Chapter 22

PROBLEMS ENCOUNTERED ON THE UPPER REACH OF THE NORTHEAST INTERCEPTOR SEWER PROJECT

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ABSTRACT

The Upper Reach segment of the Northeast Interceptor Sewer (NEIS) is a 3.2-km-long tunnel excavated in interbedded marine sedimentary deposits with approximately 40 m of cover. The tunnel was initially classified by Cal/OSHA as "potentially gassy." During excavation, high levels of hydrogen sulfide and methane were encountered, prompting Cal/OSHA to reclassify the tunnel as "gassy." In addition, the tunnel excavation encountered an abandoned, 100-year-old water tunnel known as the "Narrows Gallery." This existing tunnel was completely full of water and under 30 m of hydrostatic head. This paper will discuss the unanticipated difficulties and design solutions implemented to construct a gassy tunnel exposed to high volumes of water.

INTRODUCTION

The Northeast Interceptor Sewer (NEIS), owned by the City of Los Angeles, Department of Public Works, Bureau of Sanitation, is part of a sewerage system that will provide hydraulic relief for the existing North Outfall Sewer (NOS), located in the northeast communities of Los Angeles. Prior to construction of NEIS, the residential neighborhoods in this area experienced several sewerage overflows during extreme weather events. To mitigate this problem, the California Regional Water Quality Control Board (RWQCB), issued a Cease and Desist Order (CDO) that required the City of Los Angeles to upgrade several sewers throughout the City. The 8.5-km-long NEIS commences at the east terminus of the North Outfall Sewer—East Central Interceptor Sewer (NOS-ECIS) located just east of the Los Angeles River and extends northward to Division Street in Glassell Park, as shown in Figure 1.

For this project, the 8.5-km-long tunnel was divided into three segments identified as the Lower, Middle, and Upper Reaches. Tunneling was achieved by using two earth

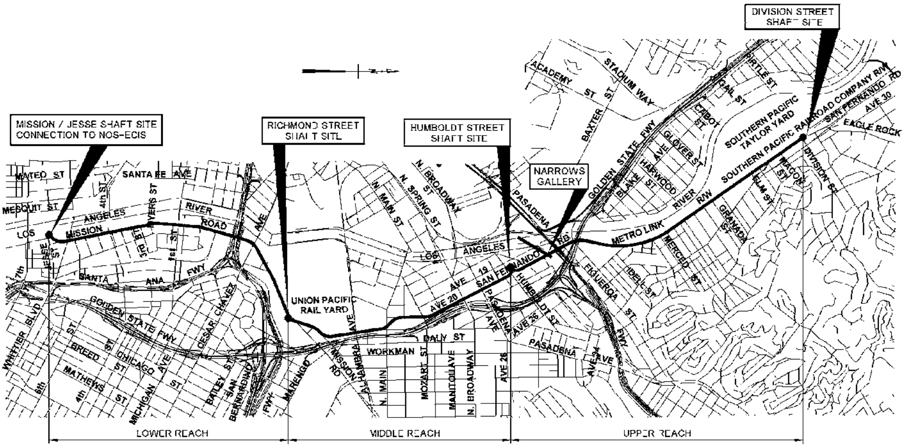

Figure 1. Alignment of Northeast Interceptor Sewer Project

pressure balance machines (EPBMs) for the Lower and Middle Reaches, and one hard rock tunnel boring machine (TBM) for the Upper Reach. The tunnel had excavated and finished diameters of 3.96 m and 2.40 m, respectively. Other structures included in this contract are construction of seven maintenance holes and three work shafts, which house permanent drop structures.

The contract for construction of NEIS was bid in May 2002. There were three bidders; the low bid was submitted by a joint venture of Traylor, Shea, Frontier, and Kenny (TSFK). Notice to proceed was given in July 2002. Construction is scheduled for completion in July 2005. The design engineers for this project were the City of Los Angeles Bureau of Engineering, with technical expertise provided by Jacobs Associates and their subconsultants. Jacobs Associates was subcontracted to Parsons Brinkerhoff to provide construction management services during construction. This paper will focus on problems associated with gas and water on the Upper Reach segment of NEIS and the solutions that were implemented.

SITE CONDITIONS

Geology of the Upper Reach

The alignment of the Upper Reach starts at Humboldt Street Shaft (Station 52+09), located at the northeastern edge of the Los Angeles Basin. It extends through the Los Angeles Narrows, a well-defined canyon cut by the Los Angeles River between Elysian Park Hills and Repetto Hills, and terminates at the Division Street Shaft (Station 85+00) in the San Fernando Basin to the north. This alignment was selected to ensure the entire reach would be mined in rock, with the possibility that overlying soil units would be encountered in the crown of the tunnel in some areas.

The tunnel crosses a potentially active fault that could cause strong ground shaking in the project area. The Elysian Park anticline and blind thrust fault, which bisects the alignment, is the major structural feature responsible for the hills on either side of the Los Angeles Narrows. The bedding orientations of the rock in the vicinity of the Upper Reach are controlled by the northwest to southeast striking anticline. To the south of the anticline's axis, bedding dips approximately 20 to 30 degrees to the

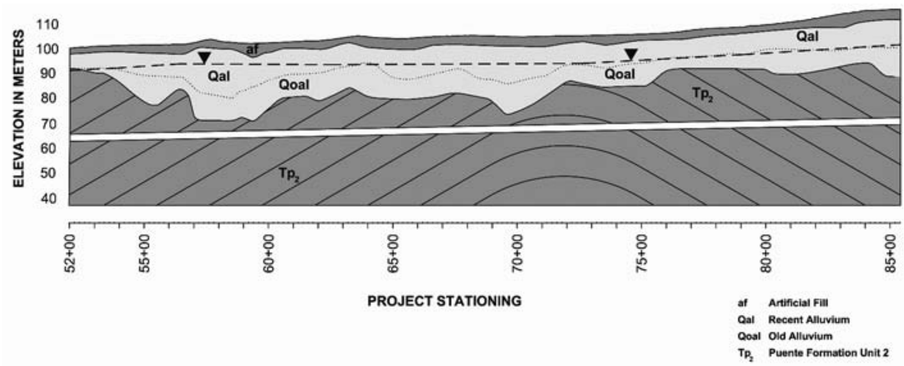

Figure 2. **Geologic cross section of upper reach**

southwest. To the north of the axis, bedding dips approximately 10 to 35 degrees to the northeast. However, local deviations from these orientations can occur anywhere within the region due to parasitic folding and faulting associated with the anticline.

The design phase borings indicated sedimentary marine deposits along a majority of the Upper Reach alignment with the possibility of encountering overlying alluvial soil deposits in two locations, as shown in Figure 2. The following paragraphs summarize the physical properties of these two formations (*City of Los Angeles 2001*).

Puente Formation, Unit 2 (Tp_2). The lower unit of the Puente Formation comprises interbedded siltstone, claystone, and sandstone of Miocene age. The Puente Formation is divided into Tp_1 and the Tp_2 for the NEIS project. The major difference is that beds of Tp_2 are thicker (up to 10 m) and notably stronger (as high as 81.5 MPa) than the thinner beds of the overlying Tp_1. Portions of this formation are friable, weakly cemented, and susceptible to softening in the presence of water. The engineering properties of these beds are closer to that of a stiff soil than a hard rock. Other portions of the formation contain strongly cemented sandstone beds. The contract documents indicated that the Tp_2 unit would vary in strength and cementation between these two extremes.

Old Alluvium, (Qoal). These deposits are generally considered to have formed between 10,000 and 700,000 years ago (Upper Pleistocene). Brown fine gravel with fine to coarse sand, containing scattered sand with gravel layers and scattered organic fragments in a clay/silt matrix. Project borings showed the rock surface within 3 to 5 m of the tunnel crown in two locations along the alignment: beneath the intersection of Interstate 5 and Interstate 110 and near the axis of the Elysian Park anticline.

Groundwater Conditions

The Upper Reach alignment crosses two distinct groundwater basins: the San Fernando Basin and the Central Basin (California Regional Water Quality Control Board 1994). The boundary between these two basins is located just north of the narrowest portion of the Los Angeles Narrows. The portion of the San Fernando Basin that NEIS crosses is located in an unconfined aquifer. The groundwater table varies along the tunnel alignment from 5 to 15 m below ground surface, which corresponds to 20 to 30 m above tunnel invert.

Oil and Gas

None of the 35 project borings along the alignment of the Upper Reach encountered gas, liquid oil, or tar within the Tp_2 or alluvial soils. However, natural hydrocarbons were found in several locations along the alignment. Oil in this part of the Los Angeles Basin originates in the petroliferous Tp_2 and propagates up along bedding planes through seams of sand and silty sand.

DESIGN CONSIDERATIONS

Designing for Existing Geologic and Hydrologic Conditions

During the exploration phase, two areas (Station 57+00 to 60+50 and Station 69+00 to 71+00) were identified along the Upper Reach where alluvium was expected to be located 3 to 5 m above the crown of the tunnel. At these locations, high permeability values were expected to exacerbate the problem. Furthermore, Interstate 5 and Interstate 110 cross the tunnel alignment within this zone. A permeation grouting program was included in the contract to protect critical structures in these areas and reduce the potential of encountering high water inflows and unstable face conditions. The permeation grouting program would be performed from street level, ahead of tunneling operations, to strengthen the ground around the tunnel and reduce its permeability.

Although probing and grouting from the TBM were not required, provisions in the contract were in place to allow these activities, if needed. The TBM required ports for drilling probe and grout holes ahead of the tunnel face, an allowance was also included in the contract to compensate the contractor for these activities when they were implemented.

Several borings detected hydrocarbon odors at depths below the invert, and there was a potential for encountering methane gas. Based on these findings, the Upper Reach tunnel was classified by CalOSHA as “potentially gassy with special conditions.” The contract documents required the contractor to comply with California Code of Regulations, Title 8, Tunnel Safety Orders, and all electrical equipment on NEIS was specified to meet electrical code standards for Class 1, Division 2.

Designing for Narrows Gallery

Historical documents (discovered at the 90% design stage) indicate that an abandoned water supply tunnel known as the “Narrows Gallery” intersected the NEIS alignment approximately 400 feet north of the Humboldt Shaft, as shown in Figure 1. This tunnel, constructed in 1904 under the direction of William Mulholland, superintendent of the Los Angeles Water Company, was later abandoned in the 1950s due to high levels of contamination. The city used the tunnel to drain water from the bed of the Los Angeles River, near the outlet of Arroyo Seco. The exact location, in plan or elevation, could not be determined because survey benchmarks indicated on the drawings signed by Mulholland disappeared some time ago. City Staff reviewed these drawings along with other historical documents to determine the approximate location of the Narrows Gallery. Mulholland’s drawings showed the tunnel to be elliptical in shape, approximately 1.6 m in height by 1.5 m wide, with a reinforced concrete lining of thickness ranging from 200 mm in the crown to 350 mm in the sidewalls. The tunnel was assumed to be full of water and hydraulically connected to the external groundwater table. The structural integrity of the liner could not be evaluated since the access shaft was capped by the foundation of an old Los Angeles Department of Water and Power pump house.

Provisions were included in the contract to find and remove the Narrows Gallery prior to the TBM excavating through it. The removal plan set forth by the contract included the following steps:

1. Verify the exact location of Narrows Gallery, using non-destructive methods.
2. Perform permeation grouting of the rock mass around Narrows Gallery.
3. Drill several holes into Narrows Gallery and fill it with low mobility grout (LMG).
4. Sink a shaft, utilizing slurry and supported by a steel casing, to within 1.0 m of Narrows Gallery.
5. Perform additional grouting from within the shaft to seal off any voids in the LMG.
6. Continue shaft excavation through Narrows Gallery to allow removal of the reinforced concrete lining.
7. Backfill the zone intersecting the NEIS tunnel with a cement-bentonite grout plug, and fill the remainder of the shaft with structural backfill.

CONSTRUCTION CHALLENGES AND SOLUTIONS IMPLEMENTED

Hydrogen Sulfide and Methane Incidents

In June 2003, shortly after commencing tunneling operations from Humboldt Street Shaft, hydrogen sulfide (H_2S) gas was encountered. After careful examination, it was determined that the hydrogen sulfide gas was emitted into the atmosphere from groundwater flowing into the TBM's cutting chamber. Gas was also emanating from grout ports when the plugs were removed during backfilling operations. Hydrogen sulfide has an odor similar to rotten eggs, and the threshold of smell is less than one part per million. Exposure may cause death in minutes when concentration levels of 1,000 ppm are encountered.

Approximately 200 m into the excavation, methane gas in excess of 20% of the lower explosive limit (LEL) was encountered. A concentration equal to 20% of LEL is considered the maximum allowed. Underground operations were shut down, personnel were evacuated, and CalOSHA was contacted to perform an investigation. The investigation revealed that air was stagnant in several areas along the TBM, and delivery of fresh air was impeded by poorly placed fans. To solve this problem, the ventilation ductwork was redesigned, and several Coppus venturi fans were installed in strategic locations along the TBM and trailing gear. The rate of air flow in the tunnel was further increased by the installation of a 100-hp Howden fan at the shaft. These improvements allowed adequate quantities of fresh air to be introduced near the heading so that dilution of toxic and combustible gases could take place to acceptable concentrations. Sodium percarbonate was also added to the sump area to help degrade the hydrogen sulfide gas.

Subsequent to CalOSHA's investigation, the tunnel was reclassified as "gassy," which resulted in a differing site condition for the project. A total of 20 shutdowns were experienced during the excavation phase of the Upper Reach, 13 associated with methane gas and 7 with hydrogen sulfide gas. Once the improvements described in the previous paragraph were implemented, the occurrence of shutdowns due to methane and hydrogen sulfide encounters was reduced dramatically.

Narrows Gallery

In January 2003, TSFK directed their subcontractor, Hayward Baker, to locate and plug the abandoned water tunnel, Narrows Gallery. Hayward Baker drilled several probe holes through the Puente Formation, using hollow stem augers and drilling mud to locate Narrows Gallery. Upon drilling the tenth hole to the assumed depth of the water tunnel, drilling mud was lost, indicating the presence of a deep void. Subsequent probe holes along a line parallel to the anticipated alignment of the Narrows Gallery exhibited similar losses in drilling fluid. The contractor lowered a downhole camera into the probe hole to confirm that a void was present. Video evidence proved to be inconclusive; however, based on the information obtained from the probe holes and from historical documents, the project team believed the Narrows Gallery had been found.

Cores retrieved from the exploratory program did not contain any indication of concrete or reinforcement bars from the Narrows Gallery lining as described on the 100-year-old design drawings. Based on this information, TSFK decided to execute only steps 2 and 3 of the removal plan. However, project engineers from construction management team and TSFK remained skeptical that the Narrows Gallery was completely grouted, since only 7 m^3 of LMG was injected into the void. A partial or total collapse of the unlined tunnel was assumed to be the reason for the low grout takes.

Ten months later, when the TBM excavated to within 6 m of the Narrows Gallery, a probe hole was advanced in front of the TBM to check on the adequacy of the plug. No water was encountered in the location where the LMG plug was placed. The probe was then extended further to check the ground conditions in front of the plug. Approximately 17 m from the face of the TBM, water measuring 1,900 liters per minute was encountered in the probe hole. A nearby observation well, instrumented with a vibrating wire piezometer, indicated a 6-m head drop when the probe encountered the water. The void that was grouted in January was not the Narrows Gallery, but most likely a joint/fracture or some other geologic feature that was hydraulically connected to the Narrows Gallery tunnel.

Based on the findings retrieved from the probe hole drilled from the TBM, TSFK mobilized Hayward Baker's crew again to drill through and grout the Narrows Gallery. This time, 32 m^3 of LMG was placed into the void. Samples retrieved from cored drill holes indicated a layer of sediment beneath the freshly placed LMG. Hayward Baker then drilled beneath the plug and attempted to displace the sediment with chemical grout. Only a minimal volume of grout could be injected. Management from TSFK and the City decided to mine through the Narrows Gallery without any further grouting. Modifications were made to prepare the Lovat Model RMP152SE Series 20900 TBM for the worst-case scenario, mining into a 360-m-long conduit full of water. Crews made every effort to waterproof equipment on board the TBM; they also installed two cells inside the muck ring to measure earth pressure. These cells were identical to the earth pressure balance cells used in the two Lovat earth pressure balance machines (EPBMs) on the Lower and Middle Reaches. The cells were necessary to monitor the earth pressures during mining so that the main bearing seals would not be damaged, which could lead to oil contamination and main bearing failure. The seals on the main bearing were only rated for 1 bar dynamic pressure and 3 bars static pressure.

The Narrows Gallery crossed the NEIS alignment at a skewed angle, and the TBM had to advance four strokes to clear the gallery. Even though 32 m3 of LMG had been placed in the void at this location, on the fourth stroke at 11 p.m. on December 1, 2003, the Narrows Gallery drained into the NEIS tunnel. For the next 2 weeks, TSFK mined less than 4 m per day, working 24 hours per day. Water from the Narrows Gallery followed the TBM, flooding the invert of the tunnel with sand and silt on every advance

Figure 3. Water inflows experienced in heading

Figure 4. Excavated material discharged into muck cars

of the machine (as shown in Figure 3). The placement of LMG failed to stop the large inflows of water.

The high-water inflows prevented backfill grouting of the extrados of the segments. A typical mining cycle included up to 4 hours to excavate, 1 to 2 hours for ring erection, and several hours to clean the tunnel invert. The high water pressures allowed crews to hydraulically mine each stroke with only minimal torque on the cutterhead. Excavated material was discharged into muck cars through a 200-mm-diameter slick line that was connected to a probe port hole, as shown in Figure 4. Pressure cells installed in the cutterhead successfully triggered multiple shutdowns that prevented dynamic pressures from exceeding 1 bar.

Stopping the water became the main priority on the project. TSFK successfully installed two steel rings affixed with inflatable grout bags, which created a bulkhead when the bags were inflated, as shown in Figures 5 and 6.

Figure 5. **Inflatable grout bag**

Figure 6. **Installation of steel ring affixed with inflatable grout bags**

An instrumented observation well showed an instantaneous head drop of nearly 14 m when the TBM mined into the Narrows Gallery. When bulkheads were inflated on December 12, 2003, the piezometer showed a sudden increase in head of 12 m, and full recharge within 3 days. A plot of the piezometer's data is included as Figure 7. Once water stopped flowing from the probe port and from the cutterhead area, backfill grout was injected around the extrados of the segments all the way back to the Narrows Gallery. A differing site condition was granted to TSFK based on presence of silt material found inside the Narrows Gallery. Contract documents did not include any reference to any silt material inside the Narrows Gallery.

Low Rock Cover

Subsequent to the Narrows Gallery incident, the excavation entered an area of low rock cover, extending from approximately Station 57+00 to 60+50 and Station

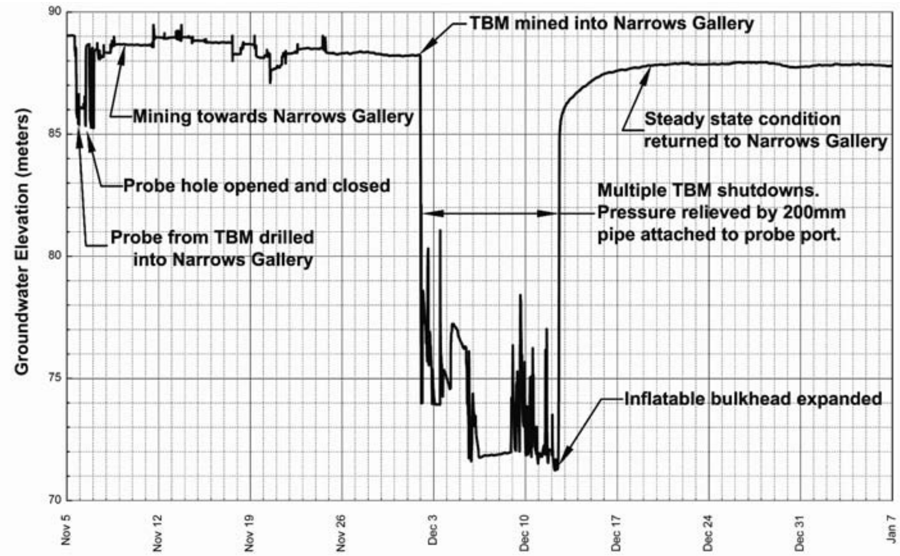

Figure 7. **Observation well data**

69+00 to71+00. The overlying alluvium in these two areas consisted of pervious sand and gravel deposits where hydrostatic heads of up to 30 meters were expected. In anticipation of this problematic area, permeation grouting with microfine cement from the surface was performed. To prevent holes from caving, an upstage grouting process was used, and grout was injected through sleeve-port grout pipes in two 4-meter-long stages. A grout zone covering an area of two tunnel diameters in each direction was required, as shown in Figure 8. To ensure uniform grout coverage, a triangular spacing of 2 meters was used for all locations; additional split-spaced holes were added, if conditions dictated. Injection pressures ranged from 45 to 57 kPa per meter of overburden, and refusal criterion of 200 kg of cement per linear meter of staged hole was used.

In spite of the permeation grouting efforts, water inflows up to 750 liters per minute, or three times the expected amount, were encountered. Again, high inflows created problems with the TBM's electrical components, and silt material from the cutterhead constantly washed into the tail shield, causing water pumps to silt up and interfering with the rolling stock. Unsuccessful attempts were made to slow the water inflows down by pre-excavation grouting from the TBM. Conditions persisted to Station 60+50 at which point the alluvium deposit had risen above the crown of the tunnel.

Excavation continued for another 100 m before the TBM was stopped so that cleanup operations and repairs to the TBM could be performed. Large volumes of water were still flowing into the cutterhead from behind the TBM through the annulus space located on the extrados of the segmental liner created by the overcut. The dosage of the accelerator in the backfill mixture was increased to a level that reduced the set time and prevented washout. A differing site condition was granted to TSFK based on this larger than expected water inflow.

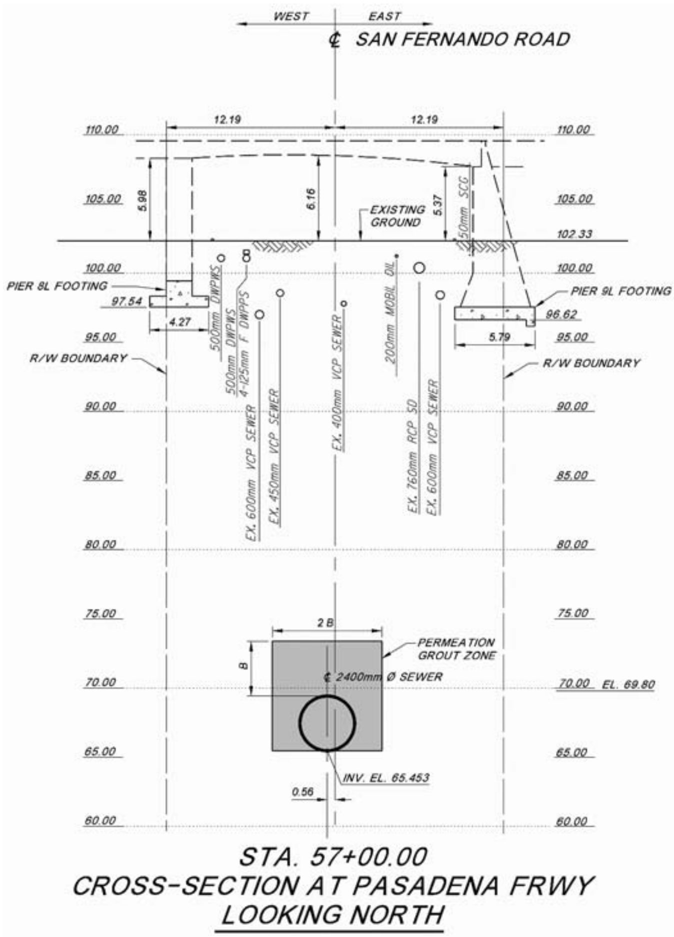

Figure 8. Typical permeation grout zone cross section

PROJECT MANAGEMENT DECISIONS

The differing site conditions discussed above resulted in slower than expected progress rates. The underground reclassification from “potential gassy” to “gassy” required a continuous probe hole to be maintained ahead of the tunnel face, which resulted in 18 days being added to the schedule. The Narrows Gallery incident set the schedule back 35 days. Slow progress through the low rock cover zone delayed the schedule another 9 days. The Upper Reach tunnel, the longest of the three reaches, also happened to be on the critical path.

The milestone date for the project to be ready to accept sewage was already over 2 months behind the CDO date when the project was awarded. By the end of December 2003, only 500 meters of the expected 1,500 meters of tunnel were completed. At this point, there was not enough time left in the contract for a total schedule recovery. Therefore, a schedule recovery plan was implemented that required the contractor to work four additional hours per day. The plan recovered 32 days of the lost time, thus extending the milestone date by 30 days.

As schedule impacts were developing, parallel efforts were under way to keep the administrators of the Cease and Desist Order, the Regional Water Quality Control Board (RWQCB) apprised of the new challenges. RWQCB staff members were invited to witness the challenges posed by the conditions in the tunnel. The RWCQB granted the City a 6-month time extension on the CDO date from the original date of November 30, 2004, agreeing to a new completion date of May 30, 2005.

The City reimbursed the contractor for all costs incurred, including workers' overtime premium and related equipment costs on a time and material basis. With the approval of the owner's oversight committee, funds for the extra work were moved from two different allowance bid items within the contract where under runs were anticipated.

CONCLUSIONS

The Upper Reach segment of NEIS presented many engineering and construction challenges. CalOSHA documented the NEIS project to be the single most dangerous tunnel project constructed in the Los Angeles area since the Sylmar tunnel, which ended in a disaster in 1971, when 17 workers were killed due to an explosion. Construction schedule delays and extra costs were minimized by cooperative efforts amongst the construction management team, Bureau of Contract Administration, TSFK, and representatives from CalOSHA's Mining and Tunneling Unit.

The Upper Reach tunnel holed through on July 16, 2004. Strict adherence to the California Tunnel Safety Orders, careful crew training, and a knowledgeable contractor were major factors that led to the success of the project under difficult and unexpected conditions.

ACKNOWLEDGMENTS

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