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A MAJOR UNDERWATER UNDERTAKING

HydroVision Brazil details pg. 71

A hydraulically operated slide gate is lowered to divers for connection to an installed spool at Cheesman Dam and Reservoir.

Renovating A Landmark:

Updating the Outlet Works at Cheesman Dam

Cheesman Dam and Reservoir, a major water supply for the City of Denver, was in need of new gates and grates. Global Diving & Salvage and Denver Water explain the strategy they used to repair the 106-year-old dam.

By Mike Langen and Jeff Martin

This spring, workers began the arduous task of abandoning 100-year-old valves from the rock-hewn outlet works tunnels of Cheesman Dam.

But before all of that could happen, the Denver Water Board had to oversee the successful completion of an even more ambitious capital improvement project: The underwater installation of new stainless steel slide gates on the upstream side of each of the three Cheesman Dam outlet works tunnels.

Cheesman Dam is an on-stream facility on the South Platte River, about 60 miles southwest of Denver, Colo. The dam is a primary water storage facility for Denver Water, serving more than 1.3 million customers in the greater metropolitan Denver area.

Once the world's tallest dam at 221 feet, it impounds more than 79,000 acre-feet of water. The dam is considered the crown jewel of Denver Water's storage system and has been designated a National Historic Civil Engineering Landmark.

Mike Langen, Construction Division Manager for Global Diving & Salvage, Inc., provided contract management and technical oversight for Phase 1 of the Cheesman Dam Project. Jeff Martin, Dam Safety Engineer for Denver Water, is the Project Manager for the Cheesman Dam Upstream Control Project.

A unique design

Construction on the dam began in 1898 and was completed in 1905. The dam structure is a gravity arch masonry dam constructed with solid granite blocks laid in cement mortar as a facing over a core consisting of granite rubble in a bed of concrete. The stone and mortar surface, built by Italian stone masons, was unique and controversial. Both the design and the materials used in construction, particularly the use of a newly introduced product called Portland cement, were the subject of much debate and discussion by civil engineers of the day. More than a century later, the dam remains sound.

The outlet works system consists of three tunnels bored through the left abutment at approximate elevations of 6,780 feet, 6,690 feet and 6,645 feet, named, respectively, the Auxiliary Outlet, the Mid Level Outlet and the Low Level Outlet. A fourth outlet tunnel was originally constructed at an elevation of 6,734 feet but was later abandoned and filled with a concrete plug. The low and mid level tunnels, mined prior to construction of the dam, combine into a single tunnel (Primary Outlet Works) approximately two-thirds of the way through the abutment.

The Primary Outlet Works is controlled by six 42-inch gate valves located upstream of the tunnel intersection. Construction of a downstream valve house in 1971 added a series of cone and free-discharge valves for additional control of the Primary Outlet Works. The Auxiliary Outlet Works was built in 1925. It is an independent tunnel with no connection to any of the other tunnels and is controlled by a single Larner-Johnson Needle Valve.

The need for rehabilitation was bore out of several key factors: (1) An aging outlet works system dependent and operating on 19th century equipment and technology, (2) maintaining key infrastructure within the Denver Water system, (3) new sediment loading from the Hayman Fire , and (4) a desire to provide upstream control of the outlet works tunnels for future work.

The facility's needs and Denver Water's organizational goals and Mission Statement2 aligned and the project was selected for implementation.

Evaluating the options

Designated the "Cheesman Dam Upstream Control Project" the program is a multi-phased plan spanning several years of design and construction.

Phase One work included installation of slide gates and associated control systems on the upstream end of each of the three outlet tunnels. Phase Two will include dewatering the tunnels, abandoning the existing valves located in the outlet tunnels, and replacing the Johnson valve with a new jet flow gate. A new tunnel bore will be completed that will allow the first inspection of the unlined waterway tunnels in 85 years. Ancillary improvements to the outlet works is also planned as a part of Phase Two.

A cost/benefit and risk analysis was performed by Denver Water comparing dewatering the reservoir and installing the new slide gates through conventional construction against underwater construction methods.

The cost/benefit analysis included a study of the South Platte Basin Hydrology and probabilities of not filling the reservoir in a single run-off season. Several different project approaches were reviewed, ranging from draining the reservoir completely for conventional construction to lowering the reservoir low enough for conventional construction at the Auxiliary and Mid levels and diving construction at the Low level.

"Global started underwater operations on April 13, 2010, and completed work on the Auxiliary Level intake on July 9, 2010, performing a total of 328 surface dives."

The construction cost analysis showed a potential savings of 20 to 30 percent in construction costs if the reservoir was drained. But this approach also included its own challenges and risks such as access to the work areas.

A barge and dive station was set up for work on the Auxiliary level intake at Cheesman Dam and Reservoir. The materials barge moored alongside provides temporary storage for sections of a removed trashrack and a stainless steel spool being prepped for installation.

More importantly,the hydrology analysis showed a significant risk of storage shortfall within Cheesman Reservoir that then could lead to watering restrictions within the Denver Water service area.

Denver Water felt that the risk of water storage shortfall within the South Platte storage system was unacceptable and the increased cost to complete as a diving project was worth the relatively low premium.

To successfully complete the work, a variety of underwater skills, including drilling, blasting, precision measurements, rigging for heavy lifts, rebar and dowel installation and underwater concrete placement, would be required. Previous experience assured that the quality and accuracy required for the project could be achieved.

The rehabilitation project was primarily designed by Denver Water's internal engineering staff. The owner-furnished stainless steel slide gates were designed by Denver Water mechanical engineers, consulting engineer Lee Gerbig LLC and Rodney Hunt Inc. (slide gate manufacturer), while the trashracks were designed by URS Consultants and fabricated by CSM Industrial Constructors.

Following a pre-qualification process, Denver Water requested price proposals from select contractors. On Oct. 28, 2009, the Denver Water Board awarded a contract to perform Phase One of the Upstream Control Project to Global Diving & Salvage, Inc., of Seattle, Wash.

Implementing a plan

Phase One of the Upstream Control Project was comprised of two distinct scopes of work. Phase 1A included the conventional construction of the new control building on the crest of the dam which housed the hydraulic power unit (HPU), bubbler system, emergency generator systems, and other control components for operating the new gates as well as a substantial upgrade to the electrical system of the entire facility. Phase 1B included the underwater construction work required to install the new spools, slide gates and trash racks at all three tunnel inlets.

In order to complete the dive work in a single season, dive operations would have to begin as soon as the ice melted from the reservoir in April. All hydraulic control lines and air transmission lines for the three gates were designed to be routed through new inclined rock borings in the left abutment. This work needed to be in place prior to the start of diving. The resulting scheduling sequence required work on the site to commence in December 2009.

Battling below zero temperatures and reservoir ice up to six inches thick, Global personnel established the site offices and managed the directional drilling operations, control building construction work, and electrical upgrade work performed by subcontractors through the winter months of 2009 and 2010. The inclined rock borings were a unique aspect of the project that deserve its own merit, as the holes (one of which was over 400 linear feet) were drilled at angles up to 15 degrees below horizontal and hit the target locations within specifications.

Once the drilling subcontractor, Hayward Baker, completed the bored holes, mechanical subcontractor Braconier began installation of the control piping and Paramount Contractors, Inc. started construction of the control building. The existing shaft house that serviced the Johnson valve was demolished and a cast in place concrete building erected. The building was finished with a granite masonry façade specifically selected to match the historical nature of the site.

Concurrent to these operations, the electrical subcontractor, Sturgeon Electric Company, began to install the electrical and control upgrades required around the site. A particularly challenging part of this work was the routing of the electrical conduit inside a manway tunneled through the left abutment. The rocky passage way winds its way from the base of the dam to just below the crest, providing a pathway for connecting the existing valve house to the new control building. Sturgeon was awarded the 2010 ACE award by the AGC of Colorado in the "Meeting the Challenge of a Difficult Job" category in recognition of its innovation in successfully completing this difficult task. As soon as spring arrived in the mountains and the ice began to melt, diving operations began.

Drilling, blasting and cutting begins

Performing the required underwater construction work at an elevation of 6800 feet and at water depths ranging from 40 to 200 feet would require both surface and saturation diving procedures.

Saturation diving is a diving procedure by which divers remain at pressure for days and weeks without incurring a proportional decompression obligation.

Divers working in the saturation mode work out of a chamber located on the deck of a barge or vessel which is pressurized using a helium oxygen mixture to a depth approximately equal to the depth at which the work in the water will be performed, termed the saturation or storage depth.

Divers live at this storage depth for up to 28 days at a time and are transported from the chamber to the worksite and back via a pressurized diving bell.

This greatly increases a diver's productivity by increasing bottom times and deferring decompression until the job is done or the diver's "tour of duty" is complete.

The mid and low Level gates were installed using saturation diving. Installation of the auxiliary level gate was completed using surface diving techniques. The auxiliary level gate was 8 feet by 8 feet and the mid and low level gates were 4 feet by 7 feet.

Three separate mobilizations occurred during the course of the project, requiring over 43 truckloads of equipment. The initial mobilization established the work site and included the required office trailers, storage containers, and construction support equipment.

During the second mobilization, the 80-foot by 80-foot dive barge was assembled onsite using sectional barges and populated with the surface diving equipment. During the third mobilization, the surface diving spread was removed from the barge and replaced with the saturation diving equipment.

In general, the work procedures for installation were very similar for each of the three valves.

However, the geometry surrounding each inlet and the individual tunnel configuration varied between locations, requiring different techniques for each elevation, primarily in the drilling and blasting phases of the work.

Installation of each slide gate required some level of rock removal from in and around the tunnel portals and the tunnel brow areas using drill and shoot methods.

Accurate drilling was critical for both proper explosives confinement and for final dimensions on the tunnels so that the new spools could be installed properly.

Drill template assembly had to be customized for each tunnel, with drills capable of drilling accurately at the various required depths. The first gate installed was at the Auxiliary Level, using surface diving operations. The relatively shallow water allowed use of a surface deployed air track drill to drill holes for the demolition of a rock outcropping that extended above the tunnel portal and interfered with the new gate and trashrack.

The initial plan was to mount, directly to the outcropping, a template designed to position and guide the drill bit. However, divers found the terrain too steep and rugged to mount the template, so a taut wire grid system was established to define locations of individual holes. Divers then mounted a guide, fabricated on the fly by support crews on the barge, at each location to align the drill bit.

Each slide gate assembly included a stainless steel spool, which provided a seal surface for the gate and served as a tunnel liner to provide shear resistance, additional tunnel brow support, and to lengthen potential seepage pathways from the reservoir to the tunnel.

The portals of the Mid and Low level tunnels required widening in order to accommodate these spools. Rock was excavated by drilling horizontally along the tunnel alignment and placing explosives in the drilled holes. To accomplish this, a TEI 300 hydraulic drifter was installed on a purpose built drill jig and template.

The drill jig mounted to the rock face outside the tunnel and provided horizontal and vertical movement so that the diver could precisely position the drill about the tunnel entry. Holes up to 12 feet deep were then drilled parallel to the tunnel alignment.

For the Low level, a considerable amount of rock and mortared rubble needed removal from around the entrance of the inlet. This required multiple blasts and an extensive vertical drilling program. A jig was designed and fabricated to accommodate the TEI 300 in a vertical orientation, once again providing movement along two axis so that the diver could precisely position the drill.

Explosives selection was very limited due to the high pressures at the greater depths, with the initiation system especially critical.

Over pressure limits imposed to protect both the existing valves and the fish population meant that charge weights were greatly restricted.

The spools were designed to be anchored into the rock walls of the tunnel to react to differential pressure forces when the tunnel was dewatered and then grouted into place to seal the tunnel entrance.

To ensure proper fit up of the gate, proper positioning of the spool in the tunnel portal was of utmost importance. As can be expected in an unlined tunnel, the floor of each tunnel was course and uneven, so the first step was to form and pour a concrete base slab in the section of the tunnel to be occupied by the spool.

A taut wire was then installed and centerline of the tunnel established. Custom tracks designed to guide the spool into position were set plumb and level and aligned with the centerline of the existing tunnel to ensure proper alignment of the spool.

The spool was then lowered from the surface and, using a diver's assistance, landed onto the tracks and pulled into position in the tunnel.

With the spool in position, each end was sealed with stay in place stainless steel forms and the annulus pumped with grout.

Once the grout had cured, divers, using a core drill attached to an alignment frame that had been pre-mounted into the spool, match drilled holes through the grout and into the surrounding rock.

Stainless steel anchors were epoxied into place, nuts installed and torqued to specification. The slide gate and hydraulic actuator mounted onto the face of the spool and bolts were torqued to affect a seal between the spool and the gate.

All gates are operated using the HPU in the control building. Piping installed in the directionally drilled borings "day lighted" in the vicinity of each of the gates.

Divers tied in the control lines to the hydraulic actuators, surface mounting the hydraulic piping along the reservoir bottom.

Owner-furnished, modular trash rack assemblies were then installed around each valve. The bottom trashrack module anchored into the rock entry way and subsequent modules bolted one atop the other.

Global started underwater operations on April 13, 2010, and completed work on the Auxiliary Level on July 9, 2010, performing a total of 328 surface dives. Saturation diving operations commenced on July 26, 2010, and were completed on Nov. 6, 2010, for a total of 103 days of saturation diving.

The Cheesman Dam project was declared substantially complete on Nov. 11, 2010, with an overall project duration of 11 months. ■

Notes

[1]Colorado's largest wildfire impacted the drainage area directly above Cheesman Dam

[2]"Denver Water will provide our customers with a reliable, high-quality water supply and excellent service. We will be responsible and creative stewards of the assets we manage. We will actively participate in and be a responsible member of our communities. We will accomplish this mission with a productive and diverse work force."