Design/Build Approach Big Success for Pine Brook RCC Dam

Del A. Shannon, P.E.[1], Black & Veatch Corporation
Jeff Allen, P.E.[2], E & C Services
Robert de Haas, Pine Brook Water District

For the first time, a formal design/build approach has been used to expedite the design and construction of a new dam in Colorado. This process began when Pine Brook Water District—a small water district serving only 400 customers, located two miles (3.2 km) northwest of Boulder, Colorado—sought to build a dam with an extremely aggressive schedule and budget.

A view looking at the upstream face of the dam during initial filling

The 400 customers of the Pine Brook Water Districts reside above the elevation to which the City of Boulder provides water service. For the last 10 years the Pine Brook Water District has suffered from severe drought conditions. The District's surface water source on Four Mile Creek has gone dry several times since 2002, with the most recent stint occurring in September 2006 and lasting nearly a month. Prior to construction of Pine Brook Dam, the District would have two to three weeks of water storage, creating extreme water restriction situations. With completion of the dam the District has a full year's water supply when the reservoir is full, with no water restrictions.

Because of aggressive schedule and budget constraints, the district determined that the design/build approach would be the most advantageous to complete this project. The district selected ASI Constructors, Inc. (contractor) and TCB, Inc. (engineer) to accomplish this project. Considerations included geotechnical aspects, flood hydrology, RCC mix design, dam layout, seepage cutoff and collection, outlet works, instrumentation, and aesthetics. By working as an integrated team the group was able to quickly address design issues and minimize costly studies and evaluation of multiple alternatives. Construction began only eight and a half months after initiation of the design process.

Dam Design

The new dam is a roller-compacted concrete (RCC) gravity structure approximately 86-feet-high (26.2 m) at its maximum section with a crest length of approximately 560 feet (170.7 m). The dam creates a 100 acre-foot (12.3 hectare-m) reservoir with a surface area of approximately 4 acres (1.6 hectares) and is designed to safely pass the inflow design flood (IDF) equal to the probable maximum flood (PMF) event. The structure includes an upstream parapet wall designed to concentrate the flow during the IDF to the central 290 feet (88.4 m) of the dam. This section is called the 'emergency spillway' section. Appurtenant structures include a service spillway

[1] Mr. Del Shannon was a senior project manager with TCB, Inc. prior to joining Black & Veatch

[2] Mr. Jeff Allen was president of ASI RCC, Inc. prior to starting E & C Services

riser structure with an uncontrolled-drop inlet and a conduit with an energy dissipater.

The RCC structure is founded on bedrock. A 10-foot (3.0-m)-wide key was built into the weathered bedrock below the base of the dam as a seepage cutoff. The depth of the key varied approximately from 5 feet (1.5 m) to 10 feet (3.0 m). The downstream face of the RCC is unformed RCC and the upstream face is air-entrained conventional concrete facing with specified compressive strength of 3,000 psi (20.7 MPa) at 28 days.

The non-overflow section consists of a vertical upstream face, a 3.83-foot (1.17-m)-high parapet wall, and a 0.75H:1V downstream face. The crest is 15 feet (4.6 m) wide. The emergency spillway section is similar to the non-overflow section except that the crest and top of parapet wall elevations are 2.5 feet (0.76 m) lower than the elevations at the non-overflow section. A 6-foot (1.8-m)-wide and 6-inch (150-mm)-deep low-flow notch was constructed in the emergency spillway to focus low flows through the spillway at one location so they can be more easily identified and handled.

Approximately six months after the initial filling of the dam in 2007, the downstream face of the dam will be covered by a soil cover with a slope of 2H:1V or flatter. The downstream soil cover was not incorporated into the structural design of the dam but was important for economic, environmental and aesthetic purposes.

No stilling basin for the emergency spillway was designed. Though turbulent flow conditions are expected at the dam toe, foundation erosion or undermining is not. Stability analyses demonstrated that the dam will be safe for the PMF event without the soil backfill.

The service spillway is a cast-in-place concrete drop inlet and riser structure founded on RCC and anchored to the upstream face of the dam. The outlet conduit discharges flood water through the RCC dam and downstream soil cover to an energy dissipation structure at the toe of the downstream soil cover. The service spillway can pass normal flows up to 500 cfs (14.2 m^3/sec). Higher flows will be passed over the emergency spillway.

The outlet works consist of one 12-inch (300-mm) outlet to provide emergency drawdown and two 6-inch (150-mm) diameter steel pipes with intakes located at different elevations to provide raw water flows to the new potable water treatment plant. An inlet screen is installed at each of the 6 inch (150 mm) intakes. The outlet works are encased in concrete through the dam and soil blanket. Only the 12-inch (300 mm) emergency outlet is operated from the upstream face. The 6-inch (150 mm) intakes are operated from below the toe of the dam by standard isolation valves and the flows are controlled with the water treatment plant also located immediately below the dam.

Service spillway uncontrolled drop inlet

The structure was designed to resist full hydrostatic uplift, so it was not necessary to install foundation drain holes to relieve uplift pressure. Seepage through the dam foundation will drain to the downstream side of the dam. After the soil embankment is placed on the downstream side of the dam, drainage will be collected through a drainage system. While all dam foundations have some level of seepage, excessive seepage can be a problem and can lead to failure. Modeling results predict that the seepage through the foundation of the Pine Brook Dam should be too minor to erode or damage the rock foundation or lead to dam failure. If actual seepage rates are larger than anticipated, and present a safety hazard or an operational concern, a grout curtain will be added.

Seepage control was provided by adequate lift bonding and minimizing cold joints between RCC lifts. Cold joints less then 14 hours required no special treatment. Cleaning and washing the lift surface was required for joints 14 to 36 hours old. Older joints required

View of upstream facing formwork during construction. Note water stops and steel rods anchoring the concrete facing to the RCC

A close up view of water stop, conventional concrete for upstream facing, and contraction joint materials

bedding mortar to bond consecutive lifts. Bedding mortar mix consisted of 2,800 lb/yd^3 (1,660 kg/m^3) sand, 500 lb/yd^3 (297 kg/m^3) cement, and 300 lb/yd^3 (178 kg/m^3) water.

Crack-control inducers were installed and seepage at the induced cracks was controlled by the use of conventional concrete facing system and water stops on the upstream face.

RCC contraction joint locations were adjusted upon completion of the excavation based on the bedrock topography and major grade breaks encountered. A total of six contraction joints were initially planned, but a total of nine contraction joints were eventually installed.

RCC Mix Design

Based on stability analyses, an RCC mix producing a one-year unconfined compressive strength of 1500 psi (10.3 MPa), tensile strength of 75 psi (517 kPa) , and cohesion of 300 psi (2.1 MPa) were specified. Freeze-thaw durability concerns were addressed by the use of air-entrained concrete upstream facing and the soil cover on the downstream face.

The selected RCC mix consisted of 2,170 lb/yd^3 (1,287 kg/m^3) on-site aggregate crushed to 3-inch (75-mm) minus; 1,532 lb/yd^3 (909 kg/m^3) imported Colorado Department of Transportation Class 4 base, 160 lb/yd^3 (95 kg/m^3) Type I/II cement, 100 lb/yd^3 (59 kg/m^3) fly ash, and 234 lb/yd^3 (139 kg/m^3) water. The design/build team quickly concluded that a design based on lower design strengths and conservative cross-section would provide flexibility in aggregate selection and proportions. The District's concerns and permit restrictions made on-site aggregate development very attractive, though not necessary. Space and budget concerns led to on-site crushing of about 55 percent of the needed aggregates.

Construction and Cost

The design of the Pine Brook Dam was initiated in January 2005 and completed in June 2005. After incorporating the State Dam Safety Engineer's comments, the project was approved for construction on September 22, and concrete placement for the dam began the next week.

RCC placement began the last week of October and continued until the first week of December when RCC construction was suspended due to cold weather. RCC placement resumed in mid-February 2006 and was completed in mid-April. The project required approximately 36,000 yd^3 (27,500 m^3) of RCC; 1,600 yd^3 (1,220 m^3) of air-entrained concrete for upstream facing; and 1,400 yd^3 (1,070 m^3) of abutment/leveling/dental concrete. The outlet works and principal spillway riser and conduit were constructed during the suspension of RCC placement.

RCC materials were mixed using an on-site compulsory mixer with a rated capacity of 300 yd^3 (229 m^3) per hour. A 100-foot (30.5-m) long conveyor belt conveyed the RCC to haul trucks and the trucks transported the product to the point of placement. A dozer spread the RCC and vibratory rollers compacted the material in 12-inch (300-mm) lifts.

The total project cost (engineering and construction) for the design and construction of the Pine Brook Dam was approximately $4.5 million. The unit cost for RCC including material processing, mixing and placement costs was approximately $75/yd^3$ ($98/m^3$). While it is difficult to compare these costs to those of other projects, it is believed these costs are significantly lower than projects of similar size and scope. Additionally, it is believed that the project schedule was reduced by as much as 70% when compared to similar projects. The price efficiency and schedule benefit was realized, in-part through contractual approach, simplified design, and productive team coordination.

In recognition of the innovative efforts undertaken by the design/build team to design and construct the high hazard dam, using the design/build approach, in only 18 months, Pine Brook Dam received United States Society on Dams' Award of Excellence in the Constructed Project. The award was presented during USSD's conference in March 2007.

Credits

Owner/Construction Manager: Pine Brook Water District, Boulder, Colorado

Contractor: ASI Constructors, Inc., Buena Vista, Colorado

Designer: TCB, Inc. Denver, Colorado

QC Testing: CTL/Thompson, Denver, Colorado

RCC Mix Design: ASI RCC, Inc., Buena Vista, Colorado

A view showing crest of dam, parapet wall, and unformed uncompacted downstream face

Equipment used to transport, spread and compact RCC

PCA
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9781
www.cement.org

An organization of cement companies to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

PL466