Drilled Shaft Foundations for the Float-In Dam on the Monongahela River at Braddock, PA

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The new gated dam on the Monongahela River at Braddock, Pennsylvania, was built for the US Army Corps of Engineers using an innovative “In-the-Wet” technology. A key feature of this technology involves construction of the foundations through the water and later mating the completed structure or a shell of the structure to the pre-installed foundation. This paper presents a description of the structure, its foundation, construction sequence and design details required to successfully implement this technology.

Introduction

Locks and dams in the United States have historically been built by blocking off large sections of the river with circular-sheet-pile cells; dewatering the area surrounded by the cells; and then proceeding with foundations followed by the superstructure. After completing one segment of structure, the area enclosed by cells is again flooded, the circular cells are moved and another section of the river is dewatered to allow a continuation of construction on the adjacent sections. This process is continued for multiple cycles until the entire lock or dam is completed. (See Fig. 1 for an example of this type of construction.)

This method has been successful in the past, but suffers from a number of drawbacks:

- The large temporary cofferdams are expensive to build and remove;
- They restrict river flow and impact navigation (This is especially true when replacing an existing navigation structure.);
- Drying up extensive areas of the river bottom requires construction and operation of large expensive dewatering systems;
- If the structure is located on ground that contains contaminates, dewatering can spread contaminates in the ground and create a need for treatment of the water once collected by the dewatering system.
- The large temporary cofferdams are typically in place for 2 or more years and are subject to overtopping and flooding of the work area during periods of high water.

An alternative to this approach is a method referred to as “float-in” or “in-the-wet” construction that involves constructing the foundation for the structure through the water and then floating in or lifting in a shell of the structure and mating it to the pre-installed foundation. This technique has been in use for centuries. Early
examples include float-in caissons used to build breakwaters and quay walls. Over the last 100 years, 125 immersed tube tunnels have been built around the world using this technique. It has been used to build paper mills up the Amazon River, power plants on the Mississippi River and large off-shore gravity base structures in the North Sea and Arctic Ocean.

The Pittsburgh District of the US Army Corps of Engineers in an effort to develop alternate and more cost effective construction methods for their navigation structure on the inland waterways of the US selected this method of construction for replacement of Dam 2 on the Monongahela River, eleven miles upstream from Pittsburgh at Braddock, Pennsylvania. See Fig. 2 for an aerial view of the dam site. The Corps developed the initial concepts and then selected a team consisting of Ben C. Gerwick, Inc of San Francisco, Bergmann Associates of Rochester, New York, and D'Appolonia of Pittsburgh, Pennsylvania, to perform the detailed design of the new 720-foot long navigation dam.

The final design developed by the Gerwick-Bergmann-D’Appolonia team was constructed by a joint venture of JA Jones and Traylor Bros. The final structure consisted of two large prefabricated concrete segments that were floated into
place, and set-down on a pre-constructed foundation. The float-in section of the new dam was a 600-ft long by 104.5-ft by 42-ft high structure with four gate bays and one fixed-crest weir bay. The final "In-the-Wet" design called for breaking the dam into two segments of 333-ft and 265-ft. The segments were constructed as closed bottom boxes in a two level casting basin. The exterior walls, bottom and top slabs of the boxes were 12-in thick and the interior walls were 10 and 12-in thick. The bottom slabs were post-tensioned and contained recesses to allow the pre-installed foundation to penetrate the bottom of the slab during set-down of the segments.

As each segment was completed, it was launched by flooding the basin and then towed to the outfitting pier two miles upstream of the dam site for final outfitting. The dam segments were then floated downstream to the dam site and positioned over the foundation caissons with a mooring system mounted on top of each dam segment. The foundation system consisted of sheet-pile cut-off walls upstream and downstream, H-piles below the tailrace area and 72 inch diameter drilled shafts installed in a pre-excavated area upstream of the existing dam. Each segment was ballasted down onto 6 landing shafts and leveled with flat jacks installed within the piers of the float-in dam segments. The under-base was then grouted, and 8-ft of tremie concrete was placed in the segment compartments. Each compartment within each segment was then dewatered and the remainder of the dam including tainter gates was completed in the dry. After all cells within a given segment had been filled with concrete, the dam segment was locked on to the tops of the drilled shafts by grouting the pile-top annulus.

**Sequence of Construction**

Construction of the dam was carried out in seven stages. See construction sequence stages 1 through 7 below:

Stage 1 – Cast segment in two level casing basin.

Stage 2 – Launch and tow segment to outfitting pier.

Stage 3 – Position segment over pre-installed foundations.
Stage 4 – Ballast and land segment.

Stage 5 – Underbase grout segment.

Stage 6 – Infill segment with concrete.

Stage 7 – Complete segment infill, grout pile tops, dewater bays, and install tailrace panels.

First Stage Excavation and Bottom Preparation

Dredging was performed in two stages. The first stage of pre-excavation for the dam foundation was performed below the footprint of the dam and consisted of excavation the river bed to El. 690, from the existing lock river wall to the left bank abutment toe in a strip about 140 feet wide. The depth of the excavation ranged from 14 feet to 32 feet across this reach. The excavation was inclined up the existing river bed grade at a slope of 1 on 10 upstream and 1 on 5 downstream to El. 702. Dredged materials were transported by barge to the upstream disposal site.

Cut-Off Walls

After pre-excavation, steel sheet piling were installed to provide both upstream and downstream cut-off walls and to serve as retaining walls for various stages of work on the dam. A prerequisite pile driving program was used to determine the elevation of rock to which sheets were to be driven. Sheets were ordered to accurate lengths once these elevations were determined. The upstream cut-off wall, located 3-ft from the upstream face of the
future dam, was installed first. This 600-ft long wall was installed in two stages using a barge mounted pile driver. The first stage involved installation of 75-ft long H-piles on a 19-ft spacing. These H-piles were driven to the top of rock and were outfitted with pre-installed interlocks welded to one flange. At completion of driving, the top of the H-piles and the interlocks extended above water and provided a guide for installation of 18-ft wide sheet pile wall panels between the H-piles. The sheets were driven to final grade, approximately 29-ft under water, and thereby eliminated the need for divers to cut the sheets off under water.

The downstream cut-off wall was then installed in a similar manner. The downstream cut-off wall consists of a structural system of 24-inch diameter pipe piles and sheet piles. Pipe piles were used rather than H-piles because the pipes supported the downstream end of the precast tailrace panels, and this wall system was required to resist the loads imposed by the retained alluvium when the downstream face of the wall was excavated to rock for installation of scour protection. The pipe piles were first driven and a 6-ft deep reinforced concrete rock socket was installed in each pile tip. The sheet piles were connected to the pipe piles by a special interlock section that was pre-welded to each side of the pipe pile prior to driving.

**Second Stage Excavation, Bottom Preparation, Dam Foundation System**

With the cut-off walls in place, the area between the walls was excavated an additional 8 ft to El. 682, and a 12 inch layer of 1.5 inch stone placed and levelled. Eighty nine drilled shafts were used to support the dam piers and gate sills. Two rows of H-piles on 8-ft spacing driven to the claystone rock layer were used to support the dam tailrace. The tops of the H-piles extended up into the first tremie concrete poor below the tailrace slabs.

**Drilled Shaft Foundations**

The base of the dam is at El. 683.7 ft which is about 38 ft below the normal pool level and 15 ft below the existing riverbed. The stratigraphy below the dam consists of approximately 16 ft of alluvium comprised of sandy gravel (GM) to silty sand with gravel (SM). Below this layer is soft to medium hard clay shale and claystone down to El. 658 ft. Medium hard to hard siltstone is encountered between El. 658 ft and 626 ft. The drilled shafts for the dam were founded in this layer. The average unconfined compressive strength of the clayshale is 840 psi and the siltstone 3600 psi. Two test shafts were installed and loaded both laterally and vertically. See Fig. 4 for a stratigraphic section of the river bottom relative to the river bottom and the drilled shafts.

![General Geologic Section](image-url)
Two types of drilled shafts were installed under the main body of the dam:

- Six set-down drilled shafts under each of the floating-in dam segments provided initial support of the float-in dam segments at set-down;
- Seventy seven foundation drilled shafts provided long-term support of the completed dam.

See Fig. 6 for a schematic of the two drill shaft types.

All drilled shafts were step-tapered with a 72” diameter rock socket drilled through a 78” diameter permanent steel casing. Permanent casings were driven and seated into the top of the claystone rock layer.

Drilling removed all material from within the casing and the 72” diameter rock socket were then drilled roughly 6 feet into the lower siltstone rock layer.

All drilled shafts were positioned using a four-legged two-level template. The fixed lower template was installed first to a tolerance of +/- 12 inches, and the sliding upper level template was set and fixed into position to a tolerance of +/- ¼ inch. Casings were then installed and barge mounted equipment performed the drilling. After the drilled shafts were thoroughly cleaned out, a steel reinforcing cage was installed, and the shaft was filled with tremie concrete to an elevation approximately 6 ft below the bottom of the future dam.

After the tremie concrete attained sufficient strength, the casings were dewatered and latent concrete was manually removed in-the-dry. A tension-anchor/shear-pin assembly consisting of a 14” steel wide flange tension anchor and 36 inch diameter pipe shear pin was then installed and fixed in position by concrete placed in the dry. The top of each casing was then cut-off to a vertical tolerance of +/- ¼ inch using a temporary circular cofferdam that was installed over the top of the drilled shaft casing and sealed to the outside face of the casing below the cut-off point using inflatable rubber seals. The annulus between the casing and the temporary cofferdam was then dewatered and the drill casing was cut off in-the-dry from the inside the casing.

The 12 Set-down drilled shafts were generally constructed in a similar manner to the foundation drilled shafts. However, instead of installing a tension-anchor/shear-pin assembly, a levelled grout surface was constructed at the bottom elevation of the dam. A tolerance of +/- 1/8th inch was obtained by milling the top surface of the drilled shaft concrete. The casing was then
cut-off underwater using the same technique described above.

**Precast Shell Fabrication, Launch Transport and Outfitting**

While the dam foundations were under construction, the two float-in dam segments were constructed at a two level casting basin located at a 15-acre site 27 miles downstream from Braddock on the Ohio River. The two level casting basin allowed the segments to be cast on an upper level, a few feet above normal pool elevation in a protected area behind an earthen berm. See Fig. 7 for an aerial view of the casting basin and launch site at Leetsdale, PA.

The total 600-ft length of float-in dam was divided into two segments. The 333-ft long Segment 1 weighed approximately 12,000 tons and the 265-ft long Segment 2 weighed approximately 10,000 tons. The float-in segment included: the gate sills, a portion of the stilling basin, and the pier bases up to El. 726.0. Segment No. 1 included the fixed weir bay, the water quality bay and one of the standard gate bays while Segment No. 2 included two standard gate bays. All bays were 110’ wide. The joint between Segments 1 and 2 occurred at Pier 3, which made it 11 feet wider than adjoining piers to facilitate this connection.

The walls and diaphragms of the float-in segments were precast panels. The top and bottom slabs were cast-in-place concrete. The largest individual precast wall panels were 21 feet by 30 feet and weighed approximately 80 tons. All wall panels were tied together with cast-in-place closure pours positioned at the intersection points of the walls. Sixty-inch diameter corrugated sleeves were cast into the bottom of the dam segments over the connection points to the tension-anchor/shear-pin assemblies installed in the tops of the drilled shafts. After erection of the wall panels, installation of post-tensioning ducts and bottom recess sleeves, the bottom slab was cast in place. See Fig. 8 for a view of the erected precast wall panels and corrugated recess sleeves used to provide connection to the drilled shaft tension-anchor/shear-pin assemblies.

When the precast dam segment was ready for launch, the upper and lower basins were flooded to a common water level and the segments were floated one at a time over the lower basin. The water level in the lower basin was then returned to the outside river elevation, the exit sheet-pile wall was removed and the segment was towed out of the casting facility. The segments were
completed to a partial stage such that the maximum draft of the segments did not exceed 11 feet. Segments were transported from the off-site assembly location to the project site for additional outfitting prior to set-down. All handling and transport were by towboats.

Each segment with a draft of approximately 11 feet was then towed to the outfitting site upstream of the dam site. Transport of the segment was performed using a primary tow boat and guided as necessary by a snubbing tow. The segments were transported through two locks on the Ohio River, past the city of Pittsburgh, and up the Monongahela to a site upriver of the Braddock Dam site. See Fig. 9 for a view of the Segment No. 1 under tow.

Figure 9 - Dam segment No.1 towed up the Ohio past Pittsburgh.

Once a segment arrived at the outfitting site, it was moored to the outfitting pier. The outfitting pier consisted of a system of circular sheet pile cells and arcs, and included a 15-ft high braced fendering system to keep the segment on the face of the pier during high water.

Each segment was completed and readied for set-down at the outfitting pier. The piers of each delivered segment were extended approximately 21 feet. Temporary bulkheads for immersion were added both upstream and downstream on each gate and weir bay. Additional permanent concrete ballast, ballast piping and portions of the mooring and alignment equipment were also added. Work platforms and vertical tremie pipes for post-set-down underbase and concrete infilling operations were installed. Once completely outfitted, each segment had a draft of approximately 14 feet. Additional water ballast was added as necessary to trim the segment before transport to the project site.

**Positioning and Guidance Systems**

After completion of outfitting on a given segment, it was maneuvered down river by a primary tow boat and guided by a snubbing tow boat. After positioning close to the set-down site, 8 mooring lines from winches mounted on top of the segments were connected to the drilled-shaft anchors pre-installed upstream of the dam site. The segment was then rotated transverse to the current, winched downstream, and then positioned directly over the top of the prepared foundation. The segment was then aligned with two horn guides located on the face of the river wall. See Fig. 10 for an aerial view of Segment No. 1 being positioned at the dam site.

Figure 10 - Segment No. 1 being positioned at site.
**Ballast Systems**

After each outfitted segment was maneuvered into position, it was ballasted onto its 6 set-down drilled shafts. Water was first added to the interior compartments of the segment and as the segment sank deeper into the water, ballast water was added to the individual bays. As ballasting progressed, all interior tanks were continuously sounded to monitor free surface effects and maintain hydrodynamic stability of the segment at all times.

By adding ballast water to the gate bays and using the horn guides, mooring lines and land based survey control for guidance, each segment was accurately lowered into position and the tension-anchor/shear-pin assemblies were threaded into the hollow recesses built into the bottom floor of the dam segments. Ballast water was then fed into the dry piers until the hydraulic jacks register the required initial loading. See Fig. 11 for a view of the ballast system positioned on top of Segment No. 1 during float-in.

**Figure 11 - Segment No. 1 with ballast system on the top deck.**

A hydraulic ram on the downstream corner of the Segment 1, adjacent to the lock wall and in conjunction with the mooring lines, was used to align the segment on its longitudinal axis.

**Segment Leveling System**

Each segment was landed on 6 set-down drilled shafts. These drilled shafts were laid out to provide two support points on the longitudinal centerline of each dam pier. In order to provide even support and level the segment to the specified tolerances, two hydraulic pistons were built into each pier. When a given dam segment was properly aligned and landed, the 6 pistons were directly aligned over the top of the 6 set-down drilled shafts. The pistons were 36” diameter steel pipe sections with end caps and were built into the floor of the pier, flush with the bottom of the dam segment. The pistons were fitted with rubber seals to prevent water leakage and their sides were greased prior to placing the bottom slab concrete. A pair of 36” diameter, 1000 ton capacity flat-jack was stacked on top of each piston and the upper surface of the flat-jack was in direct contact with a concrete reaction beam spanning the 12-ft width of the pier shell. The 6 flat-jacks were connected into three hydraulic circuits to provide a three-point support system for each segment.

Once a segment was levelled to the specified tolerance, the flat jacks were “locked-off” and the hydraulic fluid in the jacks was replaced with a high strength 2-part resin.

**Underbase Grouting**

Following set-down, the 12-inch deep void area between the underside of the dam segment and the preleveled, stone-covered river bottom was filled with grout to eliminate flow below the dam. To make the underbase grout placement more manageable, the area under the segment were divided into five 70-foot wide
transverse strips by using inflatable grout bags pre-attached to the underside of the float-in segment prior to set-down. Both transverse and downstream bags were used. First, the space between the upstream cut-off wall and the dam was sealed to stop flow beneath the segment. Then each 70 foot wide strip was filled with grout using the vertical grout pipes installed at the outfitting pier. Typically, each grouting area contained six rows of 8-inch diameter grout pipes spaced at a maximum of 21-ft on center. Underbase grouting was started at the downstream row of grout pipes and continue upstream until the space below the dam was completely filled. Grouting was stopped when grout filled the 8-ft high by 3-ft wide vertical gap between the dam shell and the upstream cut-off wall.

**Structure Infill**

Once all the underbase grouted had attained minimum strength, the dam was infilled with concrete which acted compositely with the hollow segment. Thirty two compartments in Segment 1 were filled with concrete in a two stage operation. The first stage placement consisted of filling the bottom 8 feet of each compartment continuously with tremie concrete while the segment was fully flooded. The second stage placement was placed in-the-dry after the first stage tremie concrete had cured and the compartment had been dewatered. Typically, each compartment had one or two 10 inch tremie pipes. The downstream compartments also had 8 inch evacuation pipes in each corner.

After infilling was completed, the dam segment was “locked” onto the foundation drilled shafts by pumping a sand/cement grout into the hollow recesses surrounding the tension-anchor/shear-pin assemblies.

**Pier Completion Tailrace Construction and Gate Installation**

The upper portion of the dam piers between EI 726 and EI 765 was placed in-the-dry after the float-in dam segment were set-down and filled with concrete. This portion of the dam piers was completed with a combination of precast concrete and conventional cast-in-place concrete.

Trunnion girders were attached to the downstream face of each of the five piers for support of the four tainter gates, the trunnion girders were constructed of cast-in-place concrete.

While the piers were being constructed, the dam’s tailrace was constructed in-the-wet. The tailrace was built utilizing precast panels that were 30’-6” wide by 20’-0” long by 15” thick. The upstream end of the panels was supported on a ledge cast in to the downstream edge of the dam segments and the downstream end of the panels was supported on the row of previously installed 24” diameter pipe piles, which were integral with the downstream cut-off wall. The area below the tailrace panels was filled with tremie concrete to create a mass concrete tailrace section supported by the previously installed H-pile foundation system.

Following the completion of the pier and tailrace structures and prior to installation of the left closure weir, the 220-t tainter gates were installed by floating in the assembled gates one at a time on the deck of a barge. Once the gate was located in its final position, the two hydraulic operation cylinders were installed. The cylinders were connected to each end of the tainter gate and to the cylinder girders which are anchored to the upper pier structure. See Fig. 12 for a schematic of the completed dam.
Figure 12 - Schematic diagram of the complete dam and closure cells.

Conclusion

The new Braddock was designed and constructed using “Float-in” technology. The project was the first use of this technology by the U.S. Army Corps of Engineers and was the largest float-in navigation structure built in the United States. The successful and economical first time adaptation of this technology to the design and construction of navigation structures has demonstrated the applicability of this technology to other inland waterway projects within the United States and offers the potential of revolutionizing the future construction of navigation projects within the Corps of Engineers.

References


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