The Sunnydale CSO Tunnel—Dealing with Urban Infrastructure

Renée L. Fippin
Jacobs Associates, San Francisco, CA, USA

Heather E. Stewart
Jacobs Associates, San Francisco, CA, USA

Manfred M. Wong
SFPUC, San Francisco, CA, USA

Richard M. Nolting, III
Jacobs Associates, San Francisco, CA, USA

ABSTRACT: The Sunnydale Auxiliary Sewer Project is a CSO tunnel designed to prevent storm events from flooding residences near San Francisco Bay. Although this 2.44–3.35 m (8–11 ft) diameter sewer pipeline is less than 1,219 m (4,000 ft) long, its installation will require a single-pass, segmentally lined EPB drive, a microtunneled drive, a jacked-shield tunnel, and a short cut-and-cover section. Undercrossings include a major four-track commuter rail station, deeply buried gas and high-voltage electric utilities, and a culvert carrying ten-lane State Highway 101 that will require jet-grouting for support. In addition, the EPB tunneling will encounter a plume of contaminated soil and groundwater currently undergoing remediation. This paper discusses the reasons for the multiple construction methods, including variable subsurface conditions and infrastructure crossings.

INTRODUCTION

The existing 100-year-old Sunnydale Sewer Tunnel, owned by the San Francisco Public Utilities Commission (SFPUC), transports wastewater and storm water from an approximately 720-acre service area in San Francisco's Visitacion Valley to the Sunnydale Transport/Storage Structure and Pump Station at Harney Way near Candlestick Park. The service area includes primarily residential sources, open space area in McLaren Park, and some paved roadway and parking areas. The system also accepts dry weather flows from the Bayshore Sanitary District and the Brisbane/Guadalupe Valley Municipal Improvement District in San Mateo County.

The existing 1910s-era sewer system is unable to fully accept storm flows. As a result, it is often overwhelmed during significant wet weather events, and temporary flooding occurs within portions of the service area. The proposed auxiliary tunnel will serve as a wet-weather overflow. That is, it will be empty during the dry-weather season of May through October; and only see flows of combined storm water and sewage during significant storm events. Once constructed, the Sunnydale Auxiliary Sewer Tunnel (SAST) (Figure 1) will provide capacity to prevent flooding in the Visitacion Valley community.

The Phase 1 project area, located between the San Francisco Bay and Talbert Street, is the main focus of this paper. Phase 1 will consist of the new 2.44 to 3.35 m (8 to 11 ft) diameter SAST. At Harney Way, adjacent to the San Francisco Bay, the SAST will connect to the existing below-grade Sunnydale Transport/Storage Structure and Pump Station. As the alignment heads west along the county line, the proposed SAST will run approximately parallel to, but north of, the existing tunnel. Near Bayshore Boulevard, the tunnel will be installed within approximately 6.1 m (20 ft) of the existing 1.7 m (5.5 ft) diameter Sunnydale Sewer Tunnel. The 1220-m-long (4,000 ft) SAST is a gravity sewer and relatively shallow, having an average of 7.6 m (25 ft) of cover. The SAST downstream invert is fixed based on the invert of the transport box.

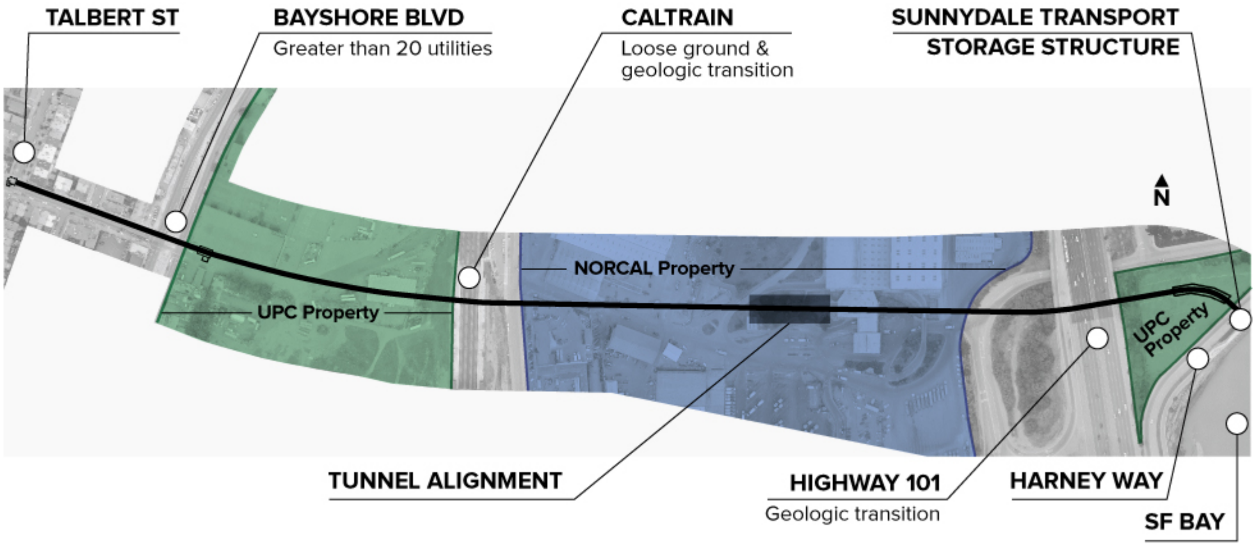

Figure 1. Sunnydale Auxiliary Sewer tunnel alignment

GEOLOGY

Site Investigation

The final excavation methods and support systems were recommended in part based on anticipated ground conditions in the project area (Figure 2). Preliminary site investigations were performed in 1996, with the final site investigations being completed by Arup in 2008. The investigations included a total of 45 borings. In addition to the drilling and sampling, exploration included: cone penetration tests, downhole seismic suspension logging, installation of vibrating wire piezometers, and packer tests at selected boring locations.

The subsurface conditions vary widely from soil deposits of sand and clay to Franciscan Complex bedrock. Portions of the site between Bayshore Boulevard and Tunnel Avenue and between Highway 101 and the Sunnydale Transport/Storage Structure at Harney Way are located outboard of the historic (1848) shoreline.

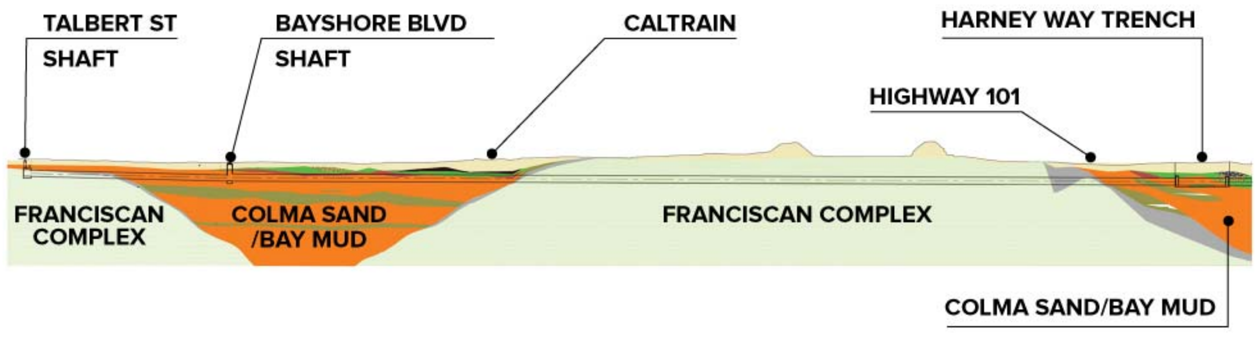

Figure 2. Geologic profile along the alignment

Regional Geology

The project site is located in the Coast Ranges geomorphic province, which is characterized by northwest-southeast trending valleys and ridges. These are controlled by folds and faults that resulted from the collision of the Pacific and North American plates and subsequent strike-slip faulting along the San Andreas Fault Zone. This highly active zone of faulting has been the source of numerous moderate to large-magnitude historical earthquakes that have caused strong ground shaking in the project area; however, none of these faults cross the project alignment.

The bedrock, 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. 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.

This mixture of rock materials exhibits a range of characteristics, including massive, closely jointed, completely crushed, 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.

Sediments

The Quaternary 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. At the east end of the alignment, the Colma Sand decreases in thickness from about 27.4 m (90 ft) at Harney Way to where it pinches out below the center of Highway 101. The Colma Sand is also present between Tunnel Avenue and the western extent of the alignment. In this reach, the Colma Sand increases in thickness to a maximum of greater than 30 m (100 ft) and decreases to a 3-m (10-ft) thickness near Talbert Street.

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. Along the project alignment, the Bay Mud overlies the Colma Sand and is up to 3 m (10 ft) thick. 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 varying in thickness from less than 0.3 m (1 ft) up to 4.6 m (15 ft).

Groundwater levels throughout the alignment vary from 1.5 to 4.9 m (4.9 to 16 ft) below the ground surface.

PROJECT CONSIDERATIONS

The proposed SAST alignment crosses under Highway 101; Union Pacific Railroad (UPRR) spur tracks; Caltrain Railroad Station and main tracks; structures located at the San Francisco Recycling & Disposal Inc. property (Norcal); property being developed by the Universal Paragon Corporation (UPC); and Bayshore Boulevard, a busy city street with numerous deep utilities and surface light rail facilities. Efficient permitting and agreements with affected agencies and property owners have been a major challenge of the project.

Structures/Easements

The structures under which the alignment crosses include the eight-lane Highway 101, a major artery serving San Francisco. The alignment crosses directly beneath a 1950s-era strutted-bottomed culvert that was originally developed as a railroad access to the Bay. There is currently no public access through the 6-m-wide (20-ft) culvert. It is maintained by the California Department of Transportation (Caltrans), and the crossing required extensive coordination with Caltrans to obtain an encroachment permit.

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. The major concerns expressed by Caltrans included the potential for settlement and/or damage to the culvert or the travel way.

Furthermore, the alignment crosses beneath existing buildings within the Norcal property and proposed buildings both on Norcal and UPC properties. The City of San Francisco (City) had numerous meetings and conversations with both property owners in order to resolve the easement requirements for the proposed sewer.

The major concerns expressed by both property owners included settlement induced by tunneling and the effect of the tunnel's presence to future development, such as increased structural complexity to future foundations and the impact on their development costs.

Railroad and Light Rail

West of the Norcal property, the alignment crosses beneath a UPRR spur and a four-track railroad station operated by Caltrain. Caltrain serves commuters on the peninsula going into and out of San Francisco to San Jose. Near the UPRR spur, the ground transitions out of rock and into the Colma Sand and Bay Mud deposits overlain by a thick loose fill.

The primary consideration at this location is the capability to excavate beneath the tracks without disturbance to train service. A stoppage in service for Caltrain would result in a significant revenue loss and passenger inconvenience. With severely limited work windows, the project team evaluated several alternatives to mitigate the potential for settlement.

At Bayshore Boulevard the San Francisco Metropolitan Transportation Agency (SFMTA) operates a light rail station, which serves the local community. Although SFMTA is also a City agency, proper compliance and coordination procedures still apply to the project. The major concerns expressed by SFMTA included settlement of the tracks and damage to their facilities.

Other Agencies—DTSC and BCDC

The undeveloped land west of Caltrain was formerly the site of the Southern Pacific Railroad Yard and more recently the Schlage Lock Factory. The soils and groundwater in this region are known to be contaminated with solvents and volatile organic compounds (VOCs). The area has been and is currently undergoing an environmental cleanup program, which is overseen by the California Department of Toxic Substance Control (DTSC). The land is currently being prepared for multiuse development; hence, the clean-up efforts have been expedited. Because the proposed SAST passes through this zone, the project requires coordination with DTSC and compliance with its protocol. The project team has also extensively coordinated with the property owner and its environmental consulting firm.

The major concerns expressed by DTSC were whether the tunnel construction could negatively impact the cleanup efforts. In addition, because the western staging portal for the tunnel is located in this area, UPC was concerned that the project may interfere with the cleanup program. The cleanup includes injections of soluble vegetable oils in a grid pattern, which must be completed on schedule to avoid delays to the multiuse development project.

Lastly, all projects within 30 m (100 ft) of the San Francisco Bay fall under the jurisdiction of the Bay Conservation and Development Commission (BCDC), whose mission is to protect and enhance the Bay and encourage its responsible use. The permit requirements include accessing the impact of the construction activities occurring within its jurisdiction near Harney Way and the impact on public access.

Utilities

Because of its urban location, an estimated 54 utilities cross over or run parallel to the alignment. Typically, a tunnel of this size would be deep enough to avoid urban utilities; however, due to the tie-in elevation constraints at the Sunnydale Transport/Storage Structure and a minimum slope necessitated by the hydraulic requirements, this tunnel will be relatively shallow with a minimum cover of 4.9 m (16 ft) and average cover of 7.6 m (25 ft). Additionally, where the alignment crosses Bayshore Boulevard, a former route for Highway 101 and main artery into San Francisco, the existing Sunnydale Sewer runs parallel to and approximately 6.1 m (20 ft) to the south of the proposed tunnel. This sewer comes within 0.6 m (2 ft) of the ground surface, which forced utilities built along Bayshore Boulevard to dive below it, resulting in deeper than usual utilities in this area. Therefore, the proposed tunnel may be within 3 feet of some major electric and gas transmission lines.

Potholing Program
During the initial design stage, utility maps were collected from utility companies. These utilities included electric, gas, water, sewer, and fiber optic/telecommunication lines. The majority of the collected information provided no depth information. Since the tunnel will be shallow and mostly excavated via closed-faced microtunneling machines, it was imperative to know the elevation of utilities before tunnel excavation to avoid damaging existing utilities or creating a hazard during construction. Also, because the vertical alignment of the tunnel is fixed, any utilities found to be in the path of the proposed tunnel would need to be relocated. Early identification would allow utility owners enough notice to complete relocation projects prior to the start of construction. As a result, a potholing program to locate the deeper utilities was developed. After reviewing the utility maps and the initial field markings, 20 utilities were identified for potholing, the majority of which are located within the intersection of Bayshore Boulevard and Sunnydale Avenue.

Summary of Risk Factors

Table 1: Risk factors along the alignment

Reach	Anticipated Ground Conditions	Primary Stakeholders	Risk
Harney Way to Highway 101	Bay Mud	Universal Paragon	• Disruption to Harney Way
Highway 101 eastward to Tunnel Ave.	Colma Sand Residual Soil Franciscan Complex	Caltrans Norcal	• Settlement at Highway 101 • Mixed Face Conditions • Future impact on Norcal development plans
Tunnel Ave. to Bayshore Blvd.	Colma Sand Bay Mud Artificial Fill	Universal Paragon Caltrain UPRR	• Disruption to Caltrain/UPRR service and settlement of tracks • Disturbance of contaminated plume and interference with soil/groundwater remediation program • Future impact on UPC development plans
Bayshore Blvd. to Talbert St.	Colma Sand Artificial Fill Franciscan Complex	City of San Francisco PG&E	• Numerous utility crossings beneath Bayshore (including critical transmission lines) • Settlement of light rail tracks

SELECTION OF EXCAVATION METHODS

During the early stages of design, the project team evaluated several potential alignments and construction methods for the proposed SAST. The methods were recommended both to accommodate the variable geology and also to address the concerns of the multiple stakeholders. The primary focus during preliminary stages was mitigating risks by approaching each geologic unit with what was viewed as the best-suited construction method. The excavation methods considered included open-trench near the Bay tie-in, conventional excavation with a roadheader within the rock reaches, and microtunneling in the contaminated ground. These options were pursued through the 35% design level.

However, increasing project costs forced the re-evaluation of alternate construction approaches. The most viable economic approach was found to be an earth pressure balance machine (EPBM) erecting a single-pass segmental lining for the majority of the alignment. A short pipe jack and microtunnel section was also recommended at the opposite ends of the project for reasons described in the following paragraphs. This approach reduced project costs by eliminating a shaft and combining the initial support with the final lining; finally, the hydraulic design criteria were re-evaluated, which resulted in a smaller-diameter tunnel.

Ground Support
The ground support system must be compatible with the TBM operations. For this reason, a TBM will be used in conjunction with a prefabricated ground support system, which commonly consists of precast concrete segments that are bolted and gasketed to form a watertight lining.

Because the SAST is a CSO-type tunnel that only carries storm overflow, and the City of San Francisco has not historically had issues with hydrogen sulfide attack, the proposed support method for the tunnel is a single-pass segmental lining. This precast concrete lining will be watertight, bolted, doweled, and gasketed. The support will be relied upon as long-term support designed for hydrostatic and ground loads as well as seismic loading conditions.

Harney Way to East of Highway 101

This 130 m (426 ft) stretch of the alignment comprises an overflow parking lot for San Francisco 49er's games that will be utilized as a staging area, and Harney Way. Harney Way is a heavily trafficked street serving as an on/off ramp for Highway 101 leading to Candlestick Park. The area is within old fills, Bay Mud, and Colma Sand. The Harney Way trench will serve as the launching trench for the EPBM. The trench length was expanded in order to aid in the set up of trailing gear from within the trench.

Because of the need to tie into the below-grade Sunnydale Transport box at an invert elevation of –7.9 m (–26 ft), the design originally considered the open trench extending to the side wall of the transport box. However, two key considerations led to reconsideration: heavily trafficked Harney Way and BCDC jurisdiction.

The staging of the construction to provide appropriate traffic flow to/from Highway 101 proved to be considerably costly, particularly with regard to two large sewer lines located within Harney Way, requiring support in place. In addition, the short stretch across Harney Way is within the jurisdiction of the BCDC. Limiting the impact to this zone and having flexibility in staging is to the benefit of the City. Therefore, a 23.1 m (76 ft) portion of the alignment is proposed to be constructed using pipe jacking from the Harney Way trench, breaking into the transport box below grade (Figure 3). The inner dimensions of the transport box are approximately 6.1 by 6.1 m (20 by 20 ft), with a large access opening on the surface located nearby. Because the sewer will be tying into the wet-weather compartment, sewage flows will not be an issue during the dry-weather season. The cost of this pipe jacking was less than the open-trench option.

Deep utility within Harney Way construction staging area

Within the proposed Harney Way staging area, of particular interest is the 0.76 by 1.14 m (2.5 by 3.75 ft) reinforced concrete egg-shaped sewer on piles (Figure 3). This sewer is of interest for two reasons: the piles will interfere with pipe jack excavation and will need to be cut, and the as-builts indicate that the bottom of this sewer is less than 0.3 m (1 ft) above the top of the proposed tunnel excavation. The depth of this sewer was confirmed based on invert measurements in adjacent manholes and as-builts. Due to the limited clearance, the contractor will be required to pothole and daylight this sewer prior to pipe jack excavation to visually confirm its plan and elevation. Should the bottom of this sewer be located within the area of planned tunnel excavation, the contractor will be required to develop a plan outlining its proposed methods to construct the pipeline in this area. Because of the traditional design-bid-build contract on this job, this potential work will be considered as change-order work and will be compensated as such. Should the sewer be found where expected, the ground surrounding the utility will be jet grouted. The jet grouting will provide stability and prevent the ground (a combination of shells and riprap) from raveling during pipe jacking, which could ultimately leave the sewer unsupported.

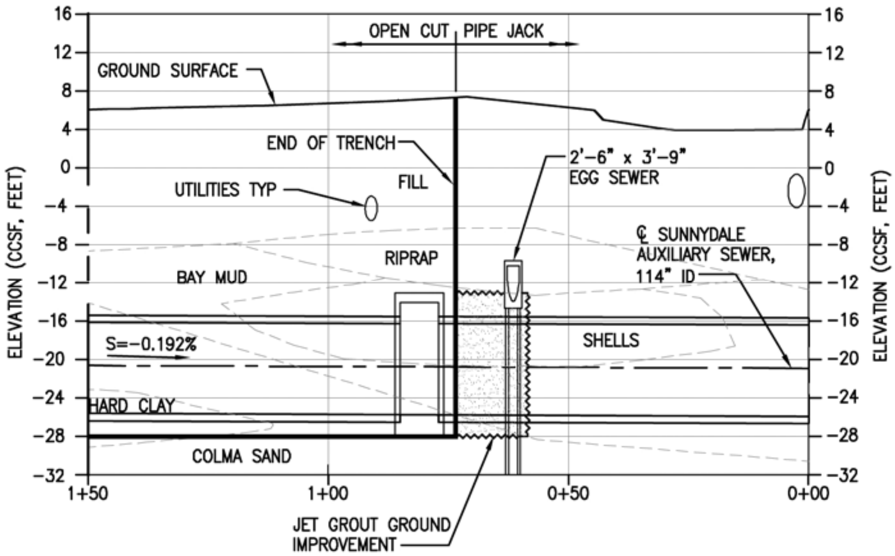

Figure 3. Profile of egg-shaped sewer within the Harney Way construction staging area

Highway 101 to Bayshore Boulevard

Highway 101

The alignment beneath Highway 101 crosses through ground transitioning from fill, Bay Mud, and Colma Sand to Franciscan Complex bedrock, where it reaches a pinnacle then transitions again into a valley of residual soil and weathered rock. Although the soils and rock beneath Highway 101 are suitable for tunneling as individual units, the numerous transitions in relative hardness were viewed as complications for the TBM excavation. Although numerical models predicted low levels of settlement, experience dictates that the inability to adequately condition the soil and pressurize the face could lead to significant settlement. To mitigate these concerns, the project team recommended jet grouting a tunnel envelope from the surface. The addition of ground improvement will reduce the amount of expected settlement and angular distortion and create a consistent transition for the TBM beneath the highway. In addition, the jet grouting will create a zone for potential retooling of the cutterhead.

Norcal

For the subsequent 610 m (2,000 ft) west of the Highway 101 undercrossing, tunneling will continue through greenstone, sandstone, siltstone, and chert within the Franciscan Complex bedrock beneath the Norcal property. Overall, the rock mass within this reach segment varies; conditions include limited zones of intensely fractured rock, but on average are moderately blocky and blocky. As the reach approaches Tunnel Avenue, the rock degrades to residual soil and slopes downward, where Colma Sand is present in transitions throughout the remainder of the excavation. Ground cover throughout the reach averages approximately 6.1 m (20 ft) above the tunnel excavated crown.

Although the alignment passes beneath existing buildings, their shallow foundations, built on the rock, are not anticipated to be impacted. The tunneling machine will be required to have the necessary capabilities to excavate the widely variable rock. The major design consideration for this stretch is to provide a final tunnel lining with adequate capacity to carry heavy foundation loads from future solid waste transfer station facilities. The tunnel lining design is capable of meeting the loading requirement of the future development. In addition, the specifications require design submittals to address the potential loading.

Caltrain

As the tunnel passes beneath Tunnel Avenue and approaches the UPRR spur, the ground transitions out of rock and into the Colma Sand and Bay Mud deposits overlain by a thick loose fill. Settlement through ground loss is a significant concern to the project team and Caltrain. Without ground improvement, settlements could potentially exceed the limit of 13 mm (0.5 in.) set by the railway engineers. For this reason, the project team investigated different ground improvement methods for the loose fill above the tunnel crown, including chemical and jet grouting.

The width of the station platform would have required ground treatment to be performed from the ground surface, thereby obstructing the tracks. With only a maximum four-hour window on most days between continually serviced routes, the scheduling of any productive ground improvement work from the surface would prove to be impractical. In addition, Caltrain engineers expressed concerns about the potential for track heave and ballast contamination. In the end, a joint decision was made to not pretreat the ground, but to instead perform the tunneling work during a 72-hour weekend work window, when trains are less frequent, and to utilize a stand-by reballasting crew. This will require the contractor to tunnel around the clock until out of the railroad right-of-way. In addition, extensive instrumentation and monitoring of the track was specified for this crossing.

Universal Paragon

The tunnel alignment will pass through mostly Colma Sand in this stretch. Because the site is unoccupied, settlement is not a major concern. The largest concern is the contaminated soils/groundwater and the impact on the ongoing DTSC cleanup program. Environmental analysis of the soils and groundwater within the former factory site indicated that contamination at the depth of the tunnel was less than originally anticipated. It is anticipated that the soils will be hauled to a California Class 2 disposal facility, while the groundwater will require treatment for VOC contamination prior to disposal into the City sewer system. The site will, however, require an extensive clean-up program for the upper soils; which is being performed by the developer.

Although an open-cut was evaluated for this stretch, it was seen as having a potentially negative impact on the remediation program. Not only would this have obstructed the developer’s activities, but also it would have generated large volumes of water to treat and would have potentially obstructed the localized groundwater flow. The environmental analysis showed no impact to the program from the tunnel construction; however, the specifications include provisions for the tunneling contractor to closely coordinate with the clean-up contractor because the staging area at Bayshore is primarily within land owned by the developer with on-going remediation activities.

In addition, it is anticipated that the site will be developed with single-story and multistory buildings. The multistoried buildings will require pile foundations. The tunnel lining was redesigned to accommodate increased loading from shallow foundations. Where pile foundations are required, the property owner will be compensated for the increased cost of spanning the tunnel.

Bayshore Boulevard to Talbert Street

As the alignment heads west from the Bayshore Boulevard shaft, it will closely parallel the shallow existing Sunnydale sewer. The diameter required to meet the project hydraulic criteria along this is segment of the tunnel is 2.44 m 8 ft). As discussed above, the 46-m-long (150 ft) crossing beneath Bayshore Boulevard will encounter numerous utilities running north-south (Figure 4) as well as the SFMTA light rail system. Once across Bayshore Boulevard, the shallow alignment will end about 152.4 m (500 ft) west at the Talbert Street intersection.

Potholing above the water table was very effective, and utilities above this depth were easily located. However, potholing for deep utilities was substantially more difficult. The potholes were excavated through variable loose to medium dense fills and medium to very dense Colma Sand. Below the water table, the holes had a tendency to ravel and flow and then collapse. Because of the quickly recharging groundwater table, water could not be removed or blocked from the holes fast enough to obtain visual observation.

This was a major concern due to the presence of four Pacific Gas & Electric (PG&E) 110 to 115 kV high voltage electric lines and one 0.61 m (2 ft) gas line in a 0.76 m (2.3 ft) casing crossing the alignment within Bayshore Boulevard. Although all of these lines were marked, after the initial potholing, only one of these utilities was able to be located. The located line was felt at a depth within 1.5 m (5 ft) of the excavated diameter of the tunnel. For the remaining locations, the utility locators probed to a depth of approximately 3.2 m (10.5 ft). The failure to find these lines resulted in concerns that the remaining utilities could be even deeper, which was confirmed after further communication with PG&E and the discovery of additional as-builts.

Because of the extreme consequences associated with hitting any of these utilities during tunnel excavation, a second potholing program was completed. Initial field marks for the PG&E utilities had been placed by as-builts.

For the second program, PG&E entered nearby vaults and connected equipment directly onto the gas and electric lines to provide a more accurate location. This proved effective as two of the electric lines were discovered to be in significantly different locations than originally thought, and the gas line was discovered to be under the edge of the Muni light rail concrete slab, which meant that potholing would have to occur on an angle.

The angled potholing and ultimate depth of the gas utility meant that a visual would not be feasible, although it was attempted. With PG&E assistance, the top of the gas line was probed at a depth of 3.4 m (11.2 ft), with the bottom of the cased gas line anticipated to be within 0.64 m (2.1 ft) above the top of the proposed tunnel excavation. Two more electric lines were felt by probing at depths of approximately 3 m (9.8 ft) below ground surface. The fourth electric line was never found, despite three separate potholing attempts. The City has requested that PG&E locate this line. Because of relatively good correspondence between the as-builts of the other lines and their potholed depths, the depth of this line is also estimated to be at a depth of 3 m. Although none of these electric lines appear to be in direct conflict with the tunnel, they are all within 1 to 1.5 m (3.3 to 4.9 ft) of the proposed excavation.

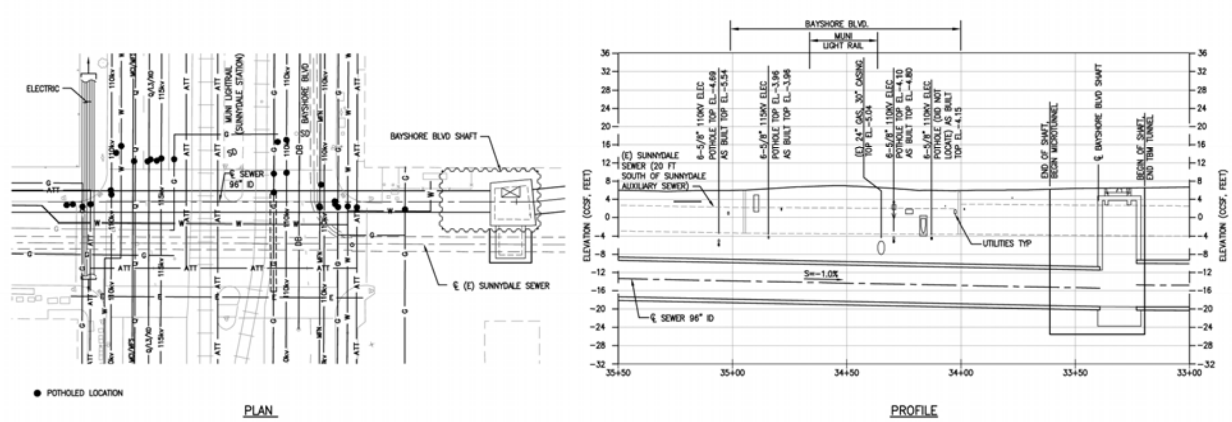

Figure 4. Utilities beneath Bayshore Boulevard

Although probing in conjunction with coordination with PG&E was adequate for the design stage, these lines will need to be daylighted prior to tunnel excavation. Because the utilities are both deep and within different traffic lanes of a very busy intersection, this will present its own series of challenges. In addition, the option remains for the contractor to coordinate with PG&E to schedule a gas line outage during construction.

While it seems intuitive to have continued excavation with the EPBM machine to Talbert Street, these four high voltage transmission lines and gas transmission line dive deep beneath the existing sewer. This resulted in inadequate clearance to continue with the larger diameter machine.

A deep open-trench with dewatering was viewed as too disruptive to the residential community, impractical to cross the utilities within Bayshore Boulevard, and having the potential for extending the contaminated plume through dewatering. For this reason, several trenchless methods were evaluated for this stretch; in the end, microtunneling was cost comparable and advantageous to reduce settlements to tolerable limits at the Muni light rail station and for impacted utilities.

SUMMARY/CONCLUSION

Transition Zones

The SAST alignment crosses beneath several transit structures, two of which are critical: Highway 101 and the Caltrain Bayshore Station. The crossings are also the transition zones of geology—transitioning from fill, Bay Mud, and Colma Sand into residual soil and Franciscan Complex bedrock. The material with the lowest strength and compaction is the fill that overlies Bay Mud near the crown of the tunnel. The project team recommended ground improvement at the Highway 101 transition zone. However, the risk of heaving the track or contaminating the ballast led to the decision to perform the Caltrain railroad crossing during a low traffic weekend work window with a reballasting crew on standby.

Utilities

To aid in the design and planning phase, an extensive potholing program was undertaken and several deep utilities were located. Depths indicated by probing closely coincided with as-built locations, providing relative certainty that the lines are all located outside of the tunnel's path, even though some utilities are close. As with any project, there always remains a chance that unknown utilities will be encountered. An allowance item for all work related to the protection, maintenance, or relocation of unconfirmed or unknown existing utilities is included in this contract.

Recommendations for future pothole programs include an evaluation of anticipated utility depths, especially when obstructions or deep utilities are anticipated, and a workable plan for probing several feet below the anticipated depth. If there are critical utilities, it must be ensured that the personnel performing the field marking have taken the time to connect to the line at a nearby vault. It is also recommended that an owner's representative be on site during the potholing to make decisions on where to pothole and what amount of additional effort should be spent on locating a particular utility.

Excavation Methods

Table 2: Summary of Reach Construction Methods

Reach	Reach Length	Anticipated Ground Conditions	Pipe Inner Diameter	Construction Method
Harney Way to Highway 101	130 m (426 ft)	Bay Mud Colma Sand	2.9 m (9.5 ft)	• Open trench • Pipe jack beneath Harney Way
Highway 101 to Bayshore Blvd.	895 m (2,935 ft)	Colma Sand Residual Soil Franciscan Complex bedrock	2.9 to 3.4 m (9.5 to 11 ft)	• EPBM excavation • Single-pass, bolted, gasketed reinforced concrete segments
Bayshore Blvd. to Talbert Street	196 m (643 ft)	Colma Sand Artificial Fill Franciscan Complex bedrock	2.4 m (7.9 ft)	• Microtunnel

Based on the final hydraulic analysis, the inner diameter of the EPBM tunnel has been set at a hydraulic minimum of 2.9 m (9.5 ft). At the same time, it is beneficial to choose a tunnel size that is familiar to U.S. contractors and that will allow the use of machines that are widely available, hopefully resulting in a lower bid price. Given these considerations, the project team set a minimum tunnel inner diameter at 2.9 m, allowing for an inner diameter up to 3.4 m (11.2 ft) in the contract documents, should the contractor be better equipped to supply a larger tunnel.

With the goal of balancing the cost benefit of mitigating risks with completing the envisioned project, the project team recommended that the project be constructed as an EPBM tunnel, erecting a single-pass, gasketed segmental lining, with supplemental work at either end of the alignment by microtunneling and pipe jacking. Although other options were pursued, they ended up making the project cost impractical. The recommended methods result in a cost-effective solution, which allows the SFPUC to achieve all the goals of this project.

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