

Trash Rack Rail System Rehabilitation Using An Asymmetrical Cofferdam

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ABSTRACT: There are a number of medium head, 40 to 110 feet of fresh water, hydro facilities throughout the United States reaching the end of design life cycles. While routine maintenance of facility generating and operating equipment is often well understood and vetted through procedure revision, significant maintenance of static portions of the main structure of these facilities is rare and unique. Included in this paper and presentation is a case study of one such project including: the feasibility study, cofferdam design and fabrication, cofferdam installation, removal of an existing trash rack rail system, design and fabrication of a new trash rack rail system, installation of a new trash rack rail system and removal of the cofferdam. The project served as a prototype rehabilitation approach for the 44 such rail systems at the facility and included disciplines of mechanical and civil engineering, as well as, skilled labor professions of iron workers, commercial divers and concrete masons. The case study serves as an aid in determining the feasibility of medium head facility rehabilitation projects using cofferdams.

Introduction

The Conowingo Hydroelectric Generating Station is located on the Susquehanna River near Darlington, Maryland. The facility is owned and operated by Exelon Generation with a 548 Mwe generating capacity and average pool depths between 85 to 90 ffw. The 4,648-foot dam, completed in 1928, serves as a bridge for U.S. Route 1, which runs along the top of the structure. This conventional hydroelectric generation facility consists of vertical lift gates and a powerhouse containing 11 turbines. Water is delivered to the turbines through a penstock and wicket gates and exits from a draft tube to the tail race. The 11 intake bays are divided by main piers and further separated by narrower splitter piers that divide each intake bay. River debris is restricted from entry by a combination of a cantilevered upriver concrete curtain wall and removable trash racks. Both the vertical lift gates and trash racks are guided into position on opposing sets of steel rails. The steel rails and steel embedded seals for all 11 unit intake powerhouse trashrack and headgate areas have deteriorated to a point where maintenance is required. The purpose of the cofferdam is to dewater the 11 unit intake areas so the rails and embeds can be replaced.

Feasibility Study

Routine maintenance at the facility involved removal of the trash rack units and debris cleanup inside the intake bays upstream of the head gates. Throughout the 1990s and into the 2000s removing and replacing trash rack segments became increasingly difficult. A preliminary diving investigation found significant deterioration of portions of the trash rack rail sections in intake Bay 9. In summer 2011 a feasibility study was undertaken to determine the course of action by which the trash rack rails may be rehabilitated and project goals determined.

During initial discussions the approach for the project was dependent on feasibility. Following investigation dives and classification of the deterioration, an innovative approach was derived from a solution matrix that addressed numerous concerns raised during the investigation. The solution matrix involved assigning values based on engineering assumptions addressing systemic variables and design commitment, as well as constructability topics such as fabrication complexity, work space restrictions, and installation feasibility. The values developed for the input data were based on experience with existing technology and designs pertaining to bulkheads, stop log systems, and cofferdams.

Systemic concerns and installation feasibility pertaining to a single stop log system across the entire bay or a bulkhead installed across one bay indicated unacceptable risk. Due to the splitter pier configuration, the installation of a bulkhead across a single bay would have resulted in unacceptable bearing requirements on the upstream nose of the splitter pier. Similarly, installation of a stop log system across an entire intake would have required a structure of incompatible size, unacceptable loading of the cantilevered debris wall, and systemic concerns associated with the dewatering of an entire intake bay. Conversely these concerns were minimized by the use of a semi-circular or C-shaped cofferdam. Further analysis revealed the work space restriction inherent with a semi-circular cofferdam adjacent to the sealing surfaces would unacceptably complicate the rehabilitation efforts. Analysis of the solution matrix indicated an asymmetrical cofferdam would best accommodate the requirements presented including the lowest systemic risks and meeting the work space needs.

Cofferdams have a long history of creating dry, workable environments for projects that may otherwise have taken place underwater. The question was, “Could a rehabilitation project actually deliver the required repairs within the confines of what would be one of the deepest asymmetrical cofferdams ever constructed and installed in the United States?” Classified as a medium head facility, Conowingo has average pool depths of 85 to 90 ffw. In addition, the long open fetch approaching the dam required adequate free board for safety of the workers within the structure. For these reasons the design parameters were set at 100 feet. Further complicating the project were the extreme restriction of space due to the nature of the headworks and overhead lift restrictions resulting from the existing gantry cranes on the headworks. As a result, the cofferdam would be fabricated in 25-foot sections and shipped in a configuration that would not require any realignment once on site.

Cofferdam Design

The cofferdam was designed for installation in Units 1 to 7 and Units 8 to 11 to accommodate the different rail geometries. The cofferdam system was designed to allow transportation on standard highway trailers and assembly using Exelon Generation's existing 90-ton gantry crane. Vertical lift was limited due to the gantry crane geometry. Therefore, the cofferdam had to be composed of individual sections that could be assembled above water and lowered into position. A blocking system was required to aid assembly during erection of each section of the cofferdam. The blocking system provided a temporary foundation for erected section(s) while the section above was moved into position and mechanically attached to the section(s) below. Significant analysis of the available vertical space was performed to ensure sufficient space was provided for the cofferdam section(s), blocking system, lifting beam, and rigging.

The cofferdam assembly consists of four 25-foot- high sections that are mechanically connected as they are positioned for final installation. Each welded steel section consists of horizontal beams, bracing members, and an outside skin plate. Frame models were prepared for each section at critical locations using three-dimensional computer software. The computer software was used to compute the forces, compute deflections, check welding requirements, and check the steel code. Due to the configuration of the piers, the upstream leg of the cofferdam is 6 inches longer than the downstream leg. This increased length on the upstream leg results in an unequal pressure causing a lateral force in the downstream direction on the cofferdam. Adhesive anchors were designed to anchor the upstream leg of the sections through a bearing plate to prevent the lateral movement. The adhesive strength used the appropriate anchor spacing and edge distance requirements along with the requirements for saturated concrete. The shear capacity of the anchor was also checked against bending due to the moment arm created by the seal thickness in relation to the steel bearing plate. In addition, the anchors would serve as a primary reaction force to bring the cofferdam into sealing position following erection of the cofferdam segments. The tension force created in the anchorage would provide the reciprocal force needed to cause initial deformation of the seal needed to dewater the cofferdam.

Three specific categories of seals were designed: cofferdam section to cofferdam section, cofferdam leg to existing concrete, and combination capture plate seal for the assembled cofferdam to come to rest on the floor of the dam. Selection of the material for the cofferdam section to section seal was relatively straightforward with durometer and thickness prescribed by weights of individual cofferdam sections and anticipated forces within the mechanical connections between cofferdam sections. During the investigation dives conducted for the feasibility study, significant effort was expended to determine the variance from plumb in the concrete sealing surfaces. Measurements indicated the cofferdam leg seals needed to accommodate a variance of up to 3.5 inches. Design of the cofferdam leg seals was further complicated by the known linear change in hydrostatic pressure along the height of the cofferdam and variable Young's modulus of the seal material based on deformation,

containment, and pressure. Final design of the leg seals incorporated steel flat bar attachment plates and a combination of different material durometers both horizontally across the seal cross section and vertically along seal segments. Following assembly of the cofferdam sections, placement of the cofferdam on the dam floor in the precise location required a semi-permanent capture structure that would allow final alignment, measured in inches, of the entire system as the cofferdam was dewatered and the leg seals underwent deflection. The capture plate seal design incorporated a steel framework, multiple durometers of seal material, and a high density low friction coefficient polymer. Seals are located between sections and between each section and the concrete sealing surface. The seals along the concrete had to conform to a highly variable surface.

Lifting eyes were located on the interior of each cofferdam section. These provided for segment erection from the horizontal to vertical position and provided sufficient capacity to be used to lift the sections when assembled. Additional lift points were designed into the bearing plates at the end of each cofferdam section leg to provide for transportation loading, unloading, and movement of sections along the headworks.

To support the individual cofferdam sections during the erection phase of the project, a blocking beam assembly was prefabricated and placed on the headworks. The blocking system consists of a network of steel beams that creates two tiers. The upper tier provides load transfer from the cofferdam sections to the upper tier wide flange beams that run east-west across the intake bay. The lower tier provides load transfer from the upper tier to the headworks concrete from steel wide flange beams running north-south or upstream-downstream across the intake bay. The cofferdam sections bear on the upper tier beams using a welded steel attachment assembly fixed on the side of the cofferdam sections. The system was designed to support the entire assembly of four cofferdam sections bolted together and bearing on the beams. Torsional effects were used in the design, and the beams in the assembly were reinforced with vertical stiffeners. To accommodate the increased width of cofferdam sections associated with the welded steel attachment assembly, slots were located at strategic points throughout the assembly. The slots allow space between the upper tier beams to be widened by up to 6 inches during the erection of cofferdam sections.

Erection of the cofferdam sections required the use of the existing gantry crane. However, the original design of the gantry crane lift beam provided for two lifting points spaced approximately 18 feet apart for removal and replacement of the head gate and trash rack sections. Analysis of the existing gantry crane lift beam revealed insufficient capacity for the planned single point lift of the assembled cofferdam sections from the center of the lift beam. A custom-designed gantry crane lift beam was designed and fabricated to accommodate the anticipated loading from the assembled cofferdam sections as well as the required dimensions to receive the existing gantry crane lift blocks.

Cofferdam Fabrication

Following successful review at the 60%, 90%, and 100% design level, a fabrication contract for the cofferdam sections, main lift beam, and blocking beam system was awarded. Shop drawing reviews were conducted for each segment of the cofferdam along with reviews of the blocking beam assembly and main lift beam. Project specifications were revised to include specific testing requirements for the seams of the cofferdam sections and weld testing conducted per AWS D1.1. Milestone meetings were conducted at the fabrication facility with the project engineer, owners, and fabricators to ensure the quality control procedures were implemented and to streamline the resolution of conflicts.

Cofferdam Installation

The equipment necessary to complete the successful installation and dewatering of 100 vertical feet of trash rack rail with a cofferdam is substantial, and tremendous planning was required to ensure that all project requirements were satisfied and schedule milestones met. To accommodate the mobilization and equipment layout needs of the project, managers of the undertaking planned every detail -- from placement of ancillary equipment on the headworks to delivery orientation of the four 25-foot cofferdam sections to meet the obvious space restrictions and limitations of existing lifting and hoisting equipment on the headworks.

The usable space on the headworks to conduct the installation was limited, first by the 18-foot width of the overhead gantry crane drive rails, and secondly by the 33-foot lift height capacity of these cranes. All equipment delivered to the site, including the 8-foot side by 25-foot-long cofferdam section, control and storage containers, and support equipment had to be delivered in the proper orientation given that spinning of this equipment during offload was prohibited by the gantry crane geometry. Once on site this equipment was strategically placed to ensure adequate accessibility and safe transit along the headworks by personnel and the gantry cranes at all times. Throughout the project the configuration of the equipment was methodically changed to accommodate the needs of each phase.

Upon completion of mobilization Phase one and before the arrival of the cofferdam sections, a deep air diving crew was deployed using the latest U.S. Navy In-Water Air/O2 Decompression Tables to prepare the inlet bay to receive the cofferdam. The tasks assigned to this crew included extensive debris removal, investigations of and preparations to the vertical concrete surfaces on which the sides of the cofferdam would seal, and installation of a steel receiver framework on the inlet bay floor designed to capture the bottom of the cofferdam and establish initial cofferdam alignment.

The four cofferdam sections, once fully assembled, measured exactly 100 feet tall and weighed approximately 137,000 pounds. With 33 feet of crane headroom available on delivery, each cofferdam section was staged on its back for righting immediately before placement. To support

the sections vertically during assembly they were placed within the inlet bay in which they were to be installed and supported by a blocking beam assembly. Designed to support the load of the completely assembled cofferdam, the blocking beam assembly was constructed above the inlet bay before cofferdam erection and supported cofferdam sections, allowing the crane to be disconnected to hoist another cofferdam section into place for bolt-up. All sections were bolted together using structural steel bolts. Custom-designed four-part slings were used to hoist the cofferdam sections. This required a single-point centered pick from a gantry crane block that was designed to lift head gates and spillway gates from two lift points. As an added deliverable to the project the design team engineered and delivered a special-purpose, custom gantry crane block that provided a central single lift point rated at 140,000 pounds. Placement of the assembled cofferdam within the capture assembly completed erection, paving the way for divers to anchor the cofferdam to the inlet bay vertical walls.

Working within the confines of the interior of the cofferdam to a maximum working depth of 95 feet, divers core-drilled 1 1/8-inch diameter holes 12 inches deep in the concrete to install 1 1/4-inch-diameter epoxy anchors. The anchors were drilled and installed through the side seal plates on each cofferdam leg, requiring specially designed tooling to fit within the structural beams on the inside of the cofferdam legs. The anchors served a dual purpose of resisting shear and pulling the cofferdam side seals flush with the concrete for dewatering.

To dewater this impressive structure, early substantial head pressure was required to create an initial seal with the concrete allowing slower educators to take over to completely dewater the cofferdam down to 100 feet. High-capacity 460V, 3-phase electric submersible pumps, powered by 100 kw generators, established this initial dewatering. The educators were installed at the bottom of the cofferdam and received motive pressure via 2 1/2-inch hoses supplied by a 1,350 GMP diesel jet pump on the headworks.

Once dewatered, the cofferdam was converted into a workable space through installation of ventilation, sump pumps, lighting, and a powered personnel platform to convey workers down and up within the 100-foot-deep space.

Rail System Design

The new rail system was required to be compatible with the existing trash racks and also to be able to accommodate the head gates in a dewatered state. The stainless steel rail system consists of five 20-foot sections and a 3-foot tapered top guide section, attached to the concrete with adhesive stainless steel anchors. The design incorporated splice plates and anchor bolts to aid in installation.

Each section is composed of a series of adjacent plates forming a C shape with an upstream, middle, and downstream rail. The three rails provide alignment in two axes to the trash rack sections and head gates. The downstream rail also provides the bearing surface for the trash racks and a sealing surface in the event head gates are installed in the trash rack slots.

Rail System Fabrication

Simultaneous with the installation of the cofferdam, fabrication of the new stainless steel rail sections began. The parameters determined during the initial design dictated a robust section able to withstand the loading resulting from installation of the head gates in an emergency situation. In addition, the space restrictions from the existing lodges required the robust section to be fabricated in a compact section. Further, the existing dimensions and seal requirements for the possible head gate installation dictated extremely tight tolerances, ¼ inch both vertical and horizontal maximum allowable deviation for each 20-foot section and ¼ inch both vertical and horizontal maximum allowable deviation for the entire 100-foot rail system. Fabrication of the austenitic stainless steel rail sections required a custom jig to be fabricated to prevent distortion. The design incorporated a male to female type connection with splice plates to provide bearing capacity between rail segments. Temporary removable braces were installed to provide the required minimal clearance between sections to allow fit up. Additional temporary alignment appurtenances including vertical and horizontal alignment bolts and jacking lugs were installed on each section to facilitate alignment.

Rail System Installation

The design of the new rail inserts and the quantity of anchors necessary to secure the system to the concrete was based upon information available at the onset of the undertaking. With the cofferdam successfully installed and tested, project design personnel obtained the ability to further investigate current characteristics of the concrete within the inlet bay. The new trash rack rail inserts were fabricated with a number of anchor holes to accommodate a quantity of anchors necessary to satisfy the design criteria based upon the 2000 psi concrete strength specified in available facility construction drawings.

In keeping with the dynamic nature of this prototype project, project design personnel obtained concrete core samples within the existing trash rack rail slots at 3 elevations. Compression tests of these core samples proved that as the facility aged, the strength of the concrete dramatically increased. As a result the number of anchors required to secure subsequent trash rack rail insert sections were decreased reducing overall production values.

Upon arrival at the facility, the new trash rack rail sections were studied to develop a plan for rigging and installation. Since the use of a template for anchor hole drilling over 100 feet of new rail section was unreliable and cost prohibitive, the anchor holes in the sections needed to be large enough to receive the outer diameter of the core drill bit required to produce the hole necessary to install 1 inch diameter epoxy anchors. Additionally, a method of securing the core drilling apparatus to the rail inserts to drill the holes had to be developed and implemented in the field. Within days, the input from design engineers, fabricators, production managers, and on site workers came together to develop and implement the plan for installation.

Initial investigations of the current condition of the existing rail slots upon initial dewatering revealed that while the overall strength of the concrete structure increased, the outer layer up to 1 inch deep had decayed over time. As part of the developing installation plan, demolition of the existing rail system was modified to include the removal of this detritus layer. Workers, devising a method of capturing spoils from this demolition activity over the 100 foot depth of the rail slot removed up to 1 ½ inches of degraded concrete in addition to the existing steel rails prior to the installation first new rail insert.

Similar to the installation of cofferdam sections, the five 20 foot tall stainless steel rail inserts were delivered and staged horizontally and had to be righted prior to lowering into place within the cofferdam and the trash rack rail slot. For this evolution, a 10 ton air-operated chain hoist with 80 feet of chain was employed and utilized in conjunction with the facility gantry cranes to right the pieces, position them over the cofferdam, and lower them into place.

As each new rail section found its new home within the prepared rail slot, constant checks were required to ensure that the original rail alignment was repeated with this new system. An alignment system, consisting of a combination of lasers, string lines, and detailed measurements was utilized to ensure that the alignment of each new piece matched that of the existing rail system and that no further concrete demolition was necessary prior to final anchoring.

With all five new rail sections installed, aligned, and anchored the annular space created by the initial concrete demolition was filled with high strength grout. Since the pressure exerted by 100 feet of grout is significant, the cofferdam was flooded during grouting to relieve pressure on formwork and divers were utilized to connect and shift grout hoses as the grouting process progressed from bottom to top. Following prescribed curing time for the grout the cofferdam was again dewatered for final inspection and cofferdam clean-up.

Cofferdam Removal

By far the easiest phase of the overall project, the removal of the cofferdam was not taken for granted. Careful and thorough documentation of the cofferdam installation phase to include rigging details provided valuable information throughout the process. Essentially and as one might expect, the removal of the cofferdam was basically a reversal of the installation process. Prior to final flooding of the structure, anchor nuts were backed off to allow the hard rubber seal to return to its original shape. Additionally all pieces of ancillary equipment were removed and inventoried to ensure that nothing was left behind. The cofferdam was flooded, and prior to removal of the system, divers were sent in to the flooded structure to remove all anchors utilizing an underwater oxy/arc torch.

The cofferdam was raised as a single unit, blocked into place and unbolted one section at a time. Each section was placed strategically on the headworks to accommodate each demobilization task and to allow safe passage along the headworks.

Conclusions

Early in September 2012 the existing trash racks were reinstalled into intake Bay 9 East. The newly installed stainless steel rail system provided guidance to the trash rack sections along the east, and the old existing rail system provided guidance along the west. With the alignment confirmed and installation of the trash rack rail sections complete, project success was confirmed. The success of the unique approach applied to the design and rehabilitation of the structure depended on a number of critical engineering analyses and experience-based implementation of the skilled professions involved with all aspects of the project.

The design, fabrication, installation, and resulting rehabilitation of the trash rack rail system at Conowingo Dam during summer 2011 provides a case study for one of the deepest asymmetrical cofferdams installed in the United States. Future projects of medium head facilities requiring rehabilitation efforts of major static structural components must perform significant feasibility studies to determine project goals and design parameters. Feasibility studies for cofferdam installations must include an evaluation of the potential sealing surfaces. Significant experience is required to accurately predict the properties exhibited by seals under the variances in pressure associated with the change in hydrostatic pressure experienced at depths up to 100 feet. A combination of experience and complex multi-variable analysis may lead to accurate predictions of seal material reactions to stresses under changing conditions and material properties, including Young's modulus. Preliminary testing of in-situ materials may provide a design economy and reduce resource expenditures for installation and continued operation of medium head dewatering devices.

Biographical Sketch of Authors:

Mr. Mrowiec is the principal engineer at Crofton Industries. He obtained degrees in Marine Technology from the College of Oceanerring in Wilmington, California and a Bachelor of Science in Civil Engineering from the University of Nevada, Reno. He is a certified commercial diver and commercial dive supervisor with 17 years of dive experience. As an engineer, Mr. Mrowiec has over 10 years of experience conducting inspection, engineering, construction and evaluation of structures including bridges, water resource facilities and waterfront structures, specializing in underwater investigations and rehabilitation strategies. Mr. Mrowiec is a Registered Professional Engineer in eight (8) states and currently serves as the Chairman of the Engineering Diver Committee for the Association of Commercial Diving Contractors International (ADCI).

Mr. Fearheller has more than 15 years of performing underwater and marine construction and inspection specializing in the inspection, design, construction and rehabilitation of waterfront facilities. In addition Mr. Fearheller has served as the principal investigator and inspector of bridge rehabilitation, scour countermeasures, cofferdams installations, dam rehabilitation, intake and outfall structures, bulkheads, piers, and wharfs. Mr. Fearheller is qualified in performing hydrographic surveys including side scan sonar and single beam echo sounding. Mr. Fearheller is a dive supervisor and primary diver with experience in underwater inspection and construction in special diving situations including differential pressure, intakes, contaminated water, drift and debris, zero visibility, high velocity current and penetration.

Todd Rudolph is a civil engineer at Ayres Associates Inc in Eau Claire, Wisconsin. He received his BS in Civil Engineering from the University of Minnesota. For the past 15 years he has been involved with hydraulic and hydrologic analyses, dam inspections, design of dams and other hydraulic structures, and structural design and analysis. He is a licensed engineer in Minnesota, Pennsylvania and Wisconsin.