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SELF HARDENING SLURRY WALL INSTALLATION BY HYDROMILL AT THE HERBERT HOOVER DIKE – AN INNOVATIVE SOLUTION

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ABSTRACT

In 2007 the US Army Corps of Engineers classified the Herbert Hoover Dike in Florida as a DSAC 1 dam, and started the implementation of one of the largest dam rehabilitation projects in the nation. The construction of the cutoff wall is a key feature of this rehabilitation work to upgrade the dike to current dam safety criteria. The cutoff wall installation is currently being completed on Reach 1, which extends from Port Mayaca to Belle Glade, under a Multiple Task Order Contract based on performance specifications and stringent verification criteria.

For the construction of the cutoff wall TREVIICOS selected the self-hardening slurry method. Since the cutoff wall is installed through a layer of highly variable limestone with UCS up to 14,000 psi, the excavation requires the use of the hydromill equipment. This is the first successful application of the hydromill technology with self-hardening slurry in a large scale project in the US. This paper presents the details of the method utilized, the quality control procedures, and the experience gained over seven miles of cutoff wall installed.

INTRODUCTION

Projects Location

Lake Okeechobee in South Florida is the second largest freshwater lake in the lower 48 states of the United States. The lake is 33 miles wide from north to south and 30 miles wide from east to west and has a surface area of 730 square miles. The average water depth of the lake is 9 ft.

Lake Okeechobee is the primary drinking water source for numerous communities around the lake and to millions of people living along the lower east coast. The lake is also a vital source of irrigation for the agricultural industry in the South Florida region.

The Herbert Hoover Dike (HHD) system, around the lake consists of a series of levees, culverts and locks and is approximately 143 miles long (Figure 1).

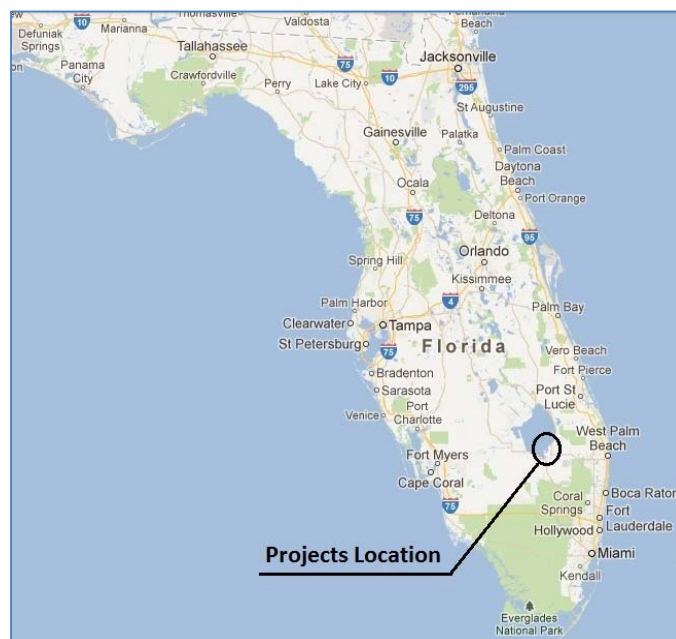


Fig.1. HHD Projects Location

History of the Herbert Hoover Dike

Built in the early 1900's, the original levee system, located along the southern portion of Lake Okeechobee, was constructed mainly by local farmers pushing muck and other superficial materials into a mound to provide flood protection to the surrounding communities and as an aid to irrigation. The original levee system averaged six feet high.

Despite the original levee system, hurricane winds in 1926 and 1928 caused lake waters to overtop the levee resulting in massive flooding and the loss of many lives. These tragedies lead to the United States Congress to authorize the US Army Corps of Engineers (USACE) to improve and lengthen the levee system for flood protection for the surrounding region. Between 1932 and 1938 the levee system was constructed to a height ranging from 30 to 35 ft (NAVD88).

Again, following major flooding in 1947, after two back-to-back hurricanes, Congress authorized the improvement of the levee system surrounding Lake Okeechobee, which raised the levee to its present height ranging from 30 to 45 ft (NAVD88). The last section of the current levee system configuration was completed in the late 1960's.

HHD Seepage Problems

The 143 mile long Herbert Hoover Dike levee system surrounding Lake Okeechobee does not meet current dam safety criteria and has been classified by the USACE as a DSAC 1 dam. Due to early construction methods and standards used for construction of the original levee, the earthen embankment of the levee is subject to potential failure because of internal erosion, piping, and slope instability at high water levels.

In recent years HHD has experienced a high degree of seepage under and through the levee, which has the potential to cause a sudden failure of the system to contain the lake water, resulting in major flooding, loss of life, property and natural resources.

In 2007, the USACE placed HHD on the Top 6 list of dams in the nation needing repair and has prioritized and budgeted more funding for HHD than any other dam safety construction project in the nation. Rehabilitation of the levee system at high risk, "Reach 1" (Port Mayaca to Belle Glade) was further prioritized (Figure 2).

Reach 1 was subsequently divided into four sub-reaches, Sub-Reach 1A through 1D and further divided into nine Task Order contracts, Task Orders 1 (A) through 9 (I), which have

been released based on completion of design and funding availability.

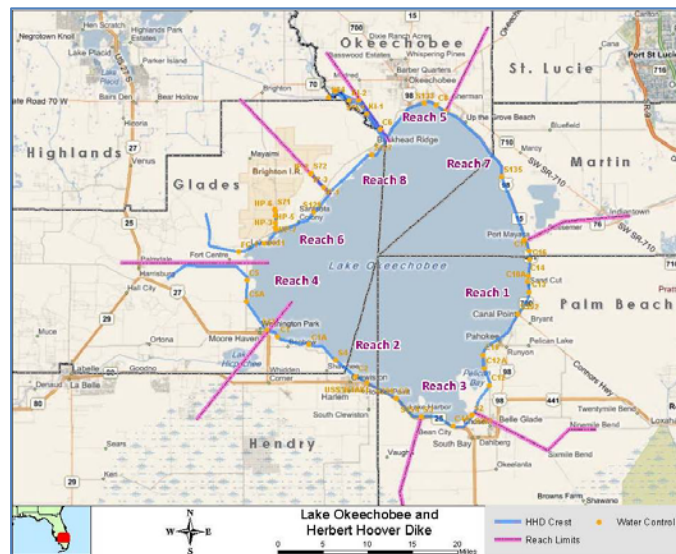


Fig. 2. HHD Rehabilitation Reaches

Previous Experience at the HHD (by Others)

Early attempts of cutoff wall construction were performed by others. Excavation was performed using long reach excavators and bentonite slurry as stabilizing fluid (Figure 3).



Fig. 3. Long Reach Excavator (by Others)

The method was disregarded due to the occurrence of walls cave-ins and collapses.

Rehabilitation Concept

One of the main components of the HHD Rehabilitation Project is the construction of a cutoff wall within the levee that will eliminate the existing seepage through the levee

foundation and limestone layers below (Figure 4).

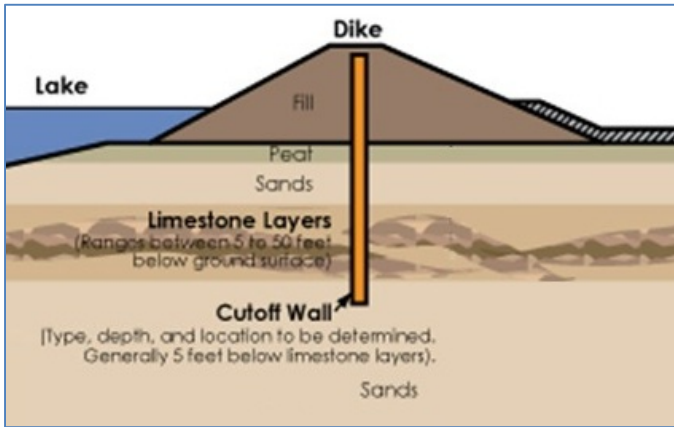


Fig. 4. HHD Rehabilitation Concept

In 2007, the USACE instituted a selection process for the seepage cutoff wall contract(s) that was heavily influenced by the proposing contractor's technical approach to the work. The procurement process was a performance based contract that did not dictate the technique or specification for cutoff wall installation but provided the means and methods of testing for acceptable performance criteria. Also in 2007, TREVIICOS South, Inc. (TIS) was selected as one of three contractor's prequalified to bid on Task Order contracts within Reach 1 of the HHD Rehabilitation Project.

CUTOFF WALL CONSTRUCTION METHODS

Self-Hardening Slurry (SHS) Cutoff Wall Method

For the construction of the cutoff wall, TIS selected the Self-Hardening Slurry (SHS) method. Since the cutoff wall is installed through a layer of highly variable limestone with UCS up to 14,000 psi, the excavation required the use of the Hydromill equipment.

The SHS method utilizes the self-hardening slurry as the supporting fluid during excavation and then it acts as the final backfill material after excavation is completed and the SHS sets and hardens. After setting, the SHS backfill material will provide controlled strength and permeability characteristics.

The SHS backfill material is made of water, bentonite, cementitious binder and additive.

Cutoff Wall Installation Means and Methods

The SHS cutoff wall was constructed by the single-phase

method, i.e., the trench was excavated to the full depth under the self-hardening slurry with clamshell(s) and Hydromill equipment. Excavation through the embankment fill and soil was performed with mechanical and hydraulic clamshells and in the limestone rock and sand with Hydromill equipment, to a maximum depth of 80 ft from the top of the levee and for a width of 24 inch.

Clamshell Excavation

Excavation with the clamshell, either hydraulic or mechanical (Figure 5), was performed through the embankment fill and soil down to the top of the limestone layer. Soil material that was excavated with the clamshell was dumped directly into off road dump trucks and stockpiled on site for drying and then later disposed off site.



Fig. 5. Hydraulic & Mechanical Clamshells

Self-hardening slurry was transported from an on-site batch plant to the trench in concrete mixer trucks, which continuously fed the trench as excavation advanced. The self-hardening slurry was maintained at a sufficient level above the groundwater to ensure a positive head on the side of the trench.

It is important to note that this method of construction removed all the in-situ embankment material above the limestone rock and sand layer. The removal of all the peat and other fill material provided excellent quality and a very homogeneous product.

Once the excavation with the clamshell reached the top of the limestone layer, the Hydromill equipment was moved into position for excavation.

Hydromill Excavation

The Hydromill equipment system is made up of a crawler crane, milling unit and desanding plant. The milling unit is comprised of a heavy steel frame on which are mounted two counter-rotating and independent cutting wheels with carbide tipped teeth (Figure 6). A powerful submerged mud pump, located directly above the cutting wheels, creates a reverse circulation of the self-hardening slurry, which acts as a transport medium to evacuate the limestone and sand cuttings, and delivers the cuttings-laden slurry to a desanding plant.

As the self-hardening slurry is circulated through the desanding plant, a screen removes the rock particles in excess of ¼ inch. After passing through the desanding unit, the self-hardening slurry sets and becomes the wall backfill material.



Fig. 6. Hydromill Equipment

One of the significant achievements of this project includes the first successful application of the Hydromill technology with self-hardening slurry in a large scale project in the United States.

Panel Method

The Panel Method was used to create a continuous cutoff wall with overlapping primary and secondary panels (Figure 7).

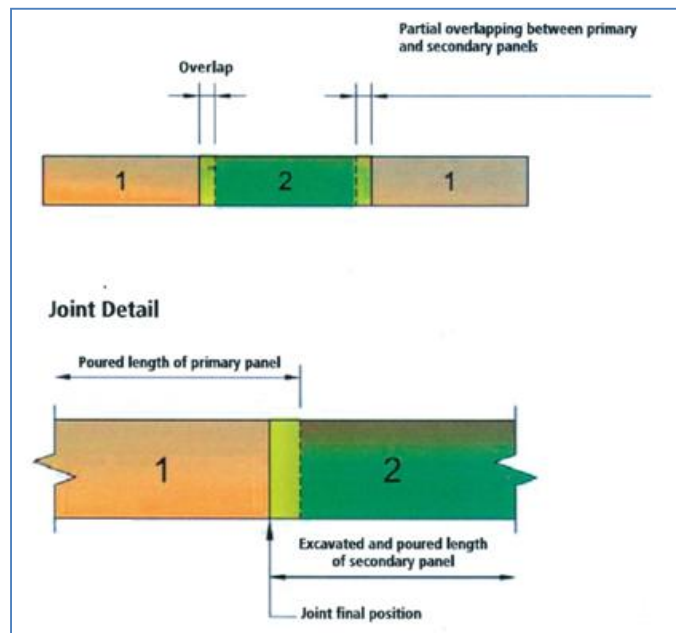


Fig. 7. Panel Joint/Layout

The primary panels typically ranged from 23 feet to 35 feet long and were made of multiple bites. The secondary panels, which were individual bites, were typically 9 feet long. The secondary panels provided a 1.5 feet of overlap on each side of the adjacent primary panels ensuring good continuity. During the excavation of the secondary panels, the Hydromill cutter creates a rough, clean contact surface on the ends of the primary panels, resulting in a high quality watertight joint.

Panel verticality was controlled through a down-the-hole inclinometer mounted within the body of the Hydromill milling unit, which provides verticality information in real time and allows for corrections for any deviations, if necessary. Longitudinal deviations can be corrected by independently varying the rotation speed of the cutting wheels; transverse deviation correction is made by inclination of a tilt plate, on which the cutting wheels are mounted.

Site Preparation Works

The cutoff wall was installed from a temporary work platform constructed on top of the existing levee. The work platform was relocated along the levee with cutoff wall construction as it progressed.

In addition, a concrete guide wall (Figure 8) was constructed about 1.5 feet below the existing levee road along the alignment of the cutoff wall. A guide wall is used to control the start of excavation and as a fixed referenced for panel location, depth measurements and verticality measurements as excavation advances.



Fig. 8. Guide Wall

The cutoff wall was validated mainly through a combination of onsite laboratory testing performed on verification borings. The verification boring locations were spaced at an average of 143 feet, with a maximum spacing of 200 feet along the centerline of the cutoff wall.

Verification Borings

The Technical Specifications required at least 95% core recovery for the entire length cored, therefore a rotary core drilling method was selected in order to provide the necessary samples for testing (Figure 10). Coring was performed using a wireline system with a double tube type core barrel. Drilling fluid was typically water with a small amount of polymer added to help lift the drill cuttings out of the borehole.

Site Overview

The whole construction process can be followed in Figure 9, below.



Fig. 9. Site Overview

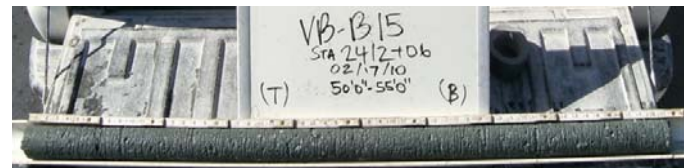


Fig. 10. Verification Boring & Typical Core Sample

CUTOFF WALL VALIDATION/QUALITY CONTROL

The Technical Specifications specified stringent performance requirements for the completed cutoff wall, which were demonstrated through an intensive quality control program. The main acceptance criteria elements included:

- Continuity and homogeneity of the cutoff wall,
- Cutoff wall permeability less than 1×10^{-6} cm/s, and
- Cutoff wall strength between 100 and 500 psi at 28 days (running average on core samples)

Borehole Televier

Upon completion of the verification boring, the hole was flushed with a light bleach solution and surveyed using an Optical Geologger, manufactured by Robertson Geologging Ltd., which was lowered down the hole. This logger recorded a 360-degree view of the borehole surface and projected the image as a “flat core” with description of depth and orientation (Figure 11). In addition, the Geologger output provided a graphic display of the borehole alignment (verticality), which was measured continuously along the full depth.

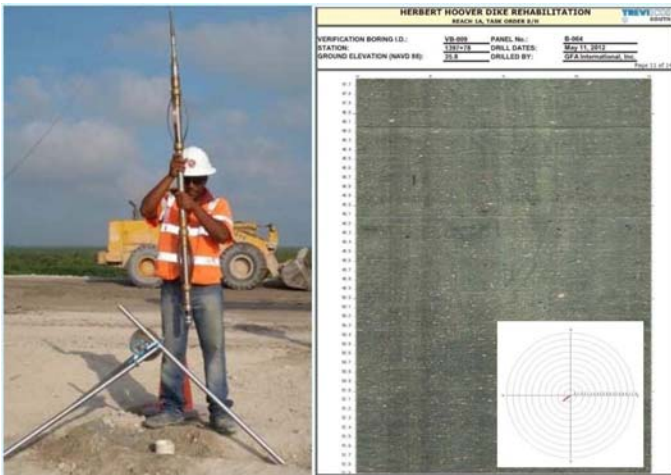


Fig. 11. Video Log Record

Continuity and Homogeneity

The continuity of the cutoff wall was confirmed by the core samples from the verification borings and the borehole televiewer logs. In addition, the use of the successful performance of the Panel Method was proved through verification borings located at the joint between primary and secondary panels. The retrieved core samples showed good bonding and color difference between the different aged self-hardening slurry mixes (Figure 12).



Fig. 12. Core Sample at Joint

In-Situ Permeability Testing

At 28 days after completing the cutoff wall, an in-situ permeability test was performed in the verification boring by means of a falling head test.

Before starting the test, a pressure transducer was installed inside the boring (usually at ~ 25 ft below platform elevation). The transducer was maintained in the hole for the whole duration of the test, and provided continuous readings of the water level. In addition, a water level sounding was also lowered inside the boring and the beginning/completion of the test, and the water elevation was recorded. Transducer/water level sounding information readings were crosschecked afterwards, to verify accuracy.

After the boring was filled, the water level drop was recorded over a half hour holding period. The formula used to calculate the permeability was specified by the Technical Specifications using the Hvorslev Method, which is shown in Formula (1), below:

$$k_h = \frac{d^2 \times \ln\left(\frac{2mL}{D}\right)}{8L(t_2 - t_1)} \ln\left(\frac{h_1}{h_2}\right) \quad (1)$$

- d: stand pipe diameter
- D: borehole diameter
- m: 1 (assuming kh=k_v)
- L: Length of the zone tested
- t₂-t₁: testing time (30 min)
- h₁ & h₂: initial and final water head

In order to validate the cutoff wall for in-situ permeability, the performance requirement must be less than 1x10⁻⁶ cm/s for the entire length of the verification boring (Figure 13).

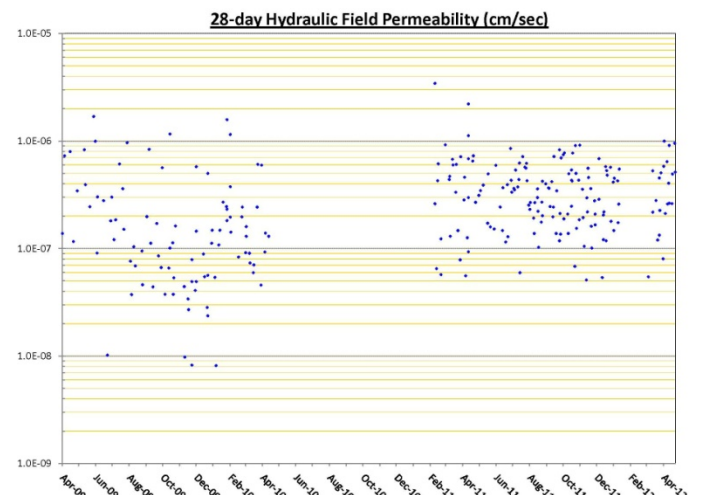


Fig. 13. Summary of Field Permeability Test Results

Strength Testing

UCS testing was assessed on core samples from the verification borings. Four samples were selected per each verification boring; two from depth ranges of 10 to 20 feet and two below 30 feet, with one within 10 feet of the bottom.

In order to validate the cutoff wall for strength, the performance requirement ranged from 100 to 500 psi. Strength was evaluated by a 10-point moving average (Figure 14).

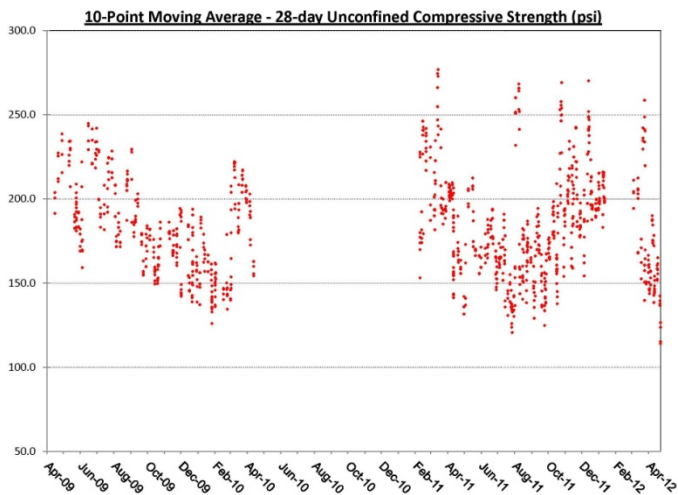


Fig. 14. Summary of UCS Test Results

CONCLUSIONS

The installation of a self-hardening slurry cutoff wall by the Hydromill system at the Herbert Hoover Dike Rehabilitation Project has shown that the performance requirements can be successfully achieved by proper quality control and installation techniques.

One of the significant achievements of this project includes the first successful application of the Hydromill technology with self-hardening slurry in a large scale project in the United States.

Another successful and unprecedented achievement is the first time use of self hardening slurry in panel construction method.

Full replacement method provides excellent quality and a very homogeneous product, mitigating the nature of the existing material and its variability. The removal of the existing embankment materials allows better quality control of the

composition of the wall since it is largely composed of manufactured materials.

The self-hardening slurry had a relatively low strength when secondary panels were formed allowing for good bonding between primary and secondary panels. The high moisture content of the self-hardening slurry and its very low permeability prevented desiccation and cracking of the top of the hardened wall, as demonstrated when a portion of the cutoff wall was exposed more than one year after construction. The wall exposure provided a very good indication on the long-term performance of the cutoff wall.

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