Authors

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Brett T. Campbell has worked on many challenging tunneling projects across the United States, after receiving his Civil Engineering Degree at Michigan Technological University 1993. His current position is a Project Manager, with James W. Fowler Company and is completing the Naicimiento Lake Intake Project in San Luis Obispo County, California. He considers himself to be fortunate to have worked with many talented engineers and supervisors. He and his wife have four children and reside in San Diego, California.

Bob Lewis acted in the capacity of Resident Engineer as the construction management representative of the District for the construction of the Intake shaft, tunnel and 'snorkel' tube structure. He carried out these duties through the design constructability review and the field installation phases. Mr. Lewis has been involved in the planning, constructability review, installation and construction of marine structures and facilities, both domestically and internationally, since completing his education at Portsmouth Polytechnic in the United Kingdom in 1971.

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HOT TAP CONSTRUCTION OF LAKE NACIMIENTO, CALIFORNIA

John R. Hollenbeck, P.E., Thomas Trott, P.E., Brett Campbell and Bob Lewis

ABSTRACT

The paper describes design and construction for the excavation and lining of a 20-foot diameter, 180-foot deep shaft; the microtunneling of a 54-inch diameter, 500-foot long tunnel and lake hot tap; and the underwater construction of an inclined, surface-mounted, multi-port, 48-inch diameter intake pipe for the Nacimiento Water Project located in San Luis Obispo County, California.

In late 2007, the San Luis Obispo County Flood Control and Water Conservation District (District), a relatively small government entity located on the central coast of California, commenced construction of a 45-mile long raw-water conveyance to withdraw 15,750 AFY of water from Lake Nacimiento to various communities within San Luis Obispo County (County). The $176-million project, known as the Nacimiento Water Project (Project), faced many challenging design and construction aspects, including the construction of an underground lake tap for the Project's intake pumping facility. The intake facility construction consists of three main elements:

- Shaft. Excavation of a 180-foot deep vertical shaft constructed in structurally incompetent sandstone and lined with concrete. The shaft will serve as the wet well for vertical turbine pumps.
- Tunnel and Lake Tap. A lake "hot" tap constructed by tunneling from within the excavated shaft using a slurry balance microtunnel boring machine. The microtunnel machine entered the lake at approximately 140 feet below the maximum lake surface elevation.
- Inclined Surface-Mounted Multi-Port Underwater Intake Pipe. The seven-port intake is 48 inches in diameter and about 400 feet long, and connects to the terminus of the lake-tap tunnel. Each port has actuating valves to allow water to be drawn from various lake depths.

This paper is a case history of the Project and describes a Project overview, the design, the prequalification of the general contractors, the construction of the intake facility, and concludes with lessons learned on this challenging work.

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PROJECT OVERVIEW

Background. The District received annual rights to 17,500 acre-feet of water from the Lake Nacimiento impoundment in October 1959, when they executed an agreement with Monterey County Flood Control and Water Conservation District, now known as Monterey County Water Resources Agency, who owns the Nacimiento dam and reservoir. The District conducted several feasibility studies over the next four decades assessing the cost and benefit to build the infrastructure to distribute the water to various areas within the County. These studies indicated groundwater pumping as the most feasible water supply. The demands on the groundwater basins are currently nearing their safe yield; thus, an alternative water source is needed to protect them. The next feasible water source identified in the 1990's was the Nacimiento Water Project.

The Project is divided into two parts. The lakeside usage of the water equates to 1,750 acre-feet annually, and that water will reside in the lake for users around the lake. The remaining volume, 15,750 acre-feet per year, will be conveyed via pumps and pipeline.

Lake Nacimiento holds 377,900 acre-feet when at normal maximum pool elevation of 803.07 feet (NAVD88 Datum used herein).

The "Final Environmental Impact Report Recommended" Project. The District's Board of Supervisors adopted the Final Environmental Impact Report (Final EIR) (Marine Research Specialists 2003) on January 6, 2004, and directed the County's Public Works Staff to implement the recommended project consisting of a multi-port lake intake, three pump stations (one at the lake, and two booster stations), three water storage tanks, and 45-miles of pipeline. The initial phase of the Project will serve the communities of Paso Robles, Templeton, Atascadero, San Luis Obispo, and Cayucos. These communities are contracted to receive 9,655 acre-feet per year. The remaining 6,095 acre-feet per year is the reserve water that is available to the existing participants, or can be contracted by other communities or water agencies anywhere within the boundaries of the County.

The "Final EIR Recommended" Intake Configuration. The Final EIR recommended a vertical shaft drilled or excavated into the ground from the shoreline to a depth of about 160 to 170 feet, and this shaft would serve as a wet

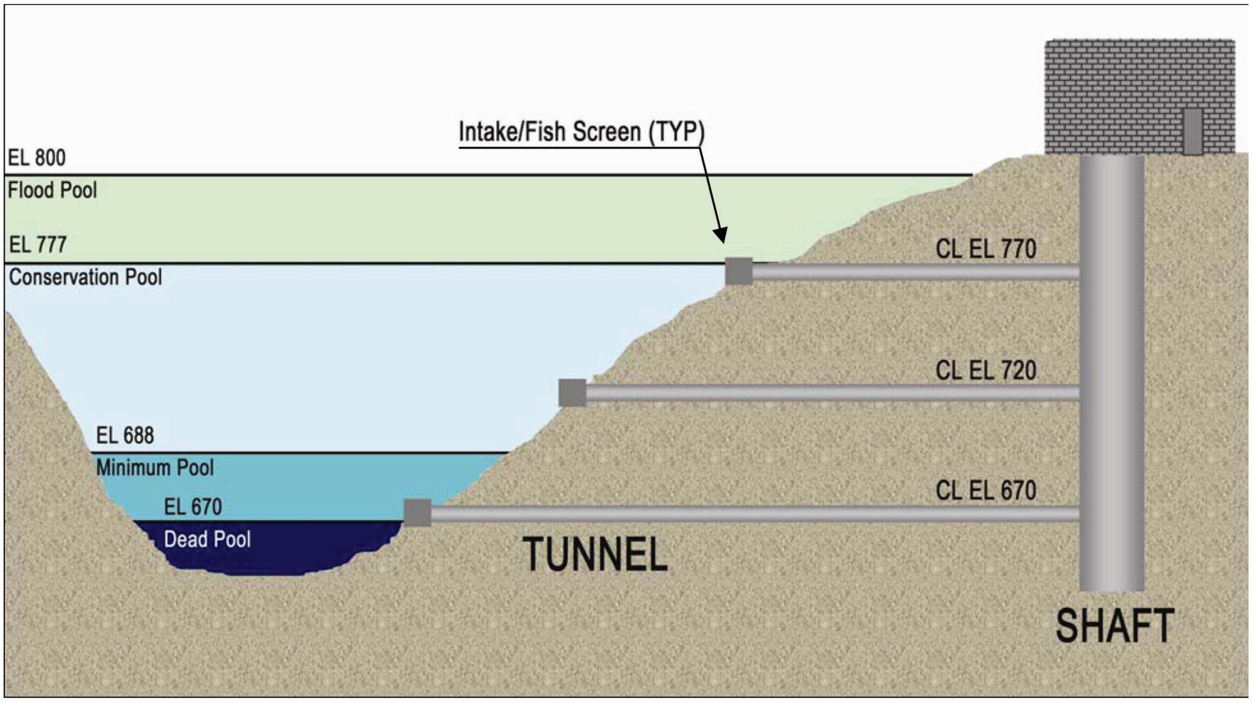

FIGURE 1. Intake Configuration Presented in Final EIR.

well for vertical turbine pumps. The shaft connects to the lake via three horizontal tunnels with approximate diameter from 36 to 72 inches bored at elevations 670, 720, and 770 feet. Figure 1 illustrates this configuration.

Value Engineering Assessment. The District assembled a value engineering team (VE Team) to review the Preliminary Design Report (Black & Veatch 2006) created by the design team at the 30-percent design phase. The VE Team evaluated the entire Project; however, only the assessment concerning the intake will be summarized herein.

Fifteen value engineering proposals were evaluated by the VE Team and presented in Value Engineering Workshop, Final Report (Value Management Institute 2006). Three were accepted immediately and implemented into the design, while five were declined immediately. The remaining seven were evaluated further. The value engineering concepts carried forward into final design were:

- Eliminate the upper two tunnels, and design a multi-port sloping intake pipe connected to the lower tunnel.
- Conduct additional geotechnical investigation and prepare a Geotechnical Baseline Study to include in the bidding documents.

The VE Team estimated that the net change in the bidding price for the intake would be approximately $4-million.

Final Configuration and Hydraulics of the Lake Intake. The final design configuration of the intake is a 16- to 20-foot diameter concrete lined vertical shaft,

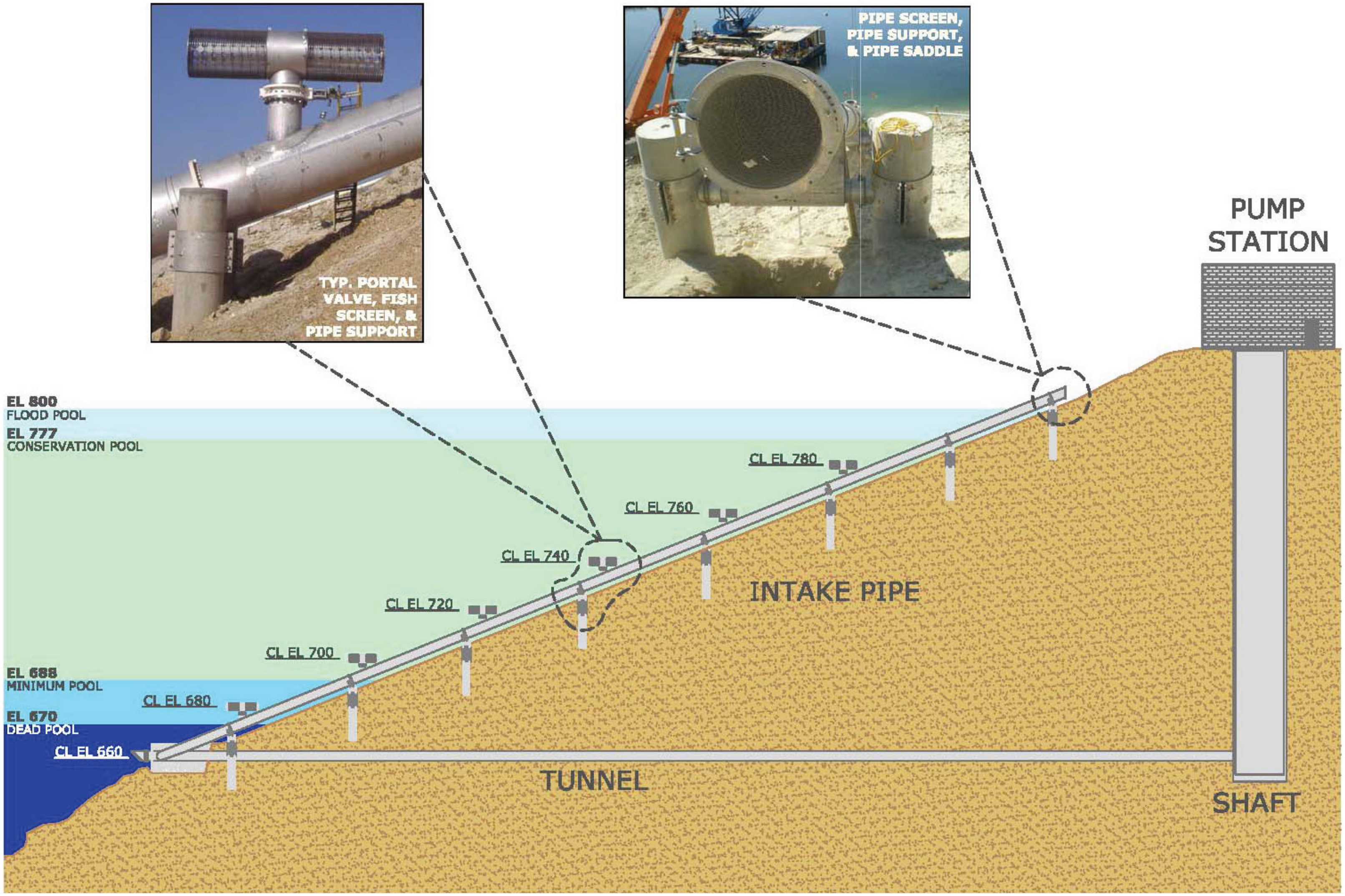

Figure 2. Final Design Configuration of Intake Shaft, Tunnel, and Intake Pipe.

180 feet deep, with a 500-foot long steel-lined horizontal tunnel with minimum diameter of 48 inches. Figure 2 illustrates the final design configuration.

The sloping intake pipe is 48 inches in diameter with seven intake portals. The first is at the centerline of the tunnel and is 48 inches in diameter. The other six are evenly spaced up the slope at 20-foot elevation intervals and are 24 inches in diameter. The quantity and spacing was chosen to maximize the quality of the water withdrawn and delivered to the Projects participants. Each portal is protected with a screen assembly to keep debris and fish from entering the system. The design approach velocity for the screens is about one-quarter foot per second.

The Project has a maximum hydraulic capacity of 32.79 cubic feet per second (cfs), expected to be realized during the summer months. The initial participants in the Project provided their peaking requirements, and the hydraulics of the Project was designed to meet their peak flow rates. The design velocity in the tunnel was set at a maximum three feet per second.

The intake shaft hydraulics were modeled at a hydraulic laboratory with a 1:3 scale model. Tests were run on prototype diameters of 15 and 20 feet. Slight modifications to the tunnel exit in the shaft and the configuration of the vertical turbine suction bell were proposed by the laboratory, as presented in the Intake Pump Station Physical Model Study (Northwest Hydraulic Consultants, 2006), and implemented into the design.

Constructability Review. The District selected a construction management firm just prior to the 90-percent design milestone. The review suggested a change in the supports of the sloping intake pipe. Originally, the supports were anchor blocks founded like a spread footing. The proposed change, which was implemented in the design, was to a “pipe support” system using drilled piers on both sides of the intake pipe, and adjustable custom hardware spanning between the piers used to support the intake pipe.

The construction management firm also conducted an independent opinion of probable cost, and confirmed the designer’s opinion of cost; however, bidding yielded a much greater price. Factors that contributed to this will be discussed in the concluding remarks at the end of this paper.

DESIGN

Geology. (Geomatrix 2007a and 2007b) The intake site is located in the central California Coast Ranges Geomorphic Province. The intake shaft and tunnel construction take place in the Vaqueros Formation. This formation consists of moderately lithified, massive, poorly- to well-graded sandstone. The formation is predominantly quartz with minor constituents that include feldspar and clay minerals. The formation encountered in the subsurface exploration was further subdivided into its characterization as Subunits A, B, or C.

Subunit A consists of generally fine to medium grained sandstone, which is weakly cemented to locally uncemented and friable, and breaks under modest hand pressure. The material was frequently washed out during coring operations and recovery, and Rock Quality Designation (RQD) was quite poor with an average of approximately 25-percent.

Subunit B has texture and mineralogical composition similar to that of Subunit A, yet the most significant difference between each is the strength of the deposit. Subunit B is comparatively strong with strength that ranges from weak cement grout to structural grade concrete, with an average RQD of approximately 50-percent.

Subunit C differs substantially in texture and mineralogical composition from either Subunits A or B. Subunit C will be encountered in the last 100-feet of the tunnel. This unit is blue-gray to green-gray, fine-grained, and comprised of interbedded siltstone, claystone, and clayey sandstone. This unit is bedded with intervening hard and soft layers and displays an average RQD of approximately 50-percent.

Groundwater inflows were estimated to be as much as 500 gallons per minute (gpm), with flush flows up to 2,000 gpm (Black & Veatch 2007). Design included pre-excavation grouting to mitigate these inflows. The discussion on the construction of the shaft explains the actual groundwater conditions encountered.

Shaft. The design gave the contractor the responsibility for selecting the methods appropriate for performing the shaft excavation and providing the initial support; however, the following four allowable methods were specified for shaft construction and lining:

1. Conventional excavation with steel liner plate for initial support
2. Slurry wall panels constructed with hydrofraise excavators
3. Secant piles
4. Blind shaft boring with a casing support

Other methods proposed by the contractor would be subject to review by the District and the construction management team. Ultimately, the contractor employed a method similar to the first method listed above, which will be discussed in the Construction section.

Tunnel. The tunnel design was to jack a coated (Powercrete J-HB liquid epoxy) and lined (Tenemec product, Pota-Pox 80, Series 141) steel pipe following a microtunnel boring machine (MTBM), with the pipe serving as the initial support and the final liner. The steel lined tunnel connected to a fabricated fitting placed underwater in the lake, and that fitting connected to the sloping intake pipe. The specified minimum diameter is 48 inches. The joints specified are all welded steel, or Permalok© pipe with Type 7 gasketed joints.

A 48-inch, oil-hydraulic operated, stainless steel butterfly valve was mounted to the tunnel pipe at the bottom of the shaft. Mounted to the valve was a tee-fitting that redirected the water entering the shaft into a vertical direction (both up and down). The Intake Pump Station Physical Model Study (Northwest Hydraulic Consultants, 2006) identified unfavorable motions in the pump column for the two pumps located directly in front of the tunnel, and the tee-fitting resolved that condition.

Multi-Port Inclined Intake. The intake system was designed as a sloping seven-port intake pipe fabricated from ASTM A312 stainless steel. The lowest intake port is 48-inch in diameter, and the upper six intake ports are fabricated in a vertical direction with 24-inch diameter openings. Each port is equipped with a stainless steel fish/debris screen having maximum screen slot opening of 1.5 inches. The screen assembly in front of the bottom 48-inch intake was an elliptical shape screen mounted to a 45-degree mitered pipe configured in the downward-direction. The upper six screens were cylindrical shaped.

All ports are equipped with an isolation butterfly valve and oil hydraulic operated actuator. A single manufacturer was specified to design, furnish, and test the Intake Valve System that included the valves, hydraulic cylinder actuators, hydraulic power unit, and interconnecting hydraulic piping.

Isolation Butterfly Valves. Atop each of the upper six ports was a 24-inch diameter, oil-hydraulic actuated butterfly valve, with the oil being a food-grade product. The upper four valves were specified as AWWA C504 Class 150 ductile iron body valves, stainless steel body high performance valves, or stainless steel metal seated-triple offset valves. The ductile iron body valves were deemed acceptable because the lake fluctuates frequently over a large range, and these valves will be exposed for inspection several times over their technical life; however, the lower three valves will rarely be exposed, so they were specified as stainless steel, either high performance valves or metal seated-triple offset valves.

The lower intake port, centered on the centerline of the tunnel, is a 48-inch diameter port, equipped with 48-inch stainless steel butterfly valves, specified to be either a high performance type or metal seated-triple offset type.

Each valve will be operated by a double-acting hydraulic cylinder actuator. The actuators are specified for underwater use and stainless steel construction. The specified maximum working pressure is 1,500 pounds per square inch (psi).

Hydraulic Power Unit. The intake valve actuators are powered by a hydraulic power unit (HPU). The unit consists of two major components: the HPU Panel and the Valve/Piping Panel. Each is skid-mounted. The HPU Panel consists of the oil reservoir tank, oil pumps, filters, strainers, and the control panel. The Valve/Piping Panel consists of the eight groups of solenoid control valves, pressure gages, piping, and flow control/isolation valves. Stainless steel socket welded piping was specified to convey the hydraulic oil between the HPU and the valve actuator cylinders (see Figures 3 and 4).

Figure 3. Preparing for Hydraulic Line Installation

Figure 4. Hydraulic Lines in Intake Pipe.

PREQUALIFICATION OF GENERAL CONTRACTORS AND BIDDING

The District prequalified the general contractors for this work because of the unique nature of the construction, including the shaft, tunnel, lake hot-tap, and the marine work to support the intake portal piping. The District judged the need to have an experienced general contractor in one of the three major construction elements: the shaft, the tunnel, or the marine work. The prequalification statement, uniform system of rating, and the appeal process were derived from the templates developed by the California Department of Industrial Relations.

The District received eight prequalification submittals from contractors, and seven were judged qualified to bid the Intake work. Three bids were received on July 16, 2007, and opened, and the bid summary is as follows:

Engineer's Opinion of Probable Cost	$13.1-million
Low Bidder – James W. Fowler Co.	$20.8-million
Second Low Bidder	$21.2-million
Third Low Bidder	$29.4-million

The District believes the prequalification of general contractors is important even though the final quantity of bidders was lower than expected and the contract price was higher than estimated. The District predicts that having the best qualified general contractor to perform and manage this specialized work is an essential element for success. The District learned that an important strategy for managing the bid price would have been District-owned risk for the lake elevation, which was overlooked during bidding. The bidding documents specified the contractor shall expect the lake to be at normal maximum elevation, whereas the actual lake elevation was much lower than that elevation. The bid price for all bidders accounted for a higher water level, and the bid values reflect that cost for the marine and underwater operations.

CONSTRUCTION

Shaft Construction. The contractor constructed a 23-foot rough diameter, 20-foot finished inner diameter, liner plate and ribbed shaft, 180 vertical feet deep, with conventional methods. The shaft was constructed in 12 to 15 vertical foot lifts, employing top down construction methods, as shown in Figures 5 and 6. As the shaft was excavated, liner plates were installed every 18-inch vertically as a complete course. In addition, an internal (circular) steel support (rib) was installed every four vertical feet. At the end of each shaft excavation day, the extrados of the liner plates and the ground were filled with a 200 psi backfill grout, followed by the entire 12 to 15-foot lift being filled with backfill grout. The ribs were then removed after each lift, and the reinforcing steel and 4,000 psi concrete were placed. As a contingency measure, these completed lifts planned on encountering high water inflows based on the pre-excavation probing and grouting plan defined in the contract; however, none of the defined probe holes encountered enough water to trigger the pre-excavation grouting program. Maximum groundwater inflow encountered during shaft excavation was five to seven gallons per minute. Drill and shoot methods were implemented for 72 vertical feet (40-percent) of the shaft excavation. The contractor executed ten rounds of explosives totaling 1,227.3 pounds with a powder factor 1.1 lbs/cyd. After bottoming out the shaft, and prior to the final wall pour, the MTBM's launch seal was cast within the shaft wall. The predicted jacking forces of the microtunnel

Figure 5. Preparing Shaft Concrete Form.

Figure 6. Pour for Lift 6 - Formwork in Place.

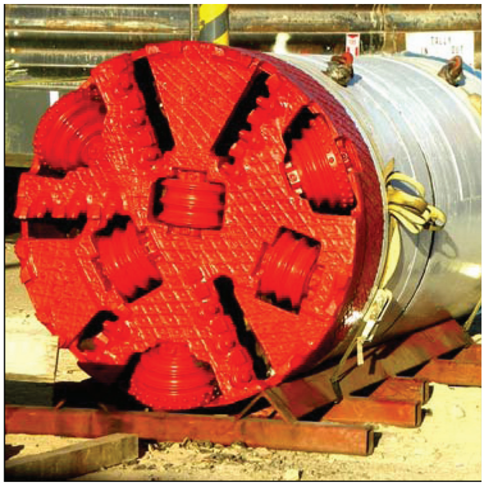

Figure 7. 54-inch Soltau RVS 600 MTBM.

Figure 8. Placing MTBM in Shaft.

did not require an augmented reaction block and/or an intermediate jacking system (IJS).

Tunnel and Lake Tap Construction. The MTBM hot tap (connection) to Lake Nacimiento posed significant engineering challenges. The designed process of having the MTBM engage a large body of water without jeopardizing the safety of the workers, the newly driven tunnel, and damage to the MTBM required many iterations of meetings and discussions in partnership with the District, construction manager, designer, contractor, and specialized suppliers. The contractor successfully completed the 504-foot long microtunneling operation using a 54-inch Soltau RVS 600 MTBM (see Figures 7 and 8) and 10-foot sections of Permalok steel pipe in October 2008.

The work required the installation of two individual bulkheads, within the tunnel and within the transition of the MTBM tapping the lake. Each bulkhead could be described as a welded intrados ring to the Permalok pipe, which later incorporated a specialized gasket/bolted door section. Both bulkheads also had porting which allowed the MTBM's utilities to pass through the bulkheads for continuous MTBM operations. The lead bulkhead was located three feet behind the interface of the MTBM's tail can and the leading edge of the lead section of Permalok pipe. The second bulkhead was located three feet behind the interface of the first/second Permalok pipe joint (10 feet behind first bulkhead). This spacing was engineered to account for the possibility that the MTBM could rapidly lose grade as it entered Lake Nacimiento and, thus, damage the Permalok pipe in such a way that would cause immediate flooding of the tunnel. If this were to happen, the second bulkhead was located far enough behind the first bulkhead to ensure the security of the employees and the tunnel. In other words, should the first one encounter a problem, a backup bulkhead was in place.

Once the MTBM was stopped and fully exposed within the lake, the 10-foot chamber between the two bulkheads was flooded from the shaft side. This action equalized the chamber to the external pressure of the lake, which allowed divers to safely cut the MTBM and the first bulkhead from the tunnel. After this, the tunnel pipe was pushed to the final allowable stop point and the shaft and tunnel were flooded. Divers then cut the second bulkhead from the tunnel and used metrology jigs to connect the tunnel pipe to the multi-port inclined intake pipe with a specially fabricated piece of pipe.

Multi-Port Inclined Intake Construction. The construction sequencing specified in the Project's construction specifications called for construction to occur in the following order: shaft, tunnel, then multi-port inclined Intake pipe. The contractor chose to perform installation of the Intake pipe concurrent with shaft excavation and tunneling, saving valuable time for the overall Project. The design anticipated Intake pipe installation to be performed entirely by marine operation; however, low lake levels permitted drilling operations for three of the Intake pipe supports, installation of three isolation butterfly valves, implementation of three fish/debris screens (see Figure 9), and the placement of a portion of the pipe to be performed on dry land. The remaining installation activities were performed via marine operations and included, drilled piles, clam shell excavation, installation of three fish/debris screens, Intake pipe placement from a crane-mounted barge, critical lift and placement of 161-foot long section of Intake pipe (see Figures 10 and 11), Intake pipe support placement, underwater (tremie) concrete placement, and custom metrology sections to fabricate pipe closure sections (connection tunnel to Intake pipe).

Figure 9. Fish/Debris Screen.

Figure 10. Placing Intake Pipe

Figure 11.
Intake Pipe, Barge, and Equipment.

CONCLUSIONS AND LESSONS LEARNED

Several lessons were learned through the design, implementation, and construction of the Project's intake, and they are:

1. The District should have taken ownership of the risk of lake level fluctuations. This could be accomplished by specifying a mean lake level in the bid documents and seeking a bid value on elevation intervals above and below said value. The owner would pay the contractor accordingly for higher lake levels and would be afforded deducts for lower lake levels. This strategy will likely lower high contingency values from the bids.
2. The District recommends including a Geotechnical Baseline Report (GBR) in the bid documents. This Project did have a GBR, and the contractor did benefit from using it to bid and plan his work. This document presents the engineer's anticipated groundwater levels and subsurface conditions for the intake site. Also include proposed construction methods for shaft and tunnel construction, which allowed the contractor to better anticipate the intake work.
3. The District recommends assembling a Disputes Review Board (DRB) to settle any disputes developed during construction. A DRB is especially effective when complex, specialty work is involved. The combination of shaft excavation, microtunneling, and marine construction on this Project created a need for an experienced, unbiased panel to help avoid claims and encourage partnering. This project assembled a three-person team, and at the time of publication of this paper, no hearings are scheduled.

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Figure 12.
Intake Site - PreConstruction

Figure 13.
Intake Site - During Construction

NOTES

Unit Conversion

1 mile = 1.6093 kilometers
1 foot = 12 inches = 0.3048 meters
1 acre = 0.4047 hectare
1 cubic foot = 0.02832 cubic meters
1 cubic yard = 0.765 cubic meters

1 pound per square inch = 6894.76 pascals
1 ton = 2,000 pounds = 907.18 kilograms
1 acre-foot = 1,233.5 cubic meters
1 horespower = 0.746 kilowatts