Successful Overtopping Protection Projects in the Eastern U.S.

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Abstract

The two most commonly used systems for erosion protection of embankment dams and earthen spillways in the United States consist of roller-compacted concrete (RCC) and articulating concrete blocks (ACB). Schnabel Engineering has designed and observed the construction of nineteen RCC and eleven ACB armoring projects during the past 20 years. These overtopping protection systems are most frequently selected as economic solutions to address various spillway deficiencies, in lieu of more conventional alternatives. This paper tabulates the basic details of each project, including project name, location, completion date, armoring height, and design depth of overtopping. Three RCC projects and three ACB projects located in the eastern U.S. are then highlighted to provide additional design details (including project cost) and present unique aspects and challenges associated with each project. Finally, the successful performance of one of the RCC projects during an estimated 25-year storm event in September 2009 is described. The information presented in this paper regarding the design application, installation, and performance of RCC and ACB overtopping protection systems in the eastern U.S. should be of interest to engineers involved with dam safety and erosion protection systems worldwide.

1 Introduction and Projects Summary

Erosion and breach by overtopping flow is a common failure mode for dams, accounting for 30 percent of the failures in the U.S. over the last 75 years (Reclamation, 2012). Many older dams may have been designed for floods that no longer represent a remote flood event, or for smaller floods consistent with a lower downstream hazard classification than is currently warranted by downstream development. Regulated dams that fail to meet flood passage requirements, generally equivalent to the Probable Maximum Flood (PMF) or some percentage thereof, must be modified by the dam owner to satisfy those requirements. Common methods in the past have been to construct a wider or more efficient spillway to increase the discharge capacity and/or raise the dam crest to increase surcharge storage. However, the provision of dam overtopping protection has become a popular alternative in recent years, offering numerous potential benefits over more conventional methods. Schnabel Engineering (Schnabel) has designed and observed the construction of 30 overtopping protection projects during the past 20 years, consisting of nineteen RCC projects and eleven ACB projects, as summarized in Tables 1 and 2. These represent the two most commonly used systems for erosion protection of embankment dams and earthen spillways in the U.S., among the various alternatives described in the Federal Emergency Management Agency (FEMA) *Technical Manual: Overtopping Protection for Dams* (2014).

1.1 Summary of RCC Projects

The placement of RCC in horizontal lifts on the crest and downstream face of an embankment dam is the most common method of providing overtopping protection for larger embankments and higher depths of overtopping, offering a very durable and cost effective solution for many applications. The stepped surface on the downstream slope provides some energy dissipation, thereby reducing stilling basin requirements, and rapid construction rates are commonly possible. Applications in colder climates, or in heavily populated areas, may be covered with seeded topsoil for frost protection and/or for aesthetic reasons. A summary of the RCC projects completed by Schnabel since 1998 is provided below, representing an average armoring height of over 12 m and design depth of overtopping of 2.2 m. Highlighted projects (in bold text below) are described more fully in Section 2.

Table 1. Summary of Overtopping Protection Projects Using RCC (Schnabel Engineering).

Project Name	Location	Year of Completion	Armoring Height (m)	Design Depth of Overtopping (m)
Soque River No. 29 Dam	Clarkesville, Georgia	2017	14.0	2.7
Soque River No. 36 Dam	Clarkesville, Georgia	2016	8.8	2.5
Lunga Lake Dam	Quantico, Virginia	2016	16.2	1.8
Lake Laura Dam	Basye, Virginia	2016	24.4	2.7
Colyer Lake Dam	Tusseyville, Pennsylvania	2015	12.8	1.7
Speedwell Forge Lake Dam	Lititz, Pennsylvania	2015	11.0	2.8
Bear Creek Dam	Wise, Virginia	2014	13.7	1.9
Lake Oneida Dam	**Butler, Pennsylvania**	**2013**	**9.4**	**3.0**
Stoney Creek Dam	**Bedford, Virginia**	**2013**	**17.1**	**2.7**
Fox Creek No. 4 Dam	Flemingsburg, Kentucky	2012	14.9	3.0
Lower Owl Creek Dam	Tamaqua, Pennsylvania	2012	10.0	1.5
Poe Valley Dam	Coburn, Pennsylvania	2009	10.0	1.5
Yellow River No. 16 Dam	**Suwanee, Georgia**	**2006**	**11.3**	**2.2**
Marrowbone Dam	Ridgeway, Virginia	2006	14.0	3.9
Locust Lake Dam	Hope, New Jersey	2005	7.6	1.5
Great Gorge Dam	McAfee, New Jersey	2003	10.7	0.7
McKinney Lake Dam	Hoffman, North Carolina	2003	5.2	1.5
Robinson's Branch Dam	Clark Township, New Jersey	2001	6.1	1.4
Douthat Dam	Clifton Forge, Virginia	1998	16.8	Unknown
Average Height and Depth of Overtopping (19 projects)			12.3	2.2

1.2 Summary of ACB Projects

The use of cable-tied ACBs for dam overtopping protection is generally seen as somewhat more economical than RCC for smaller projects and/or smaller depths of overtopping. FEMA (2014) suggests ACBs be used for armoring heights of less than about 12 m and for design overtopping depths of less than 1.3 m, based on experimental test data available at that time, although heavier blocks are currently being developed and tested that will likely increase those limits. A summary of the ACB projects completed by Schnabel since 2001 is provided below, representing an average armoring height of about 7.8 m and design depth of overtopping of 1.0 m. Note that in some cases below, the suggested height and depth limits for ACB applications have been exceeded. Highlighted projects (in bold text below) are described more fully in Section 2.

Table 2. Summary of Overtopping Protection Projects Using ACBs (Schnabel Engineering).

Project Name	Location	Year of Completion	Armoring Height (m)	Design Depth of Overtopping (m)
Mirror Lake Dam	Fayetteville, North Carolina	2019	5.8	0.9
Glade Run Lake Dam	**Valencia, Pennsylvania**	**2016**	**8.5**	**1.4**
Huntsman Lake Dam	Springfield, Virginia	2014	12.5	3.0[1]
Mount Laurel Dam	**Frackville, Pennsylvania**	**2013**	**11.9**	**1.2**
Lake Townsend Dam	**Greensboro, North Carolina**	**2012**	**13.7**	**1.6**
Lake Inverness Dam	Duluth, Georgia	2008	10.0	0.7
Reeves Bog Dam B	New Lisbon, New Jersey	2006	1.5	0.3
Lower Reeves Bog Dam	New Lisbon, New Jersey	2006	1.5	0.5
Ryker Lake Dam	Oak Ridge, New Jersey	2005	3.0	0.8
Harbison Pond Dam	Columbia, South Carolina	2002	6.1	0.3
Putnam Dam	Redding, Connecticut	2001	10.7	0.8
Average Height and Depth of Overtopping (11 projects)			7.8	1.0

1. Armored auxiliary spillway on left abutment of dam.

2 Highlighted Overtopping Protection Projects

Three RCC projects and three ACB projects located in the eastern U.S. are highlighted below to provide additional design details (including project cost) and present unique aspects and challenges associated with each project.

2.1 RCC Project Details

2.1.1 *Yellow River No. 16 Dam*

The Yellow River No. 16 (Y-16) Dam is a 10.4 m high earthen embankment built in 1973 by the U.S. Department of Agriculture Soil Conservation Service, or SCS (now known as the Natural Resources Conservation Service, or NRCS). The dam was originally designed as a Class A, or low hazard, structure to provide flood and sediment control for Little Suwanee Creek, a tributary of the Yellow River. The dam now also serves as an amenity feature for the surrounding residential development. Gwinnett County operates and maintains the dam. The structure is currently classified by the Georgia Safe Dams Program as a Category I, or high hazard, dam and is required to pass 50 percent of the PMF with sufficient freeboard to prevent wave action from overtopping the dam. The principal spillway for the dam consists of a 76 cm diameter, reinforced concrete pipe with a standard SCS covered reinforced concrete riser. A small rectangular orifice in the downstream endwall of the riser controls normal pool at elevation 298 m. A 30 m wide earthen channel auxiliary spillway, with a crest at elevation 300 m, was originally constructed on the left abutment of the dam. The original spillway system was only capable of passing approximately 25 percent of the PMF without overtopping. The normal pool of Taylor Lake, located immediately downstream of the structure, submerges the principal spillway outlet and downstream toe of the Y-16 embankment.

An alternatives analysis was performed in 2004 by the U.S. Army Corps of Engineers under the authority of the Planning Assistance to States (PAS) program, in cooperation with the NRCS and Georgia Soil and Water Conservation Commission. The following alternatives were evaluated:

Option 1 - Enlarge existing auxiliary spillway
Option 2 - Construct concrete chute spillway
Option 3 – Construct overtopping protection using an ACB system
Option 4 - Construct overtopping protection using RCC

Due to various factors such as existing topography, maintenance of existing flood control function, and depth of overtopping, only Option 4 (RCC overtopping protection) was developed for further consideration.

The RCC overtopping protection was designed using a two-stage, sharp-crested conventional concrete weir. This spillway configuration was intended to approximate flooding conditions that would exist with the original spillway system (both downstream of the dam and within the flood pool upstream of the dam), and incorporated the existing pipe and riser. The low-stage crest was set at the original emergency spillway elevation and has a width of 22.9 m to pass an equivalent discharge during the 100-year, 24-hour storm event. The high-stage crest was set at the 100-year flood pool and provides an additional width of 10.7 m to pass the design flood event at the same elevation as the original spillway system.

The RCC overtopping protection converges in plan about 10 degrees in order to reduce the volume of excavation and RCC, and follows the existing slope of the dam at 3H:1V. The spillway terminates in an RCC-lined stilling basin. The elevation of the stilling basin is set approximately 2.4 m below the existing stream channel elevation in order to provide a sufficient depth of tailwater to form a hydraulic jump within the stilling basin. Seeded topsoil was placed over the RCC for aesthetic purposes, with a minimum depth of 60 cm.

A cutoff wall was constructed near the dam centerline to increase the seepage path along the soil-concrete interface and to limit the potential for uncontrolled seepage. Underdrains were constructed beneath the RCC overtopping protection downstream of the dam centerline to reduce the potential for uncontrolled seepage and the transmission or piping of soils. The drainage system was designed to reduce the uplift that could occur due to the development and establishment of the phreatic surface within the embankment.

Figure 1. Y-16 Dam RCC Protection during Construction.

Construction on the US$1.8 million rehabilitation project began in July 2007, with final completion in February 2008. Approximately 2,300 m^3 of RCC were delivered from an off-site plant and placed in 0.3 m thick horizontal lifts during construction.

2.1.2 *Lake Oneida Dam*

Lake Oneida Dam is located on Connoquenessing Creek in Butler County, Pennsylvania, about 7.2 km north of the town of Butler. The dam is a homogeneous earthfill embankment with a concrete corewall and steel foundation cutoff. The embankment is about 230 m long with a maximum height of about 9.4 m. The dam and 63 hectare Oneida Valley Reservoir are owned by the Pennsylvania American Water Company (PAWC) and operated as a water supply facility.

Original construction of the dam was completed in 1918. Several repairs and modifications were subsequently performed, leading up to a major rehabilitation of the dam and spillway in 1981. The existing primary spillway consisted of a 44.5 m long concrete weir that projected into the reservoir near the right abutment (looking downstream). Flow over the weir discharged into a converging rectangular concrete chute (curved in plan) that transitioned to a concrete-lined trapezoidal channel and grouted riprap channel before entering the stream. An energy dissipator consisting of a single row of baffle blocks was located at the downstream end of the trapezoidal channel. Various repairs were performed to the spillway after its modification in 1981, including addressing structural damage suffered during Hurricane Ivan in 2005 and repairing a scour hole that formed downstream of the baffle blocks in 2006.

The Pennsylvania Department of Environmental Protection – Division of Dam Safety (PADEP) categorizes the dam as a Hazard Category 1 (high), Size Class B (intermediate) structure and requires the spillway design flood to be the PMF. In 2006, PADEP reviewed the existing spillway capacity of Lake Oneida Dam and found that the spillway was able to pass only 27 percent of the PMF without overtopping the embankment. PADEP therefore considered the dam's spillway significantly inadequate and requested that PAWC upgrade the dam's spillway capacity.

A cost-effective and practical design was developed to fit within strict design constraints established by PAWC and PADEP, as follows:

- The dam shall safely pass the PMF

- Post-construction peak outflows shall match pre-construction flows for storms up to the 100-year event
- The computed peak reservoir stage for the PMF shall be below the elevation of State Highway 38 located along the right edge of the reservoir
- Neither normal pool nor top of dam elevations shall be changed
- Construction shall be performed with limited or no reservoir drawdown to maintain water supply during construction.

A replacement box-inlet drop spillway with a crest length of 40.2 m was designed and constructed to the left of the existing spillway, by sequencing construction with a braced sheetpile cofferdam and by temporarily diverting stream flow through the existing spillway before it was ultimately removed. The replacement spillway was sized to match the hydraulics of the existing spillway up to the 100-year event. The embankment was then armored with RCC to protect the dam from a potential overtopping failure during flood events which exceed the capacity of the replacement spillway. RCC was placed in 0.3 m thick horizontal lifts on the embankment slope, with a concrete corewall cap constructed at three staged elevations designed to activate for events greater than the 100-year flood, while passing the PMF at a computed peak stage that is below the elevation of State Highway 38.

Various drains and filters were also incorporated into the proposed work to safely filter, collect and convey embankment, spillway underdrain and foundation seepage, and the slope of the RCC armored embankment was constructed no steeper than the existing embankment (2.5H:1V).

Figure 2. Lake Oneida Dam with Buried RCC Protection.

Construction was completed with a fully operational pool in 2013. The total RCC volume placed was about 11,000 m^3, with a unit price of US$133.

2.1.3 *Stoney Creek Dam*

Stoney Creek Dam is a zoned earthfill embankment about 168 m long and 16.5 m high, located on Stoney Creek, and owned and operated by the City of Bedford, Virginia. A concrete overflow spillway located on the right abutment was only capable of passing about 25 percent of the PMF, and was in poor condition with significant cracking, undermining, and deterioration. The dam was classified as a Class I (high hazard) structure according to Virginia Department of Conservation and Recreation (DCR) dam safety criteria, and was required to safely pass the full PMF. The peak PMF discharge was computed to be 1,600 m^3/s, with about 2.0 m of flow overtopping the embankment, which would likely have resulted in dam failure. An alternatives analysis of remedial measures was performed in 2005, with various combinations of increased discharge capacity and dam raise heights, as follows:

Option 1 – Spillway replacement with longer overflow crest, new chute and stilling basin, and 3.0 m dam raise.

Option 2 – Spillway replacement with 5-cycle labyrinth weir, new chute and stilling basin, and 1.8 m dam raise.

Option 3a – Spillway repairs and dam overtopping protection (RCC or ACB) without dam raise.

Option 3b – Spillway replacement-in-kind and dam overtopping protection (RCC or ACB) without dam raise.

Option 4 – Spillway replacement-in-kind and 5.2 m dam raise.

Conceptual designs and cost estimates were developed for each of the alternatives and are summarized in Table 3. Dam overtopping protection without dam raise was selected as the least costly alternative (based on RCC), with spillway repairs to be adopted for final design (Option 3a), as long as the existing spillway could be rehabilitated to a similar level of performance as a new spillway. The spillway repairs were estimated at about $1 million of the total construction cost, and included replacement of the control section, grouting voids beneath the existing chute slabs, new cutoff walls and underdrains, and a 25 cm thick reinforced concrete overlay.

Table 3. – Construction Cost Estimates for Stoney Creek Dam Modification Alternatives (2005)

Option	Estimated Construction Cost (2005)
Option 1	US$7.2 M
Option 2	US$8.5 M
Option 3a	US$4.1 M
Option 3b	US$5.5 M
Option 4	US$5.6 M

The dam overtopping protection was designed to closely follow the existing embankment slopes and geometry, which included downstream slopes of 2.5H:1V separated by four benches. Although the cost of ACBs is often comparable to or less than that of RCC, the final design overtopping depth of 2.7 m and the existence of the benches favored the use of RCC for this application. The RCC weir crest was set at 2.0 m above the principal spillway crest to limit operation to less than once in 100 years, and 0.5 m below the original embankment crest to accommodate 50 cm of seeded topsoil. An overtopping crest length of 122 m was selected for passage of the PMF, with 2.7 m high parapet walls provided on the remaining dam crest. The RCC was placed in 0.3 m thick horizontal lifts with a minimum lane width of 3.0 m, and the steps were formed vertically for improved energy dissipation. A concrete cutoff wall was provided at the downstream edge of the RCC to prevent undermining for smaller floods producing less tailwater. A sand drainage blanket was provided beneath the RCC overtopping protection, supplemented by 15 cm diameter slotted PVC pipes within a gravel filter. Converging concrete sidewalls were doweled into the RCC on both sides to maintain discharges within the armored limits.

Figure 3. Stoney Creek Dam with Buried RCC Protection.

Four standpipe piezometers were installed through the RCC overtopping protection to permit monitoring of the phreatic surface within the dam embankment. Construction was successfully completed in May 2012 for a final cost of US$5.3 million. Total volume of the RCC overtopping protection was 7,600 m^3.

2.2 ACB Project Details

2.2.1 *Lake Townsend Dam*

Lake Townsend Dam is about 400 m long and 13.7 m high, and was originally constructed in 1967 on Reedy Fork. It consisted of earthen embankments, a grass-lined auxiliary spillway, and a 10-bay gated concrete spillway with 3.0 m high vertical lift gates. The impoundment provides about 70 percent of the raw water storage capacity for the City of Greensboro, North Carolina (population approximately 250,000). The aging concrete spillway had suffered from alkali silica reaction (ASR) damage and exhibited extensive deterioration. Seepage was also observed in horizontal lift lines in the concrete spillway, raising concerns regarding internal stability. The spillway also had insufficient discharge capacity (per North Carolina Dam Safety Regulations) without overtopping the dam. Furthermore, the City was interested in reducing the operation and maintenance requirements associated with the vertical lift gates. Two additional challenges to this project included control of water during construction and the potential failure of two upstream dams during an extreme storm event.

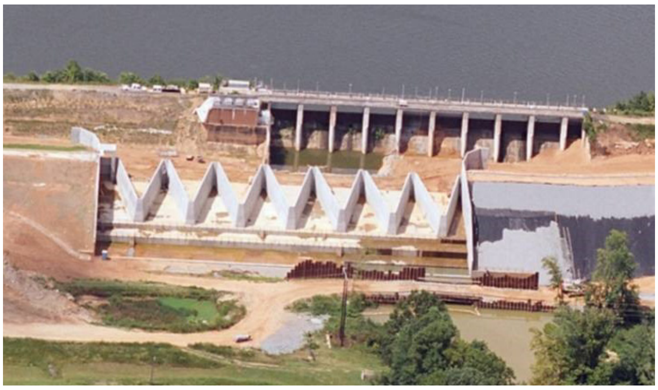
Based upon these challenges, deficiencies, and downstream hazards including the potential for loss of life, an emergency rehabilitation was performed consisting of the installation of post-tensioned anchors and steel reinforcing plates in the concrete spillway, while detailed investigations were conducted and a comprehensive rehabilitation design was developed (Paxson et al 2008).

A phased design approach was used to identify and evaluate rehabilitation alternatives. Spillway gates, a labyrinth weir, and a combination of both types of structures were considered for the following alternatives:

Option 1 - Rehabilitate existing structure
Option 2 - Replace spillway
Option 3 - Replace spillway and raise dam
Option 4 - Replace spillway and armor dam

Spillway gates would provide operational flexibility and additional discharge capacity; however, tailwater submergence would adversely affect gate performance, and maintenance costs and operational issues would remain. A large full-height labyrinth spillway would also provide the required discharge capacity with reduced maintenance; but the owner would no longer be able to control reservoir pool elevations. The preferred solution was to armor the embankment with ACBs and construct a new 7-cycle labyrinth spillway with two crest elevations to generally match existing spillway releases but with a total estimated discharge capacity of about 4,100 m^3/s. A short stepped-spillway chute was also constructed to dissipate energy for more frequently occurring storms during low tailwater. Armoring the embankment with ACBs augmented the labyrinth weir discharge capacity by about 2,300 m^3/s, with the dam estimated to overtop for storms greater than 60 percent of PMP. Potential failure of the two upstream reservoirs could also be accommodated during the spillway design flood. Maximum overtopping depth of the ACBs was about 1.6 m. The new structures were located immediately downstream of the existing spillway to facilitate water control during construction. For details regarding the hydraulic analyses, including physical and numerical modeling, see Paxson et al (2008) and Tullis and Crookston (2008).

Figure 4. Lake Townsend Dam during Construction (ACBs being placed on both sides of new concrete labyrinth spillway).



2.2.2 *Mount Laurel Dam*

Mount Laurel Dam (formerly Mud Run Dam) is located on Mud Run in Schuylkill County, Pennsylvania. The original homogeneous earthen embankment was constructed in 1879, and raised about 1.5 m in 1903 to its current configuration. A partial concrete corewall was constructed at the toe of the original dam and covered by the new downstream slope during the 1903 dam raise. The embankment is about 335 m long with a maximum height of about 12 m, and the primary spillway consists of a 15.2 m wide broad-crested stone masonry weir located at the right abutment (looking downstream). The dam and 19 hectare reservoir are owned by the Schuylkill County Municipal Authority (SCMA) and operated as a water supply facility.

PADEP categorizes the dam as a Hazard Category 1 (high), Size Class C (small) structure, and requires safe passage of the PMF. The dam has experienced significant seepage and embankment issues (boils, depressions, bulges, tension cracks) since first filling, and addressing these issues was considered a top priority by PADEP. PADEP reviewed the existing spillway capacity of Mount Laurel Dam in 2003 and found that the spillway was able to pass only 58 percent of the PMF without overtopping the embankment. PADEP considered the dam's spillway significantly inadequate and requested that PAWC also upgrade the dam's spillway capacity.

Between 2006 and 2009, several spillway upgrade alternatives were evaluated by two different consultants, including:

- Construction of a replacement labyrinth spillway (no change in top of dam)
- Excavation of vegetated auxiliary spillway (no change in top of dam)
- Raising top of dam and construction of a replacement drop spillway

While raising the top of dam was found to be the most cost effective solution, PADEP indicated a preference for options that maintained the existing top of dam to avoid increasing surcharge storage and an associated increase in flood hazard risk due to a potential dam break. Also, the PADEP permitting process for a proposed dam raise would require additional reviews by various environmental agencies which could result in an increase in the daily minimum flow that SCMA is required to discharge. For these reasons, refinements to the excavated auxiliary spillway were further evaluated.

The final design concept selected for construction consisted of:

- Replacing the existing spillway with a straight drop spillway sized to generally match discharges up to about the 100-year event (weir length of 10.7 m).

- Construction of an ACB armored auxiliary spillway on the right abutment that would activate for events greater than the 100-year event (weir length of 19.8 m).
- Leveling the embankment crest. This included placing up to 0.5 m of earthfill to fill in low spots on the existing dam crest to confine flows to the spillways during the PMF. PADEP did not consider this a 'dam raise' since the crest was simply reconstructed to the previously permitted top of dam elevation.
- Installation of an embankment drainage system and stability berm on the downstream slope

The ACB armored auxiliary spillway was designed for 1.2 m of overtopping following methods presented in National Concrete Masonry Association's (NCMA) *Articulating Concrete Block Revetment Design – Factor of Safety Method, TEK 11-12* (NCMA, 2002). The auxiliary spillway was constructed to the right of the replacement spillway using 15 cm thick, open cell, tapered ACBs (ShoreBlock SD-900 OCT). The upstream edge of the ACBs were cast into a concrete starter wall that was constructed integral with a sheet pile cutoff driven to rock. Minor rock excavation was necessary on the right side of the spillway, but the rock was generally rippable. At the downstream terminus, a concrete cutoff was constructed on rock. Construction was completed with a fully operational pool in 2013 for US$3.9 million. Approximately 750 m^2 of ACBs were installed.

Figure 5. Mount Laurel Dam with ACB Armored Spillway.

2.2.3 *Glade Run Lake Dam*

Glade Run Lake Dam is located on Glade Run, a tributary of the Connoquenessing Creek, in Butler County, Pennsylvania. The dam is a zoned earthfill embankment with an excavated cutoff trench. The embankment was originally constructed between 1954 and 1955 and is about 222 m long with a maximum height of about 8.5 m. The existing spillway consisted of a 21.3 m long ogee weir located on the left abutment that discharged through a trapezoidal concrete chute and stilling basin. The dam and 21 hectare reservoir are owned by the Pennsylvania Fish and Boat Commission (PFBC) and operated as a recreation facility. PADEP categorizes the dam as a Hazard Category 1 (high), Size Class B (intermediate) structure.

Previous studies found that Glade Run Lake Dam had inadequate spillway capacity to safely pass the PMF, which is the spillway design flood required by PADEP. Additionally, the dam had a history of embankment seepage and slope stability issues, including observations of wet areas, holes in the downstream slope and toe area, and possible sloughing or creep of the downstream slope. PADEP and others have also suspected potential undermining of the spillway slabs based on site observations of uncontrolled seepage and performance of other similar spillways owned by PFBC.

Several rehabilitation alternatives were evaluated to address these dam safety deficiencies, including: raising top of dam; spillway expansion; replacement labyrinth spillway; and embankment armoring. Construction of a replacement labyrinth spillway in conjunction with raising the top of dam was initially considered the most cost effective and technically viable concept. However, based on discussion with PADEP and PFBC, a plan that generally matches existing site hydraulics was preferred to reduce increased flooding impacts resulting from a larger and more efficient spillway.

The final design concept selected for construction generally consisted of:

- Removing and replacing the existing spillway with a box-inlet drop spillway, stepped chute and stilling basin. The replacement spillway was situated within the footprint of the existing spillway
- Excavating the downstream embankment and installing a chimney, blanket and toe drain system; flattening the downstream slope and armoring it with 23 cm open cell, tapered ACB (Submar XL9070T). Embankment overtopping was designed to occur for events greater than the computed 500-year event.

- Raising the abutments to contain flows within the armored section.

These modifications do not significantly change the computed outflow or peak stage compared to existing conditions for storms up to the 500-year event, which was considered acceptable to PADEP and PFBC. However, the computed overtopping depth for the PMF is 1.4 m, which was initially a concern and not considered acceptable to PADEP because full scale model testing of ACBs had not yet been performed for overtopping depths greater than 1.2 m (as of 2010). The following was presented to PADEP to justify selection of this design concept:

- ACB systems did not fail under 1.2 m of overtopping during full scale model testing, and therefore does not represent a threshold.
- The computed Factors of Safety (FS) exceeded the minimum recommended FS for all ACB sizes offered by several ACB manufacturers.
- 1.2 m of overtopping depth corresponds to about 90 percent of the PMF, which is considered a very extreme event.
- The computed FS for 1.4 m of overtopping is only five to six percent less than the FS computed for 1.2 m of overtopping.
- The computed overtopping duration for the PMF is 4.5 hours, and the duration of overtopping depth greater than 1.2 m is only about 30 minutes.
- The selected ACB was the thickest (23 cm) and largest (in terms of footprint) block available.

Construction was completed with a drained reservoir in 2016 for US$2.9 million. Approximately 4,800 m^2 of ACBs were installed and covered with seeded topsoil.

Figure 6. Glade Run Lake Dam with ACB Armored Slope.

3 Successful Overtopping Performance

On September 20 and 21, 2009, Gwinnett County, as well as other parts of northern Georgia, experienced exceptionally high amounts of intense rainfall. During this rainfall event, stormwater runoff within the Yellow River Basin was discharged from the reservoir through the RCC auxiliary spillway at Y-16 Dam. This discharge resulted in erosion of the layer of grassed topsoil covering the RCC.

Representatives of Schnabel performed a site reconnaissance on September 21, 2009 to observe the condition of the Y-16 Dam. Figure 7 shows water discharging from the storm events in the preceding hours. A subsequent reconnaissance was performed after flow ceased to inspect the integrity of the RCC section. The riprap, which separated the topsoil from the normal pool of Taylor Lake, had also been removed by the flow over the spillway. The extension pipes for the internal drain outlets, which extended through the riprap, had also been removed by the flow. The extension pipes were designed to be sacrificial, should the spillway engage. No damage to the RCC was noted. Figure 8 shows the exposed RCC section after the discharge over the auxiliary spillway had ceased.

Following the September 2009 event, Schnabel provided an analysis of the structure performance which included a comprehensive rainfall study of the event conducted by North American Weather Consultants, Inc. (NAWC). An observed high water mark was used to compare the computed, or theoretical, performance of the spillway and hydrologic routing to the actual peak water surface elevation.

Using the data provided by NAWC's rainfall study, Schnabel developed a rainfall hydrograph to simulate the rain event of September 2009. The rainfall occurring within the subject drainage basin during the peak 24-hour period of the September 2009 storm event was on the order of 17 cm. This precipitation is slightly greater than the 24-hour, 25-year storm event. Using aerial photography to evaluate and site reconnaissance to confirm, the basin was analyzed to compute the appropriate hydrologic curve number for routing during this event. Because of the amount of rainfall that occurred during the days leading up to the flood event, an above average antecedent runoff condition was evaluated. The aforementioned parameters were implemented into the routing computations to estimate the peak water surface elevation during the storm event. Using the rainfall data provided by the NAWC study, the hydrologic/hydraulic model yielded a water surface elevation that was within the range of actual flood crest elevations identified by surveyed high water marks.

Figure 7. Y-16 Dam Following RCC Modifications.

Figure 8. Y-16 Dam During Overtopping Event.

4 Conclusions

Six successful overtopping protection projects have been highlighted here to demonstrate the advantages of armoring embankment dams using RCC or ACB, compared to more conventional rehabilitation options involving replacement spillways and/or dam raises. In each case, an embankment dam had inadequate spillway capacity for safe passage of the design flood (usually the PMF), and an armoring option was selected for final design, either alone or as part of a comprehensive solution. In most cases, the embankment crest elevation had to be maintained to avoid permitting or other issues associated with a dam raise, and in each case a primary spillway was provided for passage of smaller floods up to some return period (typically 100 years). The projects requiring the largest depths of overtopping used RCC, but for those with smaller depths of overtopping, ACB was selected for cost savings. Finally, the successful performance of one of the RCC overtopping protection projects was described for passage of a 25-year storm event.

References

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