Dike Expansion Pilot Test at Indiana Harbor and Canal Confined Disposal Facility

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ABSTRACT

The Indiana Harbor and Canal (IHC) Confined Disposal Facility (CDF) is located in East Chicago, IN, and operated by the United States Army Corps of Engineers (USACE). The CDF was designed and constructed for the disposal and containment of dredged, contaminated sediments from the IHC, with additional storage for a water cover over the impounded sediment for air emissions suppression. It consists of a perimeter containment dike constructed of compacted clay and features a smaller interior dike (“center dike”) for dividing the CDF into two disposal cells to facilitate water management and future dewatering activities.

USACE is planning to increase the capacity of the CDF by expanding the perimeter containment dike, increasing the crest elevation by as much as 11 feet (3.4 m). Similarly, the center dike would require modification if two-cell operation is to be maintained over the remaining operating life of the facility. Several alternatives have been considered for enlarging the center dike. Sediment-filled geotextile tubes stacked to expand the dike is an attractive concept because it would allow beneficial use of the dredged sediment, conserves CDF capacity, is readily constructible in a fully or partially submerged setting, and could be configured to maintain access to the dike crest.

In Fall 2018, a pilot test was performed to study the potential for enlarging and increasing the height of the center dike with geotextile tubes. A description of the current facility and operation, pilot test design, procedure, results, and geotechnical implications, as well as recommendations for full-scale geotextile tube installation in the IHC CDF will be described. In addition, the team will explore the wider potential for implementing dike expansion projects in CDFs across the U.S., extending the life of CDFs by removing sediment and containing it in geotextile tubes, and increasing the capacity of the CDF cells by placing the sediment-filled geotextile tubes on the dikes.

Keywords: Dredging, beneficial uses, geotextile tubes, contaminated sediments

BACKGROUND

The IHC is an authorized Federal navigation project located north of the mouth of the Grand Calumet River on the southwest shore of Lake Michigan, in East Chicago, Lake County, Indiana (Figure 1). The IHC is located 4.5 miles (7.2 km) east of the Indiana-Illinois State line and 17 miles (27 km) from downtown Chicago. The bottom sediments in the IHC, located within a heavily industrialized area, are contaminated and not suitable for open water disposal or unconfined upland disposal. The IHC was not dredged for 40 years after the passage of the Clean Water Act in 1972 until the Chicago District of USACE constructed a CDF to permanently contain the dredged materials. The current dike configuration provides a capacity of 2.7 million cubic yards (2.1 million cubic meters) of dredged material, sufficient to contain the 40-year backlog volume of sediments plus 2 feet (0.6 m) of water cover. Design is currently underway to increase the capacity of the CDF with a second phase of construction planned to raise the perimeter dike to a proposed height of 32 feet (9.8 m), providing an additional 2.1 million cubic yards (1.6 million cubic meters) of capacity for future maintenance dredging in the harbor and canal, and extend the design life of the facility to at least 30 years. The perimeter dike will be expanded in the downstream direction to prevent encroachment into the cell interiors and avoid the impounded sediments for foundation support.

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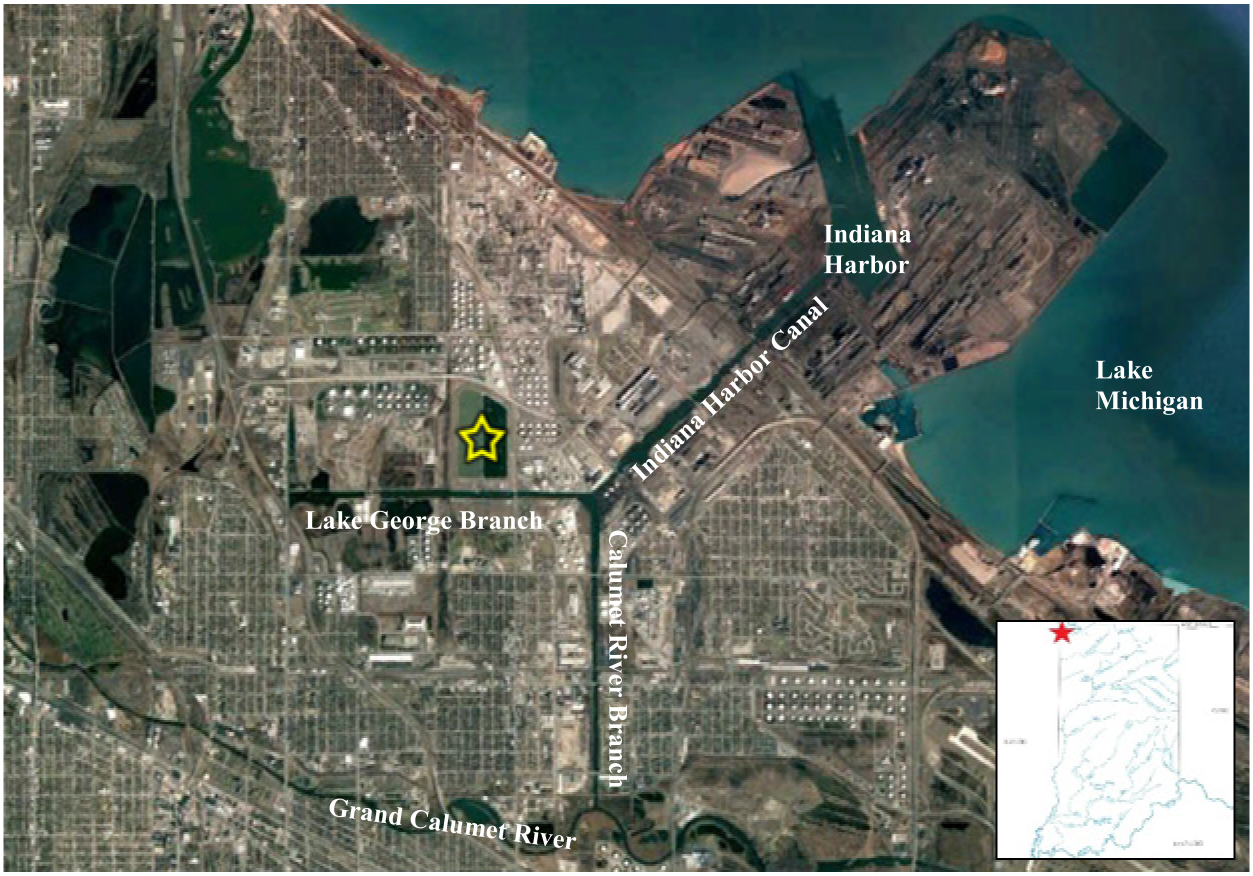

Figure 1. IHC System and CDF Location (image from National Oceanic and Atmospheric Administration 2018).

Due to the ponded operation and inability to temporarily dewater the CDF to allow conventional construction methods for the center dike expansion, alternatives are needed for expanding the center dike. Because of the expense of construction and shortage of available sites for new CDFs, it is critical to maximize the existing CDF capacity by limiting the amount of imported materials used in construction. Therefore, beneficial use of impounded sediment to construct the dike expansion is ideal. However, because construction would need to partially occur in a submerged condition and the sediments would be unstable without confinement, the feasibility of using stacked geotextile tubes filled with IHC sediments for expanding the center dike is of primary interest.

SITE CHARACTERISTICS AND OPERATIONS

The CDF was designed and constructed and is being operated to be protective of the environment. It was constructed along the IHC on a former petroleum refinery site (Figure 2, left image) regulated under the Resource Conservation and Recovery Act (RCRA) due to soil and groundwater contamination from the past refining operations. Contaminated groundwater at the site previously was uncontrolled, and offsite migration was not prevented, until groundwater control features were installed as part of the CDF construction. To suppress air emissions from contaminated sediments impounded within the CDF, a water cover is maintained over the sediments. Excess water in the CDF is treated in accordance with a National Pollutant Discharge Elimination System (NPDES) permit prior to discharge back to the canal. When the CDF reaches its final design capacity, an engineered cap system will be constructed over the dewatered sediments in accordance with RCRA requirements.

The primary feature of the CDF is a 21.5-feet (6.55-m) tall compacted clay perimeter dike for primary containment and a shorter center dike that divides the CDF into two disposal cells (right image, Figure 2). The perimeter dike is 8,833-feet (2.692 km) long, has a typical crest elevation of 609.6 feet (185.8 m) (NAVD 88) and a 32-feet (9.8-m) wide crest. Currently, the CDF is being operated as a two-cell ponded facility for air emissions control during disposal of the more highly contaminated “backlog” sediments that accumulated in the IHC over 40 years when maintenance dredging was not performed. The CDF is split into two cells by a 2,872-feet (0.8754-km) long by approximately 18.5-feet (5.64-m) tall center dike. A 2,360-feet (0.7193-km) long section of the center dike contains a core of site debris encapsulated within a thick shell of compacted lean clay (Figure 3). The debris, which included crushed concrete, railroad ties and other materials from the former refinery structures and infrastructure, was stockpiled onsite with the intent of disposal within the CDF. However, to conserve capacity for dredged materials, the decision was made to beneficially use the debris to construct the center dike core (Figures 3 and 4).

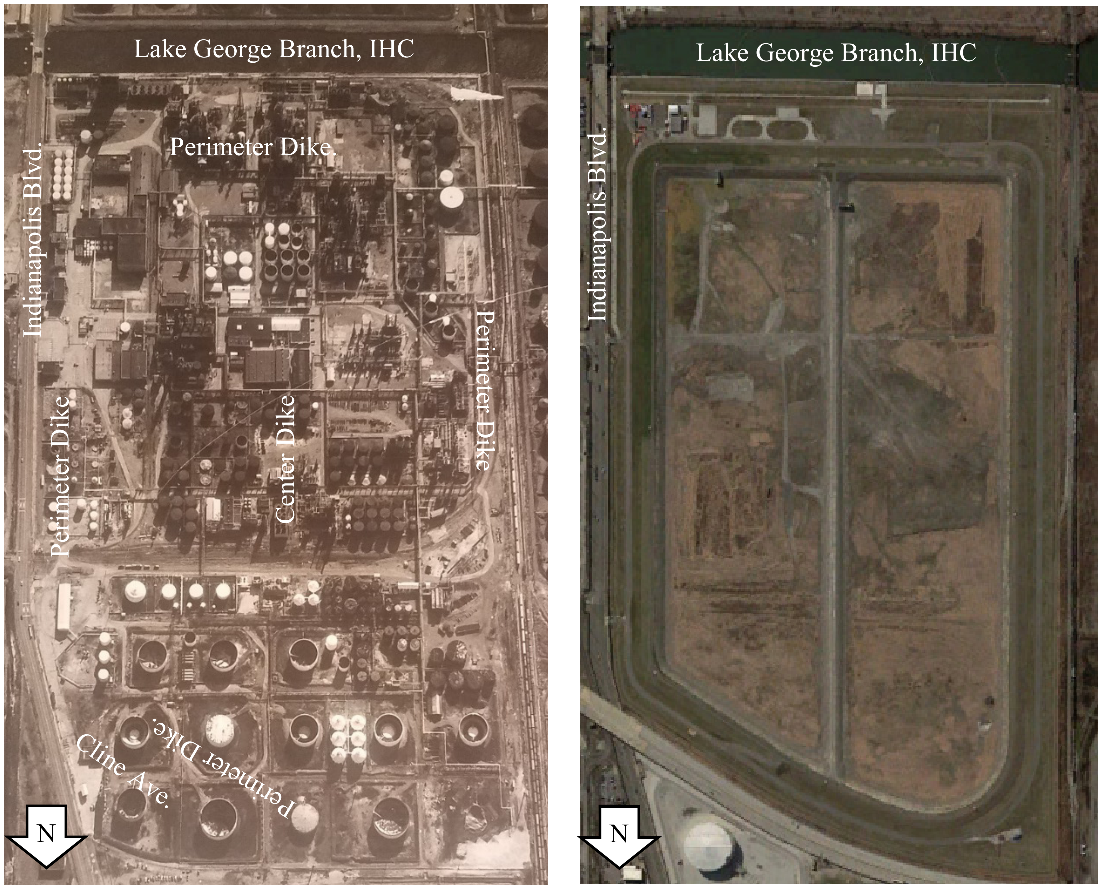

Figure 2. 2012 Landsat image showing historical aerial photo (unknown source, pre-1980s) of active oil refinery at the CDF site (left) and as-constructed CDF before filling (right).

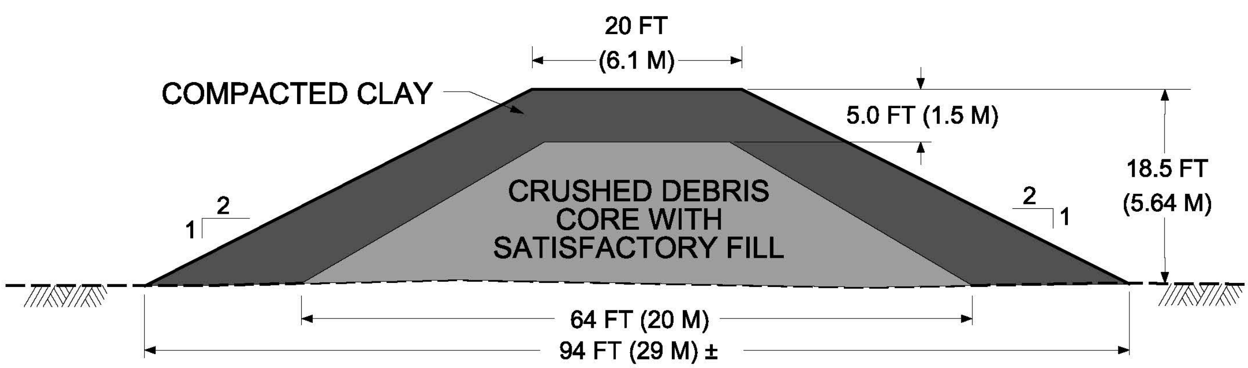

Figure 3. Typical cross section of center dike.

The facility also features significant geo-environmental components including a perimeter groundwater cutoff wall and groundwater extraction system that allow groundwater level management within the site as well as providing a year-round source for the water cover. These features make the facility unique among the USACE CDF inventory.

Figure 4. Debris being placed in core of center dike (USACE 2011).

The decision to operate the CDF as a ponded facility required some innovation and forethought in design. A compacted clay liner, typical for impoundments, was undesirable due to limited clay borrow sources, as well as the associated reduction in impounding capacity of the facility due to the liner occupying CDF space. Instead, the permeable, granular soil at the base of the CDF is sealed by the predominantly fine-grained sediments dredged from the IHC, enabling water to be impounded while conserving capacity. Water that gradually drains into the subsurface is prevented from migrating offsite by the perimeter groundwater cutoff walls and groundwater extraction system which maintains an inward gradient by lowering the site water table below the water table offsite from the cutoff walls. The groundwater collected by the groundwater extraction system is pumped back to the CDF to maintain water cover over the sediments and suppress air emissions. When excess impounded water requires removal, a wastewater treatment plant is brought online to treat the water before discharging the treated effluent to the canal. Infiltration is expected to decrease over time as consolidation reduces the sediment permeability, placing less demand for groundwater extraction but the increasing volume of accumulated water in the CDF will require more frequent removal and treatment for offsite discharge. After a sufficient volume of cleaner sediment from maintenance dredging gradually is placed in the CDF and encapsulates the backlog sediment, the need to maintain a water cover will be re-evaluated. This would reduce operating and monitoring costs and also promote an increase in capacity immediately through elimination of the water cover and gradually through sediment dewatering and consolidation.

In order to maintain two-cell operation with the upcoming perimeter dike expansion, the center dike would also need to be expanded. The center dike and two-cell configuration provide several project benefits. Sediments from more grossly contaminated reaches of the IHC are disposed into a designated cell which reduces the volume of cleaner sediment required for encapsulation. It allows transfer of water from one cell to the other in the event that dewatering is necessary for emergency repairs or maintenance on the interior slopes. If ponded operation changes to dewatered operation in the future, the center dike will provide flexibility by allowing dewatering and consolidation of sediment to increase capacity in one cell while material continues to be offloaded into the opposite cell. Finally, the center dike itself provides a platform for placement of hydraulic offloading pipes which averts issues with blocked access to the perimeter dike for maintenance and inspection, reduces pipe length requirements, and decreases pumping distances. If the center dike is not expanded, it eventually will become submerged and buried under sediment and these benefits will be lost.

The ponded facility operation presents a challenge to expanding the center dike because conventional construction techniques in the dry are not possible. Instead of expanding the center dike, installation of a sheet-pile wall was considered to raise the crest but ruled out due to a high risk of encountering refusal on underground obstructions from refinery foundations and infrastructure that were abandoned in situ when the refinery was razed. Placement of concrete blocks or barriers on the center dike crest was also considered but there would be a limit to which the crest elevation could be increased, the blocks would not be as effective at holding back water between cells, accessibility to the crest may be reduced or eliminated, and the concrete volume would take away CDF capacity. Dumping of rock and crushed concrete along the side-slopes to widen the center dike and allow dry placement of less permeable material to raise the crest height is also a potential solution, but this alternative would similarly use up capacity by using imported materials. Ultimately, the design was focused on constructing the expanded dike with sediment-filled geotextile tubes. This approach would allow beneficial use of the contaminated sediment within the CDF and avoid importing borrow materials which would otherwise reduce the available CDF capacity. However, there was a lack of experience in the Chicago District utilizing geotextile tubes for any application and it was uncertain if and how sediment-filled geotextile tubes could be stacked in submerged conditions to the desired heights, while remaining stable. The decision was made to hire a contractor to perform a pilot test and provide design recommendations and specifications for full-scale implementation.

BENCH-SCALE TREATABILITY TESTING AND SITE INVESTIGATIONS FOR THE PILOT TEST

USACE Chicago District contracted with Strata Earth Services of Palatine, IL (Strata) and their subcontractors, GEI Consultants, Inc. in Lansing, MI (GEI) and Infrastructure Alternatives, Inc. in Rockford, MI (IAI) under several task orders spanning from 2015 to 2018 which included studying the IHC CDF sediment, developing a mix design to dewater and stabilize the sediment, performing subsurface exploration and analyzing stability of the center dike and developing a pilot test program to evaluate the use of sediment-filled geotextile tubes to raise the center dike. In 2015, IHC sediment samples were obtained from the active dredge stream and provided to IAI and GEI for a bench-scale study to characterize the sediment and evaluate treatability by means of hanging bag dewatering tests (Figures 5 and 6) and strength testing on treated sediment. It was determined that the sediment samples could be dewatered to at least 88% of in-situ solids (38.5 to 48.0 % solids) with 48.5 to 70.9 pcf (7.62 to 11.1 kN/m^3) unit weight and yielded a peak internal friction angle as measured by direct shear ranging from 25.5 to 27.9 degrees (Ref 1).

Figure 5. Mixing Sediment and Polymers

Figure 6. Hanging Bags Dewatering

In support of the pilot test and technical design of the center dike raise, subsurface exploration and instrumentation installations were completed in June 2018. Geotechnical characterization of the sediment and the underlying foundation soils was required to evaluate stability of the test section and of the envisioned future center dike raise (Ref. 3 and 4).

Additional borings and testing were needed for the dike expansion. The proposed subsurface exploration program included two (2) center dike borings, as well as sediment sampling and testing in the west cell of the CDF at three (3) locations. One of the center dike borings and all sediment sampling and testing locations were located adjacent to the pilot test section. Figure 7 shows the location of the pilot test section and the explorations.

The sediment borings were offset into the west cell approximately 80 feet (24.4 m) from the dike crest to avoid the toe of slope and were spaced approximately 25 feet (7.62 m) apart within the 100-foot (30.5 m) test section. At each location, three boreholes were drilled (SD-01A, SD-01B and SD-01C). Separate borings were performed for sampling, vane shear testing and installation of instrumentation. The center dike boring adjacent to the pilot test section was completed with installation of an inclinometer designed to monitor potential slope movements within the center dike during the pilot test. The inclinometer could also be used as a long-term monitoring device for full-scale implementation if desired.

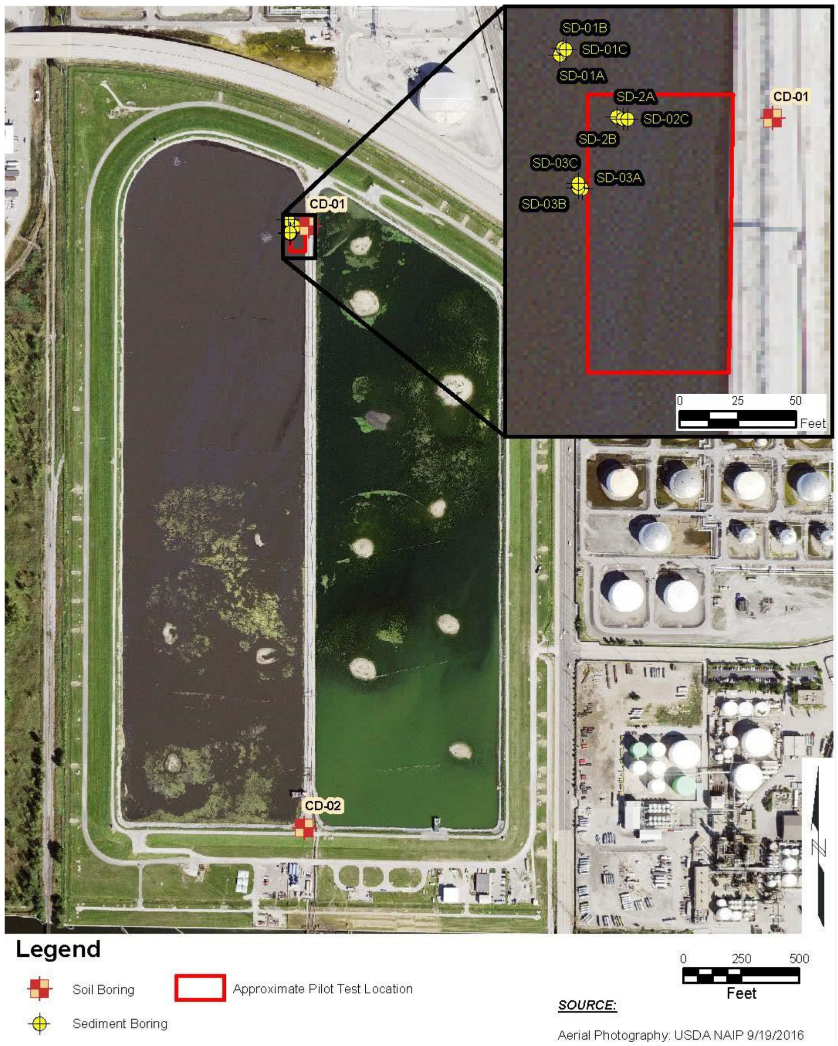

Figure 7. Pilot Test Explorations and Pilot Test Footprint (ref. 2)

GEOTEXTILE TUBE GEOMETRY AND MATERIAL PROPERTIES

The location and cross section of the geotextile tube pilot test section is included on Figures 8 and 9.

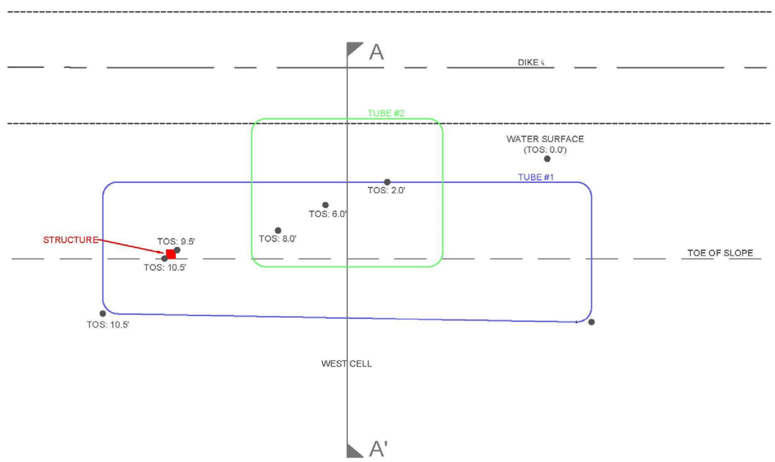

Figure 8. As-Built Pilot Test Plan View (Ref. 4)

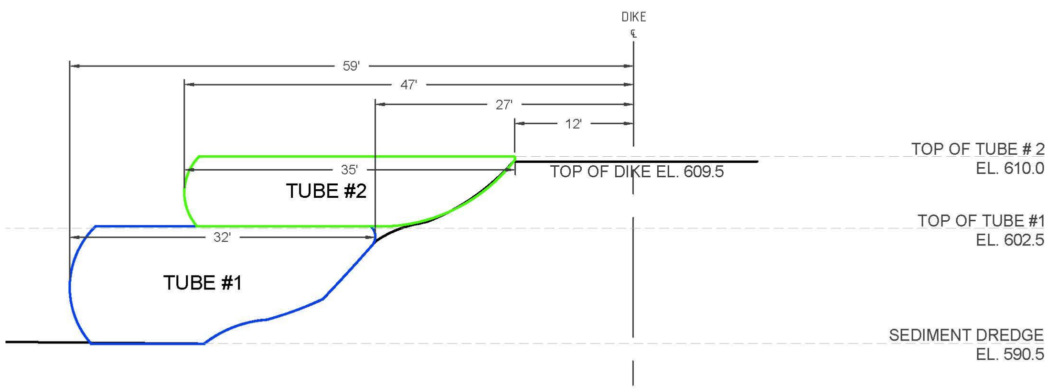

Figure 9. As-Built Pilot Test Cross Section A-A’ (Ref. 4)

A slope stability analysis was completed on the pilot test cross section and on the maximum potential expansion (Figure 10), utilizing concepts from the pilot test.

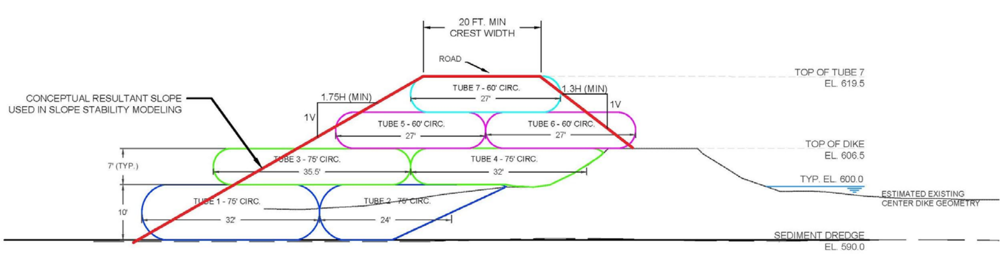

Figure 10. Conceptual Fully Expanded Center Dike (Ref. 4)

One of the recommendations and key components of the slope stability analysis indicates that the unit weight of the sediment used to fill the geotextile tubes is critically important to ensure the design meets minimum acceptable factors of safety. As a result, a draft construction specification was prepared which includes a requirement for Quality Assurance testing and visual USCS classification while filling tubes. QA testing of grain size and unit weight of in-situ sediment taken from geotextile tube fill ports after completion is also included to ensure a minimum of 110 pcf (17.3 kN/m^3) is achieved once sediment is consolidated in the tubes.

Since this minimum unit weight is needed and treatability of the oily fine-grained sediment proved to be marginal and cost prohibitive during the pilot test, it is recommended that a field sampling program be implemented prior to construction to document that there is a sufficient volume of coarse-grained sediment available. This volume should be verified and if determined to be insufficient, a plan should be developed for filling the remaining volume. One possible solution to a lack of coarse-grained sediment is to blend fine and coarse-grained sediments and treat with a polymer. A blended, treated sediment should only be considered for the top tube layer in the full-scale application and may result in limitations on vehicular access. Sliding failure of the tubes should be considered if a lighter-weight material is used for the top tube layer and if water is to be retained at a differential head equal to the elevation of the top tubes in either cell.

To meet minimum required factors of safety, all CDF sediment should be removed from within the planned geotextile tube footprint. Complete removal of sediment should be verified in the field prior to placement of any geotextile tubes.

The slope stability analysis also indicates that a limitation should be placed on allowable differential head between ponds to maintain assigned project minimum Factors of Safety (FS), per EM-1110-02-1902, Slope Stability. The most limiting condition represents a fully constructed center dike expansion and a water table in the west and east cells equal to the original dike elevation (Figure 11). In this case, the entire weight of the expansion is acting on the original center dike clay and provides a driving force great enough to reduce the FS to 1.4, which is less than the minimum required FS of 1.5 and does not allow for a difference in pond elevations in the long-term. A 3.0-foot (0.91 m) difference can be tolerated at this stage on a short-term basis. This can be avoided operationally by always maintaining a higher elevation in the west pond until enough of the geotextile tubes are submerged to sufficiently reduce the driving force acting on the existing center dike and thereby increasing the FS to within an acceptable range.

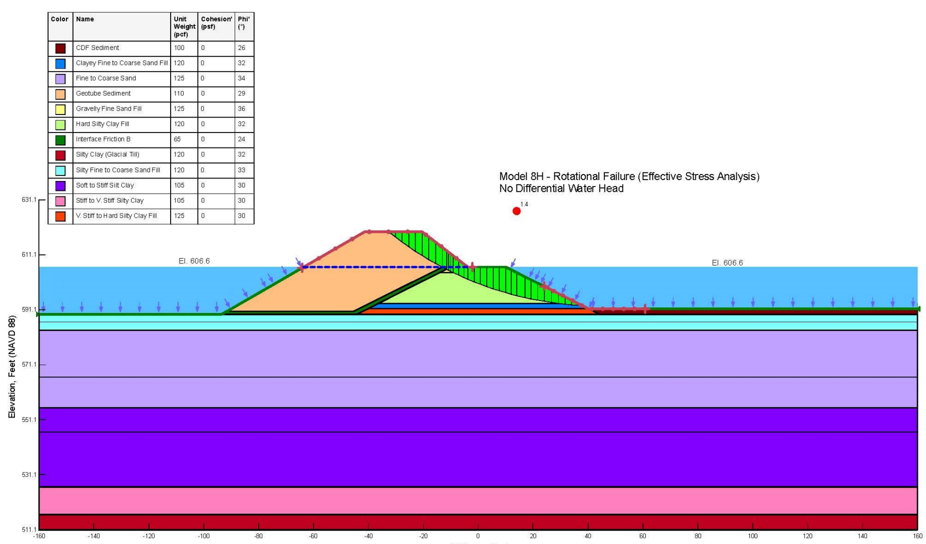

Figure 11. Critical Potential Failure Surface of Fully Expanded Center Dike

The minimum FS assigned for this project could be re-evaluated if operational limitations placed by this analysis are unrealistic. The center dike is being held to the same standards as a dam, which requires a minimum FS of 1.5 for long-term conditions and 1.3 for short-term conditions. A minimum FS of 1.3 could be considered acceptable for short-term conditions for failures of the center dike since it would not result in a loss of containment from the CDF.

Additionally, it should be recognized that the section of the center dike used in this model represents the limited portions of the center dike that are comprised of a clay fill core in which the soil boring CD-01 was drilled. The majority of the center dike is comprised of a debris core which can be modeled with a much higher friction angle (38 degrees vs 32 degrees) and would theoretically result in higher FS and higher tolerable differential water levels between ponds.

PILOT TEST PERFORMANCE AND RESULTS

The pilot test was completed by IAI, September 27, 2018 through November 8, 2018 along the western slope of the center dike at the north end of the CDF.

Figure 12. As-Built Pilot Test Photograph

Description of Equipment & Materials

Geotube® containers manufactured by TenCate were utilized for the pilot test:

- One (1), 75-ft. circumference by 115-ft. long (22.9 m x 35.1 m), with six fill ports
- One (1), 75-ft. circumference by 45-ft. long (22. 9 m x 13.7 m), with one fill port

A dual product application was selected to condition the dredged material prior to dewatering in the geotextile tubes. Flopam A-6350 and Flopam C-6237 manufactured by SNF Holding Company were utilized, during the portion of the test that polymer was applied.

- 291-gal. (1102 L) of Flopam A-6350, applied at an average dose of 6.6 lbs./dry ton (3.3 kg/metric ton)
- 621-gal. (2351 L) of Flopam C-6237, applied at an average dose of 14.1 lbs./dry ton (7.1 kg/metric ton)

For a portion of the pilot test, when targeting of coarse-grained material during the later stages of the test, no polymer was applied. The coarse material was able to dewater in the tubes without polymer treatment.

To perform the pilot test, IAI utilized a 6-in. (15.2 cm) dia. GeoForm International Dino6 hydraulic auger dredge, a 30-gph (114 Lph) Velodyne Veloblend polymer feed system, a 10-gph (37.9 Lph) Neptune Polymaster^{TM} polymer feed system, as skid-steer and various cabling, pumps, piping, barges and boats.

Procedure & Sequence of Operations

Prior to placing the first geotextile tube, sediment within the target footprint was removed. This provided a stable base for installing the first geotextile tube. First, the location of the first tube was selected. The location was measured and identified by marking along center dike. As a result of the slope stability analyses using vane shear data obtained from the sediment in the CDF, it was determined that the very soft sediment would not provide adequate factors of safety for support of the tubes even with minimal sediment depths. In order to prepare the bottom of the CDF for the bottom tube the footprint of the tube would need to be dredged to the approximate bottom elevation of the CDF prior to tube deployment. A cabling system was set up to position the dredge and the dredge was launched into the West Cell of the CDF. Sediment was removed from the geotextile tube footprint, with the dredge making several passes in each cut. The dredged sediment slurry was conveyed through a 6-in. (15.2 cm) dia. float pipe system to the center dike, where the pipeline crossed into the East Cell of CDF, and the dredged slurry was discharged. It was observed that, in this particular area of the CDF cell, very little submerged sediment material sloughed into the box cut and the sediment stood in a near-vertical shear wall around the footprint of the geotextile tube.

After sediment was removed from within the footprint of the first geotextile tube, a 6-in. (15.2 cm) dia. geotextile tube header system was installed, to allow sediment to flow into multiple fill ports in the geotextile tube. The two polymer feed systems and water pump were plumbed and connected to power. Six inch-dia. (15.2 cm-dia.) S-type stingers were installed into the fill ports on the geotextile tube, as it was unrolled and floated into position. The first geotextile tube was pulled into place by a work boat pulling from the water, via a rope passed through the straps sewn into the tube, and crew members pulling from shore. Tubes were held in position by 250-gal. (946 L) containers filled with water, acting as anchors, staged on the center dike, and by a cable (similar to the traverse cable) on the west side.

Figure 13. Geotextile Tube Deployment Photograph

It was determined that coarse-grained material, in mounds produced by other dredging activity, would be used to fill the first tube. The dredge was repositioned to an area west of the first tube, where both coarse-grained and finer material were available for dredging. Coarse-grained material was dredged into the first tube initially and dosed with polymer. The coarse material dewatered very well in the geotextile tube, consolidating rapidly; however, dredge production was significantly hampered by large rocks and debris that were mixed with the coarse-grained material in the CDF. It was estimated that the dredge was able to move this material at a rate of approximately 10-cubic yards per hour (cyh) (7.6 m^3/hr).

After encountering many plugs due to debris and settling in the pipeline, finer material was targeted for dredging. This material was black and oily, and required significantly more polymer to dewater. The black oily material pumped very well, with very good dredge production rates, similar to the material that was dredged from the Tube #1 footprint. It is estimated that an average rate of 40 cyh (30.6 m^3/hr) was achieved by the dredge. However, the black oily material was very difficult to treat and characteristically inconsistent with the samples that were analyzed during pre-project treatability testing. To treat the black oily material, approximately five times the anticipated amount of polymer that was identified in the treatability testing was utilized. In addition, the dredge slurry was purposefully removed at a thinner consistency (8% solids by mass), to help the polymer to work more effectively. This significantly reduced dredge production to approximately 10 cyh (7.6 m^3/hr). The black oily material did not dewater well in the first tube.

The pilot test plan was modified due to the difficulty in treating the black oily material and the challenges involved with pumping the coarse-grained material. The layout plan was modified to reduce the number of geotextile tubes installed from three (3) to two (2) and shortening the length of the second tube from 100-ft. (30.5 m) to 45-ft. (13.7 m). The second tube was deployed, partially overlapping the first tube, and rested on the west center dike slope along the east edge of the tube (Figure 14).

Figure 14. Filling and Placement of Second Geotextile Tube

Only coarse-grained material was targeted for filling the second tube. Though this increased the amount of line plugs and associated downtime, it proved to create greater stability. The coarse-grain material used for the second tube was not dosed with polymer, as it consisted mostly of gravel and sand, and consolidated well inside the tube without treatment.

Instrumentation Monitoring

Prior to excavating sediment from the proposed pilot test footprint and filling the geotextile tubes a baseline reading was obtained from the CD-01 inclinometer. A subsequent reading was obtained after geotextile tube filling was completed to monitor potential slope movements. In addition, four (4) settlement monitoring points were installed on the surface of the top of the completed second geotextile tube.

CONCLUSIONS AND RECOMMENDATIONS FOR FULL-SCALE APPLICATIONS

Based on the results of the pilot test, the recommendations are presented for construction full-scale dike expansions to final elevation using geotextile tubes:

- All sediment present within the footprint of the geotextile tube installation be evaluated for compressibility with the anticipated load and removed if deemed necessary (through hydraulic dredging, or another method) to prepare the area prior to geotextile tube placement.
- Prepare footprint of base tube in advance of tube deployment, such that the prepared footprint is no more than three geotextile tube lengths ahead of the tube(s) currently being filled. This will minimize potential sloughing of CDF sediment into excavation), by dredging to remove sediment and excavating debris, as needed.
- Target coarse-grain material, dredged at a high rate of flow, to spread material evenly throughout the length of the tubes. Accurate, representative sampling of the material to be dredged into the tubes is critical to the success of any geotextile tube installation; the material to be dredged must be thoroughly characterized and analyzed for treatability and dewatering profile.
- Polymer treatment of the granular material may be beneficial to aid consolidation of any mixed materials within the tubes and increase filtrate clarity, if filtrate water quality becomes important during construction. Excess polymer should be limited, to be verified by Kaolin clay test for the presence of unreacted polymer in the filtrate.
- Debris must be removed from the geotextile tube installation footprint, to prevent damage to the geotextile tubes.
- There are multiple combinations of tubes, stacking patterns and final geometries that could be used to construct a dike raise with geotextile tubes. Potential contractors should be allowed to consider the most cost-effective stacking arrangement that meets the requirements of the project as outlined in this report. The

contractor should be required to prepare a detailed tube layout plan and typical cross-section for review by the Owner/Engineer prior to installation.

- A composite cross section that incorporates sediment-filled geotextile tubes in combination with other materials, such as conventional fill in the portion of the dike extending above the pool level, could be considered if a sufficient volume of suitable sediment is not available to reach the full desired dike height, to offset some of the expense of geotextile tube construction, or for other reasons where the dike cannot be completely constructed with sediment-filled geotextile tubes.

Application for Other CDF or Pond Facilities

This type of beneficial re-use of contaminated (or non-contaminated) sediments has many applications. Care should be taken to properly analyze the functional materials on which the geotextile tubes will bear, the overall stability of the expansion considering unit weight and grain size of the targeted sediments, in order to develop a project-specific mix design that is flexible for in-field application and careful consideration for economically-optimal geotextile tube stacking configurations. Based on the results of the IHC CDF pilot test, this type of application could be successfully implemented at other CDF facilities to raise internal diking systems in lieu of concrete barricades, clean fill materials that would otherwise occupy CDF capacity and provide a useful alternative to simply storing the contaminated sediments.

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