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# APPLICATION OF THREE DIFFERENT TRENCHLESS METHODS TO SOLVE UNIQUE CROSSING CONSTRAINTS

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**ABSTRACT**: During heavy storms, combined sewer overflows can occasionally overwhelm the existing 1910s-era Sunnydale Sewer, resulting in localized flooding that impacts hundreds of residents in the Visitacion Valley neighborhood of southern San Francisco. The San Francisco Public Utilities Commission's (SFPUC) solution was the construction of the new 4,000-foot-long Sunnydale Auxiliary Sewer Tunnel, ranging from 6.9 to 12.0 feet in diameter, to alleviate the flooding problems. Three trenchless methods were employed for the new tunnel: an earth pressure balance (EPB) machine to construct the concrete segment–lined tunnel; hand mining through a jet-grout plug beneath a frontage road leading to a freeway onramp; and conventional microtunneling for installation of jacking pipe. The new tunnel crosses beneath US Highway 101, congested existing infrastructure, Union Pacific Railroad and Caltrain railroads, and through contaminated ground. It passes through a variety of ground conditions—from soft Bay Mud near the San Francisco Bay margins to a quick transition into highly variable Franciscan Complex bedrock to, finally, alluvial deposits of the Colma Sand Formation. This paper will focus on the trenchless methods applied along three segments of the tunnel alignment.

## 1. INTRODUCTION

The Sunnydale Auxiliary Sewer Tunnel, owned by the San Francisco Public Utilities Commission (SFPUC), will transport storm water overflows from San Francisco's Visitacion Valley to the Sunnydale Transport/Storage Structure and Pump Station at Harney Way near Candlestick Park. The tunnel will serve as a wet-weather overflow, alleviating temporary flooding in the neighborhood that occurs when the existing 6.5-foot-diameter sewer is overwhelmed during significant wet weather events.

The Phase 1 project area, located between the San Francisco Bay and Talbert Street, is the main focus of this paper (Figure 1). Phase 1 consists of the new 6.9- to 12.0-foot-diameter, 4,000-foot-long tunnel. The tunnel is a gravity sewer with a fixed downstream invert at the tie-in to the transport box and, as a result, is relatively shallow, with 15 to 50 feet of ground cover. Three different trenchless excavation methods were required to complete construction of the sewer: an earth pressure balance machine (EPBM) in both open and closed mode, microtunneling, and conventional mining through jet grout-improved ground. Phase 1 will relieve a majority of the flooding issues seen in the neighborhood. Phase 2 will consist of additional microtunneling sewer work upstream between Talbert Street and Schwerin Street. Jacobs Associates provided design and construction support services; Super Excavators Inc. (SEI) is the contractor.

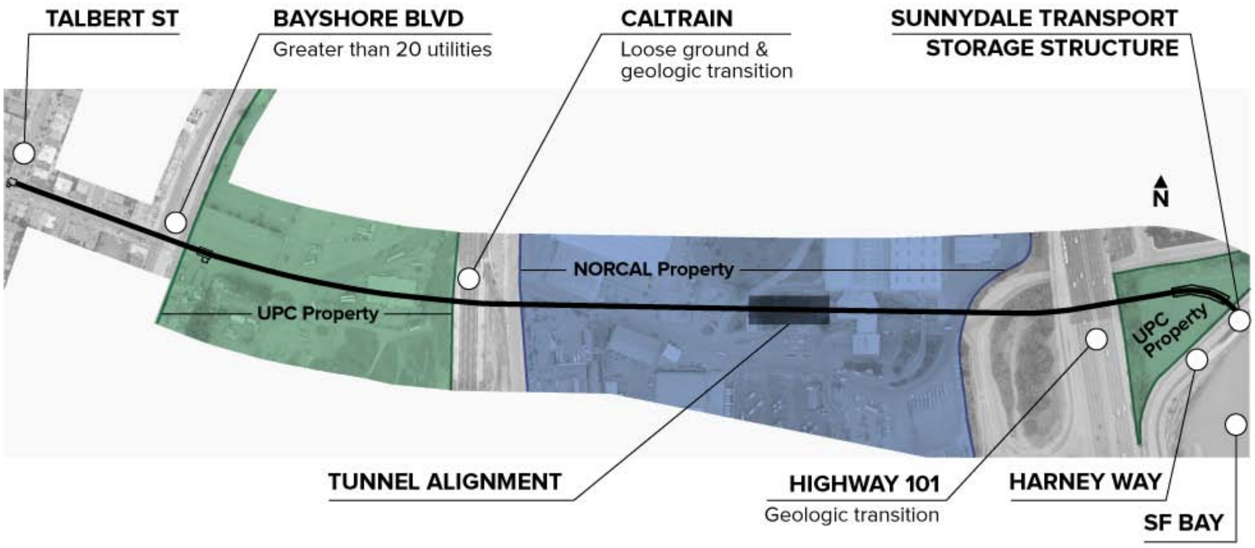


Figure 1. Phase 1 of the Sunnydale Auxiliary Sewer Tunnel alignment.

**2. GEOLOGY**

Final excavation methods and support systems were recommended in part based on anticipated ground conditions in the project area, which vary widely from soil deposits of sand and clay to Franciscan Complex bedrock (Figure 2).

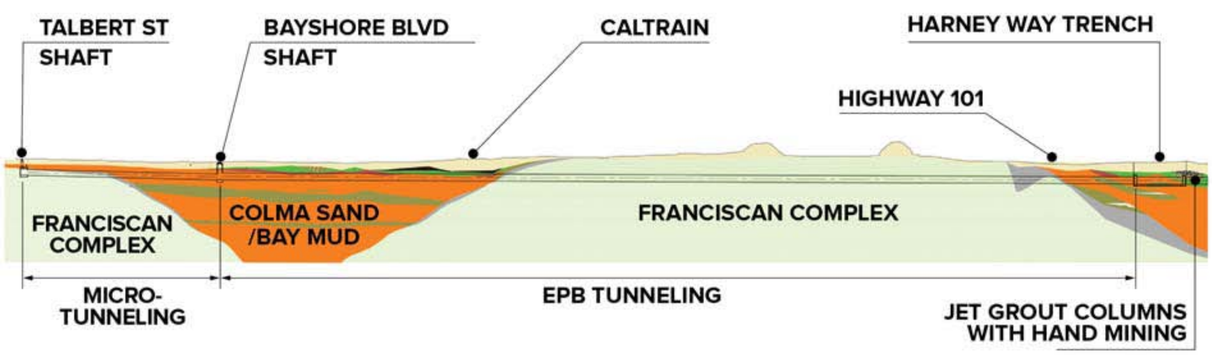


Figure 2. Geologic profile along the alignment.

Bedrock of the Franciscan Complex consists mainly of a chaotic tectonic mixture of variably sheared shale and sandstone containing resistant rock masses largely of greenstone, chert, graywacke, and serpentinite. The degree of shearing ranges from gouge (mélange matrix) to unsheared rock. This mixture of materials exhibits a range of characteristics, including massive, closely jointed, completely crushed rock, and conditions resembling soft clay. The main consequence of this geologic mixture, especially as related to the prediction of ground conditions, is that the Franciscan Complex typically lacks spatial continuity and, therefore, exhibits frequent and abrupt variations in geomechanical characteristics. Similarly, weathering is highly variable between and within geological units. Fresh, relatively unsheared rock is hard, the larger resistant rock masses are pervasively fractured, and smaller, resistant rock masses are commonly tough and relatively unfractured.

The sediments include residual soil at the rock/soil interface, discontinuous units of sand, sandy alluvium, and clayey to sandy colluvium, overlain in many places by Bay Mud with discontinuous units of peat. The main sediments include Colma Sand characterized as medium dense to very dense, medium- to fine-grained sand with variable amounts of silt and clay.

The Bay Mud consists of marine clay and silt that was deposited in the San Francisco Bay and adjacent marshlands, tidal sloughs, and tidal mudflats when the Bay was inundated by rising sea levels through the Holocene epoch. Bay Mud includes silty clay, lean clay, sandy lean clay, elastic silt, silt, and clayey sand. The unit also contains occurrences of fat clay and occasional sand layers, shell deposits, peat deposits, and organic silts and clays of varying thicknesses and extent.

The fill material overlying these sediments is composed of interbedded deposits of gravel, sand, and clay, and generally covers the entire project area. The fill is generally loose to medium dense.

Groundwater levels throughout the alignment vary from 4.9 to 16.0 feet below the ground surface, resulting in maximum groundwater pressures of 1 bar along the tunnel alignment.

## 3. EXCAVATION BY EARTH PRESSURE BALANCE MACHINE

The EPBM portion of the alignment is 3,060 feet in length, extending from the Harney Way Trench, located within the main construction staging area adjacent to Harney Way, to the Bayshore Boulevard Shaft, located at the intersection of Sunndale Avenue and Bayshore Boulevard. The tunnel was constructed using a single pass lining comprising 9-inch bolted and gasketed precast concrete segments.

Based on the final hydraulic analysis, the inner diameter of the EPBM tunnel was set at a hydraulic minimum of 9.5 feet. The contract documents specified a tunnel with a diameter ranging from 9.5 to 11 feet. The varying diameter provided some flexibility, allowing for the use of machines that are widely available, the intent being a lower bid price. SEI took advantage of this opportunity, supplying a factory-refurbished Caterpillar EPBM with an excavated diameter of 13.9 feet and a finished internal diameter of 12 feet. This met the maximum excavated diameter requirement of 14 feet.

The EPBM was launched in mid-May 2011 and holed out on September 22, 2011, taking 92 working days to complete the excavation. During this time, it went through two major ground transitions—from soft ground to Franciscan Complex, then back into soft ground. This required the EPBM to excavate a large range of ground conditions both in open and closed mode, as dictated by the ground conditions.

### 3.1 Initial Advancement and Tunneling through the Franciscan Complex

Initial excavation was in closed mode through predominantly jet-grouted ground and Colma Sand. The initial 40 feet of excavation was through jet grouted ground that was intended to provide additional support during tunnel break-out. Following the jet grouted area, the machine advanced through approximately 110 feet of Colma Sand.

The contract documents required jet grouting between Station 4+00 and Station 6+60. At this location, the alignment crosses below the eight-lane Highway 101, a major artery serving San Francisco. This crossing is particularly complex as the ground transitions from Colma Sand into residual soil and finally into the Franciscan Complex, all within the Caltrans right-of-way (ROW). To mitigate the settlement risks associated with the EPBM excavating through ground with variable hardness, jet grouting was required. At this location, the alignment crossed directly beneath a 1950s-era strutted-bottomed culvert, allowing surface access to install the jet grouted columns. The addition of ground improvement reduced the amount of expected settlement and angular distortion and created a consistent transition for the EPBM beneath the highway. In addition, the jet grouting created a zone for retooling of the cutterhead.
Throughout this part of the alignment, the EPBM averaged between 15 and 20 feet per day as the crew became familiar with the machine, finished installing the trailing gear, and completed their first face reconfiguration.

Following the launch and transition into rock, the EPBM excavated through approximately 1,700 feet of Franciscan Complex in open mode. The unit was highly variable, with the EPBM ultimately mining through four distinct areas that alternated between predominantly sandstone with lesser amounts of siltstone and chert with lesser amounts of greenstone. The rock was mainly closely to intensely fractured with lesser amounts of massive rock. The outer face of the rock outcrop near the rock/soil transition zones tended to be relatively weak and severely weathered, while rock present within the middle of the reach was relatively strong and slightly to moderately weathered.

While in the rock, the EPBM excavated an average of 30 feet per day; however, on two separate occasions, the EPBM encountered steering difficulties due to fines accumulating beneath the machine. In both cases, the EPBM started climbing, requiring SEI to stop mining. In order to regain steering control, SEI crew entered the plenum and hand mined an opening out in front of and below the cutterhead and front shield. High pressure water was then applied to wash out material packed into the EPBM overcut. The stoppages were 8 days and 3 days, respectively. Excluding these stoppages, the average production rate was 40 feet per day. Once the machine was freed and mining resumed, SEI increased the cutterhead rpm and reduced the machine's thrust as part of its solution to prevent additional stoppages. It was determined that, because of the relatively long length of the EPBM shield, the machine could easily become "bound" during excavation. Configuring the machine to excavate a larger overcut could possibly reduce the risk of this occurring.

After advancing through the jet grouted materials at the launch and prior to advancing into the Franciscan Complex, SEI completed a cutterhead tooling reconfiguration. It replaced the nose cone and rippers intended to excavate the sediments and jet grouted materials at the launch with a full face of disc cutters intended to excavate the rock. The variable nature of the Franciscan Complex—from weathered and highly fractured rock to relatively massive and strong rock—presented difficult mining conditions. Upon entry into the unit, the relatively weak, weathered, and highly fractured ground was causing the disc cutter pocket to become plugged with materials, preventing disc rotation and resulting in uneven cutter disc wear. In an attempt to overcome this issue, SEI began modifying the cutterhead face to a mixed configuration, replacing a number of disc cutters with the rippers intended for soft ground. These tools would in turn be quickly worn down when relatively strong, more massive rock was encountered. It often appeared that just as SEI would get an optimal cutting tool configuration installed for one ground condition, another ground condition would present itself. Ultimately, SEI went with a mixed face tooling configuration and the cutting tools were checked on a daily basis, with tools being replaced and the configuration being modified as necessary.

### 3.2 Tunneling below the Caltrain ROW

Immediately after the EPBM transitioned out of the Franciscan Complex, the alignment crossed beneath a Union Pacific Railroad (UPRR) spur and the Bayshore Station, a four-track railroad station operated by Caltrain (through the Peninsula Corridor Joint Powers Board). The primary consideration at this location was the capability to excavate beneath the tracks without disturbance of train service.

SEI was faced with difficult mining conditions, including shallow ground cover of only 20 feet consisting of loose fill, peat, and Bay Mud located below the water table. Settlement attributed to ground loss was a significant project concern. A joint decision was made not to pretreat the ground. This was because of a combination of factors, including limited nighttime work windows, limited access to the tracks, and concerns about the potential for track heave and ballast contamination. Instead, the tunneling work was performed during a 72-hour weekend work window, when trains were less frequent and a standby reballasting crew was made available. This required the contractor to tunnel around the clock until out of the railroad ROW. In addition, extensive instrumentation and monitoring of the track were specified for this crossing.

The instrumentation plan consisted of seven railroad monitoring points (RMPs) located on each track, including the UPRR spur. Settlement monitoring points were placed on concrete pedestals on the gravel ballast located between the tracks. In addition, rows comprising five settlement monitoring points located perpendicular to the alignment were installed on both the east and west sides of the Bayshore Station. Survey reference points were installed on both the northbound and southbound platforms (Figure 3). All instruments were recorded on a two-hour basis. Caltrain personnel were on site during the excavation to complete their own instrumentation program. Caltrain's program focused on rail deflection and its findings would ultimately be used to determine if reballasting had to occur. Per the Contract, SEI's instrumentation information was provided to Caltrain.

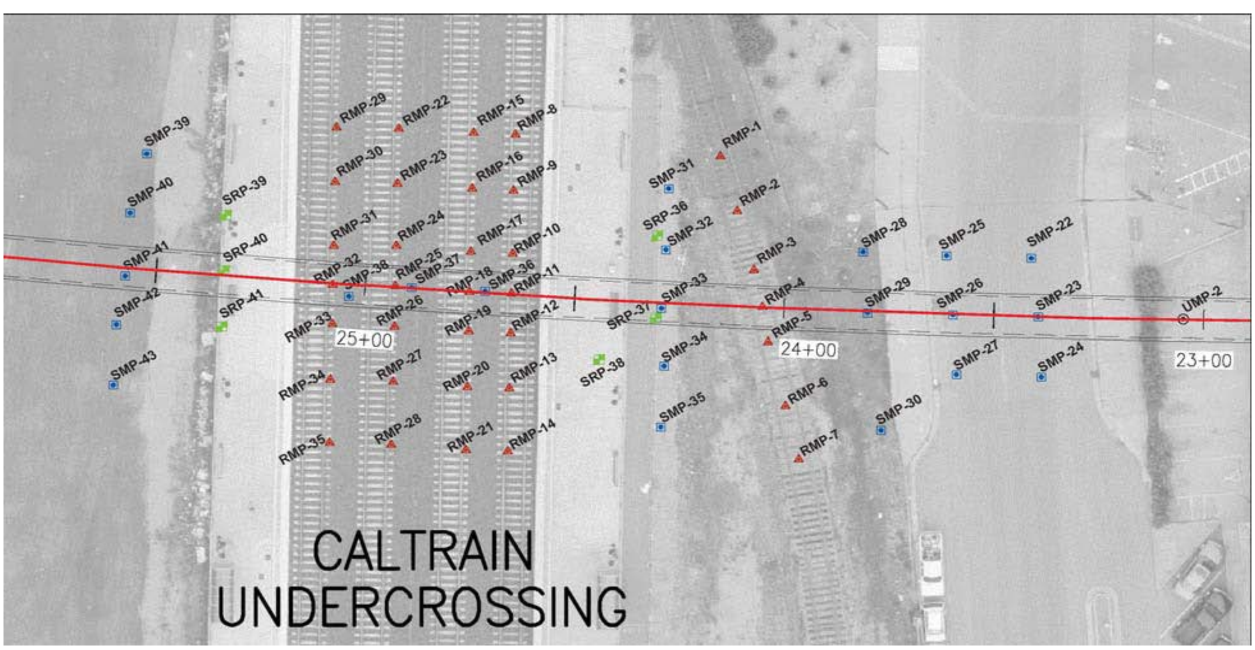


Figure 3. Geotechnical Instrumentation at UPRR and Caltrain Undercrossing.

Mining began on a Friday night just after midnight, and the contractor completed the 110-foot crossing over one 12.5-hour shift. While excavating underneath the Caltrain ROW, face pressures averaged between 1.8 and 2.1 bar. These pressures are higher than the calculated face pressures; however, this was done to mitigate the risk of over mining and resulting settlement. Through the extensive instrumentation program, the EPBM's advance could be observed. Prior to the EPBM's arrival at each track, evidence of slight ground heave was observed in the RMPs as the result of the applied earth pressures. Once the machine passed, settlement would begin to occur, with ultimate settlements dropping into the predicted range. A typical example can be seen in Figure 4.

Analysis indicates that the actual volume loss along the four Caltrain tracks varied between 0.65% and 1.05%. This is consistent with the generally expected range of 0.5% to 1.0% for EPBMs. Maximum recorded settlements were between 0.7 and 0.9 inch. Caltrain was able to clear the tracks upon completion of the mining, although the tracks have since been reballasted. Reballasting was completed prior to the settlement leveling off; therefore, the maximums reported may not represent the ultimate settlement.

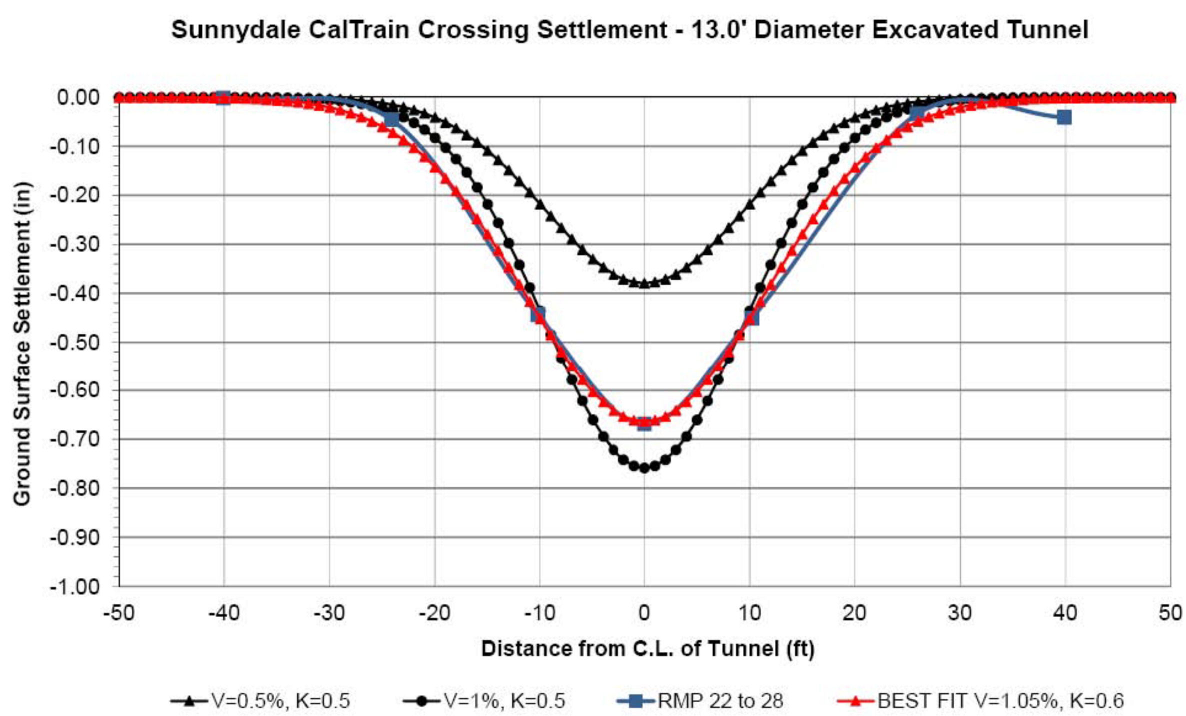


Figure 4. Example of Predicted vs. Actual Settlement at the Caltrain Undercrossing.

Once the EPBM transitioned out of the Franciscan Complex into predominantly Colma Sand, it excavated the final 860 feet of the alignment in just 9 days, averaging 95 feet per day.

SEI worked one 10- to 12-hour mining shift per day, 5 days per week, with a dedicated maintenance day on Saturday, for the majority of the tunnel drive. Including all stoppages, the average daily production rate along the entire EPBM drive was approximately 35 feet per day. The contractor achieved a maximum daily advance of 115 feet.

The as-built survey indicates that the tunnel has a maximum horizontal offset of 3.2 inches and a maximum vertical offset of 8.3 inches above the design alignment. The contract documents specified a maximum deviation in both the horizontal and vertical direction of 4 inches. The 8.3-inch vertical deviation occurred when the contractor was experiencing difficulty steering the machine through the Franciscan

Complex, as described above. Because of the very shallow slope of the tunnel (0.2%), once the contractor regained steering control, the contractor advanced the machine nearly horizontal until it intersected the design elevation to reduce the potential for ponding.

## 4. EXCAVATION BY MICROTUNNELING

In addition to the EPBM drive, the Sunnydale project included a 630-foot-long microtunnel drive along Sunnydale Avenue from Bayshore Boulevard to Talbert Street using fiber reinforced thermosetting resin (Hobas) jacking pipe with an internal diameter of 82.8 inches and an outside diameter of 88.6 inches. SEI submitted the use of this pipe as a value engineering change proposal in lieu of the contract-specified 96 inch internal diameter reinforced concrete pipe (RCP).

While it seems intuitive to have continued excavation with the EPBM to Talbert Street, the tunnel could not be lowered because of its fixed downstream invert. Therefore, a smaller diameter tunnel drive was required to clear existing utilities within Bayshore Boulevard. Reduced hydraulic sizing requirements west of Bayshore Boulevard permitted a smaller diameter tunnel to be constructed along this portion of the alignment.

The utilities of concern included four Pacific Gas and Electric 110 to 115 kV high voltage electric transmission lines and one 2-foot-diameter gas transmission line in a 2.3 foot casing. After an extensive potholing program, undertaken by both the design team during preparation of the contract documents and SEI during the construction phase, clearance between the top of the pipe and the invert of the electric lines was verified to be between 5.63 and 5.95 feet. There is 3.57 feet of clearance between the top of the pipe and the casing invert of the gas transmission line. Final clearances were greater than had been anticipated in the contract documents because of the reduced outside diameter of the Hobas pipe. The smaller overall pipe size is the result of improved hydraulic characteristics and a reduced wall thickness in the Hobas as compared to the RCP.

The microtunnel was advanced through Colma Sand, residual soil, and Franciscan Complex consisting of predominantly mélange matrix and sandstone. Microtunneling occurred over a 17-day period, with an average daily production rate of approximately 40 feet and a maximum daily advance of 65 feet. Advance rates through the cohesive residual soil and mélange matrix were considerable slower than through the sand, with advance rates as low as 10 feet per 7 hour period. The as-built survey indicates that the microtunnel has a maximum horizontal offset of 4.9 inches and a maximum vertical offset of 2.2 inches from the design alignment. Although these numbers exceeded the contract-specified maximum deviation of 2 and 1 inches respectively, due to a relatively steep slope (1%), the installation was deemed to be acceptable.

## 5. EXCAVATION BY CONVENTIONAL MINING

In order to connect the auxiliary sewer into the existing Sunnydale Transport/Storage Box, an approximately 73-foot-long, oversized horseshoe-shaped tunnel was conventionally mined between the end of the EPBM launch trench and the tie-in point at the transport box. The transport box parallels the shoreline in adverse ground conditions consisting of Fill overlying Bay Mud with shell and riprap deposits and high groundwater levels. This method of excavation was proposed by the contractor as a no-cost change order to be completed in lieu of the pipe-jacking methods described in the contract documents. Trenching was not considered feasible below the heavily trafficked Harney Way.

The horseshoe was approximately 12 feet wide and 12 feet high, with the excavation taking place over 32 days. Excavation through the jet-grout-improved Bay Mud was completed with a mini-roadheader utilizing a top and bottom heading with W4x13 steel sets on 4-foot spacing and wood lagging for initial support. The bottom heading typically lagged the top heading by 4 feet, and the contractor was typically able to excavate 4 feet at the top heading and 2 feet at the bottom heading (or vice versa) per day. Upon completion of the excavation, the contractor broke through the 3-foot-thick reinforced concrete wall of the Transport/Storage Box. A 103.8-inch internal diameter Hobas pipe was laid within the oversized tunnel and backfilled with a controlled low-strength material (CLSM).

The jet-grouted mass was approximately 24 feet wide by 20 feet high and extended the entire length of the conventionally mined portion of the alignment between the east wall of the Harney Way Trench and the tie-in to the Sunnydale Transport/Storage Box. The improved ground mass was developed by constructing 75 interconnected jet grout columns, the tops of which were held about 12 feet below the ground surface. The majority of the columns were 6 feet in diameter; however, thirteen 9-foot-diameter and four 11-foot-diameter columns were installed to avoid existing utilities. Along the majority of the alignment, the ground appeared stable and exhibited good stand-up time during excavation. The face was damp in places, but there was no water inflow.

From visual observation, the last few feet of ground excavated in the top heading did not appear to be as competent as the improved ground seen throughout the majority of the excavation. This area corresponds to the area where the 11-foot-diameter jet grouted columns were installed. This ground did not appear to be uniformly treated, and some of the ground appeared untreated. The contractor added C-channel spiling and reduced the spacing of the steel sets. In addition, groundwater inflow into the tunnel heading was observed at this location; however, the water was clear and did not appear to be eroding the material located above the jet-grouted block.

## 6. CONCLUSION

Despite its relatively short length, many urban and geological challenges presented themselves along the Sunnydale Auxiliary Sewer Tunnel alignment. Through the use of multiple mining techniques, the contractor was successful in excavating this tunnel and is on track to finish the original contract on schedule in March 2012. At the time of writing, pipe laying within the Harney Way Trench and subsequent backfilling are complete. The Bayshore Control Structure located within the Bayshore shaft is almost complete, with operations to complete the tie-in to the existing sewer set to begin prior to the end of January 2012. This is the last step required to bring the new auxiliary sewer on line. Phase 1 of the project was constructed at a cost of 37.4 million dollars.

As this phase of the project draws to a close, the City of San Francisco recently approved a $7 million change order to extend the microtunnel drive an additional 1,360 feet northwest along Sunnydale Avenue from Talbert Street to Schwerin Street. The proposed extension consists of an 83-inch internal diameter Hobas pipe installed by microtunneling. In addition to the microtunnel drive, the work will include the construction of two additional temporary shafts.