CONSTRUCTION OF A SELF-HARDENING SLURRY CUTOFF WALL AT TAYLORSVILLE DAM, OHIO

By Michael J. Fisher[1] Kenneth B. Andromalos, P.E[2].
Douglas N. Johnson, P.E.[3]

ABSTRACT

After ten major floods over a period of 100 years, the 1913 flood of record claimed 367 lives resulting in over 100 million dollars in damage. The Miami Conservancy District (MCD) was created in 1915 and subsequently built five flood control dams and 73 miles of levees to control future flood waters. The Taylorsville Dam was one of these five flood control dams constructed, between 1918 and 1922, using a hydraulic fill method of construction creating a clay core. In response to regulations issued in 1981 and flood routing studies, it was determined that Probable Maximum Flood could reach the crest of the dam, and thus cause instability and potential breaching of the dam.

Based on various evaluations, it was determined that a combination of downstream relief wells in conjunction with a cutoff wall to extend the dam core to the crest of the dam would provide the necessary dam improvements. This paper discusses why a self-hardening slurry cutoff wall was the selected method of extending the dam core, its desired performance characteristics, construction and quality control procedures, and a summary of the quality control testing.

This project also represents a good application on the use of granulated blast furnace slag (GBFS) as a major construction material because of its low permeability and high strength characteristics. For this application, a standard cement based self hardening slurry would not have been capable of meeting the required performance characteristics.

[1] Project Manager, Brayman Environmental, 1000 John Roebling Way, Saxonburg, PA 16056, phone 724-443-1533, email: m_fisher@braymanenvironmental.com

2 Technical Director, Geo-Solutions, Inc., 1250 Fifth Avenue, New Kensington, PA 15068, phone 724 - 335 - 7273, email kandromalos@geo-solutions.com

[3] Chief Engineer, Miami Conservancy District, 38 E. Monument Ave., Dayton, OH 45402, ph 937-223-1271, email: djohnson@miamiconservancy.org

INTRODUCTION

Taylorsville Dam is located near the City of Vandalia, Ohio and is an earthen embankment located across the Great Miami River. U.S. Route 40 is located along the crest of the dam. The Miami Conservancy District (MCD) built the system of 5 dams, and associated levees for flood control only; therefore the dams do not include gates or permanent reservoirs.

Figure 1. Aerial Photo of Taylorsville Dam

The MCD dams were built using the hydraulic fill method. Water was blasted into the borrow area and the material was sluiced out to the damsite. As the waterbourne fill moves to the end of the sluiceways and pipelines, the larger cobbles and gravel settled out creating the free-draining shells of the dam while the finer clay and silt particles moved into the core pool where they settled and created the clay core of the dam. The hydraulic fill was brought up in lifts as the water gradually drained out to form the dam. The top 15 to 25 feet of the dams were constructed of sand and gravel.

The dam has 4 concrete conduits through the base of the embankment near the east abutment. The conduits are sized to discharge a peak flow during an Official Plan Flood (OPF) that can be handled by the flood protection levees and channels downstream. The remainder of the floodwaters are temporarily stored behind the dam and released over time. An emergency spillway is located directly above the conduits in the same structure. Prior to the recent remedial measures, there were already an existing series of observation and relief wells at Taylorsville Dam. The relief wells are located along the length of the dam, 100 to 150 feet downstream from the toe. A toe berm extends 50 feet downstream from the toe of the dam, is 1,000 feet long and 10 feet high. Table 1 is a summary of dam dimensions and elevations.

Table 1. Dam Dimensions and Elevations

Length of Dam	2,980 feet
Height of Dam	67 feet
Width of Dam at Base	397 feet
Volume of Earth in Embankment	1,235,000 cubic yards
Top of Dam Elevation	837
Peak Elevation Probable Maximum Flood	829
Spillway Elevation	818
Peak Elevation OPF	820
Elevation Where Storage Begins	775

DAM SAFETY

MCD launched the Dam Safety Initiative (DSI) in 1999 to address weaknesses in the flood protection system. The DSI is an eleven-year, $24 million capital improvement project designed to ensure the ongoing safety and integrity of the entire flood protection system. Following inspection and investigative studies, it was determined the several aspects of the dams needed modifications to remediate potential dam safety issues, including:

- The installation of additional relief wells into the underlying sand at the downstream base of the dams,
- Increasing the size of the toe berm at the downstream base of the dams, and
- Raising the dam cut-off from the existing clay core up to the top of embankment by installing a low-permeability slurry cut-off wall at the top of the earthen dams.

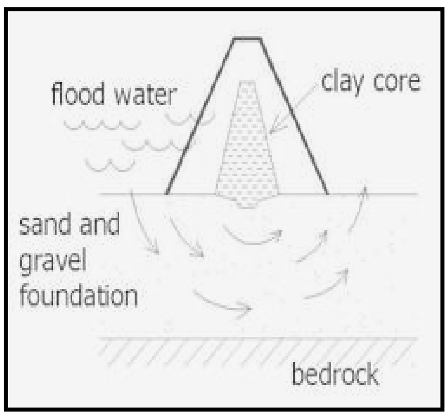

Figure 2. Dam Schematic

All three of these remedies were required at Taylorsville Dam. The Dam Safety Initiative is the MCD's largest investment in the flood protection system since the original construction in 1918-1922. The various improvements are discussed below.

Additional Relief Wells

Four of the five flood control dams of the District sit atop some of the best sand and gravel aquifers in the Miami Valley. Taylorsville Dam is one where this glacial deposit extends approximately 250 feet in depth. In 1959 this dam experienced its largest storage event. After careful evaluation of this event, a series of 20 relief wells on one hundred foot centers were installed along the toe of the dam.

Collecting data from these wells and other piezometers during recent storage events caused the installation of 46 more wells. There are 17 deeper relief wells similar to the initial 20, varying in depth from 63 to 117 feet deep; plus 29 shallow wells at 50-feet in depth. These 66 relief wells are on one continuous line at the toe of the dam on a 25 feet spacing.

Toe Berm

After the additional wells were completed an additional weighted berm 8 feet thick extended the toe of the dam 100 feet downstream. A drainage collection system connected groups of the relief wells and concentrated the seepage flow into five outlets. The berm added a safety factor by installing a redundant system to combat any uplift pressures not captured by the wells. These wells are 12 and 14 inches in diameter with a gravel pack and are screened at the water-bearing strata.

Slurry Cut-Off Wall

The MCD and their engineer, prescribed a low permeability slurry cut-off wall to provide the extended cut-off needed to prevent a breach in the dam during high water situations. The slurry wall technique uses an engineered fluid (slurry) to shore the trench sidewalls as an excavator digs a deep, narrow trench through the liquid slurry. Trenches are extended down to an existing low permeability key, in this case the dam's clay core, and key samples are brought to the surface and visually inspected. Brayman Environmental was awarded the contract to install the low-permeability cut-off wall. Brayman personnel had been involved with 2 previous cut-off installations at other MCD dams.

Backfill Mix Design: The most typical slurry wall backfill is a mixture of soil, bentonite and water. When installing a soil-bentonite slurry wall, a bentonite-water slurry (drilling mud) is used to support the sidewalls during excavation and is displaced when the final soil, bentonite and water backfill mixture is placed. Soil-bentonite (SB) backfill provides little or no shear or compressive strength which is not desirable on a dam embankment especially with a public roadway on top. Typical permeabilities for SB backfills are in the $1x10^{-7}$ cm/sec range.

An alternate slurry wall backfill is a self-hardening slurry which is prepared using a cement, clay and water slurry without the addition of soil. This slurry is typically a mixture of cement, bentonite and water (CB). The self-hardening slurry is used both as temporary excavation support during excavation and as final backfill after curing, with average compressive strengths of 15 to 30 psi. The trade off between the SB and CB methods is compressive strength for permeability, because cement-bentonite slurries achieve permeabilities in the $1x10^{-6}$ cm/sec range which is an order of magnitude more permeable than soil-bentonite backfill.

Due to the location of US Route 40 across the top of the dam embankment, MCD specified a self-hardening cement-bentonite based slurry wall backfill with a required unconfined compressive strength (UCS) greater than 100 pounds per square inch (psi) in 28 days and a permeability of less than $1x10^{-6}$ cm/sec. Brayman Environmental elected to use a mixture of granulated blast furnace slag (GBFS) and bentonite instead of traditional Portland Cement based CB slurry.

GBFS is manufactured in accordance with American Society for Testing and Materials (ASTM) – ASTM C989 Standard Specification for Ground Granulated Blast Furnace Slag for Use in Concrete and Mortars. GBFS (sometimes also referred to as GGBFS) is a product which is typically finer than Type I Portland Cement and is handled and dispensed like Portland Cement.

The slag-cement-bentonite mixture was selected to meet the UCS requirement prescribed by the project specifications. The slag-cement-bentonite slurry not only uses less material and therefore has a lower installation cost, but it also provides much lower permeabilities and much greater strengths. The slag-cement-bentonite slurry is also thinner than most self-hardening slurries which makes delivery of the material to the trench easier.

Typical CB mixes achieve unconfined compressive strengths in the 15-30 pounds per square inch (psi) range and permeabilities in the $1x10^{-6}$ cm/sec range. Slag-cement-bentonite mixes typically achieve a 28-day UCS greater than 100 psi with a permeability in the $5x10^{-7}$ cm/sec range.

Slurry Preparation and Supply: The bentonite can be supplied in 100# bags, 2,000# to 4,000# jumbo bags (or super sacks), or in bulk which is not typical for a slurry wall installation. The Portland cement is supplied in 94# bags based upon the low quantity required and the GBFS can be supplied in 100# bags, jumbo bags or in bulk pneumatic tankers. The slag should be supplied in bulk unless the project is too short to allow for mobilization and set-up of a bulk material storage silo.

Slurry for trench excavation was produced at the onsite slurry mixing plant. The slurry was composed of GBFS, bentonite, water, and a small amount of Portland cement which is added to accelerate the initial set of the mix. Prior to introduction of the slag, the bentonite slurry must first be prepared and hydrated for a minimum of several hours.

At the Taylorsville project, the bentonite slurry was prepared using a jet-shear mixer and several 21,000 holding tanks for storage and hydration. Storage ponds are preferable, if site conditions will permit.

Once the bentonite slurry is hydrated adequately and meets the required quality control testing values, the slurry is delivered to another mixing tank for addition of the GBFS and cement. The slag is transferred from the storage silo to the mixing tank using a metered auger for consistent proportioning. The slag-cement-bentonite slurry is then pumped to the trench through 4 and/or 6” high-density polyethylene piping to the trench, up to thousands of feet.

Mix quality was controlled using premeasured bentonite jumbo bags and 94# bags of Portland cement; water meters on the fresh water and bentonite slurry; and a weigh scale for the slag. These measures allow complete control of the mix by weight. Density of the mix was periodically checked, as well.

Figure 3. Slurry Batch Mixing Plant

Trench Excavation: The trench was excavated with a CAT 330 excavator equipped with an extended boom and stick. The arrangement had a maximum depth capacity of 45 feet below ground surface which was required for the wall installation which ranged from 28 to 40 feet deep. As the trench was excavated, slurry was pumped into the excavation and maintained within several feet of the workpad surface.

During trench excavation, small earthen berms were placed along both sides of the trench to contain the slurry within the limits of the trench. These berms were constructed out of dry trench spoils removed from the top several feet of the trench and were then ultimately used as capping material as the trench was backfilled back to the ground surface.

Spillway Connection: On the west side of the dam is the existing concrete spillway/bridge structure. The slurry wall was installed adjacent to the middle of three existing concrete cut-off walls which connect the spillway/bridge structure to the earth dam. At this location, the excavation proceeded without slurry to expose and visually observe the location of the top and upper side of this wing wall prior to flooding the trench with slurry and completing the slurry wall excavation to a depth of 40’.

Figure 4. Slurry Wall Excavation with Relief Well Installation Downgradient (left)

<u>Quality Control Testing</u>: Typically, slurry wall specialty contractor, the oversight engineer, or a combination of both performs the field quality control testing. At Taylorsville, an independent third party firm was required to be provided by Brayman. Geotechnics Inc., located in East Pittsburgh, PA was utilized to perform the mix design testing, field quality control testing and independent field oversight for the project.

Slurry wall quality control testing can be separated into two distinct areas: initial and in-trench slurry properties, and final backfill properties. During the installation process, slurry density, viscosity, pH and filtrate properties are periodically monitored to check that the slurry meets all specified properties. These properties are designed to ensure the slurry will have the characteristics required to maintain a stable excavation. All of these slurry properties are checked using field testing equipment according to American Petroleum Institute (API) methods. This equipment includes a mud balance for density, a marsh funnel viscometer, a pH meter, and an API filter press for filtrate loss.

To determine the final backfill properties, cylinders of trench slurry are taken, cured and tested at an off-site laboratory. At the Taylorsville project, cylinders were taken every 100 linear feet of trench, molded and stored for strength and permeability testing. These cylinders were tested for Unconfined Compressive Strength at 28 days and hydraulic conductivity (permeability) to ensure project specifications were met, as detailed below.

Table 2. Field Quality Control Testing Results

Parameter	Minimum	Maximum	Average
Permeability (cm/sec)	$3.1x10^{-8}$	$5.9x10^{-7}$	$2.5x10^{-7}$
Strength (28 day - UCS) (psi)	108	200	155

With the slurry wall technique, trench width and continuity are easily verified by passing the excavator bucket (at least as wide as the minimum trench width) and stick throughout the length and depth of the required cut. Trench depth is verified by dropping a weighted tape every 10 or 20 feet along the excavation.

Schedule: The slurry wall installation took approximately two months to complete including mobilization, set-up, trench installation, site restoration, and demobilization. The actual 2,400 foot long trench installation took 22 days of construction over a 1 month period.

CONCLUSIONS

Modifications were required at the Taylorsville Dam to improve overall dam safety during high storage conditions. By using additional relief wells in the underlying sands, increasing the toe berm and installing a low permeability slurry wall, MCD was able to improve the dam with minimal construction interruptions at a reasonable cost.

Slurry walls have been used in similar applications on dam and levee projects across the United States. They provide a cost effective method of increasing cut-off without compromising the strength of the existing dam embankment. The use of slag-cement-bentonite slurry in the United States is being used more frequently and has resulted in improved backfill characteristics and decreased project costs.

REFERENCES

Contract Documents for Taylorsville Dam Crest Improvements, January 2004

Brayman Environmental Inc.'s Workplan, March 17, 2004; and Construction Completion Report, June 30, 2004

Holcim GranCem Cement Product Data Sheet

Miami Conservancy District's Website, www.miamiconservancy.org