Paper presented at ICOLD conference 2018

COMMISSION INTERNATIONALE
DES GRANDS BARRAGES

VINGT-SIXIÈME CONGRÈS DES
GRANDS BARRAGES
Autriche, juillet 2018

REHABILITATION OF THE CENTER HILL EMBANKMENT DAM

Peter Banzhaf

Head Dam Services, BAUER SPEZIALTIEFBAU GMBH

GERMANY

1. INTRODUCTION

The US Army Corps of Engineers (USACE) in the USA is, amongst others, responsible for the surveilling and maintaining of dams. One of these structures is the Center Hill Dam in Tennessee, built in the 1940ies as a combination of a concrete gravity dam and a connected embankment dam. The structure is used for flood control of the Caney Fork River up to the town of Nashville and to generate electricity with a associated power station.

The subsoil mainly consists of karstified limestone. The karstification resulted in water conductivity below the dam soon after the filling. Several grouting measures were not able lastingly sealing these permeabilities. At the beginning of this century, not only damp spots occurred at the embankment dam but also major sinkholes opened up at the left abutment.

Subsequent examinations led to the decision to install a permanent concrete cutoff wall as a sealing-barrier in the until then coreless embankment dam and to permanently tie this cutoff wall to the existing concrete gravity dam. Due to dam safety reasons, an encasement wall for temporary use was specified to prevent uncontrolled trench collapse in case of sudden slurry loss into undetected voids during execution of the cutoff wall. Within this encasement wall, the permanent barrier wall was installed.

Beginning in 2011, BAUER Foundations Corp. (BFC) was tasked by the USACE with the installation of a seepage barrier/cutoff wall at the Center Hill Dam Foundation Remediation project.

Fig. 1 Site overview 2014 – Slurry Plant, BG 50 Drill-rig and MC128 with BC50 Hydrocutter

The executed features of work include the installation of two walls. The first wall, an encasement wall, extends vertically through the clayey embankment and is embedded into the underlying bedrock to provide embankment stability during the construction of the second wall, the barrier wall. The encasement wall is constructed of overlapping panels outstanding 2.25 m wide and up to 64 m deep. The second wall is the seepage barrier and provides a continuous wall, nominally 0.6 m wide, consisting as well of overlapping panels. The barrier wall extends through the concrete encasement wall into the underlying bedrock and is up to 93 m deep. BAUER BC40 and BC50 hydrocutters (Fig. 1) mounted on BAUER MC96 and MC128 foundation cranes were used to perform the majority of the works. Excavations were performed using bentonite slurry (encasement wall) and water (barrier wall) as supporting fluid and concrete was poured with the tremie method. Adding to the challenges, the project had to be executed in an environmentally sensitive area.

2. GEOLOGY AT THE DAM

Based on the Geotechnical Baseline Report (USACE 2011), the right rim of the Caney Fork River is characterized by a steep rock slope, while the left rim rises more gently about 70 m from the riverbed to the crest of the earthen embankment. The earthen embankment section of the dam wraps around the left end of the concrete dam assembled by twenty-nine monoliths and extents about 260 m at the crest to its end at the intersection with the left rim. The earthen embankment consists of compacted fill made of impervious silty clay and clayey silts.

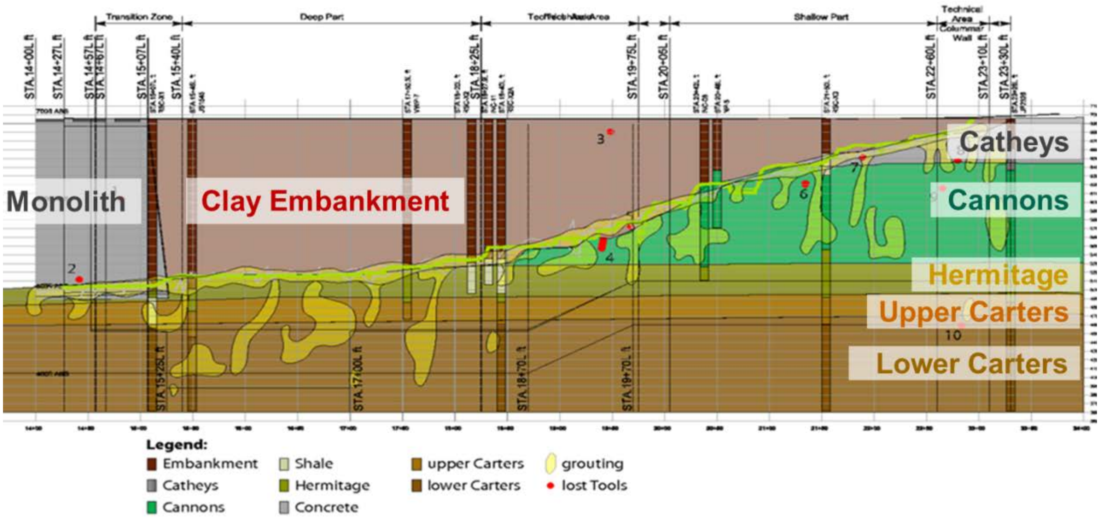

Fig. 2 Geological profile in the wall alignment including areas of high grout takes (upstream view)

The embankment was constructed directly on the existing overburden after topsoil was stripped. The alluvium is underlain by the flat lying Catheys, Cannon and Hermitage formations, with the Hermitage being underlain by the non-daylighting Carters and Lebanon formations (Fig. 2). The Cannon formation is massive bedded, all other formations are thin bedded or medium to thin bedded. The unconfined compressive strength of the rock was up to 220 MPa in the Cannons with formation averages ranging between 50 and 190 MPa.

Physical evidence of karst is visible throughout the site including disappearing streams, sinkholes, caves and extensive solution features. Bedding planes and vertical fractures have the potential to form interconnected systems of open features. These systems are especially threatening if they reach the embankment, creating piping features in the soil rock interface and potentially causing an erosion failure of the embankment.

3. PRIOR REMEDIATIONS

A grout curtain was installed during the original construction of the dam. Later, after several potentially unsafe conditions were detected in the late 1970's, a further grout curtain was installed about 3 m downstream of the embankment centerline through the embankment into the bedrock from 1982-1984. Finally, in order to reduce seepage through the bedrock and in order to allow for a safe

Barrier Wall construction, grout curtains were installed 3.6 m upstream and downstream of the wall alignment from 2009 to 2010.

4. REMEDIATION BY A CONCRETE BARRIER WALL

4.1. ENCASEMENT WALL FOR DAM SAFETY

Trenches excavated during barrier wall construction had the potential to intersect open solution features and connect the slurry-filled trench with the reservoir or the tail water and in this way cause a sudden and substantial loss of fluid. Apart from the environmental impact, such a fluid loss could destabilize the excavation trench and therefore put the dam embankment at risk. To address such a risk, an encasement wall was built that extends from the crest of the dam down to a minimum of 0.6 m into the foundation bedrock. In this configuration, the encasement wall would support the embankment by bearing earth and water pressure in the event of trench fluid loss, protecting both the embankment and the excavation equipment. The encasement wall was installed using three different approaches (Fig. 3).

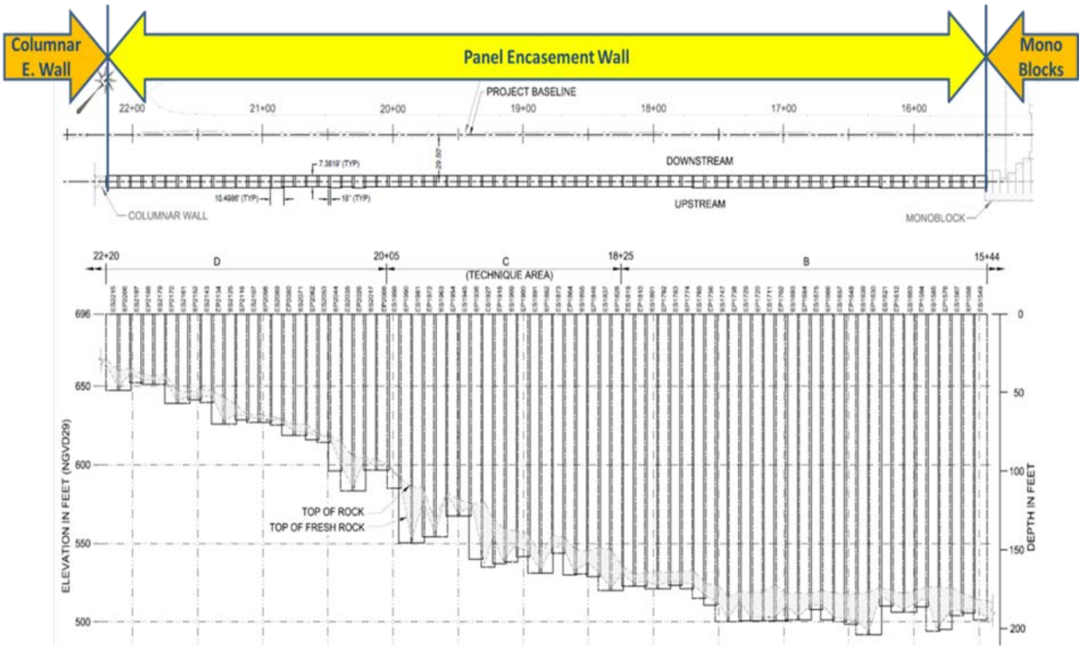

Fig. 3 As build Encasement wall panel layout.

4.2. Columnar Encasement Wall

In the shallow section at the left rim, about 36 m long, the encasement wall was specified and designed as a columnar wall consisting of 2.3 m diameter and up to 11 m deep unreinforced concrete columns. The columns were excavated under dry conditions using fully cased Kelly drilling by a BAUER BG 50, the most powerful rotary drilling rig made by BAUER at the time, capable of delivering a maximum torque of 468 kNm.

4.3. Mono Blocks

In order to tie-into the existing concrete dam monolith at the upstream face, the barrier wall runs parallel to the existing dam for approximately 14 m, which resulted in a section of the encasement wall in close proximity to the sloped upstream side of the concrete dam. This creates a wedge of embankment soil between the barrier wall and the existing dam. BFC decided to fully replace this wedge of soil with a special encasement wall. This was achieved by a series of seven, 2 m wide, 5.5 to 8.2 m long and up to about 60 m deep multi-bite panels called mono blocks, which touch each other along the long side (Fig. 4).

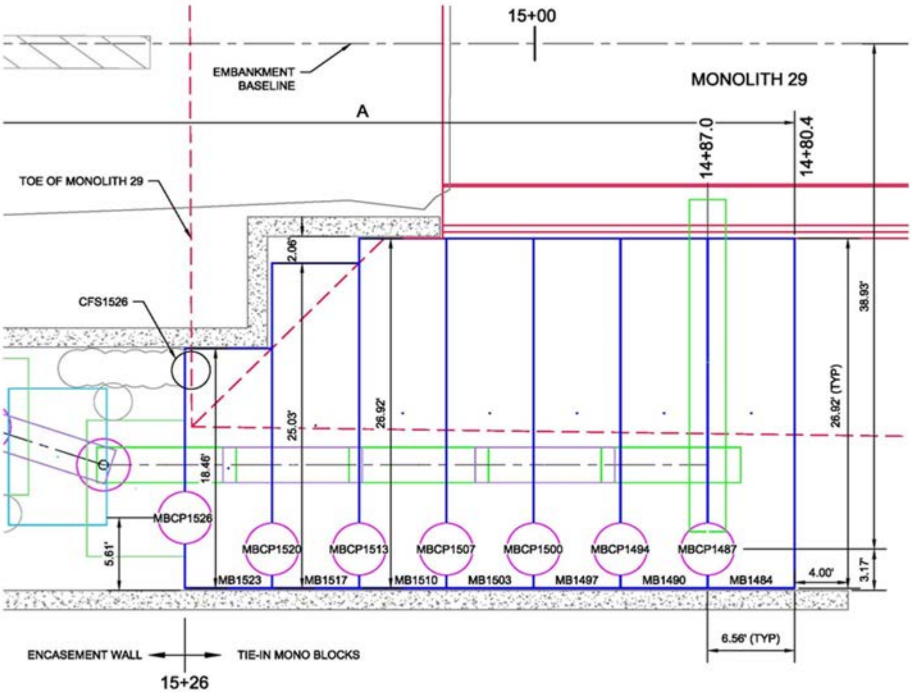

Fig. 4   Layout of Mono blocks

4.4. Panel Encasement Wall

The 210 m long main section of the encasement wall was excavated in 3.2 m long panels reaching depths of over 60 m (Fig. 3). Each primary panel was pre-excavated using a hydraulic grab mounted on the MC 96. After pre-excavation of the secondary panels by the onsite available BG50, the element was fully excavated using a BC 50 hydrocutter mounted on a BAUER MC 128 foundation crane. All excavations were performed under bentonite slurry-support. Concrete was placed via two tremie pipes per panel.

The technical specifications (USACE 2011) [2] called for tolerances of 0.25% maximum panel verticality deviation, maximum six degrees panel rotation (twist) and a minimum 0.15 m overlap between primary and secondary panels throughout the full width and depth of the wall. To achieve these goals the cutter needs to be steered, which requires both precise information about the actual position of the tool with respect to design and steering capabilities.

5. BARRIER WALL INSTALLTION

5.1. Columnar Barrier Wall

BFC's design consisted of twelve 1.22 m diameter primary columns up to 57.3 m deep, and eleven 1.37 m diameter secondary columns up to 56.7 M deep. Downhole water hammers, Wassara W150 and W200, in conjunction with a Klemm KR 806-4 drilling rig were used to drill the pilot holes. All but two pilot holes (maximum verticality 0.35%) achieved the verticality tolerance of 0.25%. Due to the active steering during drilling by means of a bent sub, a piece of drill string with a slight angle to put the hammer at an angle to the borehole axis, the maximum deviations out of plumb were observed above final depth. After final excavation, the pilot holes were tremie-grouted with flowable fill.

BFC used rock augers and drilling buckets, both equipped with stingers (extended pilot bits) to follow the pilot hole, to excavate the columns. Drilling was performed dry at the top and under water at depth with the BG 50. One tremie pipe was used to place the concrete. Geometry surveys were performed using BAUER's proprietary Drilling Inclination System (DIS) and the Koden and SoniCaliper methods with the Koden data being used as as-built data set. Two secondary elements had to be reamed to a diameter of 1.45 m to meet the 0.61 x 0.15 m overlap requirement at all investigated 1.5 m depth intervals.

5.2. Panel Barrier Wall

In their proposal, BFC followed the specifications [2] and proposed a hybrid wall configuration (primary columns and secondary diaphragm wall panels). The columns in the USACE plan were designed to provide additional wall thickness at the panel overlaps due to USACE concerns that the required vertical and rotational accuracies would be difficult to achieve at more than 90 m depth. However, based on the ability of the BAUER hydrocutter to excavate the hard rock and maintain excellent verticality as demonstrated at the panel encasement wall, BFC made a value engineering cost proposal (VECP) to eliminate the columns (red circles in Fig. 5) without increasing the nominal overlap between the barrier wall panels. The government accepted the VECP.

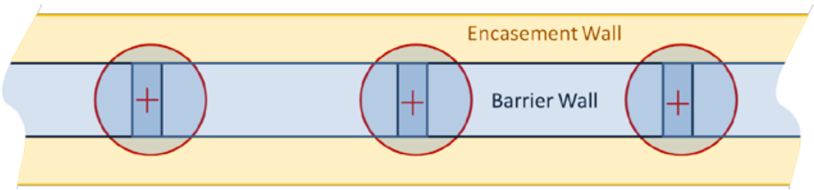

Fig. 5 Hybrid wall as specified

The barrier wall was excavated through the encasement wall concrete into the foundation rock to depths between 44 m and 93 m using two BAUER Hydrocutter. Water was used as trench support and transport fluid. Concrete was again placed using two tremie pipes. Cores and borehole images showed that the use of water as fluid in conjunction with a rigorous joint cleaning procedure allowed for an excellent bond between the primary and secondary panels.

6. TIE-IN CONNECTION TO THE CONCRETE DAM

6.3. Task to connect to the Concrete Dam

Specified was to construct a positive, continuous, full height, water-tight, connection between the encasement/barrier wall and the concrete dam [2]. The tie-in had to accommodate the sloping surface of the concrete monoliths providing a seal along the monolith to prevent floodwaters from circumventing the joint seal with the monolith. A minimum embedment of six (6) inches and a maximum embedment not exceeding four (4) feet had to be met.

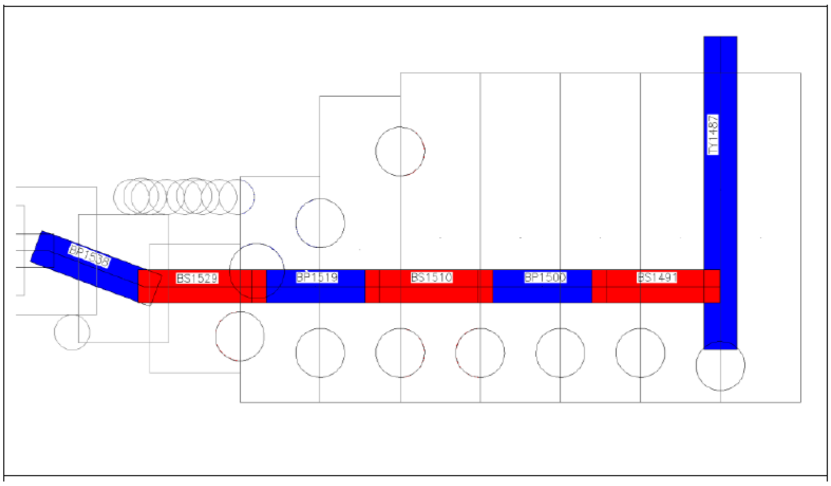

Fig. 6 Layout of barrier wall panels along the monolith 29 with perpendicular tie-in-panel element TY1487.

After installation of the special encasement wall mono blocks adjacent to each other at the upstream side of the existent concrete dam (see chapter 4.3), the joints between individual mono blocks were closed by closing piles to assure the specified function of the encasement wall.

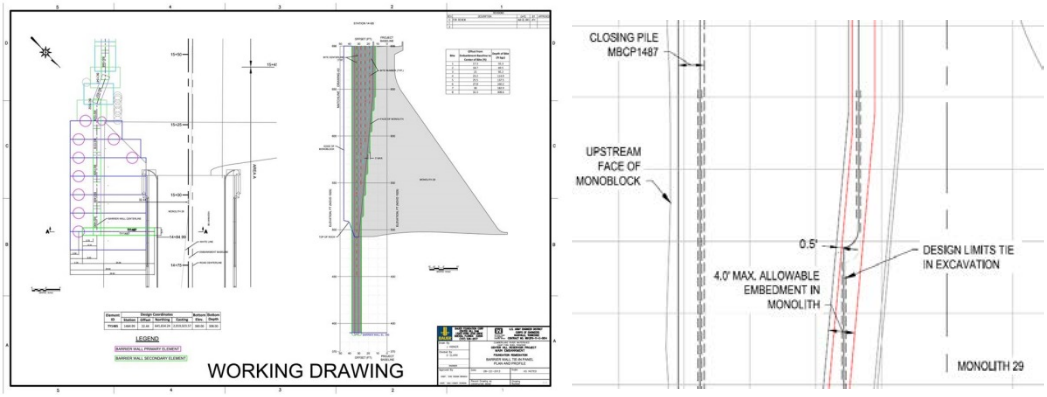

Fig. 7 Tie-in detailed design by BAUER

During the installation of the mono blocks (MB) and mono block closing piles (MBCP) construction data and quality control data had been examined and after acceptance the elements excavated and concreted. Based on these construction and quality control data and the barrier wall construction practices as proven during the installation of other elements in the main barrier wall earlier accepted to be sufficient, permission was granted to install the six typical barrier wall panels (Fig. 6) in the area along the concrete dam for the following reasons:

- All mono blocks and mono block closing piles excavations have held bentonite slurry or water without appreciable fluid loss during their construction.
- Video footage taken in mono block closing pile excavations of the mono block-to-mono block joints, and the rotated cutter panel-to-mono block joints indicate relatively tight joints between adjacent elements.

- Data from verification boring indicate homogeneous concrete from top to bottom, and a clean concrete-to-rock contact.

Only the tie-in element TY1487 was constructed differently.

The tie-in element TY1487 perpendicular to the concrete dam (Fig. 6) was installed as a primary element with a trench cutter using several bites. The first bite was furthest away from the concrete monolith and was cut to the foundation level of the concrete dam. The cutter was controlled lowered to defined depths cutting into the concrete of the monolith. Guidance was assured by the standard cutter guide frame at the top. After cutting the other bites from top to down into the monolith, finally at the position of the first bite, the cutter was lowered and excavated to the specified final depth. Due to this sequencing, the cleaning of the bottom of the element TY1487 was assured.

7. SUMMARY

The risks associated with failure of Center Hill Dam were significant and urgent which prompted the USACE to address this risk producing a remediation program of unprecedented scope with stringent specification requirements. Execution of the remediation provided many lessons learned for the USACE and BFC and the project achieved great technical success.

In spite of strict specification requirements, BFC met or exceeded the required plans and specifications with a value engineering approach that also resulted in significant cost savings to the government. BFC was able to achieve this using innovative techniques and equipment for diaphragm wall construction that allows for extremely accurate excavations in very challenging geologic conditions.

It was observed that for the steered hydrocutter excavation the maximum deviations out of plumb – like the maximum panel rotations – typically occur well above final excavation depth since corrections are made during drilling or excavation. The maximum deviation is not a function of depth but the system-inherent result of survey accuracy and steering capabilities. For this reason, the verticality tolerance for deep cut-off walls installed with steerable techniques should be specified as an absolute value similar to rotation and not as a percentage of depth.

The challenging tie-in connection to monolith 29 of the existent concrete dam executed successfully proved, that such connections are feasible. Connecting perpendicular was required due the highway running across the dam. Contractor detailed designed and execution achieved the specified task.

8. REFERENCES

[1] ARNOLD M., FAULHABER B.. Cutoff Wall Construction for Center Hill Dam Foundation Remediation, 2017.

[2] USACE (United States Army Corps of Engineers). Center Hill Foundation Remediation, Solicitation, Amendments, and Technical Specifications, 2011.

9. KEYWORDS – ENGLISH

CUTOFF WALL, CONCRETE DAM, DIAPHRAGM WALL, EMBANKMENT DAM, TIE-IN

10. KEYWORDS – FRENCH

MUR PARAFOUILLE, BARRAGE EN BETON, PAROI MOULEE, BARRAGE EN REMBLAI, LA VISÉE