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C. K. Maglio

U.S. Army Corps of Engineers, coraggio.maglio@usace.army.mil

B. M. Scully

U.S. Army Corps of Engineers

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Confined Disposal Facility Improved Weir Designs

C.K. Maglio, and B.M. Scully
U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
USA
E-mail: coraggio.maglio@usace.army.mil

ABSTRACT

One of the initial constraints of any dredging project is deciding where to place dredged material. When placed upland, materials can be used beneficially, as beach nourishment or for habitat restoration, or can be placed in an upland confined disposal facility (CDF). Several times the solids volume in water is required to fluidize and hydraulically pump the materials. Once in the CDF, materials settle out of suspension, with clarified water decanted. This paper describes in general a current weir design used by the U.S. Army Corps of Engineers (USACE) and illustrates the innovations of the new Jacksonville District standard weir. The new outfall structure is safer, easier to construct, and has inherent environmental protection features. It also has a longer lifecycle and lower lifecycle cost than traditional structures. This paper also discusses a new composite weir system that is in the patent and construction phase. These new corrosion-resistant systems have the capability of revolutionizing and standardizing water control structures due to basic changes in material selection and operational controls. The construction, management, and maintenance of weir systems are a significant cost incurred by USACE navigation projects; improved systems are available that can reduce maintenance costs while improving the safety of personnel who operate them.

Keywords: *Dredging, water control structure, box riser, composite weir, dredged material disposal.*

1. INTRODUCTION

The ability to control fluid levels in a system is a fundamental aspect of water management, whether in the form of stormwater detention, raw water holding, wastewater treatment, industrial, agricultural, or other applications, instances where retaining variable head volumes of fluid are common. This is true also for nearly every port or waterfront facility around the world with confined disposal facilities (CDF) for dredged material. In the continental United States of America, the U.S. Army Corps of Engineers (USACE) maintains over one thousand CDFs, and within the Department of Defense (DoD), other state and federal agencies, and the private sector, thousands of water control structures within CDFs are in operation.

A CDF normally includes a water control structure in the form of a weir to separate water from dredged material. The supernatant water returns to the natural water body from which it was entrained by the dredge. In general, CDF weirs are designed with three objectives: to retain all of the dredged sediment solids within the CDF, to return clarified water from the CDF to the natural water body, and to control the release of water in such a way that turbidity, sediment resuspension, and scour are minimized.

One of the primary decisions made during any dredging project is where to place the dredged material. In basic terms there are only two alternatives; place the material in the water or place it on land. When dredged material is placed on land in a CDF, it is typically placed using a hydraulic pumping method that entrains sediment in a slurry with roughly four times as much water. Separating water from dredged material frequently employs an outlet weir structure to decant supernatant water back to the receiving water body. The outlet structure is usually a weir box (see Figure 1), half-pipe riser (see Figure 2), or other water control apparatus.

These facilities are often placed in very remote locations (disposal islands); thus, any construction that occurs at these sites is often at a premium. Maintenance of these facilities is also often neglected due to the inherent operation difficulties and funding constraints. In coastal areas, the dredged material pumped into these CDFs evaporates and leaves behind highly saline and dissolved oxygen deficient liquids, creating extreme corrosion conditions. These structures are normally built out of coal-tar coated steel and/or sheet metal and wood and are highly susceptible to degradation and corrosion if the protective coatings have the slightest scratch or defect. Traditional alternatives to controlling fluid at variable heights include designs with materials such as concrete, steel, and wood and mechanisms such as weirs, sluice gates, and fixed orifices.

The relatively rapid degradation of materials within and adjacent to coastal environments are common throughout the world with significant damage caused by chloride-induced corrosion, chemical attack, physical deterioration (e.g., abrasion and erosion), thermal and freeze/thaw cycling, and biological and UV degradation. In many cases, the use of new, non-corrosive materials and designs can reduce initial construction costs and greatly reduce the life-cycle costs of these facilities.

Figure 1. Box riser weir crevice corrosion at water-air interface after one use cycle.

Figure 2. Half-pipe riser weir's sheet metal skin experiencing pitting corrosion after one use cycle with protective asphaltic coating.

Most weir structure designs have not evolved and still require operators to climb into the structures to manually alter the weir elevation (see Figure 3). The usefulness of a CDF is dependent on the ability of the weir structure to decant water at varying elevations during and after the dredge material placement event. Elevation control of the pool in the CDF is crucial for maximizing disposal capacity and adhering to water quality standards. For a weir to decant at varying elevations, the most common method involves stacking timber boards into vertical slots along the face of the weir, starting at the bottom, until the weir stack reaches the desired decanting elevation. Adding weir boards increases the pool elevation of dredge slurry in the CDF, which increases retention time and settling efficiency. Clean water remaining at the top of the water column after entrained solids have settled are released over the weir crest. The frequency with which crest heights need adjustment depends on several variables. It is not uncommon to adjust elevation several times each day during a dredging operation. Adjustments made to the weir board stack after material placement are usually much less frequent and depend on the level of material management intensity.

Figure 3. Traditional USACE fluid control operation (removing timber weir boards) with harnesses within confined disposal area (front view - left) and (plan view - right).

Historically, weir structures averaged 2.5-3.5 m (8-10 ft) in height but have grown as CDFs are incrementally raised to match dredging needs. Currently, weir structures between 8 and 10 m (25 and 35 ft) in height are commonly found. Operators are required to wear fall protection gear to make adjustments to the weir crest (decanting) elevation. To make elevation adjustments, the operator generally enters into the weir structure at the top, climbing through a tight lattice work of steel structural members to reach the face of the box. Once the operator climbs down to the top board of each stack, they must continuously secure their fall protection gear and brace themselves within the structural members in order to physically remove or install the boards. Wooden boards frequently swell into the slots and require the operator to dislodge them by swinging a claw hammer or pick-axe into the face of the board, which may be submerged several inches below the surface of the pool. In a worst case scenario, the operator must use a chainsaw to cut the boards into pieces for removal.

Given the dangerous working conditions and level of effort needed to keep the stack of boards at the optimum elevation during and after a dredge event, weirs may be operated improperly. Improper operation of the weir has negative impacts relating to adherence to outflow water quality standards and the overall operational inefficiency of the site. In most cases across the nation, CDF capacities are at a premium given their vicinity to port growth and other valuable uses of land along waterways. Inefficient uses of CDFs due to improper operations of a weir box can usually be traced to the difficulties relating to removing or adding weir boards. To address operational life-safety and greatly improve the life-cycle of CDF weirs while lowering initial costs, the following designs were developed.

2. NEW JACKSONVILLE DISTRICT STANDARD WEIR

The new Jacksonville District standard weir design was developed to resolve lifecycle concerns while increasing overall functionality. This redesign of a standard system looked at all of the competing issues and maintained three basic design tenets that guided the process: simplicity, flexibility, and redundancy. The result of this process was a new outlet structure design that uses a wrap-around floating dock to access the dual coal-tar epoxy coated steel box riser weirs on a single concrete slab foundation, as shown in Figure 4 (Maglio, et al. 2014).

Figure 4. Set of 4.9 m (16 ft) tall 1.2X1.2 m (4x4 ft) Box Riser Weirs with floating dock access, Buck Island, Jacksonville, Florida. (Maglio et al. 2014).

This new weir design uses composite weir boards that are lighter, stronger, more dimensionally accurate, and tighter fitting than traditional treated timber weir boards. The wrap-around floating dock allows for safe and easy access for the installation or removal and storage of the weir boards, as shown in Figure 5. An internal emergency flap gate is installed within the box at the discharge pipe, as a redundant environmental safety feature. The modular nature of this system allows the design to be easily adapted for a particular application without significant alterations (Maglio 2014).

Figure 5. Bartram Island Cell F floating dock in use with composite weir boards removed and stacked on the docks deck from two sides of each box riser (Maglio et al. 2014).

Another significant improvement of this design over previous systems is the fact that these weirs are installed in pairs. This ensures that dredging can continue in the event that a single weir becomes compromised during the course of a dredging event. The risers are connected to continuously fused, high-density polyethylene (HDPE) outfall pipes that are permanently installed, as shown in Figure 6 (Maglio 2014). This type of plastic, continuously fused pipe has far less lifecycle issues than other pipeline materials.

Figure 6. Permanently installed and elevated 30 inch outfall pipes to minimize wetland impacts Bartram Island Cell B2 (Maglio et al. 2014).

The approximate total construction cost for a set of coal-tar epoxy coated steel box riser weirs on a concrete spread foundation with HDPE return outfall pipe is $350,000 in 2014 U.S. dollars. This includes all associated earthwork, fabrication, and material costs (Maglio 2014).

This design solved the vast majority of issues related to traditional CDF weirs associated with safety and lifecycle; however, it did not address the construction cost and practices, especially in remote locations. It also employed structural steel in a highly corrosive environment with only a thin protective coating.

3. INCREMENTALLY ADJUSTABLE FLUID CONTROL MECHANISM

The Jacksonville District weir re-design overcame two critical issues through material selection and general arrangement. The first critical issue was environmental compliance and safety shortcomings that arise from the mating issues inherent in the use of wood in a steel guide channel. Dimensional inconsistency in the wood results in leakage or difficulty in operation. Neither improved the function of the system. System performance benefitted from the selection of a dimensionally stable, corrosion-resistant composite material, in that leakage was reduced. The second critical issue was operator safety, which was also improved by selection of lighter material that was less prone to jamming in the guide channel. Operators no longer require the use of hammers, pick-axes, or chain saws to remove flashboards. Safety was further improved by the use of a floating dock, which enables users to access flashboards without entering the riser; fall protection is no longer necessary to operate weirs safely.

Despite these improvements, it was recognized that further operational gains could be achieved. Owing to the composite material's shape and strength, it is possible to lift individual or multiple boards using a simple lifting mechanism inserted into the open face of a board, which has been modified from a rectangular cross section to a c-shaped cross section. By lifting boards in this manner, it is possible to create a weir crest or orifice anywhere within the stack of weir boards. By enclosing the riser box and affixing the operation mechanism to its exterior, the need to approach the weir face during operation can be eliminated, as can the necessity and cost of floating docks used for that purpose.

Recognizing the available benefits, the USACE applied for a patent for the incrementally adjustable fluid control mechanism. The mechanism combines the function of both a weir and an orifice, traditionally used independently, enabling flexible fluid height control and operation modes over a varying head range, limited only by the strength of riser boards and the lifting mechanism connection members, see Figure 7.

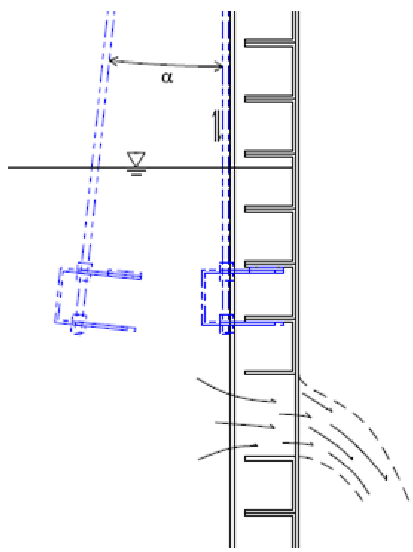

Figure 7. Side view - incrementally adjustable fluid control mechanism concept, employing a stack of composite c-channels and a picking mechanism.

The picking mechanism is lowered to the desired elevation of fluid withdrawal, usually just below the water surface, then inserted into the flange of the C-channels. This picking mechanism is similar to a picking beam utilized for evenly lifting heavy loads. The vertical lifting force can be produced by an actuator, winch, jack, or similar mechanism. The withdrawal depth can be determined by measuring the inserted length of the picking mechanism using pre-determined marks or a line counting system.

4. COMPOSITE WEIR SYSTEM

USACE is currently working to develop a fully composite weir system that takes advantage of the incrementally adjustable fluid control mechanism. The primary benefits of the proposed Complete Composite Box Weir System is the ability to open a window at any elevation from the top of the structure using the picking system (see Figure 7). The removal of boards is no longer necessary when using this system as the guide channel can be fabricated to account for the required "window opening" height, rather than removing all the stop logs to the desired elevation. The structure can be entirely fabricated out of available composites and plastics products, and can also be easily excavated and moved to a new location and reinstalled because it does not require a typical concrete or pile foundation due to its light weight.

The complete composite weir system is a conceptual design for a 7.9 m (26 ft) tall adjustable weir with composite C-channels and an integral spread foundation using composite beams, timber, and granular backfill to distribute the structural load and to counter uplift buoyancy forces. One of the benefits of this proposed system is the elimination of the need for external ladders, floating docks to pull boards, or other access methods because water withdrawal control is handled from the top of the structure. The system functions by using a picking mechanism controlled from the top of the riser to regulate the weir crest elevation on all sides of the riser at any elevation. Removal of boards is no longer necessary when using this system as all weir boards remain in the channel permanently (Maglio 2014).

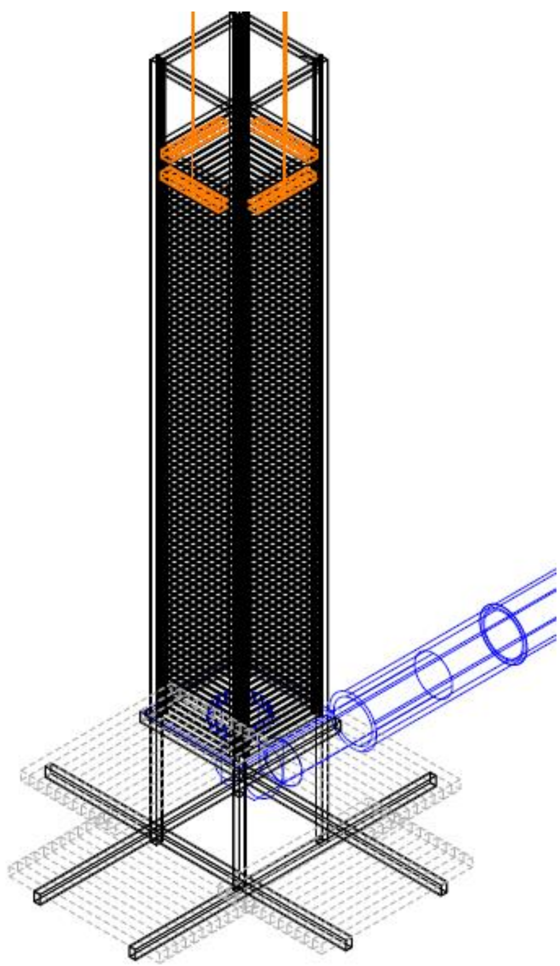

Figure 8. Isometric view of conceptual Complete Composite Weir.

The system is entirely fabricated from fiberglass reinforced composites and plastics. It includes a slip joint of HDPE pipe to preclude forces due to settlement of the adjacent dike from transferring along the outfall and causing the weir to lean or connections to fail. This slip joint also allows for easy extraction of the riser structure so that it can easily be moved to a new location and reinstalled in the event that the structure must be relocated for material management purposes. Extending the foundation of the structure downward into the subgrade and the use of onsite granular backfill for stability and to offset floatation or settlement forces provides a relatively inexpensive and more expedient construction option compared to typical foundation systems (Maglio 2014).

This concept is intended to provide an improvement in terms of design lifecycle, operations, and costs to common existing systems. It consists of vertical guide channels containing a stack of C-channel members that make up a vertical wall. The C-channels are oriented such that their flanges are exposed to the working fluid, while the c-channel webs make up the vertical retaining wall. The flanges of the C-channels provide an easy lip for raising the C-channels to create a window at any level.
The composite weir system design characteristics:

- C-channel composite shapes are lightweight when compared timber or steel.
- Fiberglass reinforced composite materials are non-corrosive, can be made UV resistant, and with the proper resin, can be manufactured to be heavier than seawater, and they can have a 50 year design life.
- The C-channel shape is such that there is an easy picking lip that in integral to the structures design.
- The stack of C-channels with their flange's out looking provides a flat matting wall surface against the back guide channel flanges.
- The C-channel composite shapes are able to withstand large hydrostatic forces.
- Flexibility due to the composite c-channels inherent strength; these gate systems can be made wider or taller depending on the application needs.

The total initial cost of one of these systems is relatively similar to traditional steel frame designs if fabrication and installation cost are included.

5. CONCLUSIONS

A weir is a barrier that operates like a small dam, pooling fluid behind the structure while also allowing it to flow steadily over their tops at a semi-adjustable elevation. Common uses of weir stacks include altering the flow of rivers to prevent flooding, measuring fluid discharge, and rendering rivers navigable. Traditional weir stacks consist of a stack of "stop logs" fabricated out of timber or aluminum and held into place with vertical channels. Water flows over the top, with stop logs removed or added to control the water level upstream of the weir stack. There are several limitations inherent to weir structures. One of the design problems is that the buoyant stop logs can float, compromising the control of the stack. Additionally, water level control is only possibly from the top, by removing logs from or adding logs to the stack.

Incorporating materials from other industries to improve standard systems design can reap huge benefits in terms of lifecycle management and long-term project costs. The implementation of such an initiative was conducted within the USACE Jacksonville District. This has led to initial and long-term cost savings as well as many other benefits. This improved system has been embraced by project Sponsors and their consultants, and numerous installations have been completed. The primary drawback of the Jacksonville District's new standard design is the use of carbon steel, which in the marine environment, is easily corroded if the coating system is compromised. However, this material selection issue has been addressed by the conceptual full composite weir system design. This concept removes the issue of corrosion and lifecycle concerns by the use of composites to replace the steel members. The concept also allows for easier relocation of these structures by dispensing with a solid foundation in favor of an easily excavatable, granular backfill. The floating weir system employs standard marine materials and a constant withdrawal depth to achieve production efficiencies while maintaining an extended life cycle (Maglio 2014).

6. ACKNOWLEDGMENTS

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