Chapter 35

TUNNELING AT HOLLYWOOD RESERVOIR

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ABSTRACT

This paper focuses on the underground tunnel work at the Hollywood Water Quality Improvement Project (HWQIP) in Los Angeles, CA. The HWQIP is being constructed to provide a water distribution system to bypass the existing Hollywood Reservoir System, which supplies drinking water for 500,000 people. The major project features include, a 2.9-meter diameter 1,829 meter long bypass tunnel, a 1.8-meter diameter 366 meter long utility tunnel, 3 jack and bore tunnels, two 136 million liters underground circumferentially wrapped pre-stressed concrete water storage tanks, associated piping, and mechanical facilities. The physical project location coupled with strong community involvement and stringent environmental concerns was a considerable driving force for this project located in the Cahuenga Pass area of the Hollywood Hills north of Los Angeles, CA.

PROJECT DESCRIPTION

The Los Angeles Department of Water and Power (the Department) is the agency that built the 380-kilometer Los Angeles—Owens River Aqueduct in the early 1900's under supervision of chief engineer William Mulholland. The water derived from this project paved the way for the City of Los Angeles to support growth to become the second largest city in the United States with a population of over three million people. The Hollywood Water Quality Improvement Project is being constructed adjacent to one of the keystone features of the Aqueduct system, the Hollywood Reservoir, to meet new water quality standards imposed by the State of California Surface Water Treatment Rule.

The Hollywood Water Quality Improvement Project (HWQIP) consists of an $80 million program of two large underground water storage tanks and a system of tunnels and regulator station located in a residential neighborhood near the Cahuenga Pass region of the Hollywood Hills, approximately seven miles northwest of downtown

Los Angeles. The surrounding neighborhood includes several active homeowners groups as well as famous influential people. To address their concerns, the Department entered into a formal mediation process with community representatives to identify and mitigate impacts of the project from project conception through project construction.

The Hollywood Reservoir Complex contains the Upper and Lower Hollywood Reservoirs; two pump stations and appurtenant distribution systems. The HWQIP will bring the Hollywood distribution system into compliance with the water treatment rule. When complete the project will bypass the reservoirs for the normal distribution of water and allow the reservoirs to remain, providing emergency storage capacity.

The two new underground water storage tanks provide 272 million-liters of storage capacity. Each tank is 87-meters in diameter and 12-meters high fed by a system of inlet and outlet piping. The tanks are constructed of reinforced concrete with steel strand cable circumferential prestressing and steel thread bar vertical prestressing. A one million cubic meters of soil and rock excavation was required to construct the tanks, a portion of which were slope cuts, and the remainder within the shoring system. A soldier pile and tieback anchor system and a structural slurry wall support the excavation. The excavated material was placed in fill sites on the property adjacent to the tanks site. Landform Grading techniques were implemented to mimic the natural contours of the surrounding area and replanted with native vegetation. The Department awarded a prime construction contract for $84,243,342 to Kiewit Pacific Company of Sante Fe Springs, CA on November 1, 1998.

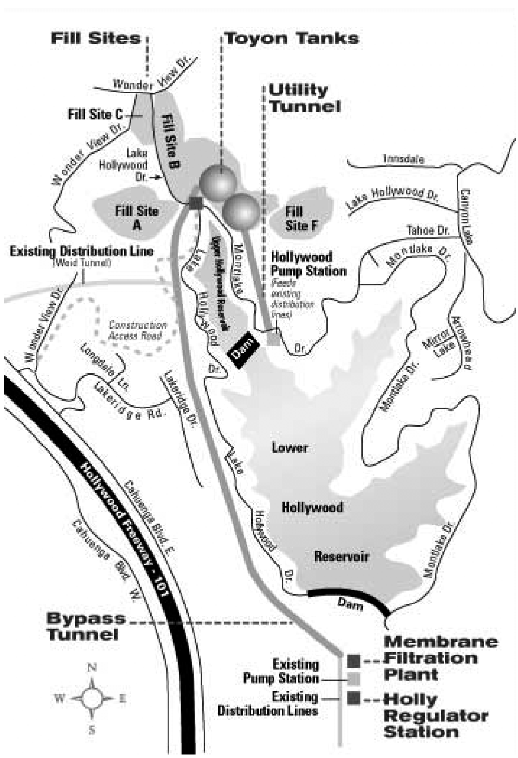

Figure 1. Project map

TUNNELS

There are six tunnels on the project. They are the Hollywood Bypass Tunnel, Utility Tunnel, Weid Connection Adit, North Tank Overflow Tunnel, South Tank Overflow Tunnel, and the Storm Drain Outfall Tunnel. The remainder of this paper will focus mainly on the Bypass Tunnel and Utility Tunnel construction activities.

Hollywood Bypass Tunnel

The Hollywood Bypass Tunnel alignment is located west of the western shoreline of both Upper and Lower Hollywood reservoirs. Ground cover over the tunnel alignment ranges from 20 to 200 meters. The tunnel was excavated on a 3.5-percent down grade from the North Toyon Tank excavation to below the existing Mulholland Dam, adjacent to Mulholland Pump Station.

Geology. The anticipated ground conditions described in the Geotechnical Baseline Report divided the tunnel alignment into three reaches. Reach I (Station 2+82 meters to Station 13+32 meters) is described as the Topanga Formation composed of interbedded sedimentary rocks consisting of sandstone, silty sandstone, siltstone, and claystone with unconfined compressive strengths (UCS) from 0.138 mPa to 20 mPa with an average 9 mPa. Reach II (Station 13+32 meters to Station 17+16 meters) remained in the Topanga Formation but, was anticipated to encounter a sedimentary rock mass that contains a greater percentage of thicker sandstone beds and less frequent siltstone and claystone beds as well as localized beds of conglomerate containing pebble to cobble size granitic clasts. UCS range from 6 mPa to 48 mPa with an average of 28 mPa. Reach III (Station 17+16 meters to Station 19+50 meters) is described to contain brecciatted basalt and fractured basalt. UCS range from 10 mPa to 69mPa with an average of 35 mPa. The GBR anticipated groundwater flush flows of up to 11,000 lpm and a maximum sustained inflows of 7,500 lpm. Cal-OSHA Division of Mines and Tunnels classified the Bypass Tunnel as potentially gassy.

Tunneling System. The Contract documents allowed several different excavation and support schemes for the Contractor to choose in constructing the Bypass Tunnel. These schemes included Roadheader excavation and EPBM excavation in the Topanga Formation and EPBM excavation and Drill and Blast excavation in the basalt. Probe hole drilling and Pre-excavation grouting were specified to be performed in concert with all excavation schemes. Payment provisions for probing and grouting

Length	1829-meters
Diameter	3.5-meter OD, 2.9-meter ID
Geology	Reach 1 – Weak to Moderate Sedimentary (Topanga) rock Reach 2 – Moderate to Strong Sedimentary (Topanga) rock Granitic Conglomerate Reach 3 – Brecciatted Basalt and Fractured Basalt
Excavation Method	LOVAT RM131 RL/SE Earth Pressure Balance Tunnel Boring Machine (EPBM)
Primary Support	Bolted & Gasketed Precast Concrete Segments
Start Date/Stop Date	July 31, 1999 - January 21, 2000
Subcontractor	Elmore Pipe Jacking (EPJ)
Cost	$13 million

Figure 2. Bypass tunnel summary data

were made through a series of allowance items. Primary excavation support schemes available for Contractor selection included expanded steel ribs and lagging, steel ribs and shotcrete, expanded concrete (junk) segments and pre-cast bolted segments.

Expectations of ground conditions described in the GBR coupled with the anticipated groundwater inflows that could be encountered during excavation of the Bypass Tunnel prompted the tunnel contractor Elmore Pipe Jacking (EPJ) to propose an alternate tunnel excavation and support method to help minimize the associated risks. The tunneling system proposed and approved was a LOVAT model RM 131RL/SE Earth Pressure Balance EPBM with a bolted gasketed precast concrete segmental lining system for primary ground support. EPJ's proposal included the use of the EPBM to replace the requirements for probe hole drilling and pre-excavation grouting. Upon successful completion of the Bypass Tunnel excavation the contractor was to be paid the full amount of the probe hole drilling and pre-excavation grouting allowance items to offset the additional cost of the EPBM and the segment gaskets. The cost for any remedial grouting to stop water inflows in excess of the post grouting inflow criteria of 60-lpm would be deducted from the allowance item monies.

The EPBM selected for the tunnel was designed with a fully convertible cutterhead with the ability to excavate with either ripper teeth (for the softer rock), or roller disc cutters (for hard rock). Cutterhead configurations could be changed underground without the removal of the machine or hand excavation ahead of the machine. The EPBM was equipped with Pressure Relieving Gates (PRG) to control plenum and discharge pressures, and to shutter off large groundwater flush flows. The machine used on the project was leased from the Kenny Construction Company and first used on the Benbrook Transmission Tunnel in Benbrook, Texas.

Precast Segments. The bolted gasketed pre-cast segment design selected by EPJ utilized a 150 mm thick by 2.9-meter ID six piece configuration (dedicated invert section, four additional Segments and a 15-degree key segment). Sealing was accomplished using a 38 mm by 10 mm flat Neoprene gasket glued to the segment joint faces. Prefabricated hard plastic shims were glued to the segments to provide installation in two 213-meter radius curve sections of the tunnel. Gaskets were doubled in thickness when shimming was used.

Economy Pre-cast of Sylmar, California received a contract from EPJ to set up a pre-cast yard and produce segments at a ready mix suppliers yard in Canyon Country, California. The steel segment molds, originally manufactured for the Benbrook Transmission Tunnel in Benbrook, Texas, were leased from the Kenney Construction Company. Segment production began on January 10, 1999 and was completed on

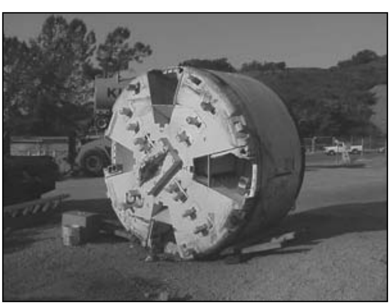

Figure 3. EPBM cutterhead

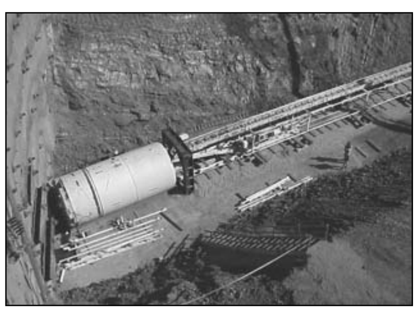

Figure 4. EPBM assembly

Figure 5. Segment casting yard

Figure 6. Segment inventory

June 15, 1999. An average of 50 complete rings were cast each week on a one-shift basis. Segment quality was excellent with only six individual segment pieces rejected.

Tunnel Construction. The Bypass Tunnel portal is located inside the north tank construction area approximately 5.5 meters below the tank invert elevation. The Prime Contractor, Kiewit Pacific, developed the tank excavation and tunnel portal. The tunnel portal area was turned over to EPJ on July 2, 1999. EPJ began construction of the concrete cradle-launch pad for the EPBM. On July 15, 1999, components of the LOVAT EPBM were lowered onto the pad and work began assembling the EPBM and the trailing gear gantries. A structural steel thrust frame was constructed around the EPBM to be the kick off post during the initial mining.

Once the EPBM assembly was complete, the EPBM pushed itself forward toward the portal wall. Crews built 'false' sets of tunnel rings after each 1.2-meter shove between the EPBM and the end of the thrust frame. On July 31, 1999, three false sets had been built and the cutterhead was in contact with the ground. Mining began in earnest on August 2, 1999. Shortly after initial start-up mining operations were halted to replace the EPBM hydraulic cutterhead drive motors damaged by contaminants in the hydraulic system. Repairs were completed and the first permanent ring was mined and built on August 16, 1999. Shortly thereafter EPJ conducted tunnel operations on two ten-hour shifts per day, eleven shifts per week. The false sets and thrust frame were removed on August 30, 1999 after a sufficient number of rings (32), had been built to withstand pushing pressure. The tunnel started out fifteen days behind schedule. The first month exhibited the 'growing pains' that every tunnel job experiences. On September 17, 1999, with 100 meters excavated, operations were shut down to change the cutterhead configuration from the ripper teeth to disc cutters to better handle the harder sandstone beds of the Topanga Formation. After switching to Disc cutters average mining times varied from twenty minutes in softer siltstones and claystones to thirty minutes in the harder materials (well cemented massive sandstone, conglomerate, and basalt) per 1.2-meter push. Excavated muck volume was 20 cubic meters per push. Concrete segments were erected immediately after excavation. Average build time was 11 minutes with a best of 8 minutes. The best day on record was 36 rings (44 meters). The best week was 146 rings (175-meters). As the tunnel progressed in length, the wait for trains between cycles became longer and longer, and at the end of the drive, a good shift would be 10 rings (12 meters). Figure 7 provides summary tunnel excavation rate data.

The machine preformed reliably without major breakdowns. The low utilization rate shown in Figure 8 is attributable to the initial hydraulic damage, cutter changes, and adjustment of the muck pick-up scraper blades on the rock cutterhead

MONTH	TOTAL RINGS	TOTAL METERS	RINGS PER DAY	METERS PER DAY	COMMENTS
AUG 1999	36	43.2	2.6	3.1	
SEPT 1999	147	176.4	5.9	7.1	
OCT 1999	287	344.4	11.0	13.2	Best Day 36 Rings
NOV 1999	423	507.6	21.1	25.3	Best Week 145 Rings
DEC 1999	279	334.8	11.3	13.6	
JAN 2000	227	272.4	56.8	68.2	
TOTAL	1368	1641.6	11.1	13.3	

Figure 7. Bypass tunnel excavation summary

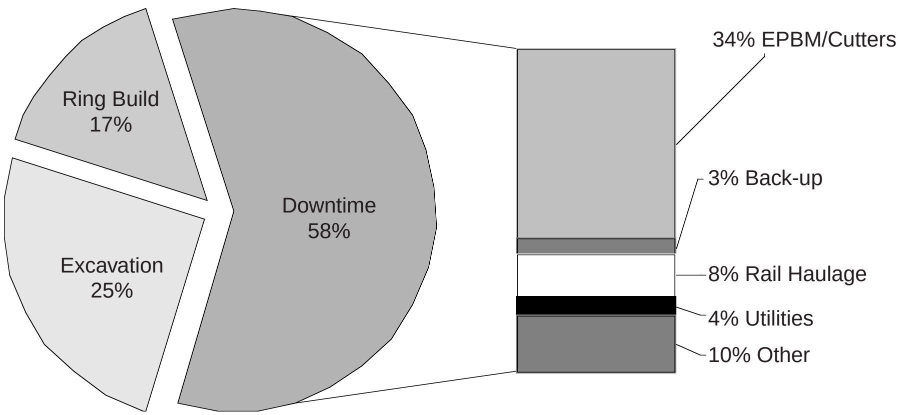

Figure 8. Bypass tunnel time study

configuration. Backfill grouting of the annular space behind the segments was accomplished through combination grout/lifting ports during the excavation cycle. The grout mix used for backfill was a 50% cement 50% fly ash blend mixed with sand. On December 6, 1999, at station 14+51 meters, the EPBM encountered approximately 50 meters of a hard granitic cobble conglomerate intermixed with the Topanga sandstone and siltstone layers. On January 3, 2000, at station 16+95 meters, the EPBM entered the basalt formation and by January 21, 2000 the EPBM holed through at the Holly Regulator Shaft, two weeks ahead of schedule.

Groundwater Behavior. The expected heavy inflow of water never materialized. Both the amounts of water at the face and also drips and leaks in the tunnel itself rarely exceeded 18 liters per minute (lpm) total. Heaviest inflow noted was 27 lpm near the end of the drive, but that volume receded back to 18 lpm after a day. The EPBM excavation throughout the drive did not encounter most of the water inflow recorded. Subsequently the EPBM was operated in open mode the entire length of the tunnel. Most of the measured inflow developed hours or days after the EPBM passed by. Total flow from the tunnel after secondary contact grouting was measured at 14 lpm.

Pipe Installation. To facilitate installation of the 12-meter lengths of 1,850 mm ID steel pipe EPJ designed and built a custom pipe carrier. Manufactured by Northwest Pipe near Victorville, California, the 12 mm thick pipe came complete with an exterior coal tar coating beneath an inch thick cement overcoat. After some minor modification

Figure 9. Segment lined tunnel

Figure 10. Hole through

Figure 11. Loaded pipe carrier

Figure 12. Welding steel pipe joint

at the job site, the carrier performed in exemplary fashion. On March 1, 2000 the first pipe was installed at the Holly Regulator end of the tunnel. Crews averaged a total of six pipes stabbed during both day and swing shift. Two certified welders would then complete a 4 to 6 pass 12 mm fillet weld on the interior joints. After welding, the outside of the pipe joint was covered with a shrink-wrap coating to protect the exposed steel joints from corrosion. On Saturday, June 17, 2000, EPJ stabbed the last piece of the pipe.

Subsequently, the annular space between the primary support and the steel pipe was backfilled with cellular concrete and the interior of the pipe was mechanically lined and finished with pneumatically applied cement mortar. The Bypass Tunnel was completed on August 18, 2000.

Change/Claims. There were no change orders issued for the construction of the Bypass Tunnel. EPJ submitted a request for change notice for a potential differing site condition. The request was withdrawn by EPJ shortly after the completion of tunnel excavation.

Utility Tunnel

Background. The Utility Tunnel alignment runs along the east side of Upper Hollywood Reservoir from the south perimeter of the tank site to an existing pump station near the east abutment of the Upper Hollywood Dam. The Utility Tunnel contains a 765 mm ID steel pipe connection between the tanks and the pumping station and two tank drain lines 610 mm ID a 460 mm respectively.

Length	354 meters
Diameter	2.0-meter OD, 1.8-meter ID
Geology	Weak to Moderate Sedimentary Rock
Excavation Method	BILL TAYLOR Tunnel Boring Machine (TBM)
Primary Support	Expanded Steel Ribs and Wood Lagging
Start Date/Stop Date	March 16, 1999 / November 5, 1999
Subcontractor	Elmore Pipe Jacking (EPJ)
Cost	$871,000

Figure 13. Utility tunnel summary data

Figure 14. Tunnel access shaft

Figure 15. TBM cutterhead

Geology. The anticipated ground conditions described in the Geotechnical Baseline Report for the Utility Tunnel are described as the Topanga Formation similar to the rock mass in Reach I of the Bypass Tunnel. The Character of the rock mass was anticipated to differ from that of Reach I by (1) having lower unconfined compressive strengths; (2) generally more siltstone and claystone than sandstone and silty sandstone; (3) more highly weathered rock; (4) higher rock fracturing; and (5) a layer of sedimentary of sedimentary breccia. UCS range from 1.0 mPa to 40 mPa with an average 7 mPa. Maximum groundwater inflows of 1,500 lpm and sustained inflows of 1,100 lpm were anticipated. Cal-OSHA Division of Mines and Tunnels classified the Utility Tunnel as potentially gassy.

Tunneling System. As described in the Bypass Tunnel section, the contract documents allowed the contractor several tunnel excavation and primary ground support options. EPJ selected a 2.0-meter shielded TBM to excavate the Utility Tunnel. The TBM was a new machine manufactured locally by Bill Taylor. The TBM utilized a four-spoked cutterhead with drag teeth. Muck discharge was achieved with rotating steel paddles loading to a conveyor belt. Muck haulage utilized custom-built self-propelled electric powered locomotive with three Akkerman Model 720, one Model 600 muck buckets. Expanded steel ribs and wood lagging was selected for the primary tunnel support.

Tunnel Construction. Tunnel excavation activities were conducted from a 4.5-meter wide by 8-meter long by 6-meter deep soldier piles and wooden lagging access structure (shaft) built by Kiewit. The Access Structure was turned over to EPJ on April 14, 1999. The TBM was delivered to the site and lowered down into the Access Structure on April 15, 1999. EPJ fabricated a thrust frame, composed of steel beams. As the TBM began mining, false sets were installed in the tail section of the machine. Thrust

MONTH	TOTAL RINGS	TOTAL METERS	RINGS PER DAY	METERS PER DAY	COMMENTS
APR 1999	1	1.5	N/A	N/A	
MAY 1999	47	73	2	3	Best Week 28 Rings
JUN 1999	93	144	3.6	6	Best Day 11 Rings
JUL 1999	40	62	2	3	
AUG 1999	43	66	2.7	4	
TOTAL	224	336	2.4	3.6	

Figure 16. Utility tunnel production summary

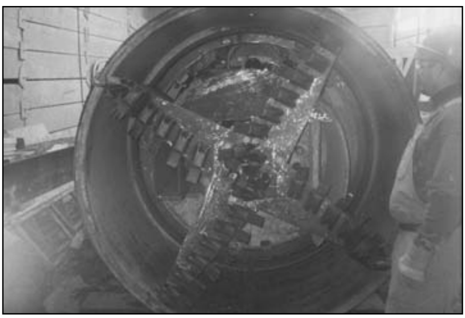

Figure 17. Refurbished cutterhead

Figure 18. Tunnel support system

cylinders pushed off of these false sets, advancing the TBM, until it was completely buried. Tunneling began on April 20, 1999. On April 21st after mining 4 meters the main shaft of the TBM gear drive mechanism sheared off. The shaft was replaced and sheared again on April 22nd. After consulting with the TBM manufacturer, EPJ decided to retrieve the TBM entirely and return it to the manufacturer’s facility for modifications. The TBM returned to the site on May 5, 1999 with the main drive gear completely rebuilt with modifications to the cutterhead including the addition of pick style teeth. Mining operations resumed on May 6th, the ground became harder at approximately Station 3+36, 30 meters from the portal. Excavation was very slow and hindered by well-cemented competent fine-grained sandstone lenses ranging from 100-mm to 400-mm in thickness. EPJ continued to make modifications to the TBM to improve excavation progress without success. Figure 16 provides summary tunnel excavation rate data.

Cutter changes continued to consume a greater portion of production time. EPJ submitted a request for change for a differing site condition. At Station 5+91 the TBM deflected off a shallow dipping cemented sandstone layer and became frozen in place. EPJ was forced to hand excavate around the outside of the TBM to free it up (Figure 20). After seven days of hand mining, the TBM was freed and tunnel mining resumed on July 28, 1999. The TBM holed-through into the south tank excavation on August 20, 1999. Major delays were attributable to (1) the inability of the TBM to effectively cut the resistant-cemented sandstone layers; and (2) the excavated volume of the muck for a 1.5-meter shove could not be loaded into a single muck train. Figure 19 provides a production and downtime summary.

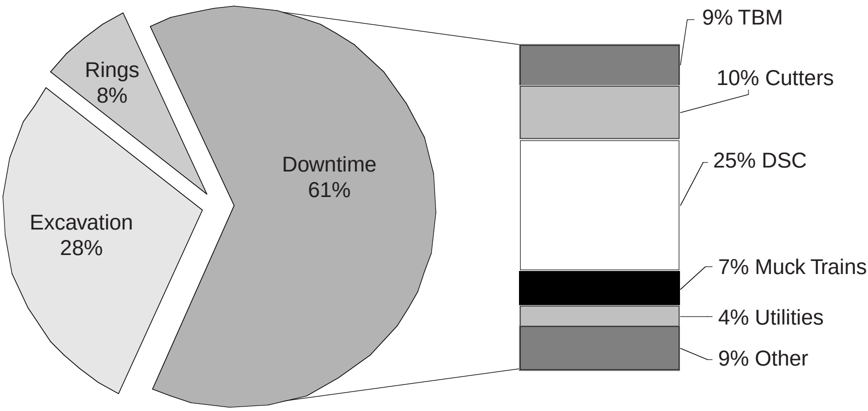

Figure 19. Utility tunnel time study

Figure 20. Hand mined cavern outside of TBM

Groundwater Behavior. The groundwater inflows predicted in the GBR never materialized. Maximum total ground water inflow was measured at 55 lpm with an average sustained flow of 40 lpm.

Pipe Installation. Elmore commenced pipeline installation on September 6, 1999. The 460 mm PVC pipe was installed in the invert of the tunnel and backfilled with lean concrete. The 765 mm steel cylinder pipe was installed from the tanks excavation site by jacking the pipe on steel channel slides. The 610 mm PVC pipe was installed and the tunnel was backfilled with cellular concrete. The Utility Tunnel construction was completed on November 5, 1999.

Changes/Claims. There were two change orders totaling $242,083 issued for the Utility Tunnel construction. A change in the amount of $52,377 was issued to replace fire-retardant treated lagging with untreated lagging. The specifications required the use of fire-retardant treated lagging in the Utility Tunnel construction. The materials were purchased by EPJ and delivered to the site for use. Review of the Material Safety Data Sheets (MSDS) showed the retardant to contain arsenic and chromium. The close proximity of the Utility Tunnel to the open drinking water storage reservoir coupled with the possibility of a direct groundwater connection to the reservoir prompted the issuance of the change to untreated lagging materials. The second change for $189,706 was issued to compensate EPJ for a differing site condition encountered during mining. The sandstone layers that prohibited anticipated tunnel progress exhibited little or no fracturing and rock strength qualities in excess of the baseline values. The compensation value was based upon 21 days delay in mining and repairs to the TBM.

Other Underground Work

Weid Tunnel Connection. The water to supply the HWQIP system will be delivered through the existing Weid Tunnel via the newly constructed Weid Tunnel Connection. The Weid Tunnel Connection consists of a 35-meter deep by 3.4-meter diameter drop shaft and a 40-meter long 2.7-meter high by 2.2-meter wide horseshoe shaped tunnel. The shaft and tunnel house a 1,370 mm welded mortar coated and lined steel pipe. The existing tunnel is intercepted near the surface adjacent to the shaft collar. The tunnel connector intersects the Bypass Tunnel at right angles near its midpoint. Malcolm Drilling, utilizing conventional foundation drilling equipment, drilled the dropshaft. EPJ cased the hole with corrugated metal pipe and grouted the annular space. The tunnel was hand mined by EPJ with spaders and jackhammers and supported with steel sets and wood lagging. The welded steel pipe was backfilled with lean mix concrete.

Jack and Bore Tunnels. To-date two of the three jack and bore tunnels to be constructed have been completed. EPJ used an Akkerman wheel type TBM with jacked steel pipe casing to excavate the two 35-meter long by 1.5-meter tunnels. The tunnels house two 1,370-mm mortar coated and lined steel Tank Overflow drain pipelines. The third jack and bore to be completed in early 2001 will house a storm drain pipeline.

SUMMARY

The HWQIP is a good example of how teamwork between all the project stakeholders can successfully aid the construction a complex project in a difficult setting. Further evidence of the success of this project is the lack of negative media exposure in Los Angeles where tunneling has received a less than friendly welcome. The Los Angeles Department of Water and Power, the Construction Management Team, the Contractor, Subcontractors, and Suppliers must be commended for a job well done.

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