Hickory Log Creek: Building a Roller-Compacted-Concrete Dam

To overcome site constraints and to meet a tight timeline for completing its new Hickory Log Creek Dam, the Cobb County-Marietta Water Authority and the city of Canton, Ga., chose to build a roller-compacted-concrete structure. Construction of the dam, completed in November 2007, taught several valuable lessons about the use of RCC.

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Construction of Hickory Log Creek Dam on Hickory Log Creek, a tributary of the Etowah River in Georgia, was completed in November 2007. Hickory Log Creek Dam is the highest roller-compacted-concrete (RCC) dam in Georgia and the fourth highest in North America. The dam is 180 feet high and 956 feet long. The need for this dam was initially identified in a 1996 study, to increase water available for the growing area northeast of Atlanta.

Before the dam could be built, Cobb County-Marietta Water Authority and the city of Canton, Ga., needed to determine whether to build an earthfill or RCC dam. Site restrictions, costs, and schedule led to the selection of an RCC dam. This option would save about $4 million and one construction season compared with building an earthfill dam.

Impoundment of the reservoir behind Hickory Log Creek Dam began in November 2007. When this process is completed in one to two years, the reservoir will provide 44 million gallons of water a day for the city of Canton and the wholesale customers of the water authority. Lessons learned from the construction of this dam could help others who are designing and building RCC dams.

Why the dam was needed

Significant population growth in the northeast area of Atlanta resulted in growing demand for water in the region. To meet this demand, the Cobb County-Marietta Water Authority and the city of Canton started the planning process for a new water supply reservoir.

The site chosen for the proposed Hickory Log Creek Dam is near an 8.5-acre lake on Hickory Log Creek that was part of the Canton Mills Lake manufacturing plant along the Etowah River. The Canton Mills heirs donated 300 acres in the area where the Hickory Log Creek Reservoir would be located.

The reservoir needed to yield 44 million gallons of water per day. Using this yield, the dam developers established the final dam site and the normal pool elevation. Inflows into the resulting 411-acre Hickory Log Creek Reservoir are supplemented by a pumping station located about 7,000 feet below the dam on the Etowah River. This station pumps water from the Etowah River when inflow from Hickory Log Creek is insufficient to fill the reservoir. Once the reservoir is filled initially, the pump station will only be used to replenish the water in the reservoir that is released during drought conditions.

Choosing the type of dam to build

Early planning studies by Schnabel Engineering, including subsurface exploration performed in November and December 2004, indicated that both earthfill and RCC dams were viable options for the site. Because the type of dam built would not affect the yield of water, the selection would be based on cost and schedule.

In September 2004, the dam owners chose a design team consisting of Brown and Caldwell and Schnabel. Schnabel's tasks included performing an alternative analysis to recommend the appropriate dam type and to design the selected dam. Design tasks performed by Brown and Caldwell included designing the pump station and the associated 42-inch-diameter pipeline.

The key parameters considered during the alternative analysis were associated with: spillway type and size, material availability, schedule, and project cost.

Due to property constraints, the difference between the normal pool and flood pool elevations was only 10 feet. This required construction of a large spillway to pass the probable maximum flood (PMF). The size of the spillway was an important factor in selecting an appropriate dam type.

The design storm used for the project was the probable maximum precipitation (PMP). Over the 8.2-square-mile drainage basin, this produced an inflow of nearly 64,000 cubic feet per second (cfs) during a hypothetical six-hour storm.

The earthfill dam option considered contained a 170-foot-high inlet/outlet tower with a large-diameter pipe through the base of the dam. This tower

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A concrete cutoff wall was built at both ends of the abutments of Hickory Log Creek Dam to provide seepage control.

would serve as the principal spillway, passing all flows up to the 100-year event. An earthen emergency spillway would be located off the right abutment. This spillway would require a crest width of 600 feet. More than 25 acres of additional land would have to be acquired to accommodate the emergency spillway. For the RCC option, no emergency spillway would be required that was separate from the dam.

For both dam types, material availability was a concern. Most of the site consisted of weathered mica schist. The ridge tops had partially weathered rock just below the ground surface. This material broke down to lightweight micaeous sandy silt.

For an earthfill dam, no suitable core material was located within the limits of the dam or reservoir. As a result, the more than 200,000 cubic yards of core material would have to come from off site. In addition, about 1.2 million cubic yards of shell material would have to be collected from within the reservoir area, with care taken to prevent the creation of unstable slopes in the reservoir. This would mean that haul distances would exceed 4 miles, and some land above normal pool would have to be purchased to acquire all the fill material.

With regard to the aggregate needed to build an RCC dam, the hot construction market in the Atlanta area created a shortage of No. 57 stone. Consequently, the design team decided to base the RCC mix proportion plan on using a graded aggregate base material, supplemented with 15 to 20 percent of No. 4 stone. Historically, projects that used a single aggregate stockpile experienced problems with segregation. In addition, if cooling of the RCC was required, the options were limited when the fine and coarse aggregate were combined.

Another concern was the project schedule. The city of Canton had an ambitious goal of completing the project by the fall of 2007. It would have been difficult to construct a 180-foot high earthfill dam on this schedule, due to the normal yearly rainfall of more than 52 inches. Placement of large quantities of earthfill during the wet winter months typically would have been impossible.

However, designers determined an RCC dam could meet that schedule, if the project could be separated into two construction phases. Separating the project into two phases would result in filling of the reservoir at least six months earlier than single-phased dam construction.

The Phase I contract for Hickory Log Creek Dam would consist of foundation excavation and treatment; infrastructure improvements such as construction of roads, bridges, and staging areas; and erosion and sediment controls.

The Phase II design work, consisting of the dam and ancillary facilities, would take place while the Phase I construction was under way. The design and construction schedule had RCC placement occurring between January and May 2007. This timeline would avoid the additional cost associated with forced cooling of the RCC, which would be required if RCC was placed in warmer months.

Finally, cost was an issue. Overall, Schnabel determined that the RCC option would cost about $4 million less than the earthfill option. The higher cost for the earthfill dam was due primarily to the cost of acquiring additional land and at least another six months of construction time.

Developing a design for the RCC dam

Work on the design for Hickory Log Creek Dam began in late 2004. To obtain more detailed subsurface information, such as rock strength parameters, the developers hired QORE Property Sciences of Atlanta to perform a second subsurface exploration in the first quarter of 2005. The results confirmed that the conditions assumed during the alternatives analysis were true and allowed determination of the foundation excavation limits.

In late 2004, the 8.2-square-mile drainage basin was predominantly wooded. However, real estate trends in the metro Atlanta area at the time indicated likely heavy commercial and residential development in this basin over the next 20 to 30 years. Georgia Safe Dams Program guidelines require that any new construction or rehabilitation of dams in the state requires evaluation of future land use during the hydrology and hydraulic study. Schnabel performed this study during the same time frame as the alternative analysis.

Estimated PMP for this drainage basin is 30.3 inches during a hypothetical six-hour storm event. Based on this information, estimated inflow into the reservoir is nearly 64,000 cfs. With a maximum dam freeboard of 10 feet, designers determined a 250-foot-wide spillway crest was required to safely pass the design storm. Schnabel designed a 110-foot-long gated spillway section, centered within the 250-foot spillway width. The 250-foot-wide spillway section has two bridge piers located on either end of the gated spillway section. The 110-foot-long gated spillway section consists of a 6-foot-high crest gate from Obermeyer. When this gate is fully lowered, this spillway section can pass 16 feet of reservoir head.

The dam site contained a very narrow valley with steep abutments. The floodplain limited the width of the stilling basin to only 130 feet. This resulted in the 250-foot-long spillway crest transitioning to a 130-foot-wide stilling basin. The design team performed a literature search to identify hydraulic model studies performed on converging spillways that would match the design configuration for Hickory Log Creek Dam. The search identified model studies performed on converging spillways up to 15 degrees, but this spillway would have a converging angle of 25 degrees. The designers contracted the Utah Water

Different sized dozers were used to spread the roller-compacted concrete for Hickory Log Creek Dam. The equipment featured a laser-guided system to obtain a level surface.

Research Laboratory at Utah State University in Logan to perform a physical model study of the proposed spillway system.

The empirical design from Schnabel indicated the length of the stilling basin should be 130 feet. However, velocities in the stilling basin measured during the physical model study indicated the stilling basin could be shortened to 80 feet. This is reflected in the final design. Results from the physical model study also indicated that the 250-foot-long spillway and 130-foot-wide stilling basin could safely pass the design storm.

The intake system designed for the dam consists of a 72-inch-diameter horizontal steel pipe at the base of the dam. Near the front face of the dam, a 42-inch-diameter steel tee protrudes vertically from the larger pipe. Three reservoir intakes at different elevations attach to the vertical pipe.

The dam design also incorporated a seepage control and collection system. The first line of the seepage control system was a double row grout curtain. The grout curtain was constructed using a real-time monitoring system to evaluate changes in the foundation and to make rapid engineering decisions regarding grout mix design, the need for secondary holes, and downhole grout pressures.

A drainage gallery with foundation drains was designed to reduce uplift pressure on the base of the dam. The foundation drains range from 25 to 30 feet deep on 20-foot centers. The center of the drainage gallery is 18 feet downstream of the dam baseline, and the gallery extends up about two-thirds of the height of the dam on both abutment faces. The seepage collection system beneath the portion of the dam founded on partially weathered rock consists of a sand and gravel trench drain discharging to the drainage gallery. All of the flows collected in the drainage gallery discharge into the stilling basin.

The dam designers specified the characteristics of the RCC to be used to build Hickory Log Creek Dam. The RCC would have a 180-day compressive strength of 2,000 pounds per square inch (psi). The RCC mix design program incorporated a total cementitious quantity of 300 pounds per cubic yard (pcy) of cement and flyash. Because of the limited time from completion of the design to the beginning of construction, a conservative RCC lift maturity of 500 degree-hours was used to define a lift cold joint for this project.

Prefabricated panels covered with a synthetic geomembrane liner were used to waterproof the upstream face of Hickory Log Creek Dam.

In addition to undergoing review by a Schnabel internal review panel, the design work was reviewed at significant milestones by the Georgia Safe Dams Program. The design team used design review workshops to keep all stakeholders informed of the design progress and results. The state was very involved because this was the highest dam it had permitted since the program's inception in 1978.

The construction documents contained two types of RCC cold joints. The first cold joint was declared when the ambient air temperature exceeded 500 degree-hours. At this point, the entire RCC surface had to be covered with a bedding mix just before placing the next lift of RCC. The second type of cold joint was declared when 36 hours elapsed between RCC lift placements. When this second type of cold joint occurred, the entire lift had to be washed with high-pressure air/water jets and the entire RCC surface had to be bedded just before placing the next lift of RCC.

Waterproofing of the upstream face of the dam was achieved using synthetic geomembrane-lined prefabricated panels. This membrane system was selected because of the nature of the "soft" rock of the dam foundation. Some stress redistribution within the RCC mass could be expected, and a crack between monolith joints could not be ruled out. The membrane liner would prevent water from entering the body of the dam if a crack did develop.

Building the dam

Work was performed in two phases to shorten the timeline for completion.

Phase I

For this phase, bids from five contractors were received in September 2005, ranging from \$5.1 million to more than \$9 million. In October 2005, Thalle Construction Inc. was awarded the contract for the Phase I work, to be completed within 270 calendar days. The major tasks in the Phase I contract consisted of the foundation excavation, abutment blanket construction, temporary stream diversion, concrete cutoff wall construction, and grouting program.

Foundation excavation, which began in January 2006, included the removal of about 170,000 cubic yards of soil and rock. Some of the finer-grained soils removed adjacent to the floodplain area were spoiled in a controlled fashion against a large, exposed rock face upstream of the right abutment. This "soil

The downstream steps of Hickory Log Creek Dam were formed using grout-enriched roller-compacted concrete (RCC), which provides an improved appearance over typical exposed RCC.

blanket" serves to reduce seepage beneath the right abutment. Thalle completed the mass excavation by late February 2006 and began blasting within the rock foundation in early March 2006. Blasting operations were completed by July 2006.

Construction of a concrete cutoff wall was necessary at the very ends of the abutment sections, which were founded on partially weathered rock. The rock contained numerous seams of fine-grained material that would limit installation of a grout curtain in this area. Therefore, Thalle constructed a 20-foot-deep, 3-foot-wide concrete cutoff wall in these locations.

The grouting program was designed with the assistance of Dr. Donald Bruce with Geosystems L.P. The program consisted of a double row grout curtain with primary holes located at 20-foot centers. The depth of the grout curtain was generally 25 feet in the floodplain area where the freshest rock was observed. The grout curtain extended anywhere from 35 to 80 feet deep within the abutment areas. Subcontractor Nicholson Construction Company conducted the grouting, which began in late June 2006 and was finished by mid-October 2006.

The procedure for the grouting program involved: drilling of each grout hole, water pressure testing of each stage within the grout hole, and then grouting of each stage in the grout hole, if required. The water pressure testing results and grouting test results were monitored in real-time using Nicholson's Spice Program. Performing water pressure testing of each stage gave the contractor and engineer an opportunity to predict or anticipate whether or not the stage would take grout.

Phase II

With a low bid of $36.5 million, Thalle was awarded the Phase II contract in August 2007. ASI Constructors, a subcontractor to Thalle, mixed and placed the RCC; set the upstream precast panels; set the downstream step forms; placed the abutment contact concrete and spillway facing concrete; and welded the geomembrane liner.

RCC was produced using a Johnson-Ross portable batch type plant and a HyDam 4500D mixer from IHI Construction Machinery Limited. This batch plant was configured to sustain a production rate of 800 tons of RCC per hour. The batch plant and mixer were computer controlled using a computerized batching system from Command Alcon Corp.

RCC was delivered from the batch plant to the dam conveyor belts supplied by Rotec Industries. RCC was delivered to different locations of the dam using a conveyor tripper and a 60-foot-long swinging conveyor from Rotec. The conveyor system was supported using a pea gravel jack post system, which consisted of 12 jacking posts spaced about 100 feet apart along the length of the dam. Each post was filled with pea gravel, which served as foundation for the post once the conveyor was raised. The conveyor system was raised every other day, using a hydraulic jacking frame after the RCC was placed.

Once delivered to the dam, the RCC mix was spread in 1-foot lifts using three different types of dozers, depending on the space circumstances. A small D21 dozer from Komatsu was used in areas around the gallery, on the upstream side where space was constrained. In the main section of the dam where space did not present problems, a large 850J dozer from John Deere was used to spread the RCC. This dozer had a special large blade that allowed the RCC top to be pushed without causing segregation. A mid-size D5 dozer from Caterpillar was used to help spread the RCC on the upstream and downstream sides of the lift. The D5 was also used to finish grade the RCC lift. All equipment used to spread the RCC was equipped with a laser-guided system to obtain a level surface.

Compaction of the RCC was achieved using double (DD-130) and single (SD-100) smooth steel drum rollers from Ingersoll Rand. To achieve the specified density, normally four passes with the double drum roller were required. The areas adjacent to the upstream and downstream sections of the dam were compacted using a smaller DD-24 double roller from Ingersoll Rand. Areas where access was difficult or restrained typically were compacted using plate tampers and jumping jacks made by different manufacturers.

Thalle used a Low Flow Pro C10 dry batch type concrete plant from Coneco Equipment to produce the structural concrete, mortar mix, and self-consolidating concrete used for the ancillary structures. The dry batch plant produced about 9,000 cubic yards (4,500 cubic meters) of conventional concrete and 1,500 cubic yards of bedding mortar. Self-consolidated concrete was produced from this plant as structural concrete for the spillway training walls.

RCC placement started in mid-December 2006 and was completed in early June 2007. Placement was typically done during the cool hours of the day during the winter, followed by a night shift placement. During late spring and early summer, RCC placement was performed during the night only.

Cold joints were cleaned by air blowing the surface using 375-CFM air compressors from Ingersoll Rand and small high-volume backpack blowers. The high-volume pressurized air was used to remove loose debris, rocks, and laitance on the surface. Air blowing was done when joint maturity was less than 500 degrees Fahrenheit (F)-hours.

Pressure washing the lift was performed using a 20203D-78 pressure washer from NLB Corporation. This procedure was done on a cold joint surface with more than 500 degrees F-hours, or a surface that did not receive RCC during 36 hours after the lift was compacted. Excess water on the surface was removed using two vacuum trucks. Continuous water curing of the surface was done after cleaning until the next RCC lift was started.

Foundation drains, piezometers, and inclinometers supplied by Geocomp were drilled and installed during the gallery construction. Instrumentation consisted of more than 50 thermistors, 18 piezometers, four inclinometers, and four observation wells. Several permanent surveying monuments will be installed inside the gallery and at top of the dam for continuous monitoring.

All concrete prefabricated panels used for the vertical upstream face and downstream chimney section were fabricated on-site. Thalle built five concrete casing beds to produce the different sizes of panels. A total of 2,000 full-size panels (6 feet by 16.5 feet) and 500 half-size/special size panels were fabricated.

The panels on the upstream face of the dam were waterproofed using a flexible CARPI 40 mil synthetic geomembrane from Carpi. Installation of the geomembrane was accomplished using the Winchester System, which involves embedding the material on the back of the prefabricated facing panels. Also, the upstream prefabricated panels served as formwork against which the RCC was placed. Prefabricated panels were aligned and installed such that the panel joints would not cross a contraction joint on the upstream face. The liner would extend across the contraction joints between the panels to prevent water from seeping along the contraction joints.

The panels on the downstream side of the chimney section do not have a waterproofing synthetic liner. A decorative stone face was used on the exposed downstream panels to assimilate the structure with its natural surroundings.

Wood forms were used to form the 3-foot-high downstream steps for both the overflow and non-overflow sections of the downstream side of the dam. Grout-enriched RCC was used to give the exposed downstream steps of the dam an improved appearance over typical exposed RCC. This was the first use of grout-enriched RCC on a dam in North America where the material is exposed.

A total of 218,000 cubic yards of RCC were placed in 117 days at Hickory Log Creek Dam. Reservoir filling began in November 2007 and should be completed within 18 months. Total cost of the project was $41.5 million.

Lessons learned

When determining construction costs, it is critical to pay close attention to market conditions when the quantity of materials is large. The day before bids were due on the Phase I contract, fuel prices doubled and there were reports of shortages for the near future. During the post-bid opening briefing with the bidders, it was determined that the bidders added $200,000 to $300,000 at the last minute to cover the fuel increase. For Phase II, the contract documents included a clause that removed the risk of a fuel spike from the contractor.

It is recommended that a set retarder be specified for the RCC mix to extend the initial set of the RCC, unless it is assured that ambient weather conditions will keep the RCC mix temperature at 50 degrees F or less. It is beneficial to try to reduce the occasions where a bedding/bonding mix is required. Placing bedding mix requires dedicated labor, and too many times this labor is directed elsewhere on the project. Bedding mix tends to be placed too far out in front of the RCC, and it starts to dry out or vehicular traffic tracks through the bedding mix and create a mess on the lift surface.

Lastly, grout-enriched RCC was successfully used for the non-overflow downstream steps. A 1:1 grout mix was specified. It is recommended that a 0.8:1 (water to cement) ratio be specified to allow for a more cementitious paste at the surface. This would allow the surface to have a somewhat troweled appearance and minimize adverse slope that impounds water on the steps. ■

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