Buttressing an Aging Gravity Dam with RCC to Remedy Flood Risk

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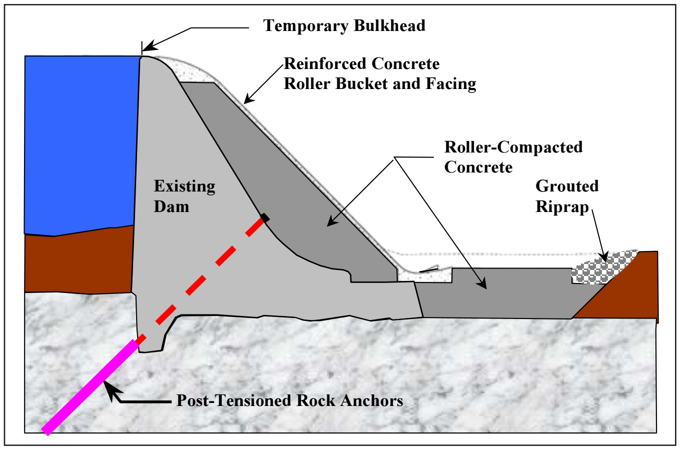
Roller-compacted concrete (RCC) was the material of choice to buttress Loch Raven Dam, almost a century old cyclopean concrete structure. The RCC rehabilitation, project initiated in 2002, brought the dam into compliance with current safety requirements and significantly increased its spillway capacity.

General view of Loch Raven Dam prior to rehabilitation.

Loch Raven Dam is a 110-ft (33.5-m) high, 700-ft (213-m) long, concrete gravity dam located on Gunpowder Falls about 9.5 miles (15.3 km) upstream of its confluence with the tidal flats of the Gunpowder River in Baltimore County, Maryland. The City of Baltimore built the dam in two stages from 1912 to 1922 to provide a raw water supply. Additionally, the dam impounds a reservoir of approximately 72,000 acre-feet or 23 billion gallons (87 billion liters).

The dam has undergone maintenance and cosmetic modifications throughout the years; however, the height and configuration of its basic operational and structural features has remained unchanged from 1922 until the present rehabilitation project. The Corps of Engineers, Baltimore District, issued a Phase I Dam Inspection Report in 1978. The report raised concerns about the safety of the dam and during the 1980s and 1990s, the City of Baltimore authorized additional inspections and investigations to evaluate the extent of safety deficiencies. These studies ultimately led to plans for improving the structural stability of the dam and increasing its spillway capacity so it would safely pass the current Probable Maximum Flood (PMF) mandated by the State of Maryland. The City of Baltimore initiated the resulting three-year construction project to rehabilitate the dam in 2002 at a construction cost of $29 million.



Cross-section of spillway showing proposed modifications.

Approximately 55,000 yd^3 (42,000 m^3) of RCC was placed to complete the stilling basin and buttress sections, and to raise the crest of the dam. This raised the dam height 21.2 ft (6.5 m) while maintaining the existing spillway crest elevation.

Other parts of the Loch Raven Dam rehabilitation included:

- removal and reconstruction of 180 ft (55 m) of a 10-ft (3-m) diameter water supply conduit situated within the footprint of the dam rehabilitation
- modifications to existing inspection galleries
- extension of the gallery entrance adit and installation of a steel door closure

Table 1 – RCC Mix Design

Mix No.	Placement Location	Design Mixtures in lb/yd³ (kg/m³)				
		Cement	Fly Ash (Class F)	Water	Aggregate	
					Fine	Coarse
1	Buttress and stilling basin	121 (72)	121 (72)	215 (128)	2270 (1347)	1512 (897)
2	Top 3 feet (0.9 m) of stilling basin	192 (114)	286 (170)	215 (128)	2103 (1247)	1400 (830)

- rehabilitation of existing raw water intake screens, and replacement of water supply sluice gate operators
- installation of toe drains and internal drains between the existing dam and RCC buttress and between the RCC buttress and spillway facing concrete.

Dam operational requirements and constricted site conditions influenced the design solution and dictated aspects of construction sequencing. Because the dam reservoir impounds water supply for more than one million residents in the Baltimore area, maintaining full reservoir head and continuous water service from the dam during construction was a design requirement. However, since structural stability was one of the dam's critical deficiencies, implementation of long-term design solutions had to be evaluated in context with appropriate construction condition design case loadings to minimize the potential for destabilizing the structure during construction. Of particular relevance in this process was the potential for, and consequences of, major flooding occurring during the construction of dam improvements.

Another issue, less critical to the long-term design objectives but more immediate in relation to onsite construction activities, was the need to provide flow diversion from a relatively large, 300 square mile (777 square km), contributing watershed. To address the stability of the dam during construction, post-tensioned rock anchors were installed. Resolution of the overall design objectives of increasing spillway capacity and providing adequate structural factors of safety for the PMF event was achieved using RCC to raise the dam and install buttress sections to provide increased structural stability.

RCC Mix Design

Gannett Fleming performed trial RCC batching and testing program by preparing approximately 220 trial cylinders using 18 RCC mix proportions with various water and cement contents. Testing of the the cylinders took place at the ages of 7, 28, 56, 90, 180, and 365 days. Based on laboratory testing and subsequent evaluation of results from onsite test section placement trials, Gannett Fleming selected mix proportions for RCC production as presented in Table 1.

The buttress mix and lower portion of stilling basin (Mix 1) was designed for an average compressive strength of 2,500 psi (17.2 MPa) at one year, while the upper 3 ft (0.9 m) of stilling basin (Mix 2) was selected for an average compressive strength of 4,000 psi (27.6 MPa) at 90 days. The gradations of fine and coarse aggregates specified for RCC production are presented in Table 2.

Table 2 – RCC Aggregate Gradation

Sieve Size	Percent Finer by Weight	
	Fine Aggregate	Coarse Aggregate
1-1/2 in. (37.5 mm)	100	100
1 in. (25 mm)	100	95 - 100
1/2 in. (12.5 mm)	100	25 - 60
3/8 in. (9.5 mm)	100	-
No. 4 (4.75 mm)	85 - 100	0 - 10
No. 8 (2.36 mm)	65 - 85	0 - 5
No. 16 (1.18 mm)	45 - 65	-
No. 50 (300 µm)	15 - 30	-
No. 100 (150 µm)	12 - 27	-
No. 200 (75 µm)	5 - 15	0-2

Construction

The joint venture of ASI-Cianbro received the rehabilitation construction contract on August 2002. Construction began in September that year and is scheduled for completion in September 2005. Construction alternated between one half of the dam and then the other to accommodate diversion of flow during construction. Work on each side was phased to sequentially install the rock anchors, followed by stilling basin/buttress construction, and finally the raising of the non-overflow portion of the dam.

RCC nearing completion on the west section of spillway while the east section is operating. Note the RCC mixing plant and conveyor system in the background.

To improve bonding between the RCC buttress and existing dam, a layer of previously installed shotcrete surface treatment was removed from the dam's face prior to the RCC placement. This was accomplished by a combination of mechanical demolition and hydrojetting to remove debris and treat concrete fractures that would otherwise diminish the quality of bond between the RCC and the existing dam. In addition, before RCC placement, drilled and grouted tie anchors were installed in the downstream face of the dam. During RCC placement, bedding mix was placed on each lift at the contact zone between the existing dam and the RCC buttress to also improve the bond along the contact surfaces. The bedding mixture consisted of cement, sand and water.

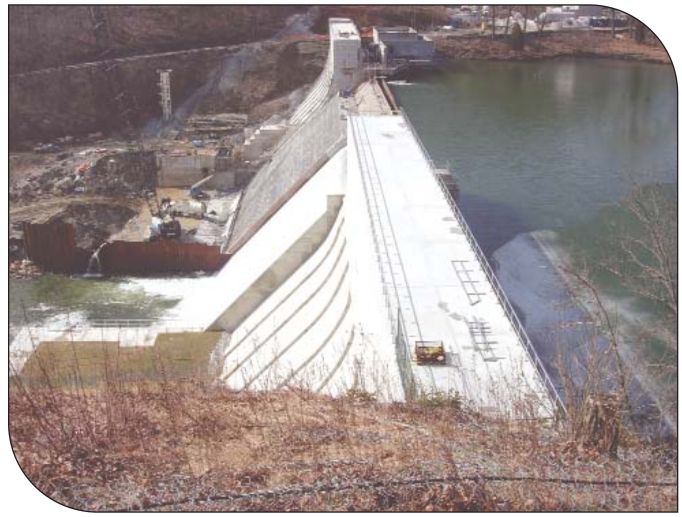
RCC placement on the east section of spillway while the west section is operating.

RCC was batched onsite using a Johnson-Ross batch plant with a capacity of 4 yd^3 (3 m^3). Conveyors delivered batched RCC to the placement area, transporting the material approximately 700 ft (213 m) horizontally and 100 ft (30.5 m) vertically. From the conveyor, a CC 200-24 Rotec Crane and telescopic conveyor with 360 degrees of swing and a horizontal reach of up to 200 ft (61 m) delivered the RCC to the lift surface. A dozer spread the RCC in a 12-inch (300-mm) lift thickness and placed it against the previously placed conventional concrete mix.

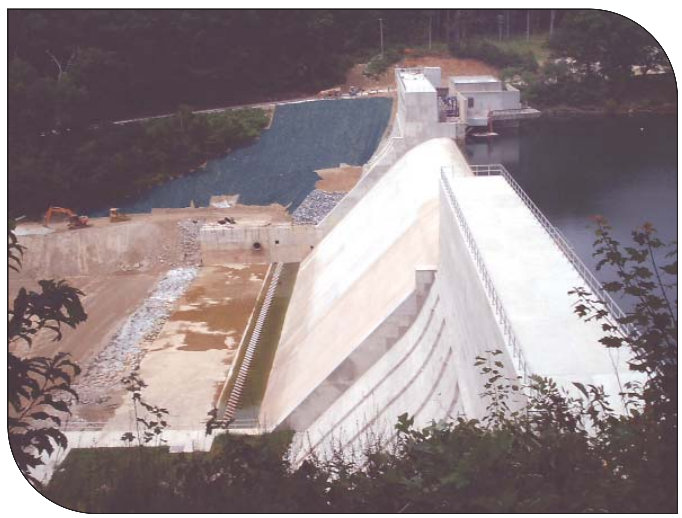
All exposed surfaces of the new construction were faced with air-entrained conventional concrete. Within the spillway the facing consisted of 18-inches (460-mm) of conventionally reinforced concrete constructed after the completion of RCC placement. Facing for the non-overflow sections of the dam consisted of a 15-inch (380 mm) nominal width of conventional concrete placed concurrent with RCC. A Rustler III mobile concrete batch plant batched the concrete facing onsite and delivered it to the placement area using crane and bucket. RCC was then delivered to the lift surface, spread and compacted adjacent to the freshly placed facing concrete. Prior to initial set of the concrete, internal vibrators were used at the zone of contact between the facing concrete and RCC to aid in consolidation.

Spillway RCC was over-placed approximately 6 inches (150 mm) beyond the design contact plane of RCC and facing concrete. A combination of mechanical, manual, and high-pressure water jetting trimmed excess RCC prior to placing facing concrete. No. 10 anchor bars were embedded 8 ft (2.4 m) into the RCC lifts at approximately 2-ft (0.6-m) vertical and 4-ft (1.2-m) horizontal spacing. The contractor utilized slip-forming techniques to place facing concrete in continuous vertical sections.

The spillway crest was reshaped to accommodate the design head for the raised dam. This work involved demolishing the top of the existing spillway and constructing a new spillway ogee crest. Conventional concrete rather than RCC was used in the upper portion of the replacement section because of space limitations and forming requirements to achieve the design shape. A roller bucket and stilling basin were constructed within the lower portion of the spillway. The roller bucket was made of conventionally formed reinforced concrete and the stilling basin slab entirely of RCC.



A view of the dam after completion of RCC placement on the west end prior to placing reinforced concrete facing and weir.



View of completed Loch Raven Dam

Vital Statistics

Remediation Features

Height of dam above foundation prior to remediation	110 ft (33.5 m)
New height of dam	131.2 ft (40 m)
Overall length of dam	700 ft (213 m)
Height of spillway crest above foundation	90 ft (27.4 m)
Spillway width	288 ft (87.8 m)
Original downstream slope at spillway	1V:0.62H
New downstream slope at spillway	1V:1H
RCC lift thickness	12 in. (300 mm)
Original spillway capacity	27% PMF
New spillway capacity	100% PMF

Credits

Owner: City of Baltimore, Baltimore, MD

Engineer: Gannett Fleming, Inc., Camp Hill, PA

Contractor: ASI - Cianbro Joint Venture

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