PREGROUTING EFFECTS ON CONSTRUCTION OF CUTOFF WALLS FOR DAM REMEDIATION PROJECTS: AN OVERVIEW AND ANALYSIS OF CASE HISTORIES

Pooya Allahverdizadeh[1]
D. V. Griffiths[2]
Gregg Scott[3]
David Paul[4]

ABSTRACT

For at least fifty years, cutoff walls have been used as a solution for seepage problems in earth dams, and in a few cases, pre-grouting is also used to secure the cutoff wall construction process. In this paper, thirteen North American dams which have been remediated against potential or existing seepage problems using cutoff walls have been summarized. The project outline, seepage issues, geological properties and cutoff wall construction technologies have been reviewed and summarized concisely for some important projects. Dam remediation cutoff wall projects both with and without pregrouting are included. The purpose of this paper is to evaluate the different parameters and circumstances affecting cutoff wall projects, and provide guidance on potential benefits or disadvantages of including pregrouting in future dam foundation remediation projects. The work described forms part of a broad USACE study that will be published as an EM on Seepage Control Cutoffs for Dams and Levees.

INTRODUCTION

Many of the earth dams in the United States were constructed during the 1930's and immediately after World War II. Nowadays fewer new dams are being constructed in United States; and thus there is less need than in past years for construction of cutoff walls and grouting design services for new dams. However, there is an increasing need for those servicing in conjunction with the maintenance, repair, or modification of existing dams and levees. Even the remote potential for catastrophic failure of one of these dams due to piping creates a need for effective and practical remedial seepage control solutions (Weaver and Bruce (2007), Kahl et. al. (1991)).

[1] Colorado School of Mines, Golden, Colorado, pallahve@mines.edu.
[2] Colorado School of Mines, Golden, Colorado and the CGSE University of Newcastle, NSW, d.v.griffiths@mines.edu,
[3] Risk Management Center, USACE, Golden, Colorado, gregg.a.scott@usace.army.mil.
[4] Risk Management Center, USACE, Golden, Colorado, david.b.paul@usace.army.mil.

One solution is to install a deep, concrete diaphragm wall along the axis of an earth dam. Such cutoff walls have been successful in elimination or greatly reducing seepage through embankments and dikes at their contact with permeable bed rock, through the permeable soils, and within the bedrock itself (Bruce et. al (2006)).

In some cases, grouting before cutoff wall construction (pregrouting) has been included, although there are some successful cutoff wall construction projects in which pregrouting was not included. Pregrouting, in most cases, has been performed to reduce the construction risks during excavation and/or concrete placement. The grout is usually injected in two or more lines to create a grout curtain in the both sides of the cutoff wall projected location along the dam.

This paper presents a summary of data relating to major seepage remediation projects using cutoff walls. In order to study the effect of pregrouting on cutoff walls construction, details of thirteen of these major projects have been presented. Cases both with and without pregrouting have been included.

CUTOFF WALL CONSTRUCTION WITHOUT PREGROUTING

In this section, six major dam foundation rehabilitation projects without pregrouting are presented. Most of the projects were completed in late 1980's and 90's. Successful performance of these dams, with no serious construction problems or slurry loss, led to similar projects proceeding without pregrouting.

Navajo Dam, NM (1987-1988)

- Navajo Dam is a zoned earth-fill embankment with a height of 402 feet and a crest length of 3,648 feet.
- The bedrock is sedimentary in origin. The rock consists of sandstones, which are moderately to highly permeable, with intervals of siltstones and shales. Joints and cracks are present in both abutments.
- Immediately after filling of the dam in 1963, seepage could be observed exiting from open joints and cracks along the tops of shale seams, and weeping from the sandstone bedrock.
- A concrete diaphragm wall on the left abutment with a maximum depth of 300 feet and width of 40 inches was constructed at a total cost of $9,756,000.
- During the construction, four slurry losses occurred. Slurry loss in the worst case was estimated at 100 to 200 cubic yards. The slurry loss was stopped through a combination of dumped sand and grouting (Davidson, L. 1988).

Beaver Dam, AR, (1990 - 1995)

- Beaver dam is a concrete gravity dam with an earth embankment and three saddle dikes located in northwestern Arkansas.
- The dam is located on relatively flat lying sedimentary rocks with limestone.
- In the late 1960's, seepage began to appear downstream of one of the dikes. Muddy flow and small sand boils covered a couple of hundred feet downstream of the dike.
- Construction of a concrete cutoff wall of width 2 feet and depth varying from 80 to 185 feet was completed using a combination of Hydrofraise and secant piles.
- Historical seepage exits all dried up with completion of the cutoff wall. The total cost of the cutoff wall construction for Beaver Dam was $30,200,000 (Harris, M ()).

Meeks Cabin Dam, WY (1993-1994)

- Meeks Cabin dam is located 2 miles north of the Utah-Wyoming state line with a maximum height of 174 feet and a crest length of 3200 feet.
- The dam site is located in a glacial valley. Glacial tills contain pockets of outwash deposits including boulders, cobbles, sand, and gravel which is very permeable.
- Seepage through the left abutment occurred after the reservoir was first filled. Sink holes appeared in the reservoir just upstream of the upstream toe of the dam. This seepage caused slope instability on the downstream side of the dam.
- A plastic concrete cutoff wall with a total cost of $6M, with depth ranging from approximately 130 feet to 170 feet was constructed. The minimum width of the panels was 36 inches which was also the width of the cutter.
- After construction of the cutoff wall, the seepage flowing into the downstream flumes decreased to 4 GPM from 400 GPM (Galiardi, J. and Routh, R. 1993).

Twin Buttes Dam, TX (1996-1999)

- Twin Buttes dam is 8.2 miles length and was constructed about 60 miles southwest of San Angelo, Texas.
- The foundation of the dam consisted of a fine-grained clay deposit which overlay alluvial gravels. Beneath the alluvial gravel was bedrock, which was a Permian deposit consisting of interbedded sandstones and shales. The degree of cementation and permeability of the alluvium was difficult to predict or model accurately.
- The combination of the lack of a cutoff trench in the central reach and exposure of the alluvial gravels to the reservoir led to significant seepage underneath the dam.
- A slurry trench was constructed, 4 miles long, 1.4 million square feet, and up to 100 feet deep.

- It was determined that a soil-cement-bentonite could be utilized to provide an effective cutoff wall meeting the necessary strength and permeability requirements (Dinneen and Sheskier 1998).

Hodge Village Dam, MA (1997-1999)

- Hodge Village Dam located in Oxford, Massachusetts, has a total length of 2140 feet and a maximum height of 54.5 feet.
- The dam was constructed mostly on gravels and sands with some boulders. Glacial outwash deposits, containing numerous interlaced open work gravel and cobble strata were also present.
- The history of repeated seepage problems, after dam construction, lack of adequate seepage control features, highly pervious foundation materials, open gravel strata, and extensive potential downstream flood impacts, resulted in construction of a full depth cutoff wall.
- A trench cutter system was used to excavate a trench along the dam into the bedrock. During the cutoff wall excavation no significant slurry loss or damage to the dam structure was reported (Vance ()).

A. V. Watkins Dam, UT (2008)

- A. V. Watkins Dam, located 10 miles north of Ogden, Utah, is a zoned earthfill structure, more than 14 miles long and approximately 36 feet high.
- Soil underlying the dam is Lacustrine peposits consisting of gravel, sand, and clay deposited in the fluctuating waters.
- In November 2006, A. V. Watkins dam nearly failed because of piping, sinkholes, and internal erosion of its foundation soils.
- A cement-bentonite cutoff wall was selected to provide the most impermeable, ductile and cost-effective solution.
- The contractor experienced some difficulty getting through the hardpan. Chipping off small pieces (12 to 18 inch) of the hardpan was considered instead of prying it up from underneath. Some equipment failures occurred (Bliss and Dinneen 2008, Demars et al. 2009).

CUTOFF WALL CONSTRUCTION WITH PREGROUTING

In this section, seven dam foundation remediation projects using cutoff walls and pregrouting have been presented. Most of these projects were completed in 2000's.

Mud Mountain, WA (1988-1989)

- Mud Mountain Dam is located in southeast Enumclaw, Washington with a height of 120 m and a crest length of 213 m.
- The dam is constructed across a narrow canyon with steep (near vertical) rock walls. The rock in the canyon floor and walls is a moderately hard to hard andesitic volcanic agglomerate, consisting of angular blocks of andesite within a welded tuff and ash matrix.
- In early 1980s, numerous defects throughout the core due to increased seepage were observed.
- A cutoff wall was constructed using two types: Type I was for a shallow wall on both shoulders of the canyon, where standard cutoff wall techniques could be used, and type II was used in the deeper areas of the canyon and its steep. The type II wall was constructed using primary and secondary elements.
- Because of anticipated deformations under pool loading, plastic concrete was used for the cutoff wall.
- During the excavation of the panels, several slurry losses occurred and several cracks could be seen in the excavation sidewalls. Total loss of slurry during the excavation approached 3,800 m^3, with individual losses exceeding 700 m^3.
- Compaction and recompression grouting was designed to fill pre-existing cracks and reduce the possibility of the Hydrofraise getting trapped. During subsequent construction of the deep cutoff wall, one minor slurry loss occurred (Eto et. al. 1991).

Walter F. George Dam, AL (1981-1985, 2001-2003)

- The Walter F. George Dam consists of a 1496 foot long concrete structure housing a spillway and two earthen wing dams with crest elevations at 215, and a maximum height of about 68 feet.
- Foundation rock for the Walter F. George Dam is a three-layer Clayton formation consisting of limestone, shell fragments and sandy soils.
- Since impoundment of the reservoir, the seepage occurred through alluvial sand and gravel, concentrated by some cavities occurring near the top of the limestone bedrock. Later, sinkholes were also observed adding to the seepage problems.
- A cutoff wall was initially constructed between 1981 and 1985 which turned out to be ineffective. The total cost of this rehabilitation was about $11 million.
- A grouting program was completed before starting a second cutoff wall construction project.
- A 1,232 foot long concrete secant wall was built in the water. This wall consisted of 469 overlapping 52 inch diameter concrete shafts, spaced 33 inches center to center. This construction was installed an average of 10 feet in front of the dam.
- The cutoff wall on the other side was installed with the hydromill placed on the crest of the dam. The slurry wall was built using primary and secondary panels.

- The total cost of construction of the second cutoff wall was about $50 million which was completed in 2003 (Ressi di Cervia, A. 2004, Simpson et. al. 2006).

Mississinewa Dam, IN (2001-2005)

- Since the construction of the Mississinewa Dam, several seepage remediation projects have been completed, e.g. installation of relief wells, sand drains, seepage blankets, and a grout curtain.
- The bedrock of the Mississinewa valley is glacial, and exhibits a weathered top, incised valleys, and solutioning on joints and bedding planes.
- In 1988, significant and abnormal crest settlement was noticed along the right abutment. Piping into a karst feature was the most likely cause of the settlement.
- A concrete panel-wall cutoff consisting of 427,358 square-feet of concrete, with depths ranging from 147 to 230 feet was chosen as the best permanent solution for the seepage problem of Mississinewa Dam.
- A 100 foot long test section was constructed to evaluate the construction method and to anticipate any potential problems. During the excavation of this section, a sudden slurry loss occurred. Approximately, 30,000 gallons of slurry was lost leading to the simultaneous collapse and loss of the panels. Slurry loss occurred at the same depth during the re-excavation of the panel.
- Two grout lines, one on the upstream and another on the downstream of the dam, with a maximum depth of 215 feet were installed. Additional grout lines were added in the critical areas.
- During the cutoff wall construction, after the grouting program, there were no slurry losses. The total cost of the Mississinewa Dam foundation project was $49.2 million of which $12 million represented the cost of the pregrouting (Brosi et. al. 2006, Schaefer 2011).

Bear Creek Dam, AL (2007-2008)

- Bear Creek Dam is a 1,385 foot long homogenous fill embankment dam in southwest Franklin County, Alabama, with a crest elevation of 618 feet and a maximum height of 85 feet.
- The geologic cross section of the foundation consists of shale and limestone. During the initial construction, numerous solution features and voids were encountered and backfilled, large volumes of extremely weathered rock were removed, and large grout takes were common.
- Although there were several grouting programs initiated after dam construction, in December 2004, numerous boils, small sinkholes, and a new seepage path exiting from the toe were observed due to a high headwater event.

- A composite seepage barrier consisting of two grout lines, 10 feet apart, of opposing holes inclined 15° from the vertical, and localized positive cutoff panels was constructed to eliminate the potentially destructive seepages flow through the foundation.
- High Mobility Grout (HMG), for relatively small, open features and fractures, and Low Mobility Grout (LMG) for large voids and subsurface flows were employed.
- Since completion of the composite seepage barrier at Bear Creek Dam, there have not been any boils or muddy flows observed, and no additional downstream sinkholes have developed (Charlton, J. E. et. al. 2010, Ginther and Charlton 2009).

Clear Water Dam, MI (2004 – Present)

- The crest length of the Clear Water Dam is 4225 feet with a maximum height of 154 feet. The structure is an earth fill embankment with a core of clays and silts obtained from the river bed alluvium.
- Below the residual clays of the embankment there exists a partially weathered zone of dolomite which is quite pervious. Below this stratum, the fresh karstic dolomite lies. During the construction of the core cutoff trench, two wide joints were found in the bedrock and were treated.
- Seepage flows have been observed at the higher pool levels since the dam was first filled. The first sinkhole was observed in January 2003.
- Two grout lines completed in Oct 2009 with a depth of 110 feet were installed into the rock. Over 6.5 million gallons of grout were placed.The final cost of grouting was $81.5 million.
- Construction of a deep concrete cutoff wall was selected by the Corps for long-term risk reduction. The wall is still until construction. The rock mill method is used to construct the composite seepage cutoff wall/grout curtain 4200 feet long and keyed 40 feet into rock. The total cost of the cutoff wall construction is estimated to be about $93 million (Bradley et. al. 2008, Harris 2010).

Wolf Creek Dam, KY (1975- 1981, 2007- present)

- Wolf Creek Dam, located on the Cumberland River in south central Kentucky, is 5,736 foot long and 258 feet high with a combined earthen and concrete structure.
- The Mississippian Plateau, located under the Wolf Creek Dam and its impoundment, consists of limestone characterized by tens of thousands of sink holes, sinking streams, streamless valleys, springs, and caverns.
- During the initial excavation of the cutoff trench, numerous solution channels, caves, and small tunnels were uncovered. Several small tunnels and caves were filled with stratified clayey silt.

- In 1968, muddy flows in the tailrace and two sinkholes near the downstream toe of the embankment signaled serious reservoir seepage problems. In spite of grouting, the seepage problems were not solved.
- A concrete cutoff wall with grout curtains was constructed in 1979, however persistent and increasing wet areas and wet material at depth in the embankment and foundation confirmed that serious problems still existed.
- In late January 2007, the USACE funded a $584 million remediation program to bring the dam back to a full operating condition. Construction of a deeper and longer concrete cutoff wall was started.
- Due to the high risk of slurry loss during the cutoff wall construction, a pregrouting program was agreed before starting the cutoff wall construction. The design concept was to use HMG under pressure to creat two grout lines seperated by 24 feet, with an inclination of 10 degree from vertical.
- The secant pile method is used to construct the cutoff wall. In some areas of the barrier wall, another construction method was utilized called the Combined Barrier Wall Method (CBWM) which consisted of constructing the wall with a combination of RCD piles and Hydromill excavated panels (Lopez and Haskins 2011, Santillan and Salas 2012, Zoccola, M. et. al. 2012).

Center Hill Dam, TN (2008 - Present)

- Center Hill Dam, located about 50 miles east of Nashville, has a maximum height of 226 feet and a total length of 2,160 feet (concrete: 1,382 and earth: 778 feet).
- The main embankment foundation consists of alluvial and residual soils. The residual soils consisted of yellow silty clay, with approximately 20 percent weathered limestone and chert fragments. Sinkholes, caves, solution widened joints, sinking streams and other karstic features were observed on the Center Hill Dam site.
- Since its original construction in the 1940's, seepage problems through the Center Hill Dam's karstic limestone foundations, has cost millions of dollars in monitoring, subsurface investigation and grouting. Despite past grouting programs, seepage and sinkholes still could be seen downstream of the dam.
- Two grout lines, 24 feet apart with a total cost of $87.1 million was completed in 2008-2010 at the main dam embankment, groin and left rim. Over 1.5 million gallons of grout were placed while drilling through approximately 10 miles of overburden and 40 miles of rock.
- The main dam embankment barrier with a total cost of approximately $106 millions is currently scheduled for completion in June 2014 (Brimm 2010, USACE 2012).

CONCLUDING REMARKS

Concrete Cutoff walls are essential for providing effective, long term seepage control through soil and rock masses, especially in the presence of karstic materials which can be eroded under working conditions, with the potential for progressively serious seepage losses. During recent decades, dam foundation grouting has been performed to seal open geological defects and reduce seepage in dam foundations. Nowadays, pregrouting is being considered as one of the most efficient alternatives to reduce the construction risks associated with cutoff walls.

As described in this paper, there are some successful dam foundation remediation projects where pregrouting reduced the risk of construction and slurry loss. The Mississinewa and Mud Mountain Dam project are among the best examples of the benefits of pregrouting.

In general, the main advantages of pregrouting can be summarized as below.

- Provides additional detailed and thorough information about the site geology.
- Pretreats the rock mass to prevent sudden, massive slurry losses during subsequent cut-off wall excavation.
- Stabilizes the soil around the excavation area of the cutoff wall and reduced the risk of losing expensive excavation equipment.
- Water losses during grout drilling could be a warning for slurry losses to come during cutoff wall construction without pretreatment.

It can be noted however, that there are numerous successful projects from the late 90's and early 2000's where pregrouting was not used. The two main disadvantages of pregrouting are cost and time. Projects mentioned in the first part of this paper are evidence that grouting is not always necessary, however the decision to pregrout must be based on cost-risk assessments, based on site specific information, experience and engineering judgment.

ACKNOWLEDGEMENT

The work presented in this paper was made possible through a grant to the Colorado School of Mines from the USACE Risk Management Center in Denver Colorado.

REFERENCES

Bliss, M. and Dinneen, E. A. (2008)."Emergency remedial actions at A. V. Watkins Dam" 28th Annual USSD Conference, Portland, Oregon, April 28 – May 2.

Bradley, J., Bruce, D., Ferguson, K., Poulos, S., Talbot, J., and Vrymoed, J. (2008).”Clearwater Dam Consensus Report” External Peer Review of DSAC-1 Projects.
Brimm, R., (2010).”Center Hill Dam seepage and remediation” US Army Corps of Engineers, Nashville District.

Brosi, B. E., Flaherty, T., Henn, K. E., and Schaefer, J. A. (2006).”Geotechnical and concrete materials completion report for installation on underground concrete cutoff wall, Mississinewa Dam” US Army Corps of Engineers, Louisville District.

Bruce, D. A., A. Ressi di Cervia and J. Amos-Venti. (2006)."Seepage remediation by positive cut-off walls: A compendium and analysis of North American case histories" Canadian Dam Association Conference, September 30 - October 5, Quebec City, Quebec.

Charlton, J. E., Ginther, C. H., and Bruce. D. A. (2010)” Comprehensive foundation rehabilitation at Bear Creek Dam” Environmental and Engineering Geoscience, Vol 16, No 3, pp 211-27.

Davidson, L. (1988).”Navajo Dam modification” USCOLD, International Commission on Large Dams, No 88, Denver, CO.

Demars, B., Pledger, C., and Barret, B. (2009).”A. V. Watkins Dam modification: cement-bentonite slurry cutoff wall” USSD, 29th Annual Meeting and Conference in Nashville, TN,

Dinneen, E. A., and Sheskier, M. (1998)”Design of soil-cement-bentonite cutoff wall for Twin Buttes Dam” Bureau of Reclamation, Water Operation and Maintenance Bulletin, No 184.

Eto, H., Satter, M. V., and Forbes, K. L. (1991).”Mud Mountain Dam seepage control cutoff wall” US Army Corps of Enginners, Construction Foundation Report, White River, Washington.

Galiardi, J. and Routh, R. (1993) “Geotechnical modifications at Meeks Cabin Dam”, ASCE Specialty Conference on Geotechnical Practice in Dam Rehabilitation, North Carolina State University, Raleigh, NC, April 25-28, pp. 755-769.

Ginther, C. H. and Charlton, J. E. (2009)”Comprehensive foundation rehabilitation at Bear Creek Dam” 29th Annual USSD Conference, Nashville, Tennessee, April 20 – 24.

Harris, M. (2010).”Clearwater Dam major rehabilitation project” US Army Corps of Engineers, Little Rock District.
Harris, M. (). “Beaver Dam cutoff wall” US Army Corps of Engineers, Dam Safety Course.

Kahl, T. W. , Kauschinger, J. L. and Perry, E. B. (1991).“Plastic concrete cutoff walls for earth dams” Department of the Army, US Army Corps of Engineers.

Lopez, J. and Haskins, T. (2011)”Wolf Creek Dam foundation remediation: Barrier wall installation methods” USACE Infrastructure Conference, Atlanta, GA.

Ressi di Cervia, A. (2004).”Construction of the deep cutoff at the Walter F. George Dam” ASCE, GeoSupport 2004, pp 530-534.

Santillan, F. and Salas, P., (2012).”Wolf Creek Dam foundation remediation an innovative successful solution” Dam Safety Conference, Denver, CO.

Schaefer, J. (2011).”Mississinewa Lake Dam internal erosion case history” US Army Corps of Engineers, Louisville District.

Simpson, D. E., Phipps, M., and Ressi di Cervia, A. L. (2006).”Construction a cutoff wall in front of Walter F. George Dam in 100 feet of water” Hydro Review, Vol 25, No 1, pp 42-51.

Vance, M. A. ().”Hodge Village Dam major rehabilitation program” US Army Corps of Engineers, New England District.

Weaver, K. D. and Bruce, D. A. (2007).“Dam foundation grouting” ASCE Press.

Zoccola, M., Haskins, T., Brown, M., Walker, A., and Bomar, J. (2012).“Wolf Creek Switchyard investigation” US Army Corps of Engineers, Nashville District.

(2012).”Center Hill Dam supplement to 2006 major rehabilitation evaluation report” US Army Corps of Engineers.