

Operational Improvements through Installation of Seepage Cutoff Wall using Soil Mixing

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ABSTRACT: The Cross Delta Dike (CDD) at the Big Island Mine in Green River, Wyoming, was originally constructed by placing random fill over hydraulically deposited tailings and decahydrate (deca) deposits underlain by fractured bedrock. The 3500-foot-long dike was used as a haul route and to provide separation between the tailings disposal cell and reclaim water cell, improving reclaim water quality. Reclaim operations, which included removal and reprocessing of deca from the tailings disposal cells, are critical to facility operations. Development of safety and operational issues related to concentrated seepage as well as internal erosion and development of voids within the dike necessitated remedial action. These issues were expected to worsen, as future expansion would increase the head drop across the CDD. The authors performed a study and identified a seepage cutoff wall as the most appropriate option. Construction was performed using the Trench Remixing and Deep Wall (TRD) method. This paper describes the field investigation, laboratory testing, design, construction, and monitoring associated with the seepage cutoff wall. It also describes successful performance of the cutoff wall and benefits in terms of improved facility operations.

1 INTRODUCTION

Ciner (formerly OCI) owns and operates the Big Island Mine facility near Green River, Wyoming. Ciner mines trona at the site, and the ore extraction takes place underground while the processing plant and disposal facilities are located at the ground surface. The dams and earthen structures are used for storage, water retention, and evaporation.

An expected increase in production and operational issues with deca harvesting required seepage enhancement of the Cross Delta Dike (CDD). In addition, future construction would require upstream construction of the west side of the CDD which will impose additional loading on the CDD. As a result, a preliminary design for a seepage cutoff, consisting of heavy steel sheetpiling, was prepared in 2012 by Barr Engineering Co. (Barr). This option was considered feasible but required heavy steel sheets to penetrate hard deca layers. However, in 2014, further discussions identified the possibility of using soil-mix technology to build a seepage cutoff. A subsequent option study identified the Trench Remixing and Deep Wall (TRD) method as feasible and most appropriate to meet the project objectives. This paper describes the background, design process, construction, and monitoring of the seepage cutoff wall at the CDD.

2 BACKGROUND

The CDD is an earthen structure, approximately 3500 feet in length, which separates the Upper Delta tailings disposal basin from Pond 1, as shown in Figure 1. In general, water is stored for

evaporation in Pond 1, whereas the tailings delta is used for tailings storage. The dike was originally constructed to provide separation between the tailings disposal area and Pond 1 to filter the water before it enters Pond 1. This provides higher quality water in the Pond 1 basin. More recently, the CDD has also been used as a barrier to minimize pumping while transferring water up to Pond 4 and as a haul road during the deca harvest. The CDD was constructed directly on top of previously deposited tailings and deca deposits.



Figure 1. Cross Delta Dike Location

Water from the Upper Delta seeps through the CDD during dewatering of Pond 1. The differential head generated across the CDD (between the Upper Delta and Pond 1) promoted internal erosion of the tailings and uncontrolled dike fill. Furthermore, the dike subsurface included deposits of deca which are susceptible to dissolution. As a result, sinkholes and surface depressions were an issue, impacting the use of the CDD as a haul road and causing concern about overall CDD safety. Figure 2 illustrates a picture of the typical development of sinkholes at the CDD.

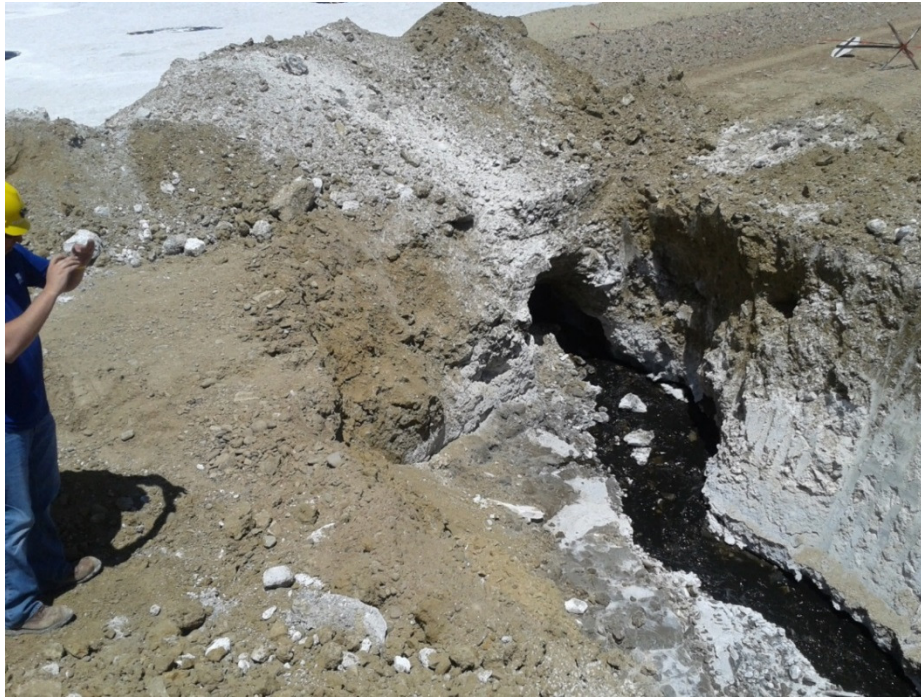


Figure 2. Sinkhole Developed on Cross Delta Dike

Operational issues related to seepage, piping development, voids, deca harvest, and dike stability during future upstream construction required attention to maintain safe operation and efficient deca harvesting. Construction of the seepage cutoff wall was necessary to address these issues and facilitate long-term operation and performance of the dike.

3 DESIGN

3.1 *Design objectives*

The objectives of the seepage cutoff wall project include the following:

- Create a barrier able to control/prevent piping and voids in the dike
- Provide a solution that allows use of a safer road
- Minimize seepage to improve the Pond 1 dewatering process
- Help preserve the quality of the deca harvested at Pond 1
- Promote movement of water from higher elevations into Pond 1
- Improve the overall stability of the Upper Delta

It was decided to develop the design of a low-permeability barrier including an area to temporarily store water upstream of the CDD to transfer the water to Pond 1. The concept involves building a soil-mix wall and inserting an intermediate barrier within the trench while the material is still fresh. Using this concept, the water upstream of the CDD is transferred to Pond 1 using a decant structure.

3.2 *Design issues*

The overall approach for design of the proposed wall involves creating a barrier (i.e. cutoff wall) with low permeability and adequate strength so that it can meet the project objectives while providing long-term durability. Many of these issues revolve around a proper mix design so that a robust wall can be built. During wall construction, while the mix is still fresh, the design should allow for the insertion of a secondary barrier within the soil mix. In this way, the final product would be sufficiently robust so that if the wall cracks or fails there is a second line of defense against seepage and piping. Additionally, the wall should be designed to withstand any potential

deformation resulting from the development of voids or deca dissolution. A review of the proposed cutoff construction identified the design/construction issues briefly discussed below:

- Permeability. The proposed wall should have low permeability to help control the seepage across the cutoff wall.
- Strength. The soil mix of the wall should be designed such that the wall is strong enough to provide adequate support for lateral pressure. Similarly, the composited section should be able to withstand any deformation and stresses resulting from the development of voids or ground loss resulting from deca dissolution.
- Set Time. Since the wall involves the insertion of a barrier while the soil mix is still fresh (i.e. vinyl sheet pile), the soil mix should have a set time long enough to allow this operation in the field.
- Durability. The soil mix should be designed to provide long-term wall durability.
- Presence of Deca in Mix. It is known that deca will be encountered during construction of the wall and deca will be part of the soil mix (soilcrete). However, the amount or proportion of deca is not constant along the wall alignment. Preliminary laboratory testing showed that deca has a major impact on the set time and strength.
- Depth of Wall. The depth of the wall is an important design feature; the previous design concept included placement of steel sheet piles driven down to refusal at bedrock level.
- Stability of Upper Delta. In the future, the south perimeter dike will be located in the Upper Delta. As a result, deformation of the cutoff wall induced by dike construction needs evaluation.

4 FIELD INVESTIGATIONS AND SUBSURFACE CONDITIONS

Several field investigations were conducted as a part of the CDD seepage cutoff wall project. The field investigations consisted of soil borings, CPT soundings, a geophysical seismic refraction survey along the entire dike alignment, and bulk sampling of the tailings and deca. These investigations were completed to gather subsurface information for design and construction. In addition, a laboratory testing program was developed. The main objective of the laboratory testing program was to explore how various mix designs would react with the presence of deca throughout the CDD, as well as to determine a baseline for soil-mix performance in terms of permeability, strength, set time, and durability.

In general, the field investigations identified stiff, sandy lean clay (fill) overlying a saturated mixture of lean clay (tailings) and deca. The deca was primarily observed as numerous inclusions or lenses, but in some cases the deca was well formed as a crystalized hard layer. The deca and tailings were underlain by native soils consisting of sandy lean clay, lean clay, and fat clay. Weathered mudstone bedrock was encountered at depth in all borings.

The seismic survey was used to delineate the depth of the native soils and bedrock at the foundation of the CDD. The seismic survey was also intended to identify zones of concentrated deca within the dike profile. The geophysical survey was completed using the Multi-Channel Analysis of Surface Waves (MASW) technique to acquire shear wave data.

5 ANALYSIS

The analyses conducted as part of the project evaluated seepage, slope stability, structural performance of the wall, and deformation. The parameters for the different materials included in the model were selected based on the results of the field investigation and laboratory testing.

Potential future conditions for the Upper Delta and Pond 1 were incorporated into the analyses. The plan for ultimate configuration of the South Interior Dike includes raising dam crests to an approximate elevation of 6290 feet using an upstream offset of approximately 105 feet between the South Interior Dike and the CDD. After simulating the initial conditions, the construction of the ultimate South Interior Dike configuration was modeled, including the filling of tailings. The simulations also included excavation of deca in Pond 1 down to an elevation of 6220 feet and dewatering to as low as 6217 feet.

A brief description of the seepage, deformation, stability, and structural analyses are discussed below.

5.1 Seepage Analysis

The main objective of the seepage analysis was to develop an understanding of the flow of water through the CDD and the proposed cutoff wall and how it relates to stability of the dike and wall. Special emphasis was placed on evaluating the parameters to model the most relevant hydrogeologic materials. Subsequently, simulations were made to predict the phreatic and pore-water pressure conditions under future scenarios.

A steady-state seepage analysis was performed for the CDD (Station 12+00) based on the planned cutoff wall. The analysis also incorporated the proposed future configuration of the Upper Delta to an ultimate crest elevation of 6290 feet. The seepage analysis is an important aspect of the modeling process because the model calculates seepage forces within the cutoff wall cross section. The model also determines a phreatic surface and allows for the prediction of pore-water pressures within the dike and at the wall; this helps in the wall and dike design. The seepage model was initially run for existing conditions with the cutoff wall and for future conditions in the Upper Delta to evaluate seepage gradients across the dike. Steady-state seepage simulations indicate a head differential of approximately 12 feet across the cutoff wall after completion (elevation of 6245 feet on the Upper Delta side of the wall and 6233 feet on the Pond 1 side).

5.2 Deformation Analysis

The main objective of the deformation analysis was to develop an understanding of the deformation, pore-water pressures, and stresses that will be generated on the dike and proposed wall due to hydraulic head differences and as a result of construction of the upstream dams on the Upper Delta. Special emphasis was made in the evaluation (estimation of parameters and boundary conditions) to model the most relevant materials while matching the model results to observed field performance. Coupled seepage-deformation models were created using the finite element method with GeoStudio software (SEEP/W and SIGMA/W).

Deformation analyses were conducted on a representative cross section (Station 12+00). The initial conditions were established by stepping the existing conditions model to equilibrium and incorporating the results of the seepage analysis under steady-state conditions. This initial state of the model reflects gravity loading based on seepage and displacement boundary conditions.

After simulating the initial conditions, the construction of the ultimate South Interior Dike configuration was modeled, including the filling of tailings. The resulting deformation, pore-water pressures, and stresses at select points within the cutoff wall were monitored during the staged modeling.

The ultimate proposed configuration of the South Interior Dike was modeled to predict the behavior of the stresses induced on the CDD cutoff wall. The behavior of the cutoff wall in response to the offset upstream dam construction was evaluated in terms of stresses, deformation, and pore-water pressures.

The results of the deformation analysis for CDD are interpreted in terms of the pore-water pressure, effective stress, and deformation. Based on the analysis and assumed conditions presented in Barr (2014), the total lateral deformation of the cutoff wall due to upstream dam construction is less than 0.5 inches. This deformation is sufficiently small to indicate that the wall should not be damaged or significantly altered by future development of the Upper Delta.

5.3 Stability Analysis

The main objective of the slope-stability analysis was to evaluate the safety of the dike and wall under different operating scenarios and construction, as well as long-term conditions. Special emphasis was placed on evaluating the impact of the groundwater flow on stability. The stability was also evaluated in relationship to the design issues previously identified.

The slope-stability analyses for the CDD and wall were performed using the same cross section as the seepage and deformation analyses. The configuration of the downstream slope of the CDD (Pond 1 side) was analyzed using a 3H:1V slope extending to the bottom of Pond 1. Analyses

were performed under different conditions utilizing undrained and drained soil parameters for stability.

Models were run to analyze a circular failure surface, as well as a wedge failure. To run a wedge analysis, stronger underlying layers were modeled as impenetrable (or “bedrock”). This forces the failure surface to truncate along the stronger layer and models the movement along the interface between the two layers. The wedge models analyzed the potential for fill and weaker native soils to move; therefore, the bedrock was set to impenetrable.

Slope-stability analyses were conducted for drained and undrained shear strength soil conditions. The drained condition generally applies to long-term, steady-state flow conditions. No excess pore-water pressure exists and, in many cases, the drained condition represents the most stable condition for dam construction. The undrained condition generally applies to short-term conditions, for example during or immediately after construction, where the soil mass and groundwater have not had time to come to equilibrium. As such, there is some strength reduction in those soils that are not permeable enough to freely drain as excess pore-water pressures will develop within those saturated soil masses (undrained response).

Slope-stability calculations of the CDD were completed using Undrained Strength Stability Analysis (USSA) and Effective Stress Stability Analysis (ESSA). The minimum recommended factor of safety for the ESSA is 1.5. The minimum recommended factor of safety for the USSA is 1.3.

All computed factor-of-safety values for USSA and ESSA conditions for CDD are greater than the recommended minimum values of 1.3 and 1.5. The results indicate that future offset upstream dam construction, cutoff wall construction, and the associated changes to the loading and pore-water pressures do not result in dike instability.

5.4 Structural Analysis

The main objective of the structural analysis was to evaluate the integrity and safety of the wall under different operating scenarios and construction conditions, as well as long-term conditions. Special emphasis was placed on evaluating the impact of the groundwater flow, soil stresses, and dissolution of deca layers on the structural stability of the wall. The stability was also evaluated in relationship to the design issues previously identified.

The structural analyses for the wall were performed under potential conditions of deca dissolution. Data from the laboratory testing on mixes was used in the analysis.

The sheet pile analysis assumed that 40-foot-long sheets would be installed at the top of the existing CDD (elevation 6252 feet) and extend approximately 2 feet into the native clay. Water elevation was assumed to be 6245 feet on the Upper Delta side of the wall and 6223 feet on the Pond 1 side.

Two different sheet pile models were made to check the loading on the sheet pile. The first model assumed 4 feet of settlement caused by deca dissolution on the CDD on the Pond 1 side. This would create a nominal 4-foot cantilever at the top of the 40-foot-deep wall in addition to the water pressure.

The second model assumed that a 12-foot void was created in the deca layer from an elevation of 6229 to 6217 on the Pond 1 side of the wall. The sheet pile flexural loading was checked assuming both a simple beam and fixed-end beam over the 12-foot span.

6 PLANS AND SPECIFICATIONS

A complete set of plans and specifications was developed for bidding and construction. The main design features of the cutoff wall included the following:

- The required maximum permeability of the cutoff wall was 1.0×10^{-6} cm/s.
- The unconfined compressive strength was established as 40 psi for a 10-point average with a single test minimum of 30 psi.
- The width of the cutoff wall was at least 18 inches.
- A secondary seepage barrier, consisting of vinyl sheet SG-325, was incorporated into the design. The set time of the mix was set to at least 18 hours to allow for vinyl sheet insertion.

- The cutoff wall was 3550 feet in length with variable depth but inserted into native soils at least 2 feet deep.
- Specifications included provisions for the process of demonstrating mixing, joint construction, and secondary barrier (i.e. vinyl) installation. Therefore, a test section prior to the beginning of cutoff wall installation was specified to provide the contractor with an opportunity to evaluate construction.

The plans and specifications were part of the bidding package. The TRD construction method was selected because it allowed for penetration through deca layers, adequate mixing, and installation of a secondary barrier.

7 CONSTRUCTION

The CDD seepage cutoff wall consists of a primary and secondary seepage barrier. The primary seepage barrier was the soil-mix wall and the secondary was vinyl sheet pile. The following describes the construction methods and equipment used for both of them.

7.1 Primary Cutoff - TRD

The primary seepage cutoff consisted of an approximately 21.6-inch-wide homogeneous soil mix wall. The barrier was installed using the TRD method. This involved cutting a vertical trench through the CDD to the design depth through the tailings and native materials while continuously adding fresh grout. The resulting soil mix (also referred to as soilcrete) formed the cutoff wall. The mixing process included vertically cycling back the excavated material that became incorporated in the soilcrete. The engineered fresh grout was prepared in an automated batch plant and pumped through the TRD to the bottom of the TRD cutter post (bottom of wall).

The primary seepage cutoff equipment consisted of a TRD (model TRD25-KM) mounted on a Kobelco 7055-2 crawler base. The TRD cutter post was installed in sections at a design depth below the ground surface, cutting a trench by rotating a chain with steel cutting teeth propagating outward—similar to a chainsaw. The intent of this method is to cut and mix subsurface materials and grout to form a homogeneous wall with no discontinuities. At locations where the design depth increased or decreased, cutter post sections were added or removed. Figure 3 shows a diagram and a photo of the TRD used at the CDD.

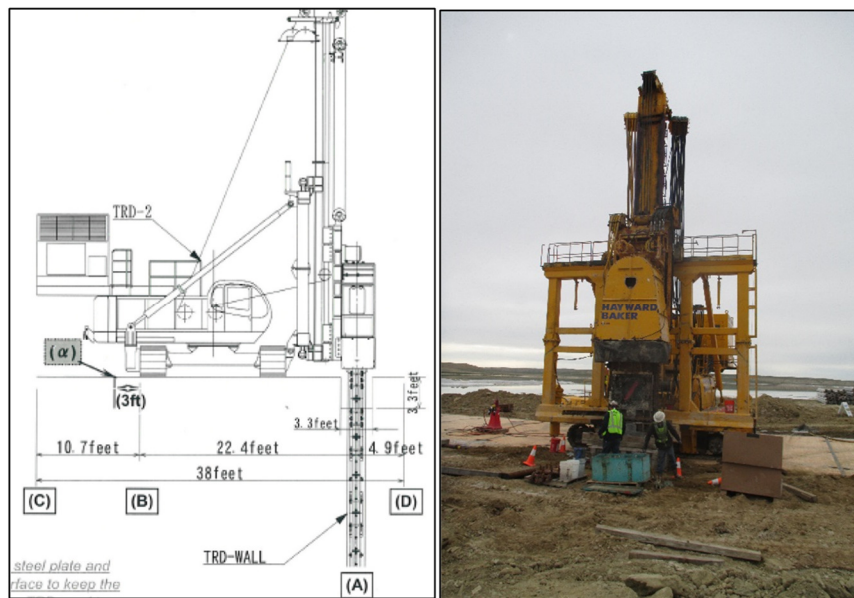


Figure 3. TRD Machine

The TRD was equipped with a Micro Motion grout monitoring system, which constantly monitored properties of the freshly mixed grout as it was delivered to the TRD from the batch plant. Properties measured include specific gravity of the grout, temperature of the grout, flow rate to the cutter post injection ports, and total volume of fluid passing through the monitoring equipment. This information was observed in real-time by the TRD operator.

7.2 Secondary Cutoff- Vinyl

The secondary seepage cutoff was constructed using vinyl sheet piling. This secondary barrier was inserted within the primary seepage cutoff and included interlocking connections, allowing for continuity of the secondary seepage cutoff. The vinyl sheet pile was installed before setting of the cementitious soil mix to achieve proper installation and contact between the two seepage cutoff elements.

The contractor used an ABI Mobilram system (model TM14/17 SL) to operate the pile hammer and mandrel. The mandrel setup was designed to support various lengths of sheet pile up to 50 feet. The ABI was mounted on tracks and progressed closely behind the TRD. The vinyl sheets were attached to the mandrel, interlocked to the preceding sheet, and then driven to depth. The mandrel was withdrawn when the vinyl sheet pile encountered the bottom of the trench, leaving the installed piling in place. The mandrel was manufactured by Crane Materials International (CMI). Figure 4 and Figure 5 show a diagram and a photo of the ABI machine and mandrel used by the contractor at the CDD seepage cutoff.



Figure 4. ABI Pile Driver



Figure 5. Mandrel

8 MONITORING

Monitoring instrumentation was installed along the alignment to track the impact of the new seepage cutoff. In the spring of 2015 (prior to cutoff wall construction), vibrating wire (VW) piezometers were installed at three locations upstream of the cutoff wall alignment at approximately Stations 11+46, 18+69, and 23+31. Once cutoff construction was complete (in July 2015), VW piezometers were installed downstream of the wall at similar stationing along the alignment (one at Station 11+46, two at Station 18+69, and one at Station 23+31). The combined upstream and downstream instrumentation provides data to monitor head differential across the dike and seepage cutoff. All piezometers installed featured nested sensors at various elevations to measure pore pressure in the tailings and the underlying fractured bedrock. In addition, one in-place inclinometer (IPI) was installed at Station 18+69 to monitor displacement post construction. The monitoring instrumentation layout is shown in Figure 6.

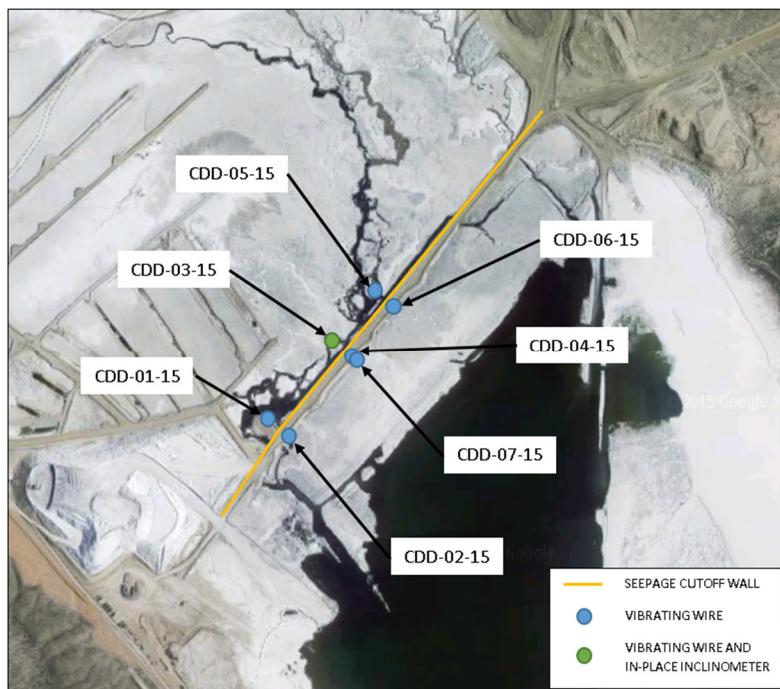


Figure 6. Cross Delta Dike Monitoring Instrumentation Layout

Figure 7 depicts a general cross-sectional layout of the VW piezometers installed along the seepage cutoff wall to monitor the performance of the wall.

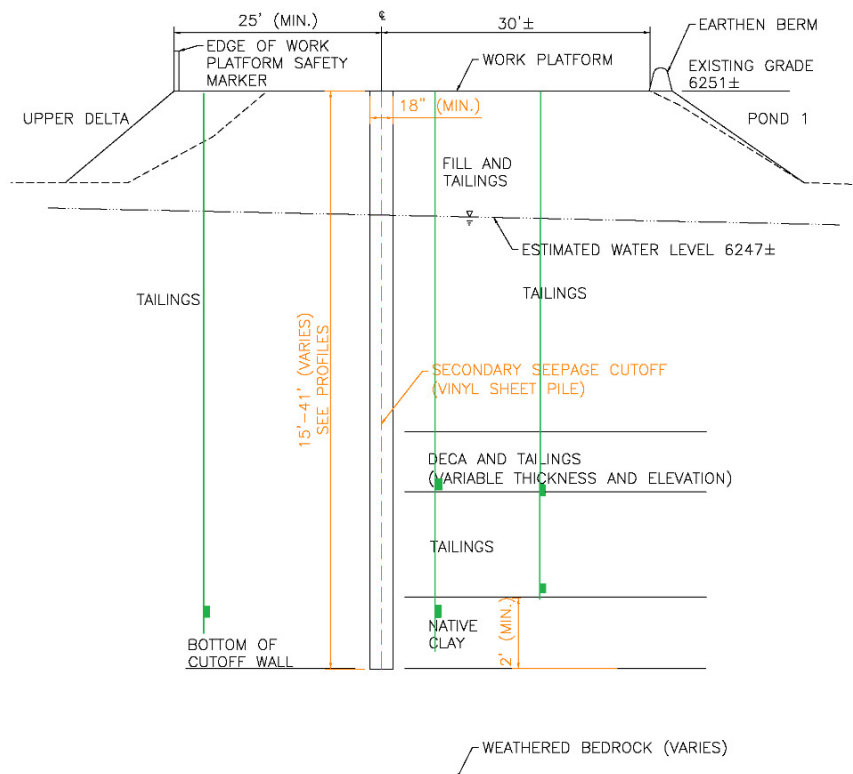


Figure 7. Typical Nested Vibrating Wire (VW) Piezometers at Cross Delta Dike Site (Not to Scale)

8.1 Performance Monitoring

The VW piezometers, installed in 2015 on either side of the seepage cutoff wall at Stations 11+46, 18+69, and 23+31, indicated a successful seepage cutoff at the CDD. The nested VW piezometers were installed specifically to evaluate the pore pressures and head differentials in specific layers. Figures 8 and 9 show the decrease in the total head downstream of the cutoff wall.

It can be seen from Figures 8 and 9 that the total head upstream of the wall construction remains fairly constant at about elevation 6247 to 6248 in piezometers 01A and 05A. After the installation of the cutoff wall, the total head in piezometers 2A/B and 6A/B (located downstream of the wall) started to decrease. By December 2015, the differential head across the wall was approximately 8 to 10 feet. Figures 8 shows the decrease of the total head downstream of the cutoff wall during two dewatering cycles of Pond 1 in 2016 and 2017. Based on these results, the seepage cutoff is performing as designed and intended.

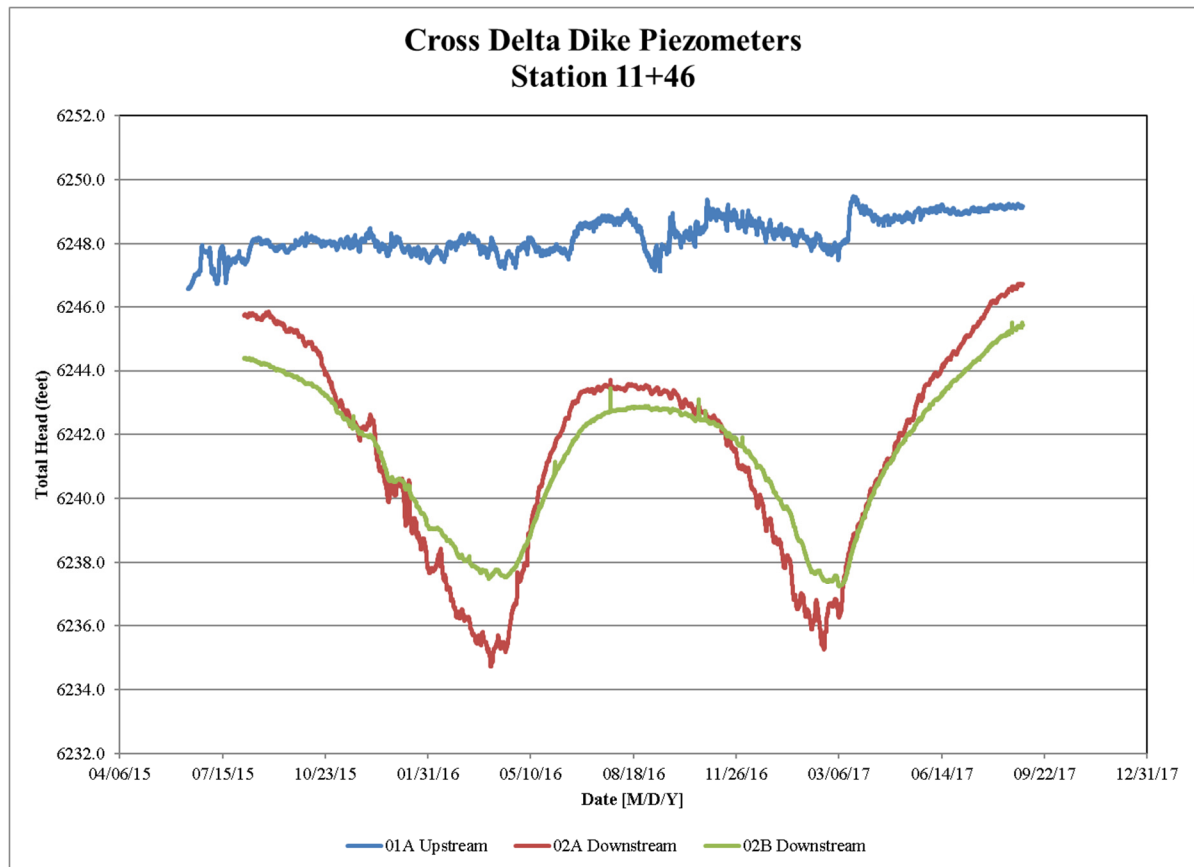


Figure 8. Total Head at Station 11+46

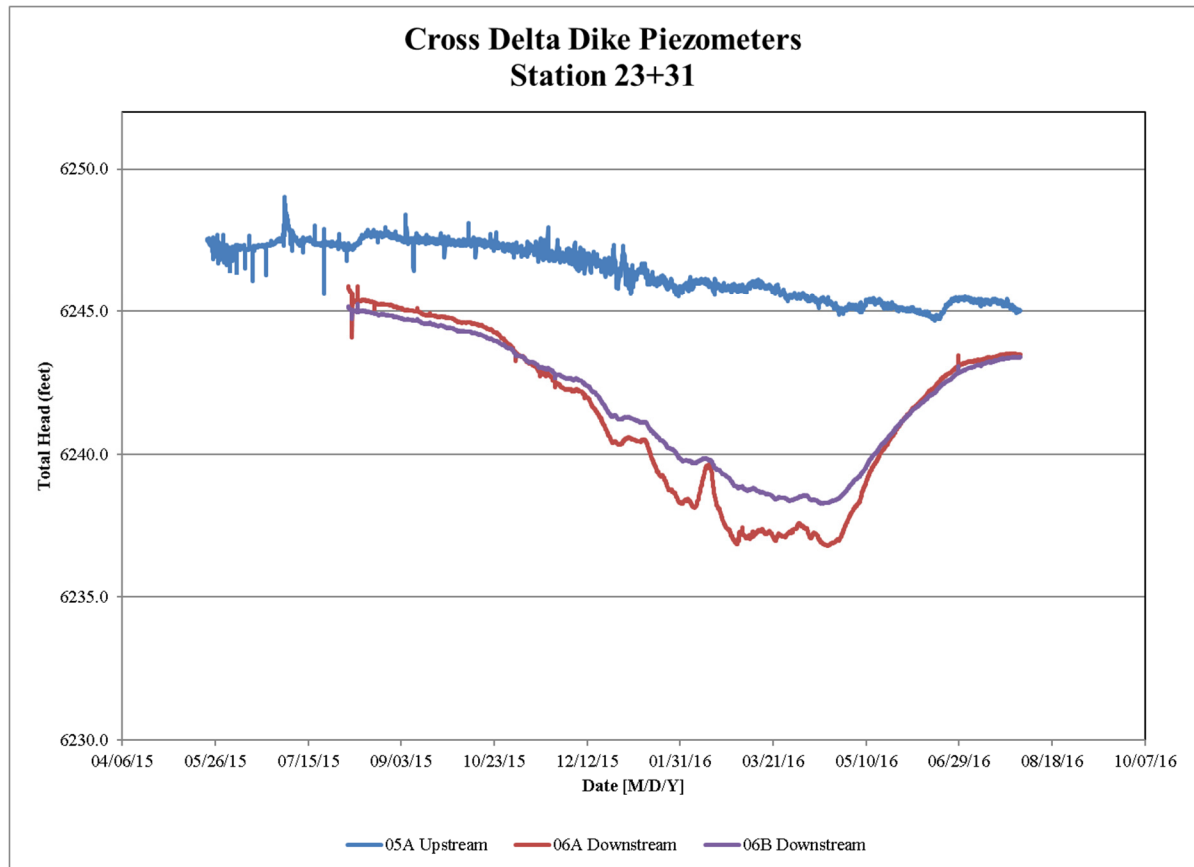


Figure 9. Total Head at Station 23+31

9 CONCLUSIONS

This paper presented the background, design process, construction, and monitoring of the seepage cutoff wall at the CDD. The objectives of the cutoff wall were to create a seepage barrier able to control and prevent piping, provide a safer road, and minimize seepage to improve Pond 1 dewatering while helping preserve the quality of the deca harvested at Pond 1. Finally, the barrier was intended to improve the overall stability of the upper dike.

The performance of the cutoff wall with more than three years of construction and deca harvesting campaigns has demonstrated that the objectives have been achieved. The monitoring dam further verifies the satisfactory performance of the cutoff wall.

10 REFERENCES

- Barr Engineering Co. 2012. "Sheetpile wall for Cross Delta Dike"
 Barr Engineering Co. 2014. "Cross Delta Dike Cutoff wall Design Report." October 2014.