Appendix H: Additional Technical Analysis – Soil Conditions & Geologic Hazards, Tunneling, Fire Life Safety

H.1 Soil Conditions & Geologic Hazards

Regional and Site Geology

The regional topography of the San Francisco Peninsula is characterized by relatively rugged hills formed by Jurassic-to-Cretaceous-age bedrock (Schlocker, 1974) and surrounded by low, flat-lying areas that are underlain by Quaternary sedimentary deposits and Artificial Fill. The sedimentary deposits were influenced by oscillating Late Quaternary sea levels that resulted from the advance and retreat of glaciers worldwide, and consist primarily of clayey and sandy soil units.

Fill of highly variable quality and density was placed over substantial portions of modern estuaries, marshlands, tributaries, and creek beds in an effort to reclaim land (Nichols and Wright, 1971). In the Mission Bay Area, reclamation of the shallow bay areas started with the development in San Francisco in the 1880s and continued through 1920. The majority of the proposed Mission Bay alignment and the 3rd Street Station are located with the reclaimed area.

Bedrock underlying the Quaternary deposits consists of highly deformed and fractured sedimentary rocks of the Franciscan assemblage, including sandstone, shale, siltstone, mudstone, Graywacke sandstone, greenstone, and occasional serpentine (Bonilla, 1964; Schlocker, 1974).

Soil Conditions

The general soil conditions underlying the proposed alignments and stations consist of the following main soil units (from top to bottom):

- Artificial Fill: highly variable, ranging from gravels and sands to silty, sandy, and gravelly clays and silt, including rubbles and debris. The density of the fill ranges widely from loose to very dense and very soft to soft.
- Young Bay Mud: soft to very soft and highly compressible fat clay, with scattered shells and organic material (peat).
- Upper Layered Sediments: medium dense to very dense sand, silty sand and clayey sand.
- Old Bay Mud: medium stiff to hard lean or fat clay, with interbeds of gravels and sands.
- Lower Layered Sediments: dense sands and clays.
- Slope Debris/Ravine Fill: older colluvium consisting of dense gravelly clay and clayey gravel, with fragments of Franciscan Complex.
- Franciscan Complex Bedrock: highly weathered and comprised of dissimilar rock types. Strength and hardness can vary significantly over the short distance.

Seismicity

The proposed alignments and stations are located within the seismically active area of Northern California, along the complex boundary margin between two tectonic plates: the North American Plate and the Pacific Plate. Under the current tectonic regime, the Pacific Plate moves northwestward relative to the North American Plate at a rate of about 2 inches per year (USGS, 2008). Although relative motion between these two plates is predominantly lateral (strike-slip), an increase in convergent motion along the plate boundary within the past few million years has resulted in the formation of mountain ranges and structural valleys of the Coast Ranges province. The San Andreas and Hayward Faults, the dominant tectonic features of the San Francisco Peninsula, are the primary structures within the broad transform boundary that accommodate right lateral motion between the North American and Pacific tectonic plates.

Since 1800, several earthquakes with magnitudes greater than 6.5 have occurred in the region, including the 1868 magnitude 6.8 earthquake on the Hayward Fault, the 1906 magnitude 7.9 San Francisco earthquake on the San Andreas Fault, and the more recent 1989 magnitude 6.9 Loma Prieta earthquake that occurred in the Santa Cruz Mountains. These earthquakes caused significant damage and ground failures in the San Francisco Bay Region. Strong ground shaking along the proposed alignments and stations can be expected as a result of an earthquake on any one of the active regional faults.

The United States Geological Survey (USGS) Working Group on California Earthquake Probabilities (2008) has estimated a 63-percent probability in the next 30 years for one or more magnitude 6.7 or greater earthquakes capable of causing extensive damage and loss of life in the San Francisco Region. The likeliest seismic source of such large earthquakes in Northern California is the Hayward Fault.

Seismic and soil engineering parameters used in preliminary engineering have been estimated from project experience in the area only and are listed at the end of this section.

Groundwater is typically encountered at shallow depths (5 to 10 feet below existing ground surface).

Fault Crossing

The proposed alignments and stations are not located within any published Alquist-Priolo (AP) Earthquake Fault Zones. Therefore, the hazard for fault surface rupture at the project area is low.

Liquefaction

According to the published Seismic Hazard Zone Map for the City and County of San Francisco, the majority of the proposed alignments and stations are mapped within the areas susceptible to liquefaction (Figure 1: Seisminc Hazard Zone Map, Source - CGS, 2000). Liquefaction will likely occur within the loose to medium dense Artificial Fill and Upper Layered Sediment.

Figure 1: Seisminc Hazard Zone Map, Source - CGS, 2000

Dynamic Compaction/Settlements

Seismic-induced ground compaction or settlement is caused by the rearrangement of soil particles following dissipation of pore water pressure during an earthquake. Soils experiencing liquefaction tend to produce greater compaction and settlements. Excessive ground compaction may lead to large differential and/or total settlements and cause damage to facilities and tunnels. Dynamic settlement can range from 1 to 4 percent of the liquefied layer thickness, depending on initial density of the soil and ground shaking intensity.

Lateral Spreading

Lateral spreading typically occurs when the soils underlying an earth slope or near a free-face liquefy during an earthquake. It can occur on gently sloped ground and extend large distances from the slope's open face.

For the proposed alignments and stations, the risk of lateral spreading is highest in the Mission Bay area. The amounts of movement and resulting kinematic forces depend on whether liquefaction extends to the deeper Upper Layered Sediment or is confined only within the Artificial Fill. If liquefaction extends to the Upper Layered Sediment, the risk would be high due to lateral movements of large soil mass above the layer.

Available data and past experiences in the project area indicates that liquefaction is likely localized and inconsistent within the Upper Layered Sediment. Therefore, the overall risk of lateral spreading in Mission Bay area is judged to be low, and it will be confined to only the lateral movements of the Artificial Fill. Note that some sites near the Mission Creek Channel have been identified as having the potential for lateral spreading. The potential for liquefaction and lateral spreading should be evaluated in detail using the station- and alignment-specific soil data that will be collected during subsequent design phases.

Increased Soil Lateral Pressures

When soil liquefies, it behaves as a heavy liquid and induces larger soil lateral pressure to station's walls and tunnels. The increased soil lateral pressure is estimated using liquefied soil unit weight. Even when a soil does not liquefy, lateral earth pressures will increase due mainly to inertia earthquake forces.

The seismic-induced soil pressures will be determined for the tunnels and stations during subsequent design phases.

Loss of Bearing Capacity

Loss of soil bearing capacity results mainly from significant reduction in soil effective stresses during an earthquake. In the case of liquefaction, soil effective stresses drop to almost zero, and soil strength reaches its residual value (soil residual strength). When soil strength is not sufficient to maintain stability, large deformation occurs, leading to foundation failure and excessive soil settlements and lateral movements.

The potential for bearing capacity loss or reduction will be evaluated during subsequent design phases.

Buoyancy

As soil liquefies, it causes an increase in buoyancy pressure on buried structures or parts of facilities located below the ground, similar to increased soil lateral pressure. The buoyancy forces are estimated using liquefied soil unit weight.

The buoyancy forces for structures and facilities located below groundwater will be evaluated during subsequent design phases.

Long-term Consolidation Settlements

Most of the consolidation settlements within the Young Bay Mud under existing fills has occurred since reclamation. However, some residual settlements from the deeper and thicker Young Bay Mud layer (> 60 feet thick) are still occurring at present (Simpson, 2006). These long-term settlements will induce down-drag forces on structural elements located above and within the Young Bay Mud, and will be evaluated during subsequent design phases.

Impact of ground conditions on structures

In order to provide an initial indication of the suitability of the structural forms adopted for the ground conditions, some preliminary analyses of the structures were undertaken.

Tunnels

The twin bore tunnels and cross passages have a history of construction in the Bay Area, and more particularly in these ground types. Therefore, these structures were not specifically analyzed.

The larger bore tunnel was analyzed with static and seismic loads using the seismic parameters provided in Appendix B, and a 2' thick segmental tunnel lining. Analysis employed a probabilistic site hazard assessment, and analyzed the tunnel lining itself using closed form solutions. Past experience is that such analyses tend to yield conservative results.

Applying the above mentioned seismic parameters, the combinations of bending moment and thrust were within the capacity of the section with reasonable reinforcement levels.

Maximum predicted diametric deformations are 6” inches. While considerable, such deflections can be accommodated into the design of internal structures.

Stations

The station structures have been checked for static and seismic loads using the seismic parameters provided in Appendix B. At this stage a simple frame analysis subject to static ground loads (horizontal and vertical) and seismic loads only has been carried out. The member thicknesses are reasonable for the loads, without requiring excessive reinforcement. Further analysis at later design stages could result in small increases in thickness should the design inputs vary from those assumed, but the design concept is structurally viable.

Seismic Sources

At the latitude of the project area, the fault system that accommodates the plate movements is comprised of several major faults, which include the San Andreas Fault, the Hayward–Rodgers Creek Fault system and the Calaveras Fault. In addition, many other named and unnamed faults within the region accommodate relative motion of the plates.

The nearest active faults that can generate significant ground shaking along the proposed alignments and stations include the San Andreas Fault, the Hayward-Rodgers Creek Fault system, the San Gregorio Fault and the Calaveras Fault System. The estimated earthquake maximum magnitudes and closest distances to the proposed alignments and stations are listed in Table B-1.

Table B1. Significant Seismic Sources in the Vicinity of Project Area

Fault Name	**Estimated Maximum Magnitude**[a]	**Distance to Alignments (kilometer)**[b]		**Distance to 3rd Street Station (kilometer)**[b]	**Distance to 22nd Street Station (kilometer)**[b]
		North End	South End		
N. San Andreas	7.9	14.5	12.4	14	12.7
Hayward – Rodgers Creek	6.9	15.7	17.9	16.3	17.4
Calaveras	6.9	31.8	32.7	31.4	32.5
San Gregorio	7.5	19.3	18.6	19.4	18.7

Note:
[a] Maximum Magnitude based on CGS fault parameters as updated in 2002 (Cao et al., 2003).
[b] Approximate closest distance to fault’s trace.

Seismic Parameters

The seismic parameters for horizontal ground motion were determined from the USGS website based on the ASCE 7-10 Standards (ASCE, 2010). The following short-period (at 0.2 seconds) spectral acceleration (S_s) and long-period (at 1 second) spectral acceleration (S_1) are listed for a location on the China Basin between the proposed 3rd Street Station and 4th Street and Townsend Station (Latitude = 37.773° and Longitude = -122.395°):

- S_s = 1.50 grams
- S_1 = 0.60 gram

These seismic parameters are for the Maximum Considered Earthquake (MCE_R) and Risk Category IV (Essential Facilities). The MCE_R spectral accelerations have been adjusted to a risk-targeted value of 1-percent probability of structure collapse in 50 years, as defined in ASCE 7-10 Standards.

The above seismic parameters are applicable for a reference site condition (Site Class B), defined as rock having an average shear-wave velocity between 2,500 to 5,000 feet/second in the top 100 feet (30 meters), per Table 20.3-1 of ASCE 7-10. These parameters would need to be adjusted based on the soil conditions encountered at a specific location along the alignments and stations, including liquefied soils, if any, for seismic loading cases.

Soil Parameters

The table below summarizes the soil engineering parameters that can be used for the preliminary design of the tunnels and stations. These parameters were developed based on the information collected from previous relevant geotechnical studies and investigations. They should be updated using station- and alignment-specific soil data that will be collected during subsequent design phases.

Summary of Soil Engineering Parameters for Preliminary Design

	Total Unit Weight, pcf	**Compressibility Index, C_c**	**Undrained S_u**	**Effective Strength Parameters**
Artificial Fill	120	-	-	$c' = 0$, $\phi' = 30^o$
Young Bay Mud	100	0.30 – 0.35	$S_u/\sigma_v' = 0.30$, min = 300 psf	-
Upper Layered Sediments	125	-	-	$c' = 0$, $\phi' = 34^o$
Old Bay Mud	125		S_u = 1,500 to 3,000 psf	-
Lower Layered Sediments	130	-	-	$c' = 0$, $\phi' = 36^o$
Slope Debris	130	-	-	$c' = 0$, $\phi' = 36^o$
Franciscan Complex Bedrock	135	-	S_u = 5,000 psf	-

ϕ =
c =
pcf = pounds per cubic feet
psf = pounds per square feet
S_u = shear strength

Groundwater is typically encountered at shallow depths (5 to 10 feet below existing ground surface).

References

ASCE, 2010	Cao et al. 2003
Bonilla, 1964	California Geological Survey (CGS). 2000.
CGS, 2000	Nichols and Wright, 1971
Schlocker, 1974	Simpson, 2006

United States Geological Survey (USGS) Working Group on California Earthquake Probabilities (WGCEP) 2008

United States Geological Survey (USGS). 2008

H.2 Tunneling

The tunnels as proposed under the rail alignment options (e.g., Pennsylvania Avenue alignment and Mission Bay alignment) would be excavated by a pressurized face Tunnel Boring Machine (TBM). A pressurized face TBM is a large machine that excavates the ground by means of a large circular cutterhead, while maintaining pressure on the ground in front of the cutterhead to minimize settlement of the ground due to tunneling. The tunnel area is protected by a circular steel shield that supports the ground above and also prevents water getting into the tunnel. At the rear of the shield a precast concrete segmental lining is erected that provides the finished, permanent, tunnel lining. This segmental lining comprises a series of segments of approximately rectangular shape that fit together to form a complete ring. The segments are provided with special compressible rubber gaskets around their perimeter that compress against the gaskets of adjacent segments to provide a watertight seal.

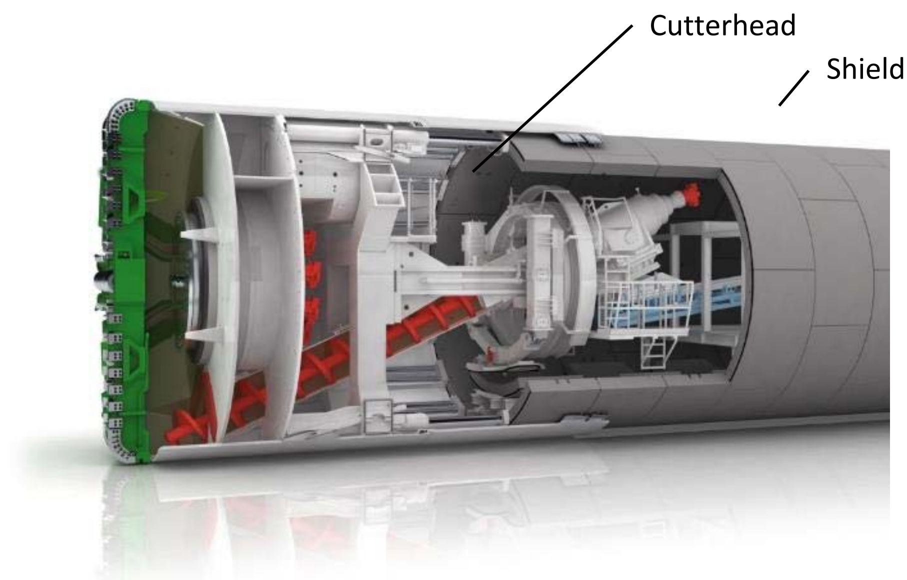

Figure 2: Tunnel Boring Machine (Picture © Copyright Herrenknecht)

The TBM would be equipped to deal with the variety of ground that appears along the alignment that varies from intact sandstone rock to soft bay mud and artificial fill. Cross passages are excavated from within the tunnel using SEM.

It is expected that the TBM drives would commence from the south portal and drive north, through the 22nd Street Station excavation and on to the interface with the cut and cover tunnels. However, it would be possible to drive in the other direction if required. Depending on schedule constraints one or two TBMs may be required.

It may be possible to decrease the length of the deep cut and cover structures by extending the TBM drives to the north. However, this has not been studied at this stage.

H.3 Fire Life Safety

General

As part of the San Francisco Railyard Alternatives and I-280 Boulevard Feasibility Study, a tunnel ventilation and safety review has been conducted to determine possible ventilation strategies. The ventilation and safety study has focused on options that provide the highest level of safety while reducing cost, minimizing surface impacts, and expediting schedule.

There are two basic alignment options that are being studied for Fire Life Safety (Pennsylvania Avenue alignment and Mission Bay alignment). In addition, there are three configuration options of the Mission Bay alignment option that are studied independently for ventilation purposes, so there is a total of four independent alternatives for ventilation.

Background

This study is considering four distinct options for ventilation and egress analysis:

Pennsylvania Avenue - Approved DTX Alignment with 4th/Townsend Street Station connected to a crossover to the south and a cut and cover tunnel that runs to 7th Street where it transitions to a twin bore, single track tunnel that runs down Pennsylvania Avenue to a station at 22nd Street. The dual bore tunnel runs past the station about 1,500 feet where it reaches a portal at the surface.

Mission Bay (configuration 1) - A new alignment composed of a triple track mined tunnel from SFTC to a station located on 3rd Street, which is about 1,000 feet long. The tunnel would then transition to twin bore, single track and continue to a station at 22nd Street.

Mission Bay, Extended Platforms (configuration 2) - This alternative has the same configuration as configuration 1: Mission Bay, except the station on 3rd Street is about 2,000 feet long in order to provide two trains platform space in each direction (double-berthing), for a total of four trains in the station at once.

Mission Bay, Option C (configuration 3) - The same alignment as Mission Bay (configuration 1), except the tunnels and stations are replaced by a single large bore with four tracks. There will be two decks, each with two tracks. At the 3rd Street station, this option provides two vertical egress elements for passengers, one on each end of the station platform.

Pennsylvania Avenue Alignment

Ventilation and Egress Plan

This option includes the approved DTX alignment through the 4th/Townsend Station. Since the train operations and scheduling has not been presented to the RAB study team to date, and the report entitled *Task 5.9 - RLPA Fire/Life/Safety Report for the Downtown Extension Project, Parsons Transportation, November 30, 2007* indicates that two ventilation shafts are required, it is assumed that the ventilation concept between SFTC and 4th/Townsend is the most efficient ventilation method possible. Therefore, there are two ventilation plants at SFTC, two ventilation plants in the tunnels between SFTC and 4th/Townsend Station, and two ventilation plants at 4th/Townsend Station as shown on Figure 3: Pennsylvania Avenue Alignment, Ventilation Plan.

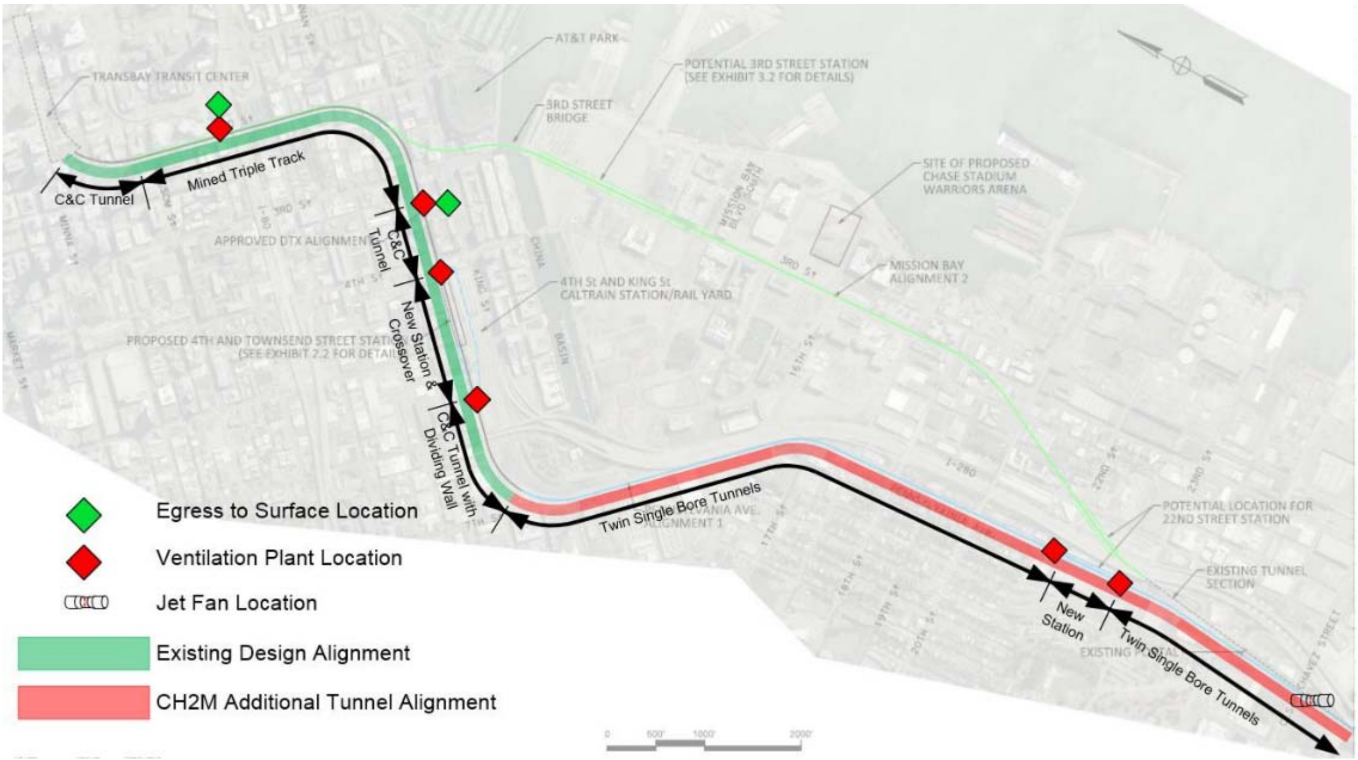

Figure 3: Pennsylvania Avenue Alignment, Ventilation Plan

A ventilation plant should be installed at each end of the station box at the 4th/Townsend Station, so the ventilation plant on the south end of the station should be on the tunnel side of the crossover. A dividing wall is recommended in the cut and cover tunnel at the end of the crossover. The cut and cover tunnel is connected to dual bore single track tunnels. These tunnels will have cross passages spaced at a maximum of 800 feet apart for egress as show on Figure 4: Cross Passage Egress Example. The cross passages take the place of egress shafts to the surface because they allow passengers to reach a point of safety, the non-incident bore. Once the passengers are in the non-incident bore, they may either self-rescue to the nearest station or wait for a rescue train in the non-incident tunnel.

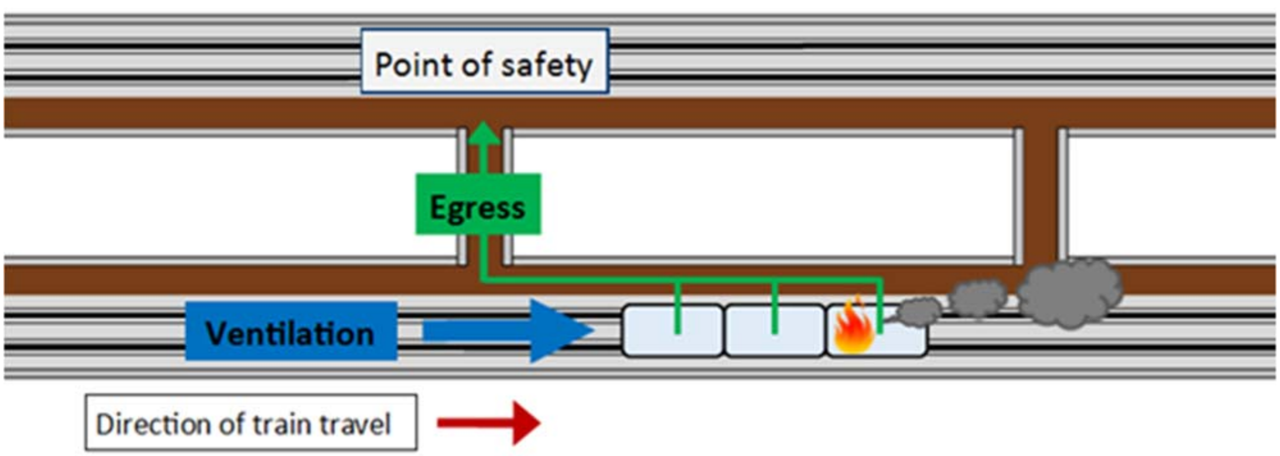

Figure 4: Cross Passage Egress Example

A fan plant is required at each end of the proposed 22nd Street Station, similar to the layout Figure 5: Typical Underground Station with Vent Plant on Both Ends. The fan plants at each end of the stations will supply and exhaust air via dampers to the incident bore. The airflow in the incident bore will be controlled and the smoke will be removed before it reaches the adjacent tunnel ventilation zone.

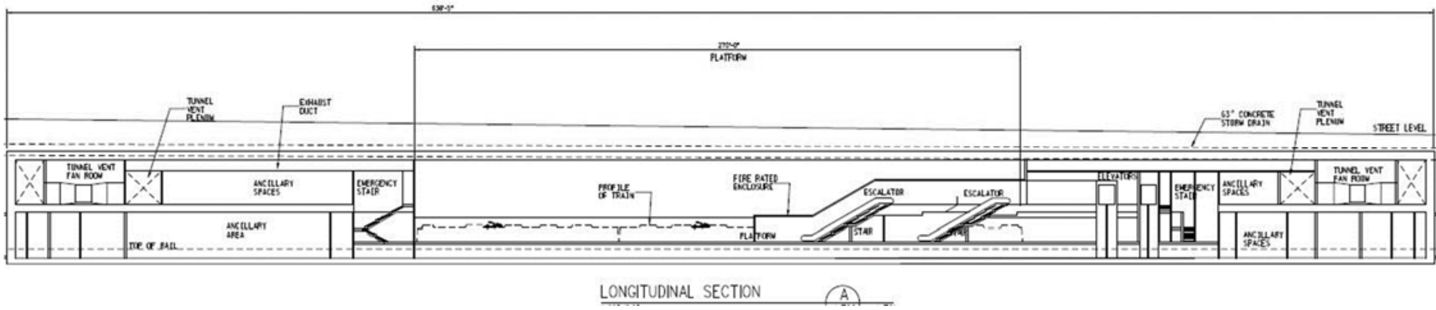

Figure 5: Typical Underground Station with Vent Plant on Both Ends

It is likely that jet fans will be required at the tunnel portal south of 25th Street. Two jet fans are typically used in each tunnel as shown on Figure 6: Example of Jet Fans near a Tunnel Portal, so for a dual bore single track tunnel, there is a total of four fans.

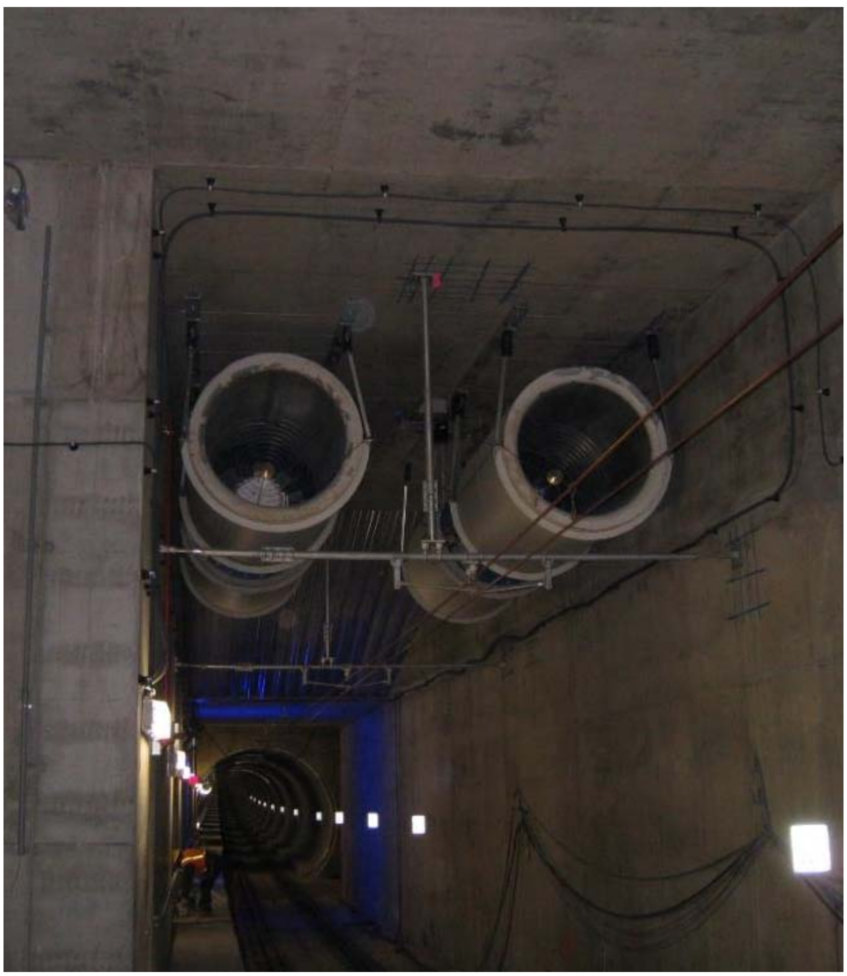

Figure 6: Example of Jet Fans near a Tunnel Portal

Mission Bay Alignment

This alignment includes alternative station options below 3rd Street between the 3rd Street Bridge and China Basin Street. The first station alternative includes a 1,000-foot station for one train on each platform. The second station alternative has a 2,000-foot long station to provide platform space for four trains concurrently (double berthing). The third station alternative has a 1,000-foot long station and a single tunnel large bore with four tracks.

Station Alternative 1 Ventilation and Egress Plan

Although the alignment for this station option is different from the Pennsylvania Avenue Alignment, the ventilation concept is the same for the segment between SFTC and the northern station below 3rd Street just to the south of China Basin and the 3rd Street Bridge. The proposed tunnel between these two stations is mined with a triple track. Since it was identified by others that two ventilation and egress shafts are required between SFTC and 4th/Townsend Station, two ventilation and egress shafts are also proposed for this section as shown on Figure 7: Mission Bay Alignment, Station Alternative 1 Ventilation Plan.

Figure 7: Mission Bay Alignment, Station Alternative 1 Ventilation Plan

A ventilation plant is required at each end of Mission Bay underground station. For greater operational flexibility, the ventilation shaft on the south end should be located at the tunnel end of the crossover. This will allow for a train to be in each tunnel bore to the south.

South of the Mission Bay underground station, the proposed alignment continues underground in twin bored pre-cast concrete segmentally lined tunnels to the southern station as described in Section 3.1.3 **Error! Reference source not found.**. The tunnels will have cross passages spaced at a maximum of 800 feet apart. The tunnels will be ventilated from the stations at both ends of each platform location (e.g., Mission Bay underground station to the North and 22nd Street Station to the south). The fan plants at each end of the stations will supply and exhaust air via dampers to the incident bore. The airflow in the incident bore will be controlled and the smoke will be removed before it reaches the adjacent tunnel ventilation zone.

Based upon the length of tunnel and alignment between the 22nd Street Station and the portal at to the south, mechanical ventilation near the portal will be required. This is most often achieved with the use of jet fans mounted in the tunnel ceiling as shown in Figure 6: Example of Jet Fans near a Tunnel Portal.

Station Alternative 2 Ventilation and Egress Plan

This alternative has the same ventilation configuration as Station Alternative 1, except the 3rd Street Station is much larger, and therefore it is recommended that additional means of emergency mechanical ventilation is provided near the center of the proposed elongated station in order to allow smoke control without potentially endangering passengers and staff on any non-incident trains. See Figure 8: Mission Bay Alignment, Station Alternative 2 Ventilation Plan.

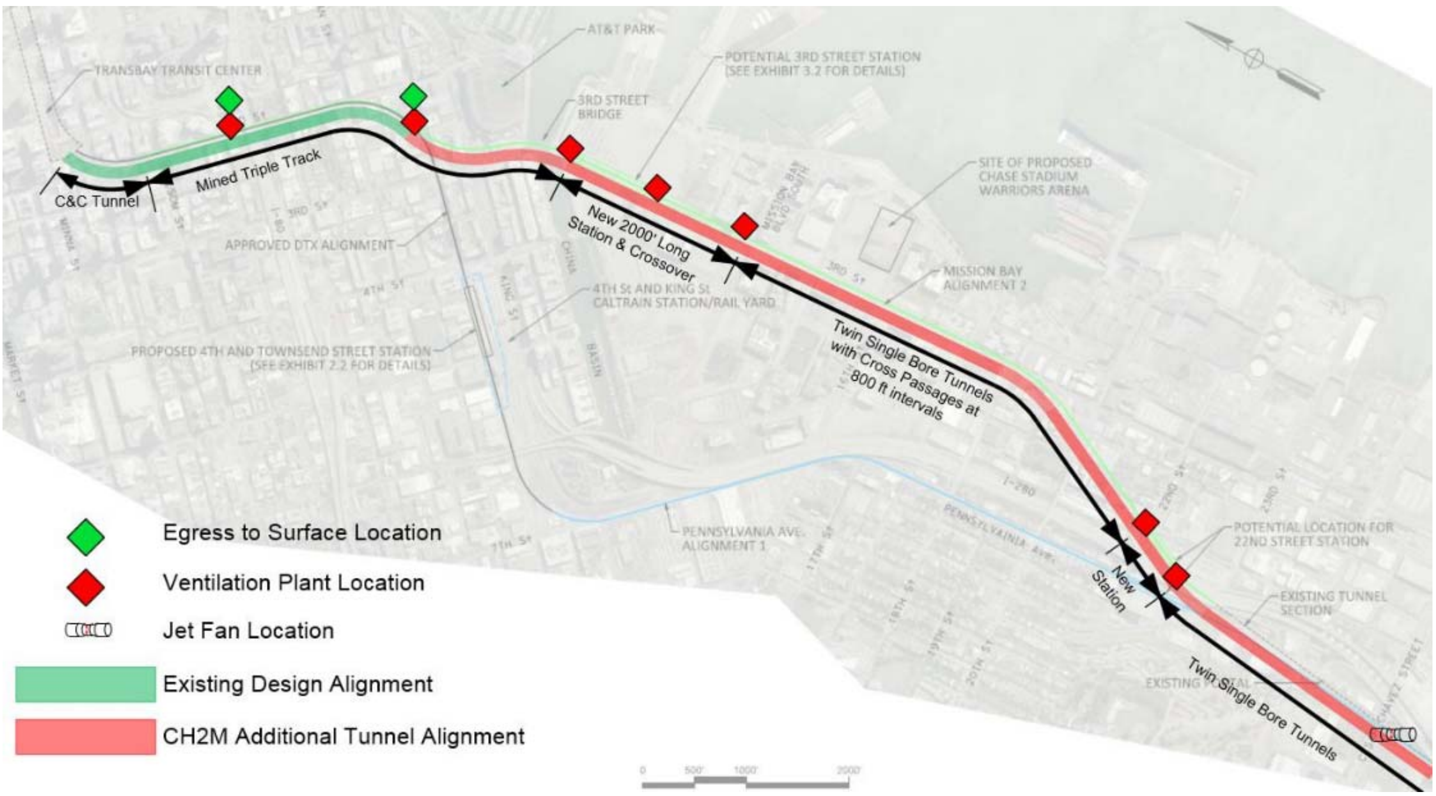

Figure 8: Mission Bay Alignment, Station Alternative 2 Ventilation Plan

Station Alternative 3 Ventilation and Egress Plan

Station Alternative 3 has a single bore tunnel with four tracks running from SFTC to the portal near 22nd Street. The single bore is divided into two levels each with two tracks. Passengers can egress between levels at 'cross passages' spaced at a maximum of 800-foot intervals as shown on Figure 9: Single-bore egress routes. The 'cross passages' are vertical egress elements that allow passengers to access the upper and lower walkway of one side of the tunnel. Once the passengers have reached the non-incident level, they will either walk to the neither station or wait for a rescue train. When the passengers have reached a station, they will use the vertical egress elements such as stairs, escalators, and elevators to exit the station and reach the surface.

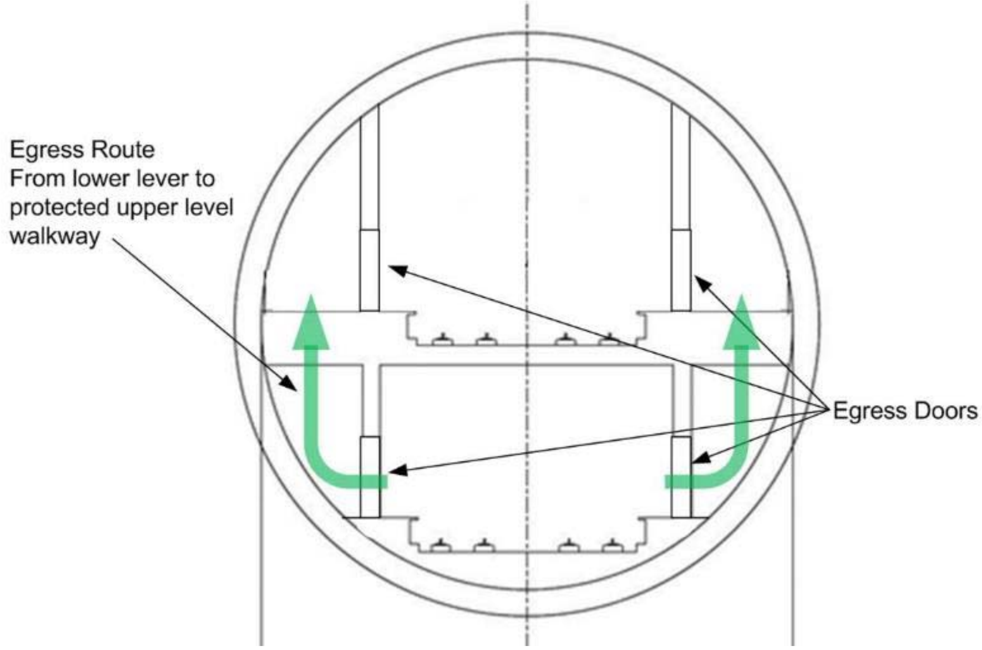

Figure 9: Single-bore egress routes

As stated before, ventilation will be accomplished via a longitudinal approach with fan plants at each end of the station platform. The fan plants at each end of the stations will supply and exhaust air to the upper and lower track levels via dampers. Airflow will be controlled and smoke will be removed on the incident level. The non-incident level will be used as the point of safety for passengers egressing from an emergency scenario.

Based upon the length of tunnel and alignment between the proposed 22nd Street Station and the portal to the south, mechanical ventilation near the portal will be required. This is most often achieved with the use of jet fans mounted in the tunnel ceiling as shown in Figure 6: Example of Jet Fans near a Tunnel Portal. The location of the suggested equipment is shown on Figure 10: Mission Bay Alignment, Alternative 3 Ventilation Plan.

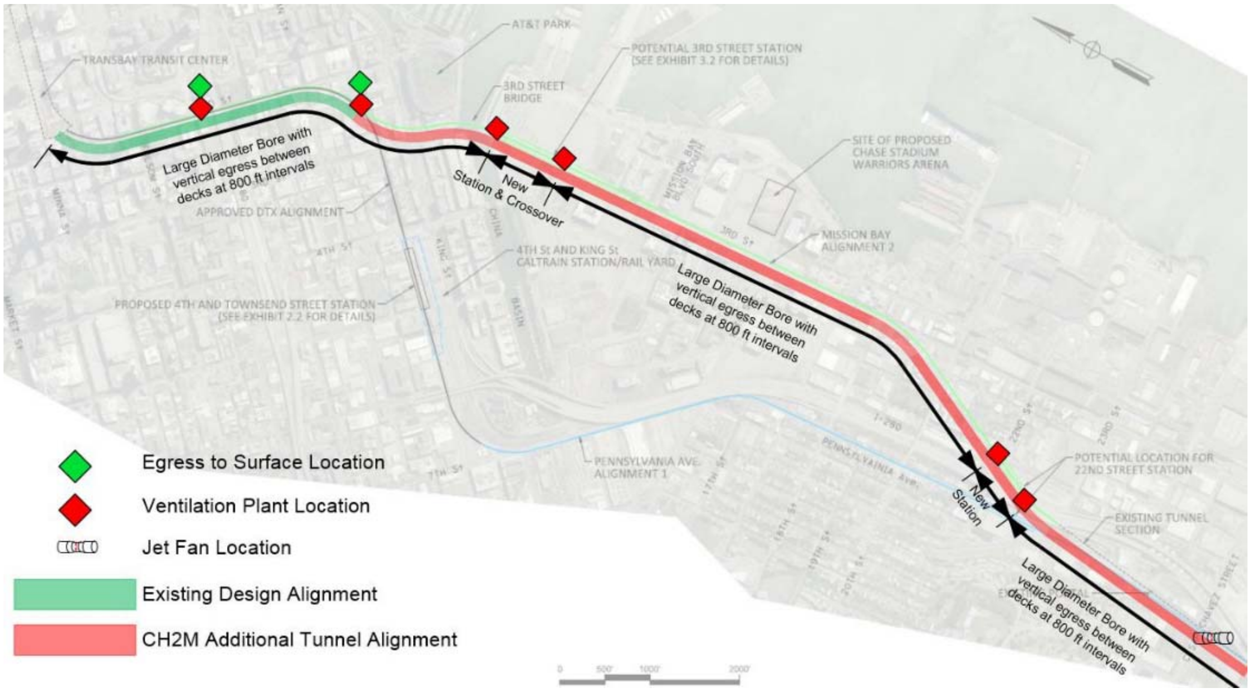

Figure 10: Mission Bay Alignment, Alternative 3 Ventilation Plan