RCC production was only permitted when the temperature of the material at placement was less than 24°C for the Gravity mix and 29°C for the Armouring mix. When the ambient temperature fell below 1.5°C, placement was stopped.

RCC placement commenced on 22 March 2005 and was carried out during daylight hours. By 23 May 2005, the daytime ambient temperature had risen such that the temperature of the RCC mixture at placement exceeded the specification. To avoid the need for expensive cooling measures, the contractor decided to place at night thereafter.

Joints
The RCC was placed and compacted in 300mm layers and placement was continuous unless a cold joint had formed. Where more than 12 hours had elapsed since placement of the last layer, a layer of grout was placed onto the surface before placement of the next RCC layer. When more than 48 hours had elapsed, the surface of the RCC was cleaned by high pressure jetting before the grout layer was placed.

Placement time
RCC had to be placed and compacted no later than 45 minutes after water was added to the material at the pugmill. The use of the conveyor or Creter Crane meant that this requirement was easily achieved. In the event of a problem the system could be stopped until the issue was resolved thereby minimizing the amount of wasted RCC.

When trucks were used to transport the RCC, production goals meant that there were several trucks waiting in line to feed the Creter Crane. This increased the volume of RCC at risk of wastage in the event of a problem resulting in the time limit being exceeded.

Curing
Following placement, any RCC which was not covered by another RCC layer was kept moist for 14 days. A sprinkler system was used by the contractor which had varying success. This posed significant challenges for the embankment armouring due to the area to be kept moist.

Testing
S&ME, a specialist materials testing company, was employed by SWS to carry out materials testing during construction. For the RCC, the site testing

consisted of moisture content and density measurement at placement. A nuclear density gauge was used to measure density.

Test cylinders were prepared for every 1500m³ of RCC placed. Four 150mm diameter cylinders were made at site and were tested off site in the S&ME laboratory. Three cylinders were tested: at 7, 14 and 28 days, with the final cylinder retained for testing in the event of unexpected strength results.

In addition to the cylinders, 41 cores up to 900mm long were taken from the gravity and armouring mixes to determine the strength of the placed RCC. The locations of the cores were chosen to provide a broad sample. The site records were used to ensure the cores were extracted from RCC that was younger than 28 days so as to enable a direct comparison with the cylinders results.

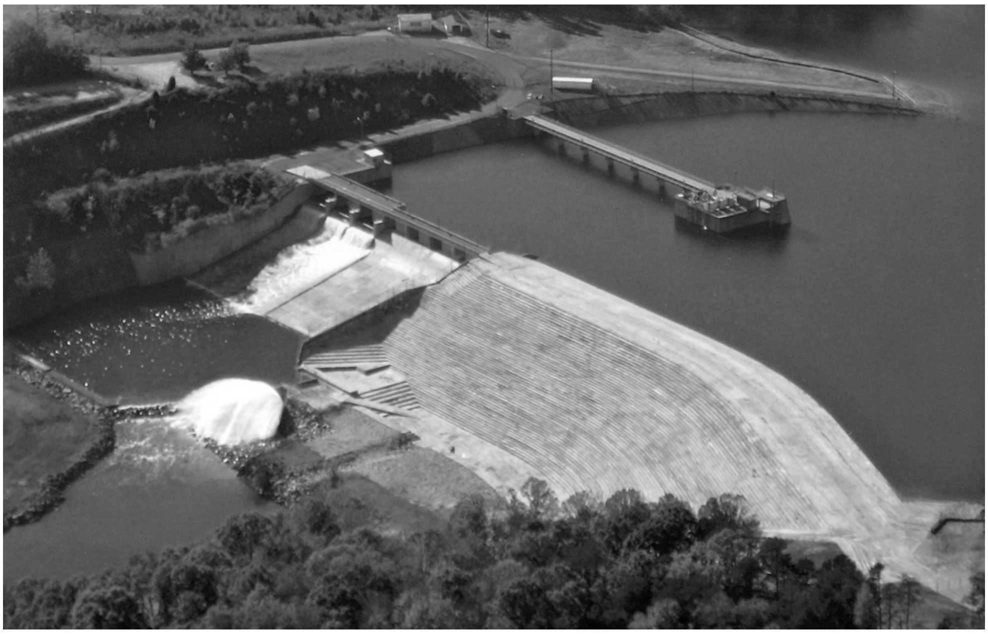

Figure 7. Finished Project

CONTRACT

The US$12.1 Million contract was awarded to Thalle Construction of Hillsborough, North Carolina. Construction started in August 2004 and was successfully completed in October 2006. The enlarged reservoir was an important asset during the droughts of 2007 and 2008 and will serve the needs of SWS for many years to come.