Appendix D

CONSTRUCTABILITY ANALYSIS AND COST ESTIMATES (HNTB CONSULTANTS)

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CONSTRUCTABILITY ANALYSIS AND COST ESTIMATES (HNTB CONSULTANTS)

SFMTA Contract No. 173:
Task Order 173-6, SFMTA T-Third LRT/Central Subway Phase 3

TASK 4:
CONSTRUCTABILITY ANALYSIS

October 2014

PREPARED FOR: SFMTA Municipal Transportation Agency

PREPARED BY: HNTB

FINAL

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Executive Summary

Since the SFMTA initiated a study to understand opportunities for optimization of existing Muni rail-based transit service and a potential for future rail transit expansion to serve northern San Francisco neighborhoods, including North Beach and Fishermen's Wharf, it became necessary to understand constructability issues related to the study alignments and potentially eliminate alternatives deemed non-constructible, non-practical or with major constructability or feasibility flaws. The constructability assessment will be used by SFMTA as an input to a broader analysis of varying expansion concepts to the existing Muni transportation corridor, primarily to the north and north-east.

The alignment study area is limited to a zone in the north-east San Francisco bordered by Beach Street to the North, Powell Street to the East, and Columbus Avenue, intersecting both streets and straddling the area in northwest-southeast direction. Three potential station locations are being considered: North Beach at Washington Square area, Kirkland Yard and Conrad Square Stations. Multiple potential alternatives initially identified by SFMTA planning efforts were assessed considering:

- Tunneling methodology through historical records and current experiences primarily from the projects in the area
- Strategic value of Pagoda Palace site and the existing shaft for future northern transit expansion considering both their temporary and permanent uses (during construction and in service, respectively)
- Feasibility of potential surface and subsurface alignment alternatives
- Feasible station locations at the areas of North Beach, Kirkland Yard and Conrad Square

Special attention was paid to identification of potential underground guideways along the study corridor in terms of finding practical and constructible solutions that would minimize temporary and permanent impacts (utilities, noise, vibration, visual, air quality, traffic congestion, etc.). Such impacts were not quantified since the study was broad and at a pre-conceptual level; however, non-practical or non-feasible alternatives to the corridor extension were labeled along with those that may have a potential to be further developed as part of a future more detailed study. The alternatives development in plan and profile and their subsequent evaluation for constructability aspects included the following factors:

- Location of the existing connecting tunnels at the Washington Square area
- Maximum track grades
- Topography and geologic profiles along the study route
- Major underground obstacles including existing tunnels and piles (supporting existing or abandoned utilities)
- Major surface obstacles (including existing cable car infrastructure)
- Major constructability risks with emphasis on subsurface risks
- Operational limitations of tunnel boring machine including minimum feasible horizontal radius (500 feet) and vertical grade (3% to 4%)

The alternatives' general constructability assessment is presented in a Constructability Analysis Summary Matrix in Appendix A. The information presented in Appendix A is pre-conceptual and based on preliminary review of limited subsurface information provided through available record and historical documentation relevant to the area of the study. It should be noted that additional studies are required to further examine existing record information. Also, detailed subsurface investigations are needed to confirm and further develop the constructability issues of each alignment alternative. Conceptual general order of magnitude costs for the feasible alternatives are based on FTA guidelines and provided in Appendix D.

4.1 Geotechnical Assessment

The information presented herein is pre-conceptual and based primarily on a review of the subsurface information provided within available record and historical documentation relevant to the area of the study. Primary source of information are Geotechnical Baseline Reports (GBR's) for tunnels and station contracts prepared for the recent Phase 2 Central Subway project, record drawings and reports for N1 and N2 North Shore Outfalls Consolidation projects of City and County of San Francisco Wastewater Program, United States Geological Survey (USGS) bedrock surface map, State of California Seismic Hazard map (liquefaction), and United States Coast Survey of City of San Francisco map of 1853. The available information was extrapolated for the purpose of this study and general assumptions made to provide basis for potentially feasible alignments as extension of the tunnels of Phase 2 Central Subway program.

The alignment study area is limited to a zone in the north-east San Francisco bordered by Beach Street to the North, Powell Street to the East, and Columbus Avenue intersecting both streets and straddling the area in northwest-southeast direction. Three potential station locations are being considered: North Beach at Washington Square area, Kirkland Yard and Conrad Square Stations (Figure 4.1.1).

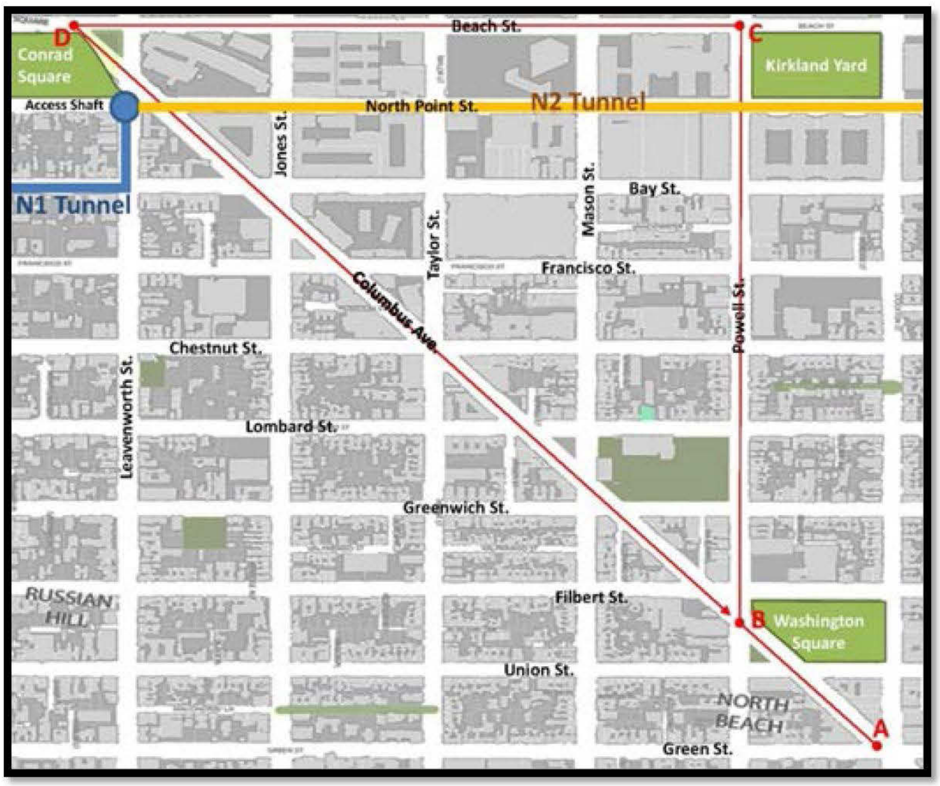


Figure 4.1.1: Study Alignment

4.1.1 Geologic Setting

The City of San Francisco is located in the central Coast Ranges of the greater Coast Ranges Geomorphic Province of California. The Project area lies east of the San Andreas Fault underlain by rocks of the Franciscan Complex, which are strongly deformed (faulted, fractured, and folded) typically. In the Coast Ranges, Franciscan bedrock generally comprises three predominant rock types including sandstone (usually referred to as greywacke), shale, and mélange. The sandstones and shales are highly variable in their degrees of fracturing, strength, hardness, and weathering. The mélange unit is characterized by a chaotic, heterogeneous mixture of small to large (i.e., up to miles in dimension) masses of different rock types, including sandstone (greywacke), shale, claystone, greenstone, chert, and various metamorphic rocks, surrounded by a matrix of pervasively crushed rock material. The geology of the San Francisco North Quadrangle is characterized by recent (historical) artificial fills and Quaternary sediments (i.e., deposits that are up to 1.6 million years old) overlying bedrock of the Franciscan Complex. Bedrock is exposed locally in the isolated hills that occur throughout the City and along parts of the coastline. The surficial quaternary deposits flanking the bedrock outcrops comprise colluvial, aeolian (dune), and near shore (beach) deposits.

a. Soil and Rock Units

Based on the geotechnical information reviewed for this study, potential subsurface alignments would encounter eight subsurface units. These units include seven units of Quaternary surficial deposits and one unit of Jurassic and Cretaceous bedrock. Not all may be present within the investigated alignments.

- **Artificial Fill (Qaf):** Generally consists of very loose to medium dense Sand (SP), Silty Sand (SM), and medium stiff Sandy Clay (CL); locally with miscellaneous debris (bricks, wood, metal, concrete, glass, etc.). Much of this deposit originates from the underlying Dune Sand (Qd).
- **Dune Sand (Qd):** Generally consists of loose to medium dense, poorly graded fine to medium-grained aeolian sand (SP).
- **Bay Mud/Marsh Deposits (Qm):** Generally consists of very soft to soft, dark greenish gray to black organic-rich Clay and Sandy Clay (CL to CH).
- **Undifferentiated Deposits (Qu):** Generally consists of medium stiff to stiff brown Sandy Clay (CL) and medium dense to dense brown Clayey Sand (SC). The unit may comprise colluvium, alluvium, or Colma Formation. The term “undifferentiated” is used because some of the soils encountered during previous investigations do not have distinguishing characteristics such that they can be classified into the surrounding soil units. Therefore, these soils have been classified into a separate unit.
- **Colma Formation (Qc):** The Colma Formation is composed of a complex, interbedded sequence of estuarine and near shore sediments. It generally consists of well-bedded dense to very dense Sand (SP or SM) with interbedded stiff to very stiff Clay and Sandy Clay (CL).
- **Undifferentiated Old Bay Deposits (Qo):** Generally consists of interbedded dense to very dense Sand (SP) and Silty Sand (SM) and stiff to very stiff Clay (CL). This unit also contains Older Bay Clay and Mud, which typically are stiff Clays and Silts that are gray to greenish gray in color
- **Colluvium (Qcol):** Generally consists of very stiff brown to gray Sandy Clay (CL) to Clayey Gravel (GC); appears to be decomposed bedrock/ residual soil.
- **Franciscan Complex Bedrock (KJf):** This unit is highly variable in composition, hardness, and strength, ranging from soft to hard and from friable to moderately strong. Observed fracture spacing varies from very close (<0.1 ft) to close (0.1 to 0.3 ft) and, in general, the severity of weathering decreased slightly with depth. This unit primarily includes sandstone, meta-sandstone, sandstone breccia, shale, shale breccia, siltstone, and mélange; and some claystone and mudstone. It can also contain Serpentine, Chert and Greenstone.

An approximate geological profile along the study alignment is presented in Figure 4.1.2 below. It should be noted that not all eight soil and rock units have been identified in the presented geological profile due to a general lack of specific geological and geotechnical data in the study area, primarily along Columbus Avenue and Powell Street.

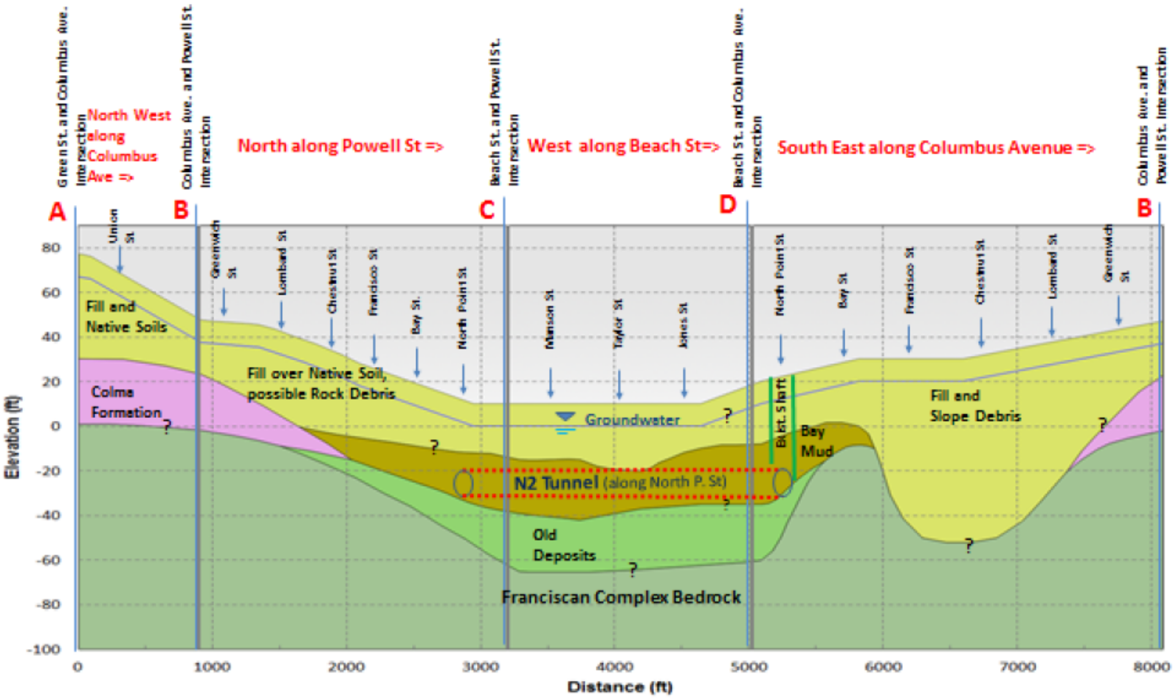


Figure 4.1.2: 'Unwrapped' Geological profile along Powell-Beach-Columbus Study Alignment (refer to Figure 4.1.1 for plan view)

b. Groundwater Conditions

The primary subsurface water-bearing materials of the study area occur in the Artificial Fill close to the Bay, Dune Sands and the Colma Formation sediments, which overlie the Undifferentiated Old Bay Deposits. Drainage is controlled generally by bedrock topography and the three-dimensional orientation of the overlying sediments. The regional groundwater flow generally follows the bedrock surface and is directed towards the northeast, i.e., towards the San Francisco Bay; it may encounter presence of 'buried underground rivers', especially considering potential for the groundwater run-off from Telegraph Hill . Based on the existing information, the groundwater levels could be within 10 feet of the ground surface in the vicinity of the Central Subway receiving pit and will likely be relatively shallow for the entire area. For the purpose of this study the groundwater levels are shown 10-15 feet below street surface; this preliminary assessment requires further study.

c. Seismicity and Related Hazards

The San Francisco Bay Region is one of the most seismically active regions in the world. The relatively high rates of seismicity in the region are associated with the San Andreas Fault system, which comprises the region's numerous active, major strike-slip faults, including (from east to west) the Calaveras, Hayward, San Andreas, and San Gregorio faults. The closest of these are the San Andreas and Hayward faults, located about 8 miles southwest and 12 miles northeast, respectively of the study area. The San Andreas Fault has been the source of numerous moderate and large magnitude historical earthquakes, including the great 1906 M7.8 earthquake, which ruptured the ground surface for over 290 miles. Seismic hazard of fault offset and lateral spreading are not anticipated in the study area.

In terms of ground motions, peak ground acceleration in the bedrock is estimated at approximately 0.5 g for the downtown San Francisco area for a M8 earthquake on the San Andreas Fault. Based on the Central Subway studies, a M7.9 earthquake on the San Andreas Fault near San Francisco is expected to produce one-second period spectral acceleration in the 0.7g – 1.6g range.

Liquefaction is a phenomenon in which earthquake shaking reduces the strength and stiffness of a soil resulting in a decrease in ground mass volume and reduction of the ground ability to support the loads imposed by the structure. Liquefaction normally occurs in saturated, loose sand and silts. The USGS Bay Area liquefaction map in Earthquake Hazard Program (USGS, 2009) identifies a good part of the study area as having a "high liquefaction hazard level". Liquefaction may also result in ground settlement or subsidence in addition to soil strength loss. (Figure 4.1.3)

Surface structures within the study area, considering the above mentioned seismic risks, would generally be subjected to the ground excitations and may experience amplification of the shaking motions during an earthquake event depending on their own vibratory characteristics, which could be further exacerbated by the area's liquefaction potential. In case of any bridge or overpass structure, if the predominant vibratory frequency of these structures is similar to the natural frequency of the ground motions, the structures would be exposed to excitations by resonant effects. In contrast, underground structures and tunnels are constrained by the ground that surrounds them and it is highly unlikely that they could move to any significant extent independently of the ground that surrounds them or be exposed to vibration amplification. In comparison to surface structures, generally unsupported above their foundations, the underground structures and tunnels exhibit significantly greater redundancy when ground support is considered. Traditionally, they also have better earthquake performance history than their aboveground counterparts.

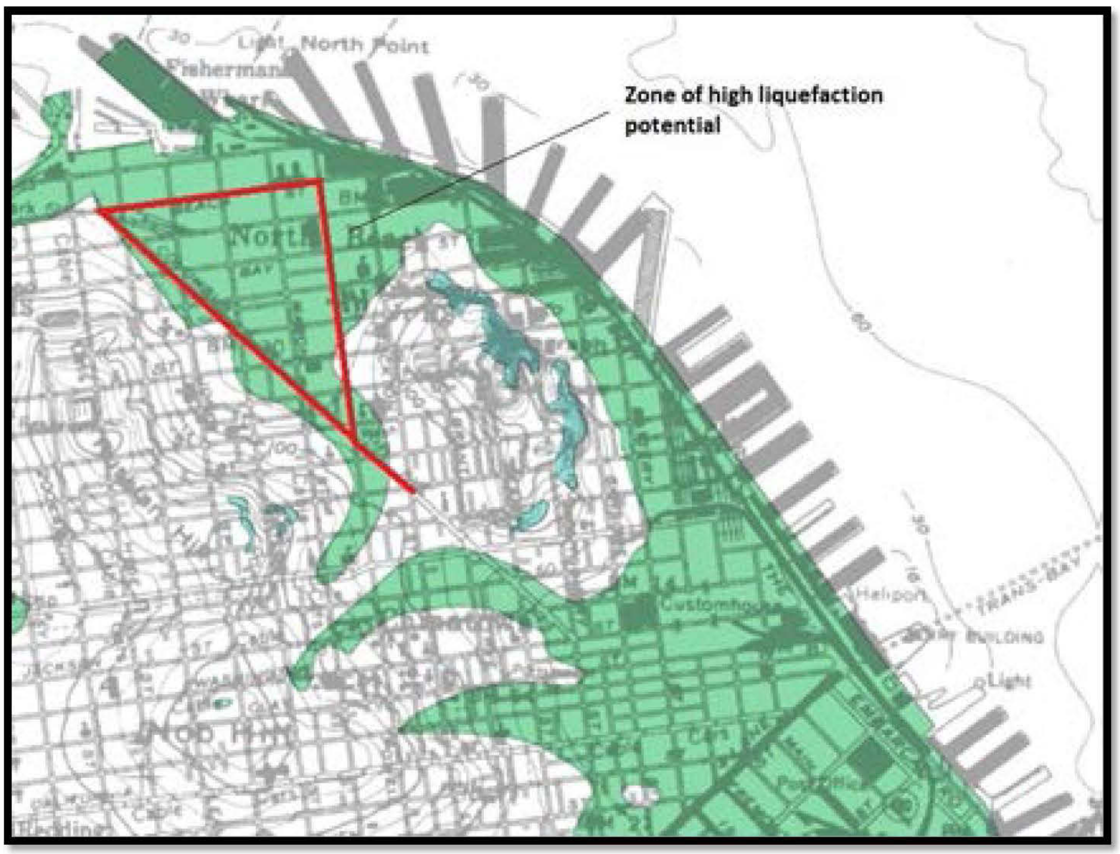


Figure 4.1.3: Zones of High Liquefaction Potential in relation to Study Alignment

4.1.2 Conceptual Matrix of Subsurface Risks:

Table 4.1.1: Subsurface Risk Matrix
(5 = Very High, 4 = High, 3 = Moderate, 2 = Low, 1 = Very Low, 0 = None)

RISKS	PROBABILITY	COST IMPACT	SCHEDULE IMPACT	CONSEQUENCES	MITIGATION STRATEGY
Seismic hazard during service life	4	4	3	Tunnels and stations damaged due to high level of seismic ground motion causing human and economic losses and operational and service delays.	Design tunnels and stations for high level of seismic ground motion. Consider seismic loads during design of the final concrete liners for the tunnels and stations.
Encountering sewer tunnels (N2 Tunnel) as a major existing underground utility that resides beneath North Point Street. See Appendix C.	5	5	5	Impact on tunnel and station profiles causing deep positioning of underground structures beneath street level.	Provide tunnel and station configuration that considers sufficient distance between the existing tunnel (N2 tunnel) and the new proposed structures. Consider ground improvement between the existing tunnel (N2 tunnel) and the new underground structures.
Mixed face excavation* of tunnels along Columbus Ave. and Powell St. and soft ground tunneling along Beach Street. *This occurs where the alignment passes or transitions through soil material and the Franciscan Complex Bedrock.	5	3	3	Potential for ground loss due to tunneling and uncontrolled surface settlements affecting streets, buildings and utilities.	Select an appropriate methodology of excavation such as use of closed face or pressurized face (PF) tunnel boring machine (TBM) or sequential excavation method (SEM).
Relatively high groundwater levels	5	3	3	Groundwater entering the excavated openings causing unstable excavation, ground loss, settlements, and human and material damage/ economic loss.	Requires watertight retaining structures for the construction of the stations, the TBM's face pressure control to maintain face stability and avoid ground loss, may require ground improvement during SEM excavation of tunnel (as grouting or ground freezing).
Potentially liquefiable soils (potential issue for both underground and surface stations/tracks)	3	3	3	Structures/utilities damage/collapse due to high ground motion levels / strong earthquakes.	Estimate potential of ground liquefaction impacts on final structures. Provide ground improvement if/where needed. Consider underground structures along the study alignment with better earthquake performance history in liquefiable soils.

RISKS	PROBABILITY	COST IMPACT	SCHEDULE IMPACT	CONSEQUENCES	MITIGATION STRATEGY
Ground settlement due to excavation which could impact existing structures, streets and utilities.	4	3	3	Impacts/damages to existing structures, streets and utilities, causing material damage and operational and service delays.	Use FP TBM, consider ground improvement during excavation of the tunnels by TBM and/or SEM, plan on detailed instrumentation and monitoring program, plan on relocating and/or supporting utilities in place.
Leakage of methane gas and other types of hydrocarbons into the tunnels (Central Subway Tunnels classified as "Potentially Gassy with Special Conditions").	2	3	3	Condition causing explosion (methane) or hazardous conditions in the tunnel.	Consider gas-proofing features of waterproofing membrane, use appropriate gaskets to seal tunnel joints.
Sea level rise during service life Impact along Beach Street and northern ends of Powell Street and Columbus	5	3	3	Flooding of the tunnels and stations.	Considering flood walls or hardening of the portals, stations entrances and openings.
Hazardous Materials within groundwater and excavated soil	3	2	2	Condition causing hazardous conditions	Investigation needed for mitigation purposes
Boulders and rock debris (possibility in soil materials along Columbus Avenue near Russian Hill).	3	3	3	Cost and schedule impacts	Selecting an appropriate type of excavation such as PF TBMs or SEM
Encountering underground utility supports (deep piles) along the alignment. See Appendix C for wooden piles along Taylor Street.	5	4	4	Impact on tunnel and station profiles causing obstructions for tunnel construction.	Obtain record drawings and provide subsurface exploration (test pits). Identify obstructions and remove/design to encounter for their presence.
Insufficient geotechnical information	4	4	5	Impact on tunnel and station construction	Provide additional record data through local geotechnical firms (Langan Treadwell Rollo and/or others); plan for additional geotechnical investigations
Encountering cable car infrastructure for both shallow and deep alignments	5	4	4	Impact on alignment configuration, cost and schedule	Alignment should be positioned to minimize impact on cable car infrastructure and where needed proper measures should be taken for its protection.
Presence of 'buried underground rivers', especially potential run-off from Telegraph Hill	4	4	4	Impact on construction staging, cost and schedule	Proper level of hydrogeological investigation shall be performed to identify presence of the buried underground rivers and their impacts on underground guideways. Design measure shall be implemented to mitigate impacts. Existing T Third Phase 2 Project data on

					the subject should be assessed.
San Francisco Public Utilities Commission (SFPUC) or other public and private agencies' future projects in the area	4	5	4	Impact on the project configuration, schedule and cost	Timely coordination with SFPUC and other public and private companies and stakeholders should be performed for a purpose of timely discovery of any future project in the area that may impact the transit corridor alignment and facilities.

4.1.3 References

1. *Baseline Geotechnical Report, Central Subway, April 2011*
2. *State of California, Seismic Hazard Zones, City and County of San Francisco, Official Map, California Division of Mines and Geology, November 17, 2000*
3. *Bedrock-Surface Map of the San Francisco North Quadrangle, USGS, 1961*
4. *City of San Francisco and It's Vicinity, US Coast Survey, 1853 (Topographic Map)*
5. *Geologic of the San Francisco Bay Region, USGS and California Geological Survey, 2006*
6. *North Shore Outfalls Consolidation Contract N2 Drawings, City and County of San Francisco Wastewater Program DWG 44101*
7. *Specification No 23, 969: Soil and Rock Data, Contract N-2, North Shore Outfalls Consolidation Project, March 1979*
8. *Central Subway Design Criteria, City and County of San Francisco Municipal Transportation Agency, June 2011*
9. *Muni Metro System Third Street Light Rail Transit Phase-2 Central Subway Final Design Drawings, DWG No. 125XEXGT001, Rev 2, Jan 21, 2011*
10. *Central Subway Geotechnical Data Report, City and County of San Francisco Municipal Transportation Agency, Contract No CS-155.1 Task 03.20, October 5, 2010*
11. *Central Subway Supplemental Geotechnical Investigations, Geotechnical Data Report, City and County of San Francisco Municipal Transportation Agency, Contract No CS-155.2 Task 03.10, November 11, 2010*

4.2 Constructability Evaluation

Since the SFMTA initiated a study to understand opportunities for optimization of existing Muni rail-based transit service including potential for future rail transit expansion, it became necessary to understand constructability issues related to the study alignments and potentially eliminate the alternatives deemed non-constructible, non-practical or with major constructability or feasibility flaws. The study input will be used by SFMTA at a later time for analysis of varying expansion concepts considering different transportation corridors, primarily the North Beach Corridor.

Considering that additional studies are required to examine detailed constructability issues related to potential extension of T-Third Phase 2 tunnels to serve the northern and north-eastern neighborhoods including Fishermen's Wharf, the following could be concluded from initial observations at a broad pre-conceptual level of analysis. The multiple potential alternatives identified required a broad-brush assessment through several categories listed below from a constructability standpoint. While initially assessed per these categories, their general constructability assessment is presented in a summary matrix in Appendix A, for compatibility with similar assessment criteria of different aspects of the study, provided elsewhere in the report.
The broad screening categories for constructability are as follows:

- Tunneling methodology through historical records and current experiences primarily from the projects in the area
- Strategic value of Pagoda Palace site and the existing shaft for future northern transit expansion considering both their temporary and permanent uses (during construction and in service, respectively)
- Feasibility of potential surface and subsurface alignment alternatives
- Feasible station locations at the areas of North Beach, Kirkland Yard and Conrad Square

4.2.1 Historical and Current Tunnel Projects in the Area/Tunneling Considerations

a. Historical projects in the area

Previous tunnel projects have been constructed in the general neighborhood and to the south of the study area within similar geological conditions. Figure 4.2.1 shows the approximate location of these projects.

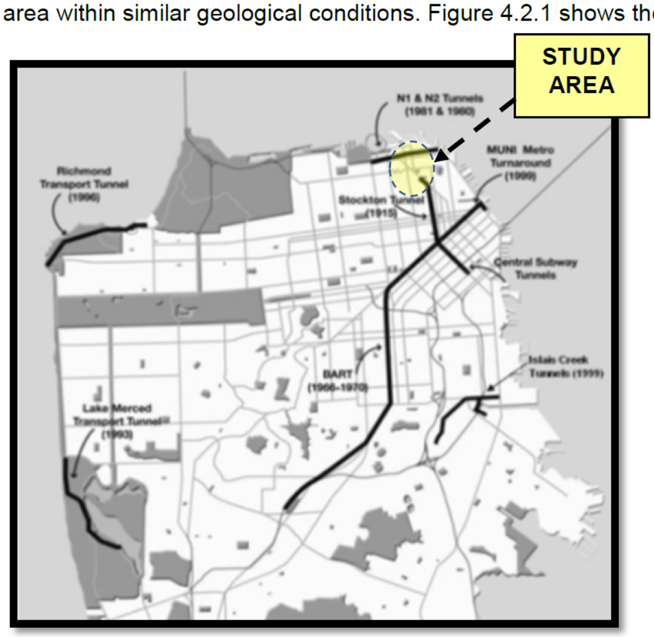


Figure 4.2.1 Neighboring Historical and Current Tunnel Projects in San Francisco

Several projects are relevant to our screening process for tunnel constructability:

- **Central Subway Phase 2 Tunnels** have been driven in varying ground condition. Over 8,200 feet of underground guide way of T-Third Phase 2 were constructed as twin bored tunnels. 211 feet is a twin-cell cut and cover box within the footprint of the TBM Launch Box. Tunnel excavation used two state- of- the- art Pressurized Face Tunnel Boring Machines (PF TBMs) using Earth Pressure Balance (EPB) TBM technology that operated in the granular and cohesive soil in the "Closed Mode" with in situ pressures of approximately three to four bars, and were retrieved at Pagoda Palace shaft (Figure 4.2.2). Tunneling was performed in variable rock, ranging from very poor, highly weathered and fractured shale to fresh, fractured sandstone. Mixed face tunnel conditions of rock and soil with gradational and variable face conditions and controlled ground loss as tunnel advances were encountered. Tunneling through soft soils and fractured and blocky rock required special machine design and operational considerations; also, it required Classification of "Potentially Gassy tunnel with Special Conditions", as determined by CAL OSHA and the Tunnel Safety Orders, and other state and federal jurisdictional requirements.

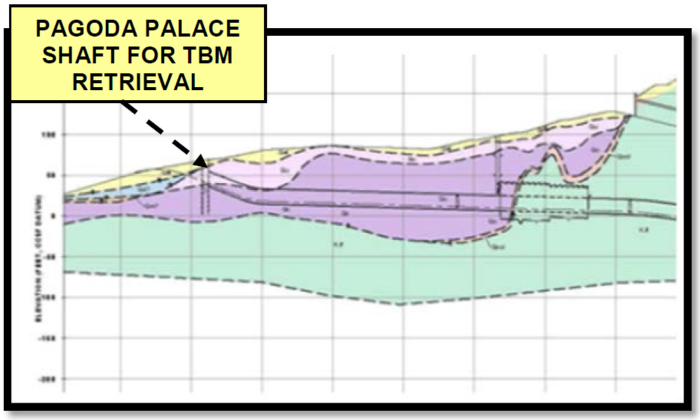


Figure 4.2.2: T-Third Phase 2 final tunnel reaches (mainly in Colma formation) before TBM retrieval at Pagoda Palace shaft

- **Muni Metro Turnaround (MMT)** had been tunneled through the Bay Mud by means of a circular steel shield under compressed air in close proximity to the location of the potential T-Third Phase 3 extension and had used jet grout as a ground improvement method for cross passage excavation.

- **The North Outfall Consolidation Sewer Tunnels N-1 and N-2** are located near Fisherman's Wharf and likely present a subsurface obstruction to the potential alignments of Phase 3 extension tunnels, especially the N-2 tunnel which extends from the N-1 tunnel to San Francisco Bay along North Point Street. The excavated diameter was approximately 12.3 feet and the tunnel was excavated with the first earth pressure balance machine used in the United States. The tunnel was excavated primarily in Colma Formation and Bay Mud. Protection of these tunnels while driving the new tunnels beneath and during potential station construction at Kirkland Yard and Conrad Square would likely be of prime importance and will require implementation of detailed instrumentation and monitoring program. N-1 tunnel was excavated primarily in Franciscan Formation Bedrock and Colma Formation and extends from Fort Mason further east. It has a finished diameter of 10 feet and was excavated with a road header (open-face shield with excavator arm). At Van Ness Avenue the tunnel was excavated in Bay Mud and ground settlement was an issue.

- **BART Market Street Subway tunnels** completed in 1970s were driven through the Colma Formation using compressed air and an open face shield. It is possible that T-Third Phase 3 extension tunnels of the Central Subway will be driven in similar ground conditions for at least portion of the alignment using a modern PF TBM.

b. Tunneling Considerations

The objectives of any potential tunnel option considered as an extension of the existing Phase 2 tunnels must continue meeting owner/user requirements as well as good tunneling practice within specific geologic conditions identified. It must provide for the appropriate tunnel size (likely same or similar to Phase 2 tunnels), meet standard industry construction tolerances and durability requirements for facilities' likely design service life (usually for 100 to 120 years), and should generally minimize long-term operational costs and maintenance. Tunnels must be safe and stable during construction and impacts to surrounding buildings, infrastructure and local communities must be minimized.

- **Tunnel Boring Machine vs. Sequential Excavation Method:** In terms of tunneling options along Powell and Beach Streets corridor as well as along Columbus Avenue two tunneling methods are possible: mechanically bored tunnel by tunnel boring machine (TBM) or sequentially excavated tunnel by sequential excavation method (SEM), see Figures 4.2.3 to 4.2.4, respectively.

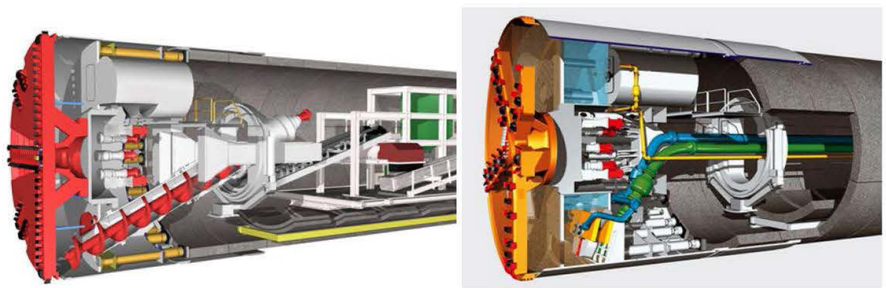


Figure 4.2.3 Earth Pressure TBM (left) and Slurry TBM (right)

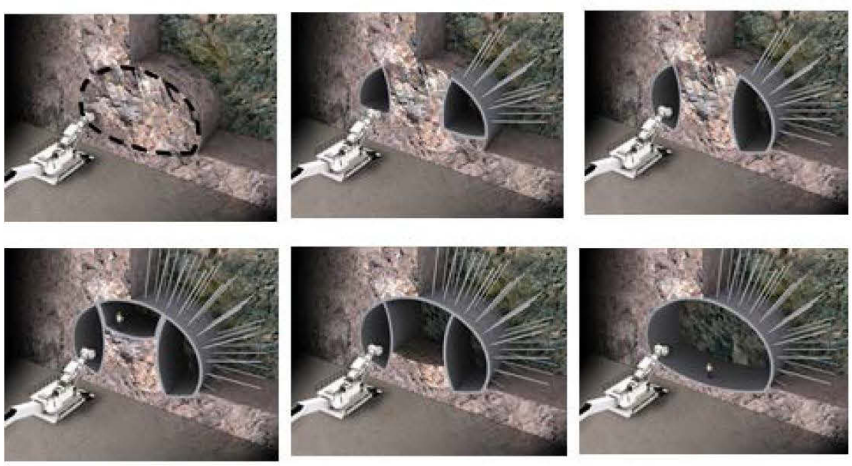


Figure 4.2.4 Sequential Excavation Method (SEM)

At this pre-conceptual study level neither of these options should be eliminated; however, based on the assumed geological conditions it is possible that along the middle and northern portion of the alignment beneath Columbus Avenue, northern portion of the alignment along Powell Street, and possibly entirely beneath Beach Street, the tunnels may need to be constructed in fill or Bay Mud, a condition which, followed with a high groundwater elevation, would likely cause assessment of SEM tunnel option non practical due to potentially extensive ground improvement work that would be necessary to control the groundwater inflow into the excavation and keep the excavation stable at all times minimizing impacts to the overlying streets, utilities and buildings. SEM tunnels within a fill or

Bay Mud accompanied with high ground water level would require ground improvement (such as jet grouting, See Figure 4.2.5) to control the groundwater inflow and overall stability of the excavation including ground settlements; generally, this method may be more expensive to execute and may produce larger overall impacts since such ground improvements would be initiated form the street as needed (traffic, utility impacts, increased instrumentation).

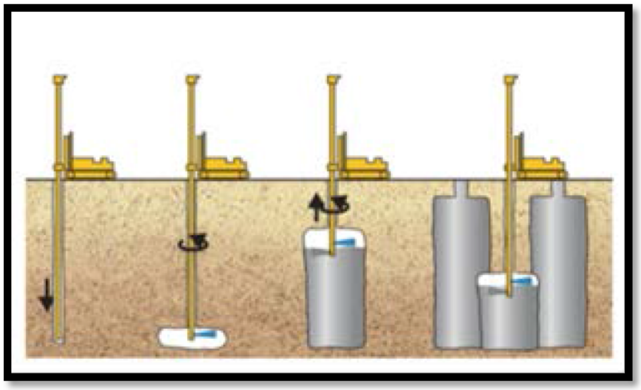


Figure 4.2.5 Ground Improvement by Jet Grouting

Although the study is dealing with short length of the tunnels (which differs for different options and it is a total or partial summary of the individual distances between the points of the 'Powell-Beach-Columbus study corridor'; approximately 0.5 miles length for each for Powell and Beach alignments, and 0.7 miles for Columbus Avenue alignment), TBM use is considered more practical. This would be the case from ground control perspective, accounting for the recent advances in the TBM technology as well as the recent experiences from T Third Phase 2 construction. From machine utilization standpoint industry-wide, due to relatively short alignments, this might not be the most economical use of the TBM; however, this aspect could be improved if potential *further* extension of the tunnels is anticipated for some future segments (in this case additional tunnel length could be constructed and then capped to await its future use).

c. Constructability issues of TBM tunneling

The tunnels could be excavated by use of the present state-of–the-art technology of pressurized face TBMs (See Figure 4.2.6). This method has been used on a recent T Third Phase 2 project and with a general success. Although it takes usually between 9 and 12 months for the specified machine to be procured, this time could be used to mobilize, establish the construction site and construct the launch shaft or cavern (which would likely be part of the overall station excavation).

Either earth pressure balance or slurry face TBM would be required for the assumed tunneling conditions in saturated soil and highly weathered and fractured Franciscan Complex bedrock conditions. Within the bedrock open mode tunneling may be permitted if probe drilling or other approved means for estimating potential groundwater inflows are used; however, diligent monitoring of face conditions, muck production, advance rates, and groundwater inflows would be essential to control the face. Any loss of face stability or ground will necessitate a return to pressure face mining. However, based on the assumed geological conditions, it would be unlikely that significant portions of the tunnel would reside within the Franciscan Complex bedrock. Therefore, design and selection of the TBM need to consider the tunnel face pressures and pressures surrounding the machine, which are affected by the earth and groundwater pressures. It is likely the ground conditions would require the TBM operation in a closed mode and fitted with disc cutters, in addition to drag cutters, to enable excavation of the harder bedrock that would be encountered, as experienced in the recent T-Third Phase 2 tunnel contract,

Figure 4.2.6 Pressure Face TBM "Big Alma"

Face stability would be extremely critical to reduce the potential for ground loss at and behind the tunnel face and be able to control the risk of surrounding ground movements and settlements to overlying infrastructure within the urban and historical environment along the study area. The loss of face pressure and face stability is a serious risk in urban construction especially if coupled with varied and mixed face ground conditions encountering Bay Mud. Subsurface investigations and analyses of subsurface ground and hydrogeologic conditions would be required to determine with greater level of certainty the geological conditions along the potential subsurface alignments-- first to qualify and then quantify the risks associated with tunneling.

The groundwater conditions are likely such that significant variations of the groundwater levels exist along the potential tunnel alignments; however, it is possible that northern and north-eastern portions of potential alignments approaching Conrad Square and Kirkland Yard have the groundwater table that is relatively close to sea level (historical groundwater level measurements indicate that water levels could fluctuate seasonally on the order of 5 feet). The groundwater table becomes shallow (about 10 ft below ground surface) near the Pagoda Palace Shaft due to the decreasing ground surface elevation. The salinity of groundwater along the project alignment is also variable but would likely increase towards the shoreline. Considering that seawater typically has a salinity of about 32 g/L, it is expected that the groundwater salinity will be portion of this value and would increase in close proximity to a tidal zone. Potential of 'buried underground rivers' need to be investigated especially in respect to the assumed station locations.

Methane gas has been historically identified during the course of previous exploration programs in the area including the Phase 2 program and it could be expected within the study zone. The gas had been encountered during tunneling during the construction of several local tunnels in ground conditions similar to those present along the potential alignment; therefore future geotechnical investigations would need to address this issue. Also, hydrocarbons may be present and have been historically reported in the area and shall be investigated in the future. Cisterns dating to the 1850s and extending (usually) to more than 20 feet below the surface may be present within the neighborhood. There may be remnants of these or many still may be present even if they were replaced or backfilled with sand and are not considered active. Locations of such obstructions will be subject of the future investigations.

In addition, archeological evidence generally suggests the presence of abandoned wells in the area filled with domestic and commercial artifacts from the Gold Rush Era. Such artifacts require preservation, proper handling and disposition and will be part of the future investigations. Native American artifacts have been also encountered in cut and cover portions of the excavations during T Third Phase 2 construction and those may be present within the study corridor.

d. Tunnel Lining System

The lining system for the tunnels is required for operational purposes to provide a functional underground opening and environment appropriate to the operation of the tunnel as a light rail transit tunnel. Precast concrete segmental lining will support the surrounding ground initially as well as for the design service life of the structure thus providing and maintaining the required operational cross-section and to control groundwater inflow, generally via special gaskets installed along radial and circumferential segment joints as single-gaskets or double-gaskets depending generally on ground corrosiveness and gas and hydrocarbons presence. (See Figures 4.2.7 and 4.2.8).

Figure 4.2.7 & 8: T Third Phase 2 – Lined tunnel and precast segments

The final precast concrete segmental lining will have the strength and flexibility to resist overburden earth pressures, hydrostatic pressures, and seismic deformations, as well as additional loads due to segment fabrication, storage, handling, demolding, and transportation loadings and related construction imposed loadings to ensure lining section adequacy during construction. See Figures 4.2.9.

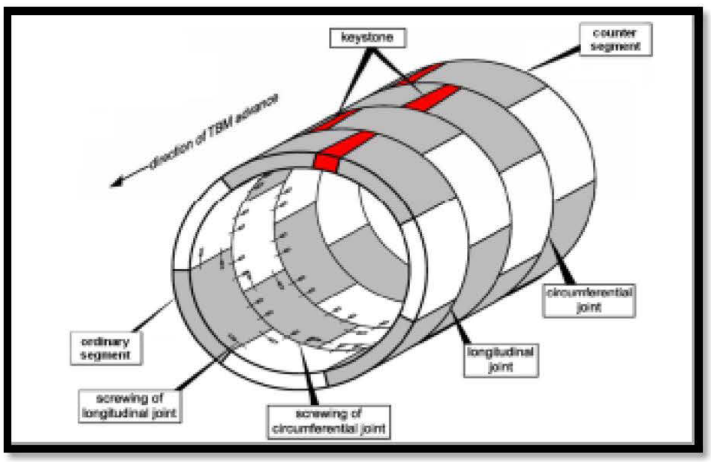


Figure 4.2.9: Typical final precast concrete segmental tunnel liner

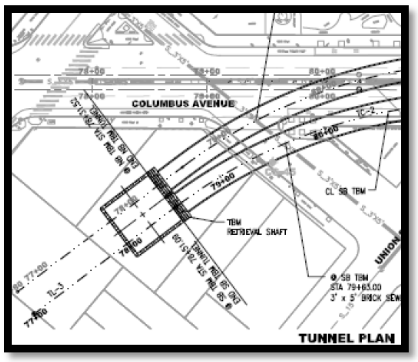
e. Settlements due to Tunneling

Tunneling induced ground settlements are usually associated with ground loss, especially for the tunnels located in the saturated soils and as they closely approach the coastal zone.

Excessive settlement would cause detrimental effects to the nearby buildings, structures and facilities (including the existing N1 and N2 sewer tunnels and the associated appurtenant facilities). The magnitude of the settlement can be minimized by appropriate tunneling methods, mitigation measures such as application of appropriate face pressures, shield gap grouting, segment backfill grouting, measurement and control of excavation quantities, ground improvement, and building/structure protection. During the tunnel construction, the annular space between the advancing shield and surrounding ground gap (gap grouting) and between the segmental support and the surrounding ground (segment backfill grouting) must be filled with grout continually as the tunnel advances. Such void grouting is the key to limiting settlement and ensuring uniform loading of the lining segments. Compensation grouting has been used to protect sensitive structures and minimize settlements during tunneling. Jet grouting has been also used to minimize ground settlements and improve the ground; it is usually performed from within the designated right of way, and from the surface. Historic structures are likely present along the alignment. These structures are sensitive to ground movements and vibrations. Future studies should address this issue in detail and assess the measures required for mitigating these impacts.

4.2.2 Pagoda Palace Shaft

The Central Subway project (T-Third Phase 2), provided for the tunnel boring machine (TBM) removal at the Pagoda Palace site in North Beach instead of the initial approved plan which called for the machine removal in the middle of Columbus Avenue (Figures 4.2.10 and 4.2.11).



Figures 4.2.10: T-Third Phase 2, Plan **Figure 4.2.11:TBM retrieval shaft at Pagoda Site**

Any future northern and/or north-eastern extension of the existing LRT alignment towards Fishermen's Wharf must connect to the existing tunnels under Columbus Avenue that are currently terminating at the Pagoda Palace shaft. It is likely the extension of the Central Subway underground guideway would take place along Columbus Avenue, fully or partially. It is also likely that such extension considerations would be coupled with a need to construct new tunnels under Columbus Avenue to replace the existing 'curved' tunnel alignment leading into the existing retrieval shaft (the existing tunnels would be partially backfilled) Considering proximity of Washington Square, the existing Pagoda Palace site and the existing shaft would continue to be instrumental as a staging site and/or temporary construction shaft for construction crew access and for storing and staging construction materials and equipment. In light of a very limited available right of way (ROW) in the Washington Square area it is highly probable that the existing Pagoda Palace site would become a crucial part of a real estate providing an opportunity for placement of permanent station facilities including ventilation shafts, entrance and emergency egress. It is possible that this site may house a future transit development over the station permanent transit facilities; therefore, securing this site for the future transit uses should be strongly considered by the transit extension stakeholders.

Pagoda Palace site would have an important function in both cases, considering the full transit corridor extension towards the Fishermen's Wharf as well as in a case that North Beach Station could be constructed first as a possible first operating segment.

Connecting the existing T-Third Phase 2 tracks with future alignment would be different for surface versus subsurface alternatives.

4.2.3 Surface Alignment Alternatives

Extending T-Third Phase 2 tracks to meet surface alignment alternatives along Powell Street and/or Columbus Avenue would likely entail permanent backfilling of the portion of the curved tunnels approaching Pagoda Palace shaft site and demolishing the tunnels within the future station limits; however, contractors may elect to use the shaft along with the portion of the connecting tunnels as temporary access to the excavations beneath Columbus Avenue. If a new station is planned at

Washington Square to serve the North Beach neighborhood (North Beach Station), it is possible to construct another shaft within Columbus Avenue right of way using the methods of a cut and cover construction for the future station box (Figure 4.2.12). Such shaft could be decked over for maintenance and protection of traffic and served via Pagoda Palace site. Alternatively, if a station box construction is delayed for any reason, or it is not a preferred construction method, a sequential excavation method (SEM) cavern could be provided in lieu of the Columbus Avenue shaft, without opening the Columbus Avenue. This cavern would be constructed and serviced through the existing Pagoda shaft and the existing or new service tunnels, per contractor's suggested methods. From this cavern, the individual SEM tunnels would be extended northward (Figures 4.2.13 and 4.2.14, also refer to Figure 4.2.12).

The existing tunnels would connect to the station box or SEM cavern beneath Union and Filbert Streets. The new tunnels could be constructed from the northern station box (or SEM cavern) wall where a sequential excavation method (SEM) would be implemented for starting new SEM tunnel excavations further north along Columbus Avenue or Powell Street. Due to a relatively short length of these tunnels use of tunnel boring machine (TBM) is not considered practical since procuring the machine would likely take 9 to 12 months and by such time SEM tunnel construction could be well advanced.

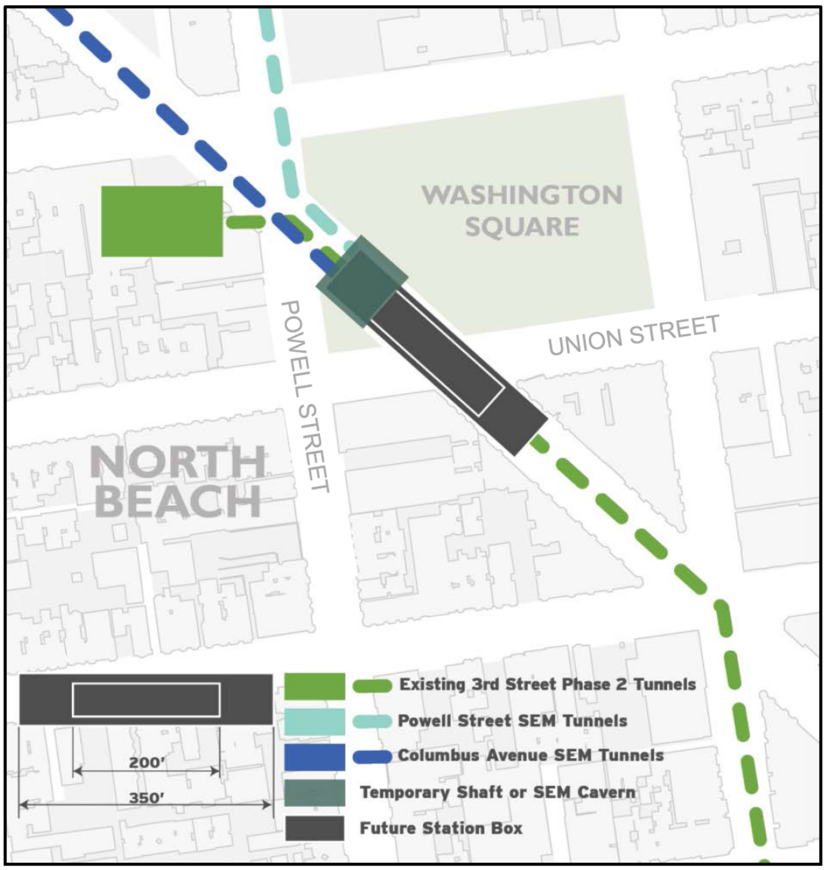


Figure 4.2.12 Pagoda Shaft Site Staging

The SEM tunnel(s) would continue into cut and cover and U-section construction at the portal locations, for either Columbus Avenue or Powell Street routes. The Columbus Avenue shaft or SEM cavern within a future station could be positioned to meet any northern extension route, either along Powell Street or Columbus Avenue. The station positioning should include generally 200-foot long platforms tangentially placed along the track alignment with sufficient approaching track lengths. It is likely that SEM cavern option would entail deepening the existing tunnel profile to achieve the sufficient cover for the SEM construction. Portal locations could vary depending on the adopted grades and/or to minimize street traffic and community impacts. In order to avoid the impacts to the existing cable car route along Columbus Avenue, it seems possible to place the tunnel portal north of Chestnut Street and complete the U-section construction south of Francisco Street using maximum ascending track grades within the portal zone. Along Powell Street, the portal is possible north of Filbert Street due to sharply descending street grade.

Instead of constructing the SEM tunnels from the north station wall, cut and cover construction for the tunnel portions is possible; this would entail decked, staged construction for maintenance and protection of traffic. The utilities would have to be either protected, relocated, or supported in place.

Figure 4.2.13 & 14 Excavations by Sequential Excavation Method (SEM)

4.2.4 Subsurface Alignment Alternatives

Extending T-Third Phase 2 tracks to meet the subsurface alternatives along Powell Street and Columbus Avenue would also entail permanent backfilling of the portion of the curved tunnel alignment approaching Pagoda Palace shaft site and demolishing the tunnels within the limits of the future station box or SEM cavern. Similarly to the surface alternatives, constructing another shaft or SEM cavern beneath Columbus Avenue at the location of potential North Beach Station is possible, where the TBM would be assembled and then launched to undertake any of the two potential routes to the north or north-east, either the Columbus Avenue or the Powell Street routes, respectively (Figures 4.2.15 to 17). Contractor would likely elect to use the Pagoda Shaft site as a staging and access area. Alternatively, in case the station construction is delayed, the existing tunnels could be used as approach tunnels to a future excavation of enlarged SEM tunnel (cavern), from where the machines could be launched after been lowered in manageable parts from either Pagoda Palace shaft site or the adjacent station and assembled within this SEM area. Similar logistics would apply if the TBM's are launched from other locations, say Conrad Square or Kirkland Yard shafts: an enlarged SEM tunnel (cavern) would need to be constructed such that the TBM's could be received within the constructed enlargements; alternatively, and in the case of north-south TBM route(s), the machines would be received at a potential shaft constructed within the limits of the future North Beach Station.

The Columbus Avenue shaft or SEM cavern within a future station limits could be positioned to meet any deep northern extension route, either along Powell Street or Columbus Avenue. The station positioning should include generally 200-foot long platforms tangentially placed along the track alignment with sufficient approaching track lengths. It is likely that SEM cavern option would entail deepening the existing tracks to achieve the sufficient cover for the SEM construction and may include ground improvement.

Figure 4.2.15 TBM assembly

Figure 4.2.16 TBM service shaft

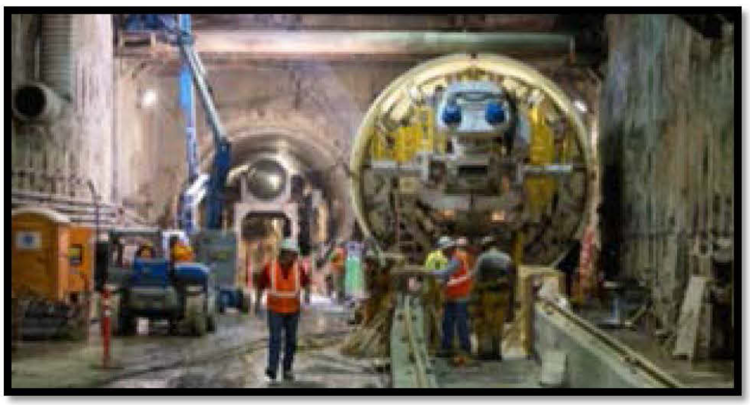


Figure 4.2.17 Phase 2:"Big Alma" TBM Launch

4.2.5 Potential Tunnel Profiles Along Study Corridor

Considering the assumed geological profile and the above constructability considerations, the following provides an assessment of potential tunnel and station profiles along the study area. As noted, the study area is bordered by Powell Street on the east, Beach Street on the north, and Columbus Avenue running northwest from Green Street to Beach Street; it is a triangular area adjoined by Telegraph Hill on the east, the Fisherman's Wharf area on the north and Russian Hill to the west. The 1853 map of San Francisco (see Figure 4.2.18) indicates that Francisco Street was the original shoreline and that the area north of Francisco Street (Bay, North Point and Beach Streets) was filled with material that is primarily dune sand. The area north of Columbus would encounter varying thicknesses of such fill.

For all underground guideways along the study corridor, the vertical alignment, and consequently the selection of the method of construction are dependent upon the following factors:

- Location of the existing connecting tunnels at the Washington Square area
- Maximum track grades (maximum 5% grade preferred, 7% to 9% grades possible for short lengths per Central Subway design criteria)
- Topography and geologic profiles along the study route
- Major underground obstacles including existing tunnels and piles (supporting existing or abandoned utilities)

- Major surface obstacles (including existing cable car infrastructure)
- Major constructability risks with emphasis on subsurface risks
- Operational limitations of tunnel boring machine including minimum feasible horizontal radius (500 feet) and vertical grade (3% to 4%)

Considering the above, general subsurface profiles have been developed for study alignments as follows (see Figure 4.2.19):

a. Columbus Avenue (Stockton/Green to Beach Street)
b. Beach Street (Powell to Columbus)
c. Powell Street (Green Street to Beach Street)

- **Columbus Street alignment:** Based on the historic maps, most of the Columbus alignment has soil varying in thickness from approximately 20 feet at Filbert Street to over 70 feet at Chestnut. The soil is likely fill at the surface with undifferentiated deposits and colluvium (the street is close to the toe of Russian Hill). In addition in the vicinity of Green Street to Filbert some of the dense Colma material may also be present, to the north of Francisco some native dune sand and Bay Mud might also underlie the fill. Along Columbus the groundwater may be within 10 to 15 feet of the ground surface. The bedrock is Franciscan Complex.

  The tunnel profile would extend to the northeast from the existing Phase 2 tunnels beneath Union Street, at first through the station box limits then further beneath Columbus Avenue following the descending grade of approximately 3% toward the Conrad Square Station. The tunnel would likely encounter fill and Colma formation first then bedrock north of Francisco Street. Further north Bay Mud and Old deposits might be encountered as well contributing to an undefined length of mixed face condition TBM would likely go through; it would possibly stay beneath the ground water table along the entire path. The tunnel would need to keep a minimum 8 to 10 feet distance beneath the sewer tunnel N2.
- **Beach Street Alignment:** Based on the historic information regarding the exploration performed for the N2 sewer tunnel the entire alignment is underlain by fill overlying about 20 to 40 feet of Bay Mud. In this area the groundwater will be at sea level. The Franciscan Complex bedrock is likely over 60 feet below sea level.

  The tunnel beneath Beach Street would possibly encounter Bay Mud, fill mixed and old deposits. The tunneling would need to control face pressure of the TBM in order to avoid potentially losing ground and causing settlements. It is possible that ground improvement including grouting may need to be implemented to control the impact of settlements on buildings, street and utilities at certain locations.

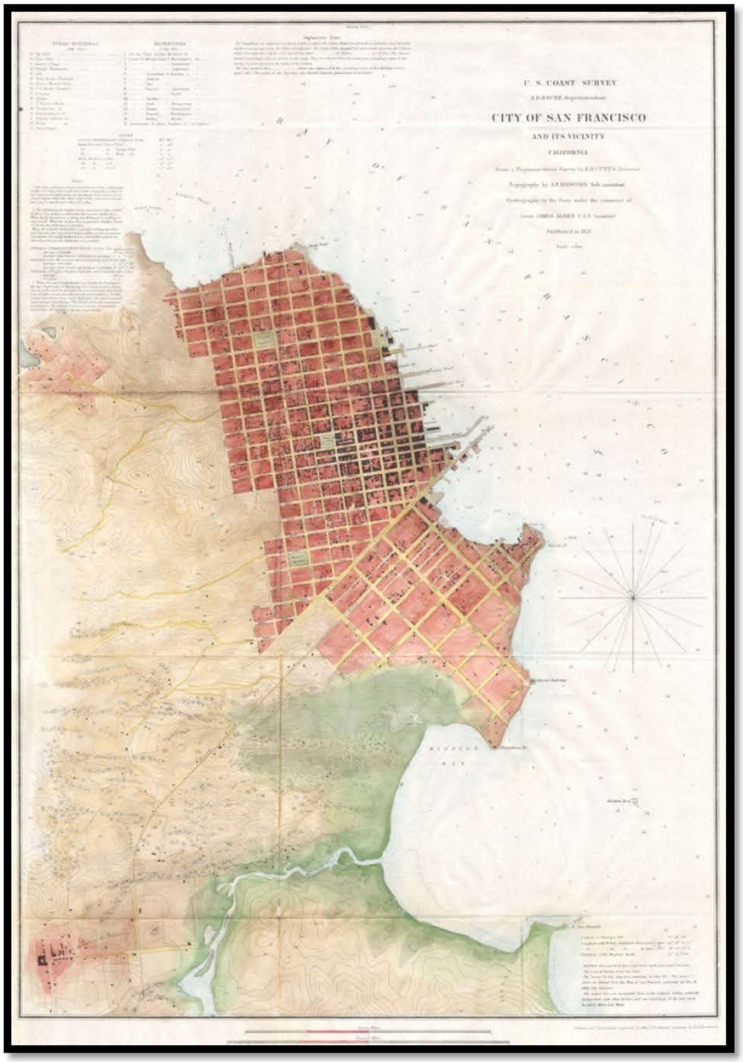


Figure 4.2.18: San Francisco Map (1853)

- **Powell Street Alignment:** At the very south end of the alignment the subsurface materials are anticipated to be undifferentiated deposits and possibly Colma formation. To the north from Union Street to Lombard Street the Franciscan Complex bedrock is anticipated to be relatively shallow overlayed with some Colma formation and fill (depth of Colma formation is unclear). North of Lombard Street the rock dips and the materials could be a combination of undifferentiated deposits, dune sand and possible some colluvium. At Francisco Street the materials transition to fill over Bay Mud. In the areas of fill the groundwater may be within 10 to 15 feet of the ground surface and north of Francisco Street the groundwater level will be at or close to sea level. The TBM would encounter mixed face condition for an undefined length while descending at an approximate grade of approximately 4% from North Beach Station to Kirkland Yard Station and passing beneath N2 tunnel beneath North Point Street.

Feasible tunnel and station alignments as it pertains to the specific alternatives are presented in Appendix A.

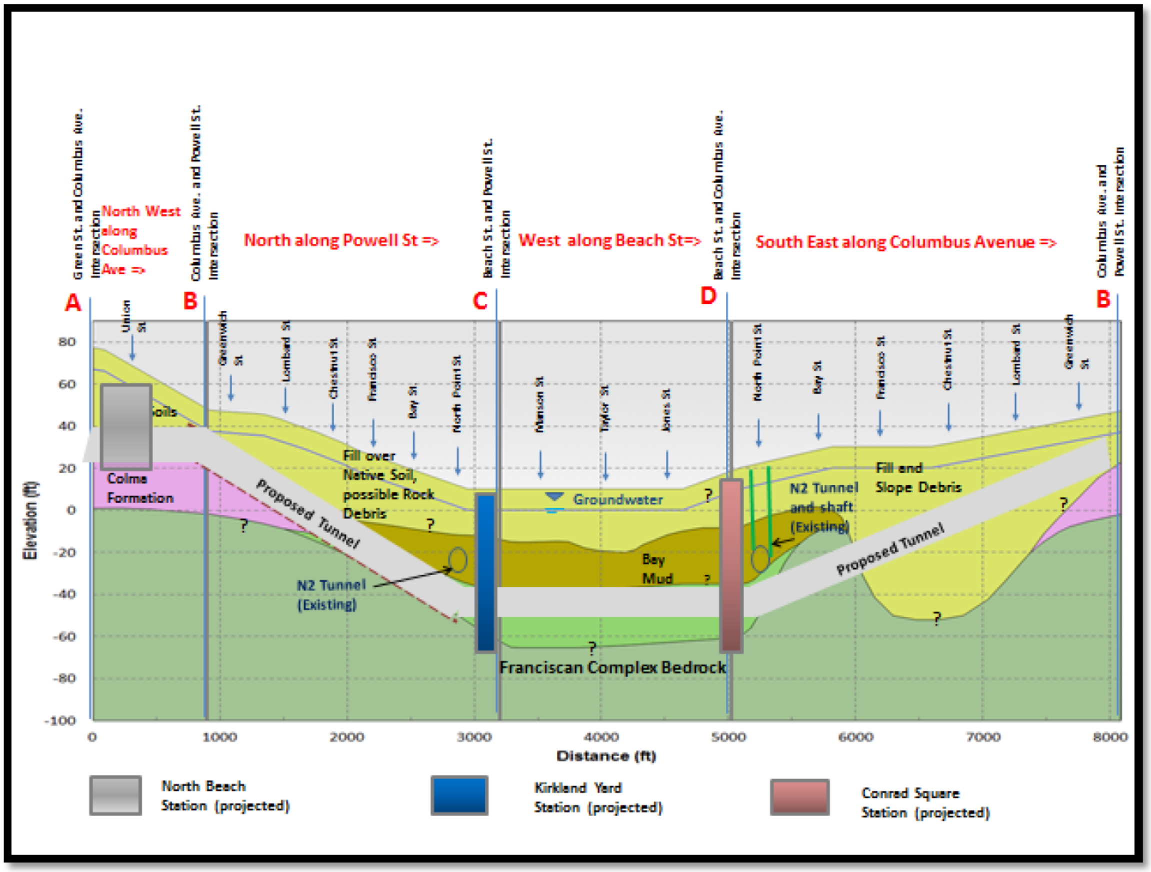


Figure 4.2.19: UNWRAPPED geologic profile with possible tunnel and station locations (refer to Figure 4.1.1 for a plan view)

4.2.6 Potential Stations at North Beach, Kirkland Yard and Conrad Square Locations

Brief analysis of constructability impacts of potential stations at Washington Square (North Beach), Kirkland Yard and Conrad Square is provided herein below at a pre-conceptual level based on assumed geological profile and historical and recent construction experiences in similar ground conditions.

a. North Beach Station beneath Columbus Avenue

Potential North Beach Station could be placed along Columbus Avenue as per the previous studies provided as part of the Phase 2 alternative alignment considerations. Station location would likely reside within the area bordered by Filbert Street at the north and Green Street at the south, generally beneath Union Street and south-west corner of the Washington Square. Such station position would allow tunnel alignment to be extended either beneath Columbus Avenue or with slight reverse curves beneath Powell Street (Figure 4.2.20). It appears that bottom of the station would be in Colma formation or within the bedrock overlaid by alluvial sediments and fill. It also appears that rock seems to drop down rather sharply from Filbert Street north beneath Columbus Avenue and that Columbus Avenue grade generally follows this trend.

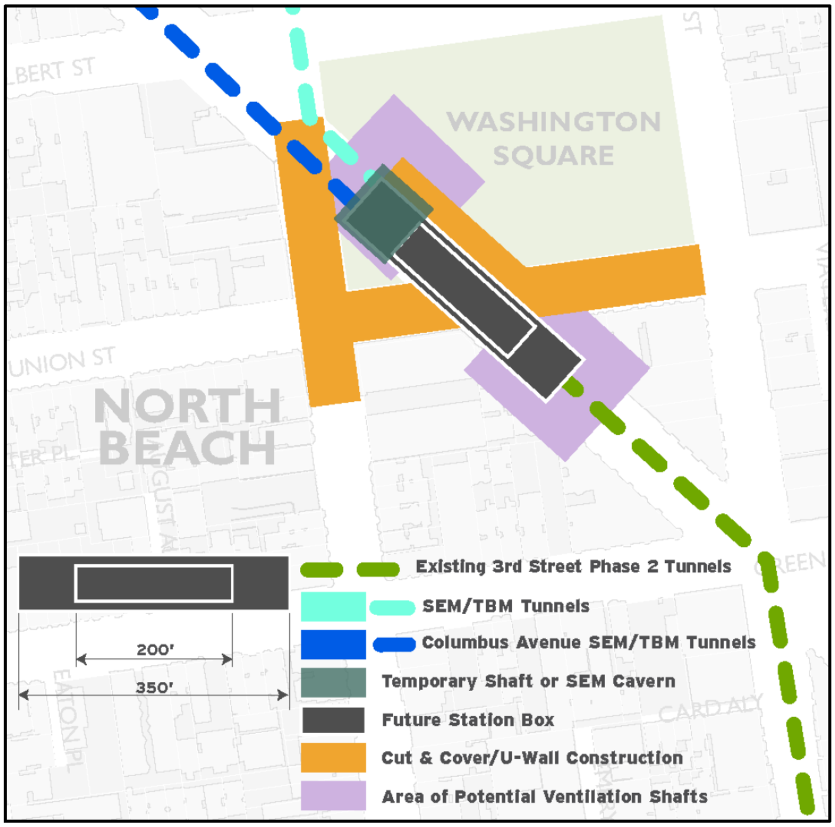


Figure 4.2.20: Potential North Beach Station location beneath Columbus Avenue*

***Note:** Areas indicated for Cut and Cover/U-wall construction (orange color) and for Potential Ventilation Shafts (purple color) are indicative of the right of way (ROW) requirements in the North Beach Station vicinity in case that the alternative sites are not provided for such purposes (Pagoda Palace Site or any other available neighboring property). Entrances, head house and ventilation shafts could be incorporated into the future transit development if desired. Ventilation stacks if stand-alone could become a part of public art (their exhaust/intake components are usually placed minimum 10 feet above street level).*

It is likely that the station construction would use sequential excavation method (SEM) or a decked cut-and-cover construction approach (See Figure 4.2.21). Existing Pagoda Palace shaft site could be used for construction staging, as a temporary construction shaft and for housing the station permanent facilities (entrance, ventilation shafts, head house and emergency egress). Ground water level is possibly 10 to 15 feet beneath the street surface.

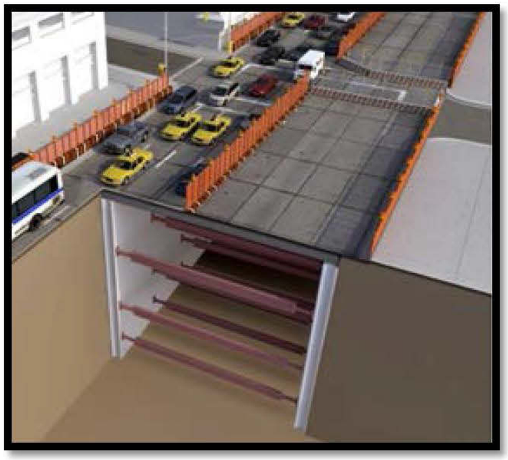


Figure 4.2.21: Typical decked street: station box construction proceeds beneath street traffic

Possible constructability considerations for North Beach Station box include as noted below. For station SEM cavern construction general sequence see Figure 4.2.4.

- Top down or bottom up cut and cover excavation with decked support for maintenance and protection of traffic during construction and utility work. The selection of top down or bottom up will be a potential future study.
- Rigid watertight support of excavation consisting either of slurry wall or secant pile wall which could be temporary or permanent. The walls forming excavation support would be braced as the excavation proceeds top-down and would likely require supporting elements (whalers, struts) within the excavation, which would be placed as the station box is being excavated. Temporary steel wales and preloaded pipe struts could be used to limit wall movements during sequential excavation as it proceed to the bottom of the box and control the ground deformations that may lead into street, utility or building settlements (See Figure 4.2.22).

Figure 4.2.22: Station Box Excavation and Support

- Watertight wall system would likely be placed to the specified cut off depth such that groundwater levels outside the station are not significantly lowered to induce settlement impacts to the surrounding structures and/or utilities. Waterproofing membrane system may be placed between the support of excavation and interior permanent structures to assure station water tightness.

High density polyethylene (HDPE) waterproofing membrane, or similarly polyolefin membranes, are commonly used as cut and cover structures waterproofing protection when hydrocarbon presence is confirmed in the ground. Otherwise, more flexible and more economic polyvinylchloride (PVC) membranes could be utilized to keep the station box and the appurtenant structures (entrances, ventilation shafts) watertight.

- Utilities within the limits of the station box excavation would be relocated or supported in place beneath the deck. (See Figure 4.2.23)

Figure 4.2.23: Major utility pipe supported off street decking

- Final reinforced concrete structure (walls, floors, roof) would likely be placed bottom up after invert slab is poured.
- It is possible that compaction grouting may be performed to mitigate potential settlements of the existing buildings and infrastructure during excavation of the station. Also, a jet grout plug may be installed around tunnel penetration zone next to each of the north and south station end walls to accommodate the break in and break out of the TBM from the station walls.
- Off street construction shaft at Pagoda Palace site or other nearby work site could be used for staging and storing the equipment and materials.
- Truck traffic would likely be planned for hauling of excavated spoils and delivery of construction materials will be necessary for the full duration of construction.
- Off street entrances will be provided. Pagoda site is a potential main off street entrance site.
- Stations will be designed to meet NFPA 130 for fire life safety aspects. Emergency exits will be provided in the sidewalks at each end of the station.

b. Kirkland Yard and Conrad Square Stations

The existing subsurface conditions and the fact that the existing North Shore Consolidated Outfalls tunnel (N2) runs beneath North Point Street between Conrad Square (Leavenworth and Columbus) and the Embarcadero, would generally impact the location of both Kirkland Yard and Conrad Square Stations as well as the final selection of feasible tunnel profiles. N2 sewer tunnel has an invert at approximately 36 feet below grade and 12.3 feet excavated diameter.

Considering that any potential tunnel option beneath Powell Street and Columbus Avenue need to have a descending profile in order to connect with the existing Phase 2 tunnels beneath Columbus Avenue at Washington Square and pass beneath the N2 tunnel allowing for a minimum clearance generally of 8-10 feet, the elevation at which the tracks would meet the Kirkland Yard or Conrad Square Stations would be approximately 60 feet below street level for Kirkland Yard Station and possibly 70 feet below street level for Conrad Square Station. Both Stations are close to the bay shore line with high groundwater level elevation possibly close to a sea level. The construction methods would be similar as described for North Beach Station box. Watertight and braced support of excavation would need to be installed mostly through the fill and Bay Mud and may encounter old deposits at the bottom of the excavation underlain by Franciscan Complex bedrock. In case of deeper Bay Mud layer it is likely that the invert stability of the excavation would be an issue and in such case ground improvement methods would need to be implemented such as jet grouting to close the excavation box and provide for its stability. Constructability consideration would be similar as for the North Beach Station box—it is likely that a cut and cover decked and braced top-down or bottom up excavation would be implemented followed by permanent structures build-out after invert stabilization was achieved. The selection of top down or bottom up will be a potential future study.

Kirkland Yard Station would likely be positioned along Powell Street north of North Point Street and might reach the right of way of Beach Street (see Figure 4.2.22). Convenience of Kirkland Yard to house the station appurtenant structures (entrances, ventilation shafts, station ancillary services including electrical, mechanical and systems) could be utilized to a great extent and would benefit the station constructability. An access shaft could be placed in the yard next to the station box allowing the easier maintenance and protection of traffic during the station box construction beneath the traffic deck.

Depending on different alignment alternatives considered, tail tracks could be extended beyond Powell Street if the station is to be considered a terminal station. Alternatively, tail tracks could curve toward Beach Street for allowing for potential future extension. This option will require underground easements under private properties. It should be noted that any terminal station consideration should plan for a cross-over. Generally, placing the cross-over before or after the station platform would extend the station box for a minimum 200 to 300 feet, depending on the type of the cross-over and desired operational speeds. In case of Kirkland Yard Station and considering geometric and subsurface constrains, it is possible that an SEM cavern construction, or an additional cut and cover construction, would be assessed beneath Powell Street between Washington Square and Kirkland Yard to allow for a cross-over. For SEM cavern, such construction would be possibly accompanied with the ground improvement to control the groundwater during the excavation, depending on actual geological conditions at a selected location.

Conrad Square Station location would face similar constrains as Kirkland Yard Station in terms of impacts of N2 tunnel. The station would need to be placed along Columbus Avenue north of North Point Street and would possibly encroach into the Beach street right of way. (See Figure 4.2.25)

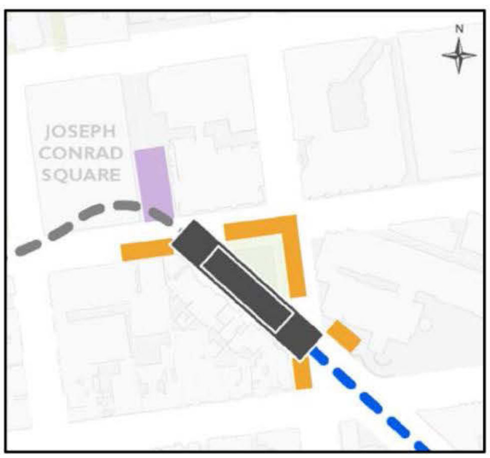
The station would need to be placed beneath Beach Street to the north for any deep alternative alignment extending from Powell Street to Conrad Square along Beach Street. It is likely that any of these two potential locations would utilize Conrad Square park area or any available right of way to position ventilation shafts while entrances could reside along the sidewalks or at locations where parallel parking exist. For sure any consideration of Conrad Station positioning would need to contemplate on potential improvements to Conrad Square as portrayed in Final Amended Mitigated Negative Declaration, Fisherman's Wharf Public Realm Plan Project and aim to meet the final improved configuration of the square while potentially allowing for temporary construction impacts during the station construction. If Conrad Square is contemplated as a terminal station, it would be possible to construct tail tracks beyond the station box to align with potential track extension layouts in the future to the west or the south-west. Similarly, any consideration of a cross-over prior to terminal station would extend the station box for 200-300 feet, depending of the cross—over size, which would be hard to accomplish beneath Columbus Avenue due to N2 tunnel constraint. In such case it is possible that an SEM cavern construction, or an additional cut and cover construction, would be assessed beneath Columbus Avenue between Washington Square and Conrad Square to allow for a cross-over. For SEM cavern, such construction would be possibly accompanied with the ground improvement to control the groundwater during the excavation, depending on actual geological conditions at a selected location.

Generally, more studies are required to arrive at optimum station locations and configurations especially for alternatives considered as having a potential for further conceptual advancement.

Figure 4.2.24: Potential Kirkland Yard Station location*

Note: Areas indicated for entrances (Cut and Cover/U-wall construction--orange color) and for Potential Ventilation Shafts (purple color) are indicative of the right of way (ROW) requirements for such purposes in the station vicinity and are subject to change.

Entrances and ventilation shafts could be incorporated into the future transit development. Ventilation stacks if stand-alone could become part of the public art (their exhaust/intake components are usually placed minimum 10 feet above street level).



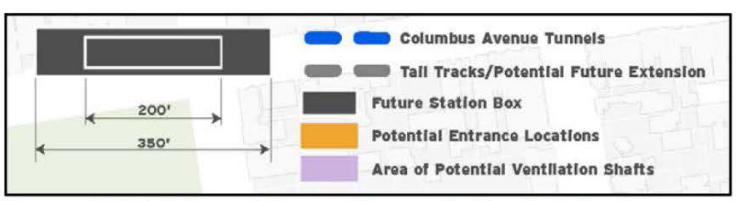


Figure 4.2.25: Potential Conrad Square Station location*

4.2.7 National Fire Protection Association (NFPA) 130 Compliance

The study's 'screening corridor' includes running tunnels, single or double depending on the option considered, and at least two stations located at North Beach, Kirkland Yard or Conrad Square and connected by adjoining tunnels. Tunnel and station ventilation and smoke extraction systems as well as provision for fire life safety egress are essential elements of underground system and need to comply with NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems. General NFPA compliance for all components: tunnels, stations, vehicles and any storage/maintenance areas are required and should be subject of later studies.

The ventilation systems requirements for an underground guideway depend on many variables, including the cross sectional area, length, provision of cross passages or dividing wall, and design fire load. The tunnel environment is mainly driven by the aerothermodynamics features of trains, passengers, ambient and ground conditions, electromechanical equipment, as well as station and tunnel interfaces. This interaction shows cyclic patterns on three timescales: yearly seasonal, daily peak/off-peak, and train headways. These factors need to be studied to arrive at a successful ventilation system that addresses the build-up within the tunnels of smoke and heat from fires during emergency conditions, the build-up of rejected heat from the trains during normal and congested operating conditions, and maintenance (diesel) vehicle exhaust (if any) during maintenance operations. The airflow rate capacity for the tunnels is determined by the train configuration, fire load, and tunnel geometry (area, height, and grade).
as set by international standards and best practices. The tunnel safety passenger egress from the train on fire would entail construction of cross-passages or exits to the street as follows:

For a twin (double) running tunnels scheme, considering NFPA 130 requirements*:

- Between North Beach Station and Kirkland Yard Station/Safety Egress and Kirkland Yard Station/Safety Egress and Conrad Square Station, no cross passages would be required if the distances between the surface egress points are less than 2500 feet.
- Between North Beach Station and Conrad Square station along Columbus Avenue one cross-passages at a minimum would be required since the distance between these two surface egress points exceeds 2500 feet. If two cross-passages are constructed they should not be spaced closer than 800 feet.

**Considering the cross-passage pattern construction for T Third Phase 2 project, it appears that more stringent requirements are adopted by Central Subway design criteria requiring cross-passage construction between the bored tunnels at distances not larger than 800 feet. This approach has been used herein for cost estimating purposes as well.*

For Loop Options (or any potential consideration of single track 'shuttle' options) emergency egress to the surface would be required at all three points of the 'screening triangle' at a minimum; also, an additional egress would likely be required between Conrad Square and North Beach Stations/egress points.

The fire and smoke control strategy for the stations — types of fire scenarios, integration of existing and new stations into a system that is able to control smoke exhaust flow rates, location of entrances, stairs and escalators, as well as fresh air paths in relation to egress paths for evacuating passengers — both informs and is impacted by the station architecture. Therefore, a station configuration needs to be studied to properly respond to all these factors. Also, existing and new stations ventilation need to be integrated into a system that can respond to emergency situation within the underground guideway, tunnels and stations and manage the heat and smoke originating from a design fire event in accordance with NFPA 130 using either push-pull or pull-pull system (Figures 4.2.26 and 4.2.27). Within each station, facilities need to be provided to assure fan plant capacities, and ventilation shafts and ducts need to be sized for optimum capacities required to manage the most critical ventilation and fire life safety scenario-- usually emergency conditions of a train on fire; they would need to be brought to the surface within the designated right of way within the station area.

Chapter 4.2.6 presents potential station locations for general feasibility screening purposes along with general area that could be designated for station ventilation appurtenances (ducts, shafts) and entrances; these need to be subject of a further study where available right of way would be confirmed.

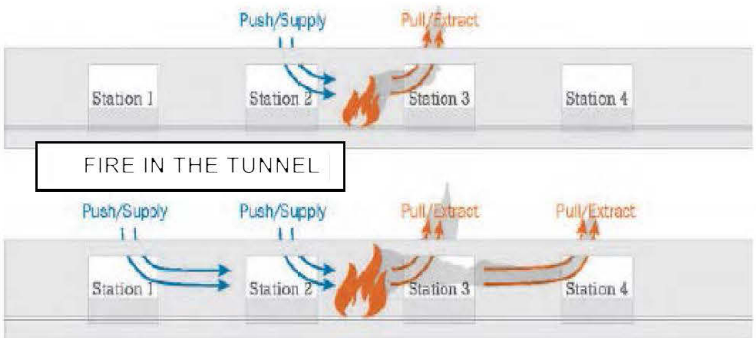


Figure 4.2.26: Push-Pull ventilation mode

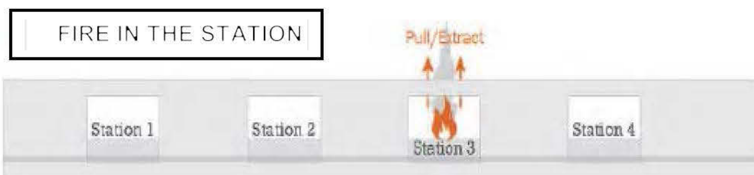


Figure 4.2.27: Pull-Pull ventilation mode

4.2.8 Constructability Analysis Matrix

Refer to Appendix A for constructability issues related to each specific alternative under consideration.

4.2.9 References

1. *Baseline Geotechnical Reports, Central Subway*
2. *North Shore Outfalls Consolidation Contract N2 Drawings, City and County of San Francisco Wastewater Program DWG 44101*
3. *Specification No 23, 969: Soil and Rock Data, Contract N-2, North Shore Outfalls Consolidation Project, March 1979*
4. *Central Subway Design Criteria, City and County of San Francisco Municipal Transportation Agency, June 2011*
5. *Muni Metro System Third Street Light Rail Transit Phase-2 Central Subway Final Design Drawings, DWG No. 125XEXGT001, Rev 2, Jan 21, 2011*

4.3: Utilities Evaluation

4.3.1 Potential Utility Issues

The SFMTA has identified 3 primary alignments along with stations that are required to be reviewed for their impacts to the existing utility infrastructure. In order to evaluate the various impacts to the existing utilities a Notice of Intent (NOI) was sent out to all public and private utility agencies so record drawings could be reviewed. The following is a list of agencies that were contacted to obtain record utility drawings.

- Astound Broadband
- AT&T
- Centurylink (Qwest Communication)
- Comcast Cable Company
- Ericsson Service (Sprint-Nextel Corporation)
- Level 3 Communications Network
- NRG Energy Center
- PG&E Electric and Gas
- San Francisco Department of Technology
- San Francisco Department of Public Works (SFDPW) – Bureau of Engineering Hydraulics
- San Francisco Municipal Transportation Authority (SFMTA) – Department of Parking and Traffic
- San Francisco Municipal Transportation Authority (SFMTA) – MUNI
- San Francisco Public Utility Commission (SFPUC) – Street Lights
- Time Warner Telecommunications
- Verizon (MCI)
- XO Communications

The utilities were then reviewed and analyzed as to how they might be affected from the proposed track alignment options, and proposed track construction methods. Each utility was assessed per three main categories and risk evaluations which were cost, schedule and constructability.

The proposed alignments consist of various options of surface and subway track alignments along Columbus Avenue, Powell Street and Beach/North Point Street. There are also proposed stations at Conrad Square, Kirkland Yard, and Washington Square. All of the various proposed alignment options are being evaluated based on general construction method used and comparing that with the type of affected utility system. The final risk assessment of each option is summarized in Section 4.3.2.

a. Surface Track and Shallow Track (within the top 20' below ground)
In general, all utility agencies will require their utility systems be relocated outside the MUNI track alignment when surface or shallow track is being proposed. This is to facilitate maintenance or emergency repairs to the utility systems without interrupting the MUNI service. If there are no separation between utilities system and MUNI track, it may be very costly and have significant impact to the operations of both the utility agencies and MUNI.

Some dry utility systems may allow for their facilities to be buried underneath surface tracks, as long as their utility structures and vaults are located outside the limits of the tracks.

This evaluation will require further study and analysis during future stages of the Central Subway project.

b. Subway Track that is more than 20' below ground

For subway track segments that are more than 20' below ground, individual utility systems should be evaluated on the options to remain and protected in place, modified or relocated. Construction method can greatly impact and determine how a utility system will be affected.

The two main construction methods being evaluated for the below ground subway track are tunneling and cut and cover (or open cut) construction.

1. If a subway track is being constructed by means of tunneling, the impact to utilities is greatly reduced. Although other factors can still trigger relocation of the utilities, however, the main concern will be vibrations and ground settlements during tunneling construction.
2. If cut and cover (or open cut) construction method is used, each utility system will need to be evaluated for possibility of the following options.
   a. Remain and protected in place:

      This is the easiest approach and has the least impact on the overall utility system. However, during construction, this may require additional construction sequencing, scheduling and cost to work around the utility.
   b. Modified and protected in place:

      Some utility system may require modification, such as slip lining combine SS system, prior to being allowed to remain in place during construction.
   c. Relocate:

      If it is identified that the utility will interfere with the construction operation and future improvements after constructability review, the utility will need to be relocated.
3. Each option is recommended based on the following considerations:
   a. Vibration/Ground Settlement: Older utility facilities and structures are more susceptible to vibrations and ground settlements and may need replacement, repair or reinforcement in order to withstand the imposed impacts. In other situations the utility may be able to withstand the impacts, but will need to be monitored for any substantial movement in order to proactively anticipate any potential damage to the utility system. Of particular concern are old cast-iron water mains or clay pipes that are susceptible to vibrations and ground settlements.
   b. Operation and Maintenance: The operation and maintenance of an individual utility system will depend on the type of material used and age of the utility system, sensitivity to construction vibration and the flexibility available within the utility system to allow for construction phasing. Evaluating each of the above criteria will directly impact the cost, schedule and constructability.
   c. Interruption to Service Laterals: The number of service laterals that are involved with a utility system and require to be interrupted during construction all will directly impact the cost of the utility system as well as the schedule. The more utility laterals affected the more construction phasing will be required and coordination with individual property owners for service interruptions.

c. Station Construction

All utility agencies will require their utility systems to be relocated outside of the proposed station footprint. The following is a list of potential station locations that will be evaluated.

1. North Beach Station
2. Kirkland Yard
3. Conrad Square

d. Utility Systems

Since each utility system has very different advantages, and disadvantages they will be assessed individually. The utility systems reviewed were divided into six main categories, along with the corresponding record utility map figure are as follows:

1. Low Pressure Water System (See Figure 4.3.1)
2. Auxiliary Water Supply System (See Figure 4.3.2)
3. Combined Storm/Sewer System (See Figure 4.3.3)
4. Electrical System (See Figure 4.3.4)
5. Telecommunication/Data Systems (See Figure 4.3.5 & 4.3.6)
6. Gas System (See Figure 4.3.7)

The utility systems were evaluated from a general constructability, cost and schedule feasibility study based on the various methods of construction. In order to determine the risk associated with each option, as they relate to the different utility systems, they were evaluated based on the following 5 criteria, which will be summarized for each utility system below.

a. Age and type of material
b. Sensitivity
c. Construction method
d. Flexibility of existing system
e. Building service laterals

1. Low Pressure Water System

The low pressure water (LPW) system is installed throughout the entire limits of the project and is used to supply domestic water, irrigation water and fire water services to public and private facilities.

a. Age and type of material: LPW systems are predominately constructed out of ductile iron pipe, but larger pipe diameters may be constructed of welded steel pipe. Older pipe material may be constructed out of cast-iron pipe material if built in the early 1900s.

b. Sensitivity: LPW pipes, since they are pressurized, are sensitive to large vibrations and settlements. During construction operations that involve tunneling or large excavations the LPW system should be monitored for any significant impacts to prevent breaks or leaks from occurring.

c. Construction method: The LPW system can be suspended in place during construction open excavations, but requires significant supports as the pipes are pressurized and heavy due to the pipe material.

d. Flexibility of existing system: An existing LPW system is quite flexible as it can be relocated and/or modified without greatly impacting the system. The LPW system also serves fire hydrants throughout the City that will require to be reviewed with the SFFD to ensure proper fire coverage is maintained. This will require further review with the City during future development of the track alignments.

e. Building service laterals: There are numerous building laterals that are required to be taken into consideration when analyzing alternative options. These services will require significant sequencing, coordination with property owners, and potential phased construction to maintain services. This may have impacts to the overall construction schedule and cost in order to perform numerous temporary shut-downs of services. In some instances if the service is modified additional work may be needed to relocate backflow preventers, meters and building wall penetrations.

2. *Auxiliary Water Supply System*

The Auxiliary Water Supply System (AWSS) is primarily located along the Powell Street and Beach / North Point Street alignments. The AWSS system is a high pressure water supply system that is used for emergency fire-fighting purposes in the event that the existing low pressure water system fails.

a. Age and type of material: New AWSS pipes are typically constructed of ductile iron pipe, but many pipes are constructed out of cast-iron as a majority of the system was built before 1920, after the 1906 San Francisco earthquake.

b. Sensitivity: Since a majority of the AWSS system is quite old and built out of cast-iron pipe it is highly sensitive to vibrations. Typically during large transit related projects these systems have required to be completely replaced as they cannot take the impacts from large street construction. Replacement of AWSS systems is quite costly and takes time to construct.

c. Construction method: The AWSS system cannot be suspended in place due to the type of material used and it being a high pressure system. It also requires access from the surface during maintenance, which will require the pipes to be relocated if it is underneath a proposed surface track. There are also large underground cisterns, and valves that will be required to be studied in future development of the options.

d. Flexibility of existing system: The AWSS system is partially flexible since it is a pressurized system it can change in horizontal and vertical alignment. However, since this system requires numerous valves, joint and thrust restraints the system is not as easily modified and can be quite expensive to relocate or modify. There are also high pressure fire hydrants that will need to be taken into consideration to ensure proper fire cover is maintained. This will require further review with the City during future development of the track alignments.

e. Building service laterals: The AWSS system does not have any building service laterals and thus does not require sequencing and coordination with property owners.

3. *Combined Storm/Sewer System*

The combined sewer (CS) system is installed throughout the entire limits of the project and is used to convey both sewer and storm drainage from public and private facilities. There is a large 9' tunnel section installed on North Point Street as well as many other 66" diameter and larger concrete pipe sizes that are present on Beach Street and Powell Street that will also need to be taken into consideration.

a. Age and type of material: Standard pipe material up to 30" diameter is typically vitrified clay pipe (VCP) with some locations being iron stone pipe (ISP). Pipe sizes larger than this are reinforced concrete pipe, concrete tunnels or brick sewers.

b. Sensitivity: A majority of the CS system is constructed out of VCP pipe which is a brittle material and is sensitive to vibrations. In some cases, depending on the vibration levels, the pipe may require to be replaced or slip-lined to reinforce the existing pipe and keep the pipes integrity. This same sensitivity will also apply to any pipe material that is constructed out of brick. The RCP pipe and concrete structures will need to be reviewed with the Public Works Department further if any reinforcement would be necessary.

c. Construction method: Gravity lines are difficult to suspend in place without being installed within either a concrete or steel sleeve to ensure that all joints remain together. Performing temporary pumping and a by-pass is also possible to allow for various construction methods. Relocating sewer lines within sidewalks are also not allowed in a permanent condition as the City will not accept the maintenance responsibility, so all pipes will need to be constructed on top of proposed tunnels or relocated outside limits of surface tracks.

d. Flexibility of existing system: The CS system is all a gravity system, which makes it difficult to easily re-route outside limits of proposed alignments or to change the vertical alignment. Drainage considerations are also required when relocating catch basins or drainage structures. This would require coordination with the street grades as well as pipe capacities if the drainage areas are increased in size.

e. Building service laterals: The CS system provides drainage to buildings throughout the entire project limits that will need to be taken into consideration when analyzing alternative options. These services will require significant sequencing, coordination with property owners, and potential phased construction to maintain services. This may have impacts to the overall construction schedule and cost in order to perform numerous temporary shut-downs and reconnections of services.

4. Electrical System

The electrical system primarily provides power for PG&E, but also provides electricity for public infrastructure such as street lights. This system is installed throughout the entire limits of the project, as well as an existing PG&E sub-station near the intersection of Beach Street and Mason Street.

a. Age and type of material: Electrical systems are typically installed in PVC or HDPE conduits; however older conduits may be installed within concrete ducts or even wood ducts. Other pipe materials may include Galvanized Rigid Steel pipe as well.

b. Sensitivity: Plastic conduits or steel pipe are quite flexible and allow construction vibrations to occur without impacting the system. If older ducts are discovered during further investigation these may be more susceptible to vibrations and may require replacement or added reinforcement.

c. Construction method: Electrical systems can be modified or relocated outside track limits quite easily. The difficulty is making sure that the entire electrical network is maintained, which takes significant cutover time and possible temporary shut-downs that may include generators to be provided. Conduits are also able to be suspended in place which allow for ease of open cut construction. Electrical systems can be installed within sidewalks which allow them to be relocated outside the limits of stations or open cut alignments. In certain situations the conduits can be underneath track alignments if the existing pull boxes and vaults are located outside the limits of the tracks. This will need to be reviewed on a case-by-case basis with PG&E.

d. Flexibility of existing system: Since electrical systems have an overall network of conduits they are easy to modify or relocate. The difficulty is the time to perform cut-overs when modifying the electrical system or network and pulling new wires/conductors within the conduits.

e. Building service laterals: The electrical system provides power to all buildings throughout the entire project limits. The building services require significant time to coordinate as well as re-connect back to the existing system. The building services need to maintain their existing service location to the building otherwise it will require significant electrical equipment modifications, which are costly.

5. Telecommunication / Data Systems

This system consists of all telecommunication and data systems, but the only utility companies that acknowledged facilities within the project limits are AT&T and Comcast. SFMTA may have additional telecommunication or data facilities within the area that will need to be evaluated in future development phases.

a. Age and type of material: Tel/Data systems are typically installed in PVC or HDPE conduits; however older conduits may be installed within concrete ducts.

b. Sensitivity: Plastic conduits or steel pipe are quite flexible and allow construction vibrations to occur without impacting the system.

c. Construction method: Tel/Data systems can be modified or relocated outside track limits quite easily. The difficulty is making sure that the entire tel/data network is maintained, which takes significant cutover time (sometimes 6-12 months). Conduits are also able to be suspended in place which allow for ease of open cut construction. Tel/Data systems can be installed within sidewalks which allow them to be relocated outside the limits of stations or open cut alignments. In certain situations the conduits can be underneath track alignments if the existing pull boxes and vaults are located outside the limits of the tracks. This will need to be reviewed on a case-by-case basis with each utility company.

d. Flexibility of existing system: Due to the extreme length of time to perform cut-overs and connections back to the existing network tel/data systems are not easily modified or relocated. Depending on the extent of modification the cut-over time can greatly impact construction schedule and will need to be taken into consideration.

e. Building service laterals: The tel/data system provides services to all buildings throughout the entire project limits. The building services require significant time to coordinate as well as re-connect back to the existing system. The building service locations need to maintain their existing service location to the building otherwise it will require significant tel/data equipment modifications, which are costly. The analysis of building services will require further review and study during the development of the final option.

6. Gas System

The gas system is all owned and operated by PG&E and occurs throughout the limits of the project. The main pipe in consideration is a 16" gas main that is installed along sections of North Point, Beach and Powell Streets.

a. Age and type of material: Gas systems are primarily installed in MDPE pipe, and in some cases installed in black steel pipe.

b. Sensitivity: Plastic conduits or steel pipe are quite flexible and allow construction vibrations to occur without impacting the system. Since the gas line is pressurized and highly flammable caution should be taken when working around gas mains. During construction operations that involve tunneling or large excavations PG&E should be involved with the review and monitoring procedures implemented to ensure the gas mains are not impacted.

c. Construction method: Gas mains can be modified or relocated outside track limits quite easily. They do not require significant cut-over times, however proper coordination with PG&E and property owners is required. Gas mains can also be suspended in place with adequate supports which allows for the ease of open cut construction.

d. Flexibility of existing system: An existing gas system is quite flexible as it can be relocated and/or modified without greatly impacting the system.

e. Building service laterals: Building service laterals occur throughout the project limits and will need to be coordinated for reconnection of services. This may also require new gas meters to be installed as well.

4.3.2 Utility Issues Matrix

Table 4.3.1: Utilities Impacts Matrix

(5 = Very High, 4 = High, 3 = Moderate, 2 = Low, 1 = Very Low, 0 = None)

Alternative	Cost Impact	Constructability	Schedule Impact	Analysis Summary
1-1	2	3	3	Least impact to AWSS system, but requires relocation of water and CS lines along surface track. May also require modifications be made to dry utilities for surface track. This option will also require coordination with SFMTA for surface track.
1-2	2	2	3	Consideration will be needed based on tunneling construction for vibrations made to existing utilities. Least impact to utilities, but will need to determine construction method for subway.
2A-1	3	4	4	Will create impacts to all wet utilities along surface track alignment. May also require modifications be made to dry utilities as well.
2A-2	2	2	3	Consideration will be needed for subway when crossing the existing tunnel on North Point (N2 tunnel). Potential issue with depth of subway and impact to existing underground CS system. Option may also create impacts to existing 16” gas main.
2A-3	3	4	4	Will create significant impacts to all wet utilities along surface track. Further review will be necessary to determine if dry utilities require modification. Option will also create impacts to existing 16” gas main.
2A-4	3	3	3	Consideration will be needed where alignment transitions from subway to surface track for relocation of all utilities.
2A-5	4	4	4	Will create impacts to all wet utilities along surface track alignment. Further review will be necessary to determine if dry utilities require modification. Option will also create impacts to existing 16” gas main.
2A-6	3	4	4	Consideration will be needed where alignment transitions from subway to surface track for relocation of all utilities.
2B-1	4	4	5	Significant impacts to all wet utilities along surface track alignment. Requires additional coordination with all dry utilities for extent of impact. 16” gas main will also need to be

Alternative	Cost Impact	Constructability	Schedule Impact	Analysis Summary
				relocated outside limits of track.
2B-2	3	4	4	Consideration will be needed for subway when crossing the existing tunnel on North Point (N2 tunnel). Potential issue with depth of subway and impact to existing underground CS system.
2B-3	3	4	4	Significant impacts to all wet utilities along surface track alignment. Requires additional coordination with all dry utilities for extent of impact. 16" gas main will also need to be relocated outside limits of track.
2B-4	4	4	4	Significant impacts to all wet utilities along Beach Street. Requires additional coordination with all dry utilities for extent of impact.
3-1	4	5	5	This option creates the most impact to all utilities as the surface track extends the longest.
3-2	3	4	4	Will need to review construction methodology and depths of existing utilities in relation to tunnel profile along entire alignment. Will still create impacts to N2 tunnel along North Point. Significant monitoring program will be required to be implemented.

4.3.3 References

1. *Notice of Intent (NOI) Letters sent to all utility agencies*

4.4: Sea Level Change Impacts

4.4.1 Impact of Sea Level Raise

Over the past century, sea level has risen nearly eight inches along the California coast, and general circulation model scenarios suggest very substantial increases in sea level as a significant impact of climate change over the coming century. Sea level rise is not expected to result in much permanent inundation within the area of the study, but would still increase the risk of coastal flooding and storm surge, increase the size of floods and expand erosion zones.

According to the research from California Climate Change Center [ref. 1], under the medium to medium-high greenhouse-gas emissions scenarios, mean sea level along the California coast is projected to rise from 1.0 to 1.4 meters by the year 2100. The amount of sea-level rise will put 480,000 people at risk of a 100-year flooding event. In addition, critical infrastructure, such as roads, hospitals, schools, emergency facilities, wastewater treatment plants, power plants, and more will also be at increased risk of inundation.

Specific to the alignments considered in the present study, the following types of impact are to be considered:

a. Flood Impacts

The length of railways in the county of San Francisco vulnerable to a 100-year flood has been estimated by the study of reference 1 to increase by 84% with a sea level rise of 1.4 meter.

The risk of flooding for the Phase 2 alignments under consideration includes flooding of surface right of way, flooding of portals and ensuing inundation of the underground facilities, tunnels and stations.

Flooding of street level alignments, resulting in minor damages and temporary disruption of service may be considered as a nuisance rather than serious impairment. However, as the frequency and height of such flooding increase, service interruptions become more frequent, and repairs more costly.

Conversely, flooding of underground facilities by water runoff through portals or other openings may present serious consequences in terms of material damages to the structures and systems, and may even present life threatening conditions if adequate precautions are not taken. The obvious remedy to this type of events is to incorporate into the design tunnels and station hardening measures and an effective drainage system. The hardening measures would include high walls extending out from the portals, flood protection gates, raising ventilation shafts and openings above the flood lines, watertight emergency exits, flood gates at station entrances, etc.

Flooding risk for a given facility is expressed in terms of the probability of occurrence of a design flood, such as a flood level with a 100-year recurrence during the selected lifetime of the facility. The referenced study points to some evidence that in San Francisco the intertidal range was also widening, and the frequency of storminess was also increasing. The former, if confirmed by further studies, could expand the flood zones to be considered, whereas the latter may cause a revision of the design basis flood level.

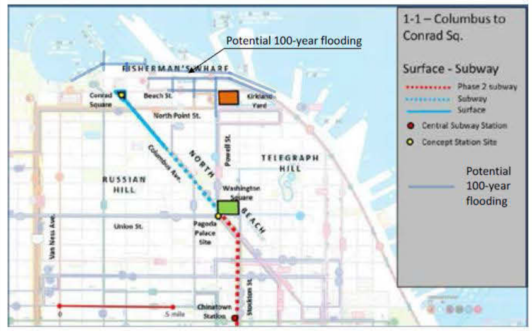
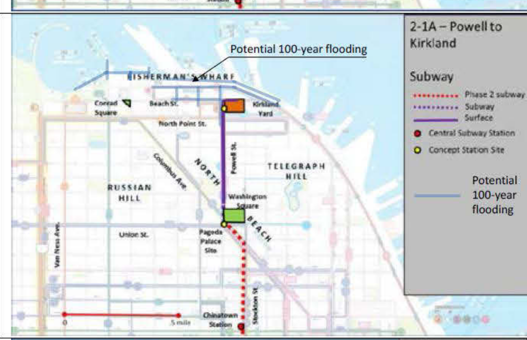
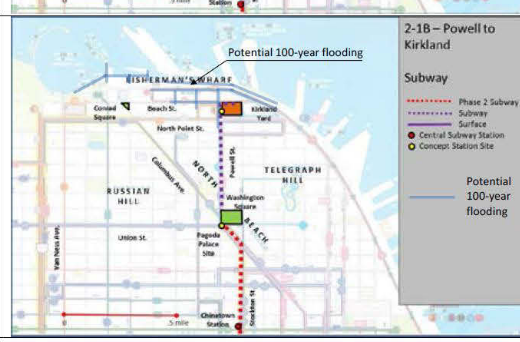
Assuming that no preventive measures would be taken city-wide to mitigate flooding, such as construction of seawalls or a raised promenade along the Embarcadero, as envisioned for lower Manhattan, the flood prone areas are determined as indicated in Figure 4.2.29. Shown on this figure is the graphical view of the impact of 100-year flood event with the 1.4 meter sea level rise. The flooded zone is indicated by pink color, and the proposed potential alignments are presented by light brown color. Based on the distribution of the flooding, it is suggested that Powell street, having total length of 2900 ft in the project area, is approximately 10 % to 15 % flooded (i.e., at the corner between Beach street and Powell street), Beach street (2500ft length) is approximately 50% flooded, Jefferson Street (1900 ft length) is mostly flooded, and Columbus Ave. (3300 ft length) will not be impacted by flooding. The red solid circle shown in Figure 1 presents the potential station (i.e., Kirkland Yard, Conrad Square, Washington Square). The Kirkland Yard Station is exposed to flooding, while the other two potential stations are not impacted by the 100-year flood events.

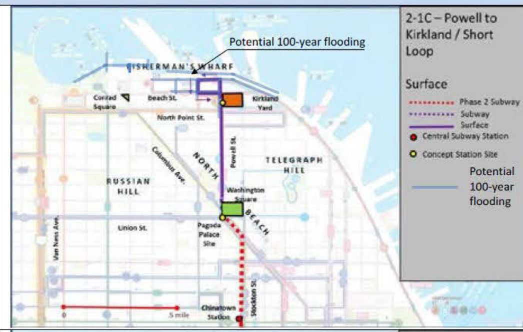
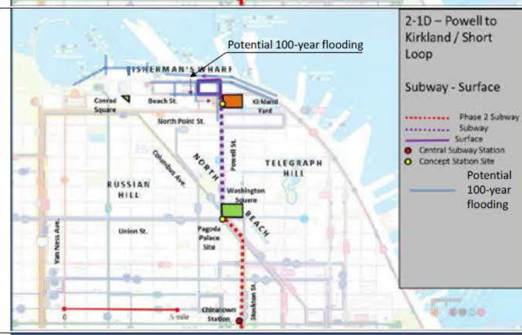
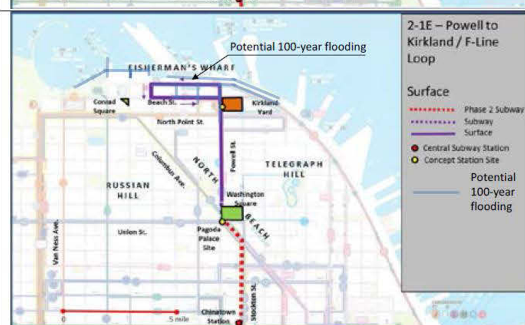
Figure 4.2.29: The impact area of sea level rise with 1.4 meter (4.6 feet) sea-level rise (California Climate Change Center, 2009).

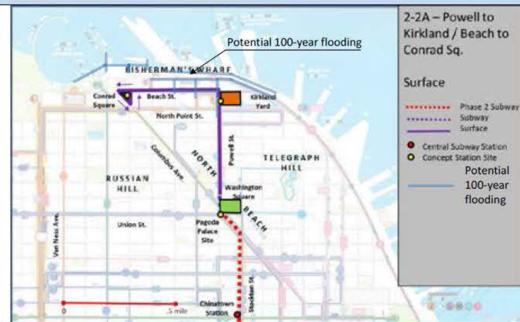
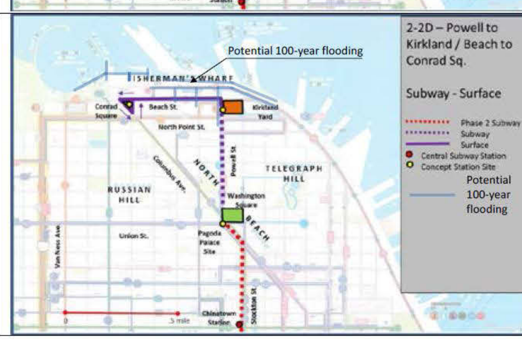
Based on the above observations, each of alternative alignment is evaluated in terms of the percentage of flooding area as summarized in Table 1. Modifications to certain alternatives considered not feasible in the present configuration have been discussed in Constructability Analysis Summary Matrix in Appendix A.

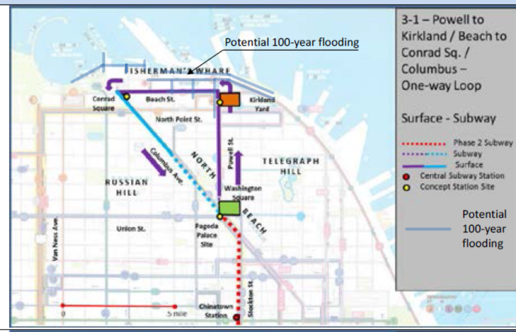
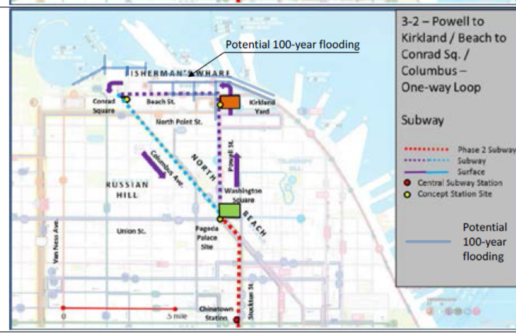
Based on the above observations, each of alternative alignment is evaluated in terms the percentage of flooding area as summarized in Sea Level Rise Impacts Summary Matrix. Modifications to certain alternatives considered not feasible in the present configuration have been discussed in Constructability Impacts Summary Matrix in Appendix A.

4.4.2 Sea Level Rise Impacts Summary Matrix (Evaluation of the Impact of 100-Year Flooding Event)

ALT.	SCORE	ANALYSIS SUMMARY	
1-1	5	No impact from 100-year flooding event.	
1-2	5	No impact from 100-year flooding event.	
2A-1	4.5	Partially flooded (approximately 10% of the alignment) at Kirkland Yard.	
2A-2	5	No impact from 100-year flooding event, but appropriate measures, such as a raised entrance structure at street level necessary to prevent flooding of the tunnel is required at Kirkland Yard Station.	

ALT.	SCORE	ANALYSIS SUMMARY	
2A-3	3.5	Approximately 20 - 30 % of the alignment flooded near Kirkland Yard.	
2A-4	4.0	Approximately 20 % of the alignment flooded near Kirkland Yard. Appropriate measures, such as a raised entrance structure at street level necessary to prevent flooding of the tunnel is required at the transition btw subway and surface alignment.	
2A-5	3.0	Approximately 40% of the alignment flooded throughout Kirkland Yard, Beach St and Jefferson St.	
2A-6	3.0	Approximately 40% of the alignment flooded throughout Kirkland Yard, Beach St and Jefferson St. Appropriate measures, such as a raised entrance structure at street level necessary at Kirkland Yard Station to prevent flooding of the tunnel is necessary.	

ALT.	SCORE	ANALYSIS SUMMARY	
2B-1	3.5	Approximately 30% of the alignment flooded throughout Kirkland Yard, Beach St and Jefferson St.	
2B-2	5.0	No impact from 100-year flooding condition, but appropriate measures, such as a raised entrance structure at street level to prevent flooding of the tunnel is required at Kirkland Yard Station.	
2B-3	4.5	Alternative not feasible.	
2B-4	3.5	Alternative not feasible.	

ALT.	SCORE	ANALYSIS SUMMARY	
3-1	3.5	Approximately 20-30% of the alignment flooded.	
3-2	5.0	No impact from 100-year flooding event. Appropriate measures, such as a raised entrance structure at street level to prevent flooding of the tunnel are required at the Kirkland Yard Station.	

b. Impacts on Groundwater Levels

The permanent state of raised sea level can be expected to affect the depth of groundwater in the coastal areas. This aspect should be taken into consideration for the design of underground tunnels and stations.

In summary, the effect of postulated sea level rise does not present an unmanageable condition for the proposed alignments. There is, however, a need to incorporate this aspect into the design of portals and the Kirkland Yard station to positively prevent the inundation of the tunnels and underground stations.

c. Impact to Potential Station Locations

- **North Beach:** This station is not affected directly from flooding, provided appropriate measures at Kirkland Yard Station entrances are taken for alternatives 2A-2, 2A-4, 2A-6, 2B-2, and 3-2. The design should take into consideration the effect of sea level rise on the groundwater for all alternatives.
- **Kirkland Yard:** Requires raised structure at entrances to prevent flooding of connecting tunnels for alternatives 2A-2, 2A-4, 2A-6, 2B-2, and 3-2. The design should take into consideration the effect of sea level rise on the groundwater for these same alternatives.
- **Conrad Square:** This station is not affected directly from flooding, provided appropriate measures at Kirkland Yard Station entrances are taken for alternatives 2B-2 and 3-2. The design should take into consideration the effect of sea level rise on the groundwater for these same alternatives.

4.4.3 References

1. *M. Heberger, H. Cooley, P. Herrera, P. H. Gleick, E. Moore, 2009, The impacts of sea-level rise on the California coast, California Climate Change Center.*

4.5: Conceptual Costs

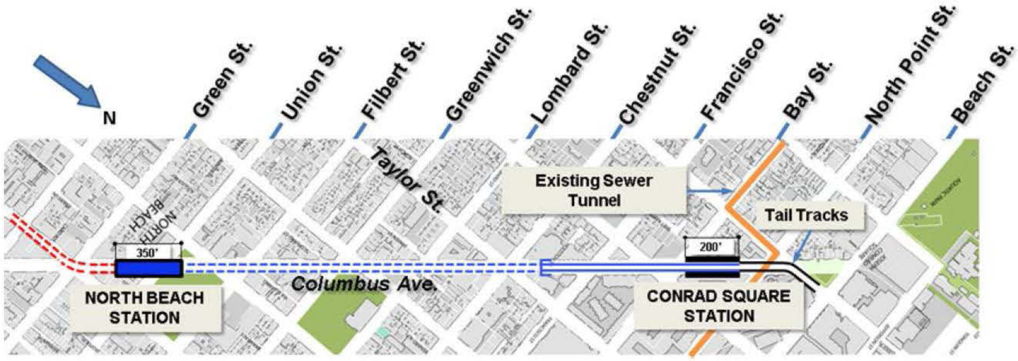
The FTA Capital Cost Database (CCD) was utilized to generate general Order of Magnitude estimates for each alternative and option (sub-alternative). The FTA CCD contains "as-built" costs for a sample of light and heavy rail projects, with project costs and unit quantities recorded at the Standard Cost Categories (SCC) level of detail (See Appendix D for SSC definitions).

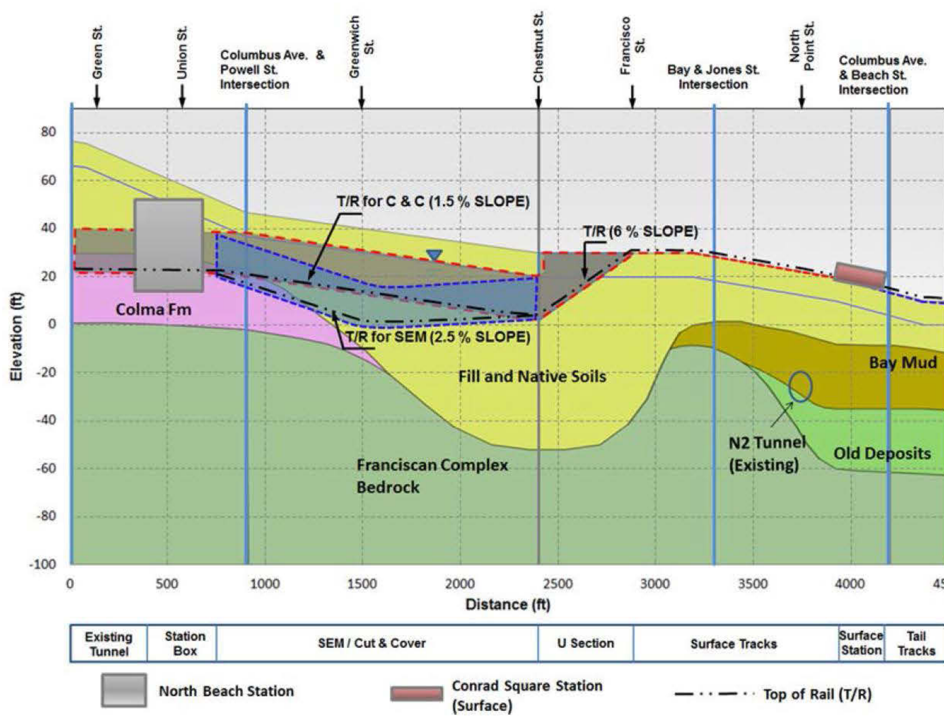
It should be noted that in addition to the schemes of 3 categories of different alternatives and their sub-alternatives, the fourth category was added to capture the costs of North Beach Station in case it is decided that this station is built first as part of a potential first operating segment. As such, North Beach Station is estimated as cut and cover box (includes opening the street) and as a cavern using segmental excavation method (SEM, a tunneling method performed without opening the street similar to Chinatown Station of T Third Phase 2 project).

The costs are in 2014 dollars, adjusted locally to San Francisco, CA and to size and scope of each alternative and option (sub-alternative). In addition, some of the unit costs were adjusted manually to reflect recent bid prices for tunnel work in the San Francisco area. All costs are based on the total lineal miles of surface or underground guideway, as applicable, including necessary tail tracks as required. Soft costs were added at 49% to account for Professional Services. Finally, a range of values was generated based on FTA guidelines of Probable Accuracy (see the enclosed exhibits in Appendix D for guidelines).

Appendix A
Constructability Analysis Summary Matrix

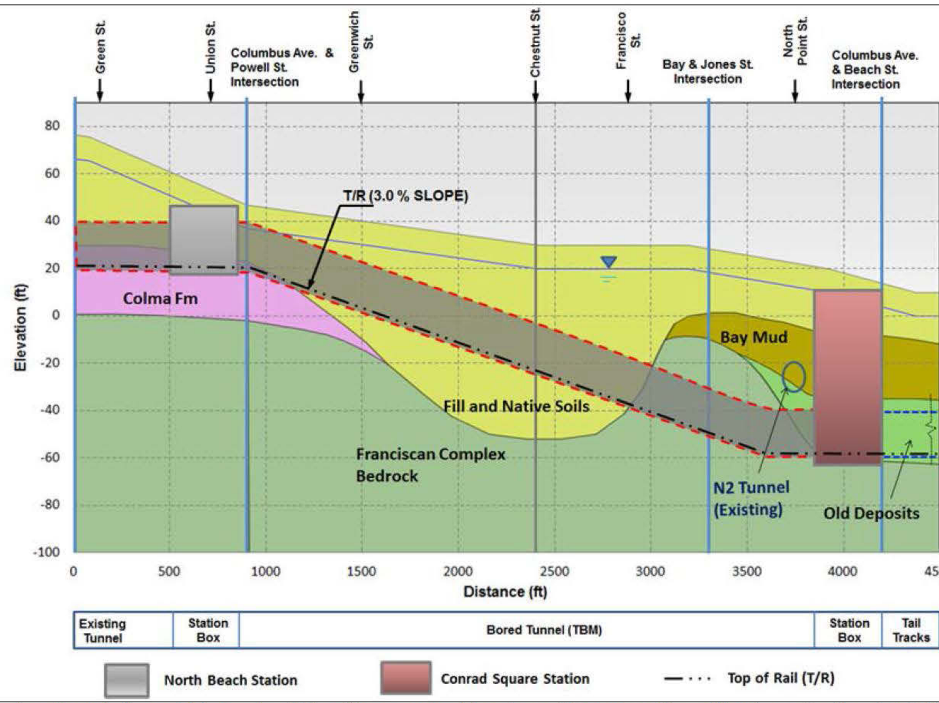
Alt. No.	PLAN AND PROFILE	SCORE
		4
1-1	(see plan and profile below)	





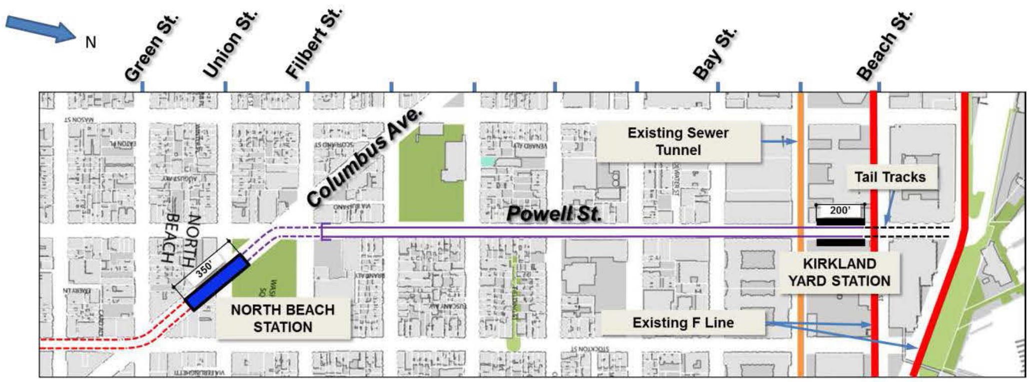
Summary: The shallow tunnel alignment is constructible-- south of Chestnut/Columbus intersection it could be provided as cut and cover (with more traffic/utilities/surface impacts) or sequential excavation method (SEM) without opening the street. Due to relatively high groundwater level observed at Pagoda site it is possible that ground improvement will be performed from the street to control the water within the excavated SEM openings (with some traffic/street disruption). The portal could be placed north of Chestnut St intersection. The SEM tunnels would likely proceed from North Beach station shaft using Pagoda site. Water, electric, sewer, gas, communication utilities would need to be relocated within the C&C and U-section area north of the portal. Detailed instrumentation/monitoring program would need to be implemented for streets/buildings/utility settlement/vibration/air monitoring. There is a possibility the buried wooden piles supporting utilities could be encountered along the shallow tunnel alignment or within the U-section. No impact for 100-year flood event is anticipated. See Risks Matrix Table 4.1.1.for other subsurface risks. It should be noted that surface station at Conrad Sq may produce long term impacts in terms of traffic congestion, noise, vibration, real estate etc. It should also be noted that for a future westward tunnel extension, a double stub tunnels should be constructed west from the North Beach Station.

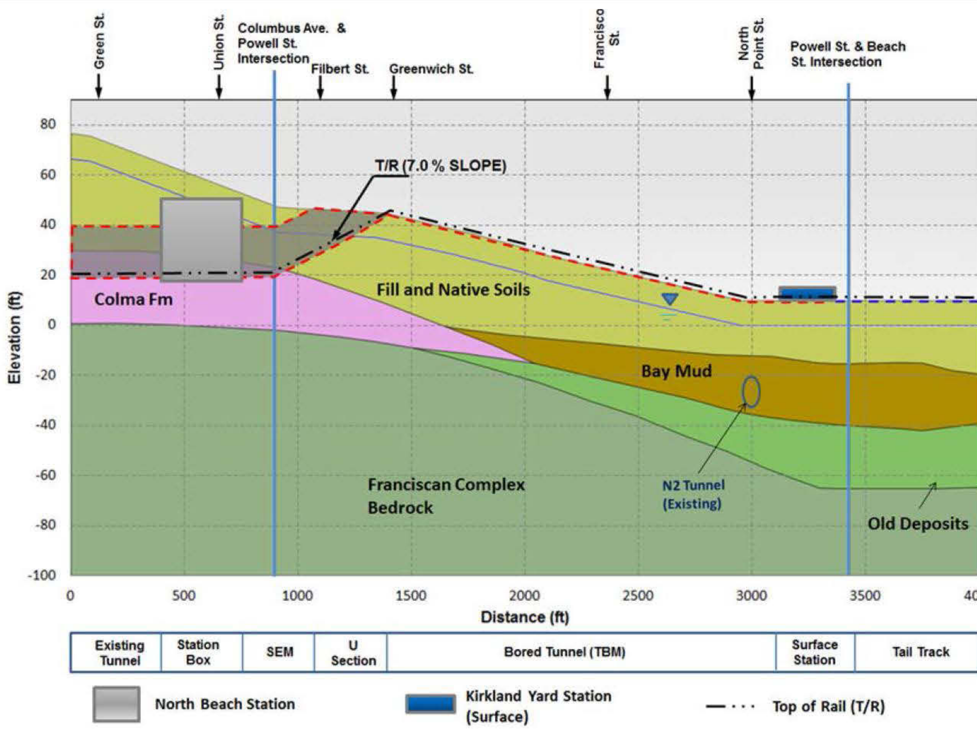
<table>
<tr><td rowspan="2">Alt. No.</td><td rowspan="2">PLAN AND PROFILE</td><td>SCORE</td></tr>
<tr><td>5</td></tr>
<tr><td>1-2</td><td colspan="2">

</td></tr>
<tr><td colspan="3">Summary: The deep tunnel alignment is constructible with pressurized face tunnel boring machine without opening the street. The tunnels would need to avoid impacting existing sewer tunnel beneath North Point Street. At least one cross-passage will be required beneath Columbus Avenue to meet NFPA 130 requirements. Due to relatively high groundwater level observed at Pagoda site it is possible that ground improvement will be performed from the street to control the water within the excavated SEM cross-passage opening with some traffic/street disruption. The construction would likely proceed from North Beach station shaft using Pagoda site. Detailed instrumentation/monitoring program would need to be implemented for streets/buildings/utility settlement/vibration/air monitoring. There is a possibility the buried wooden piles supporting utilities could be encountered along the tunnel alignment or within the station box construction. The station construction should provide for watertight support of excavation; excavation would likely proceed top-down under traffic deck with bottom-up build-out. Utilities within the station box construction/entrances/ventilation shafts would need to be relocated or supported in place. ROW would need to be identified for housing station entrances, emergency exits and ventilation shafts. Conrad Square station would need to include invert grouting for stability. Tunnels could be extended beyond Conrad Square station and later capped for future use. No impact for 100-year flood event is anticipated. See Risks Matrix Table 4.1.1.for other subsurface risks. It should be noted that for a future westward tunnel extension, a double stub tunnels should be constructed west from the North Beach Station. Subsurface obstructions in the tail track area were not evaluated and shall be part of a further study.</td></tr>
</table>

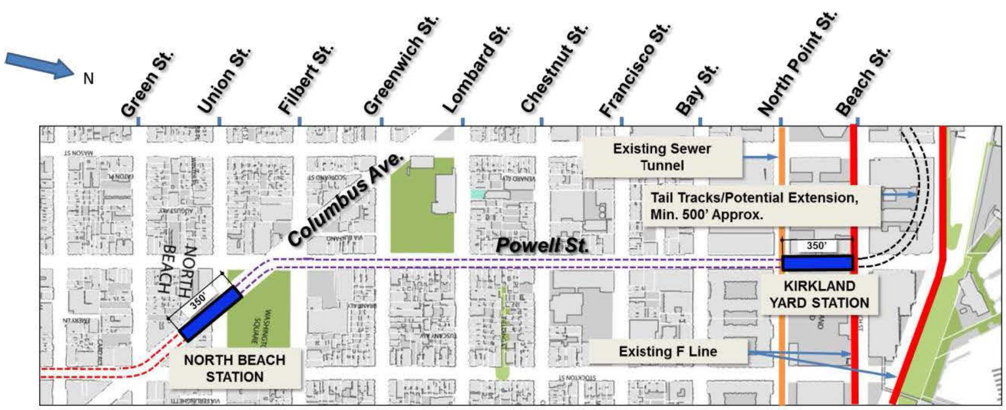
Alt. No.	PLAN AND PROFILE	SCORE
		3/4
2A-1		

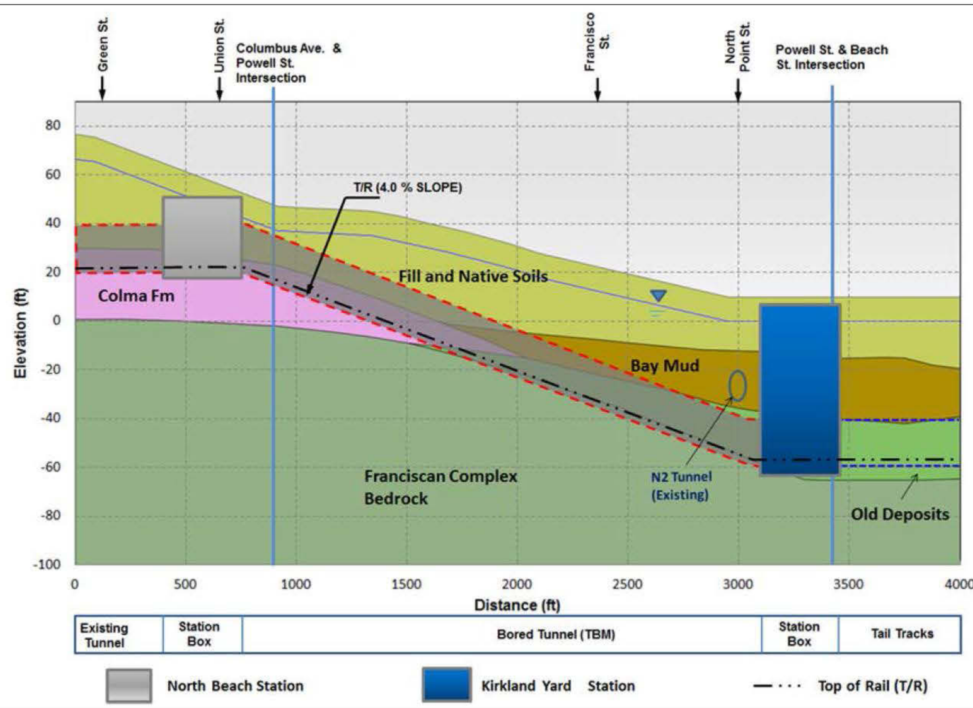




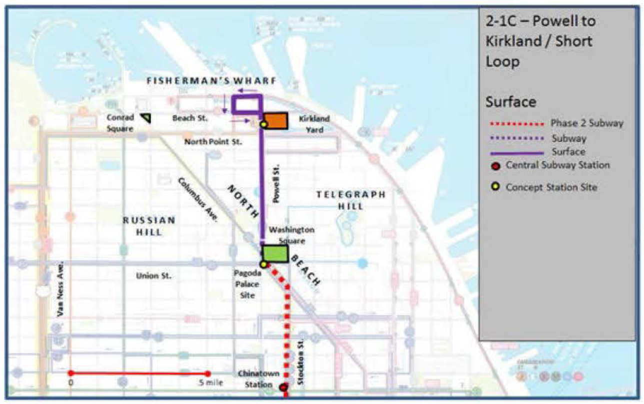
Summary: The narrow street shallow tunnel alignment is constructible—portal north of Filbert Street is possible; the tracks would surface within a U-section south Greenwich Street; the track grade to be raised to maximum allowed (7-8%). SEM or cut and cover methods could be used north of the station box construction. The C&C construction will impose more traffic/utilities/surface impacts; the SEM could be provided without opening the street (likely ground improvement will be performed from the street to control the water within the excavated SEM openings, with some traffic/street disruption). The SEM tunnels would likely proceed from North Beach station shaft using Pagoda site. Utilities would need to be relocated within the C&C and U-section area north of the portal. Detailed instrumentation/monitoring program would need to be implemented for streets/buildings/utility settlement/vibration/air monitoring. Buried wooden piles locations need investigation. Approx. 10% of the alignment will be flooded during 100-yr flood. See Risks Matrix Table 4.1.1.for other subsurface risks. *Surface station to produce impacts in terms of traffic, noise, vibration, real estate etc.*

Alt. No.	PLAN AND PROFILE	SCORE
		4
2A-2		

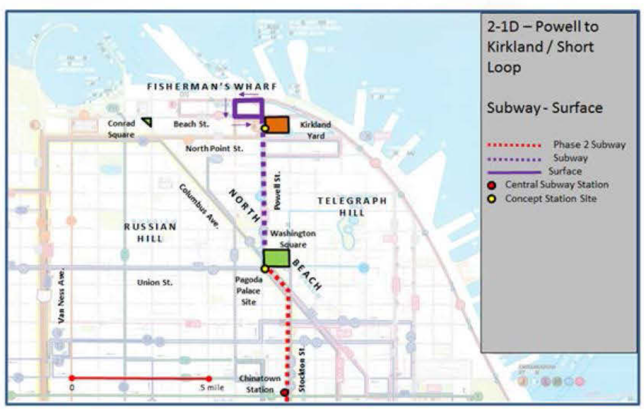




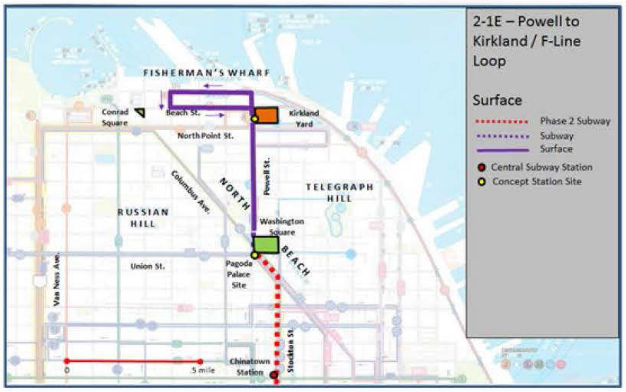
Summary: The deep tunnel alignment is constructible with PF TBM. The tunnels would need to avoid impacting existing sewer tunnel beneath North Point Street. The construction would likely proceed from North Beach station shaft using Pagoda site. Detailed instrumentation/monitoring program would need to be implemented for streets/buildings/utility settlement/vibration/air monitoring. There is a possibility the buried wooden piles supporting utilities could be encountered along the tunnel alignment or within the station box construction. The station construction should provide for watertight support of excavation; excavation would likely proceed top-down under traffic deck with bottom-up build-out. Utilities within the station box construction/entrances/ventilation shafts would need to be relocated or supported in place. ROW would need to be identified for housing station entrances, emergency exits and ventilation shafts. Kirkland Yard station would benefit from the yard availability for ancillary facilities; it would need to include invert grouting for stability. Tunnels could be extended beyond KY station and later capped for future use. No impact for 100-year flood event is anticipated if proper measures are implemented to station design. See Risks Matrix Table 4.1.1.for other subsurface risks. Subsurface obstructions in the tail track area were not evaluated and shall be part of a further study.

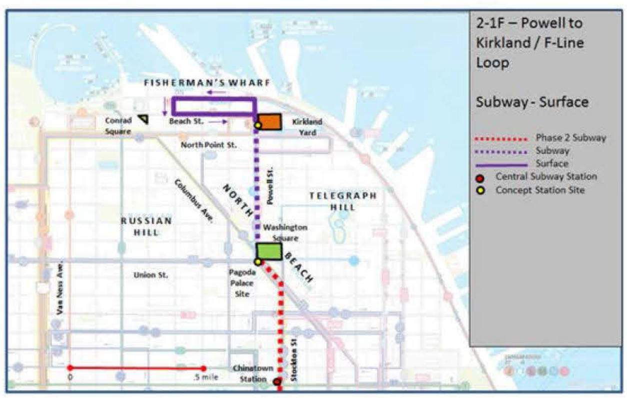
Alt. No.	PLAN AND PROFILE	SCORE
		3/4
2A-3		

Summary: Alternative similar to 2-1A for constructability aspects. Traffic feasibility of northern surface loop not considered.

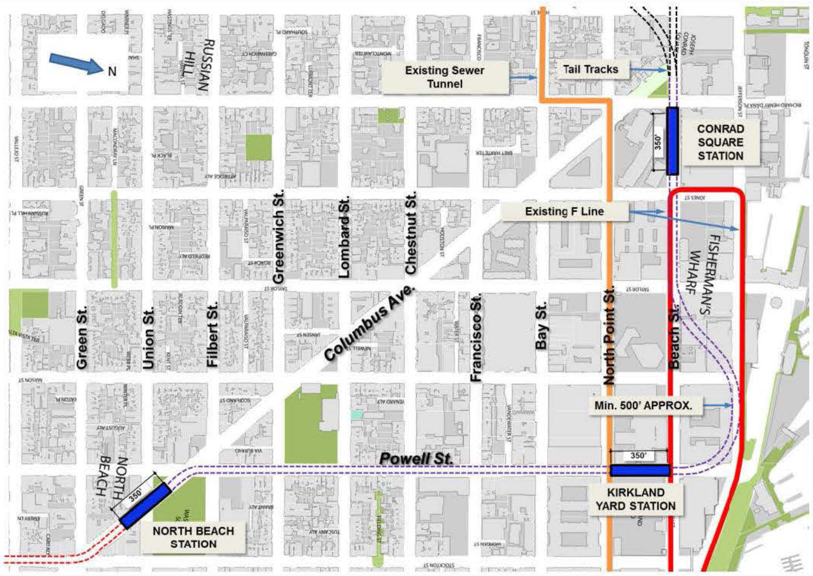
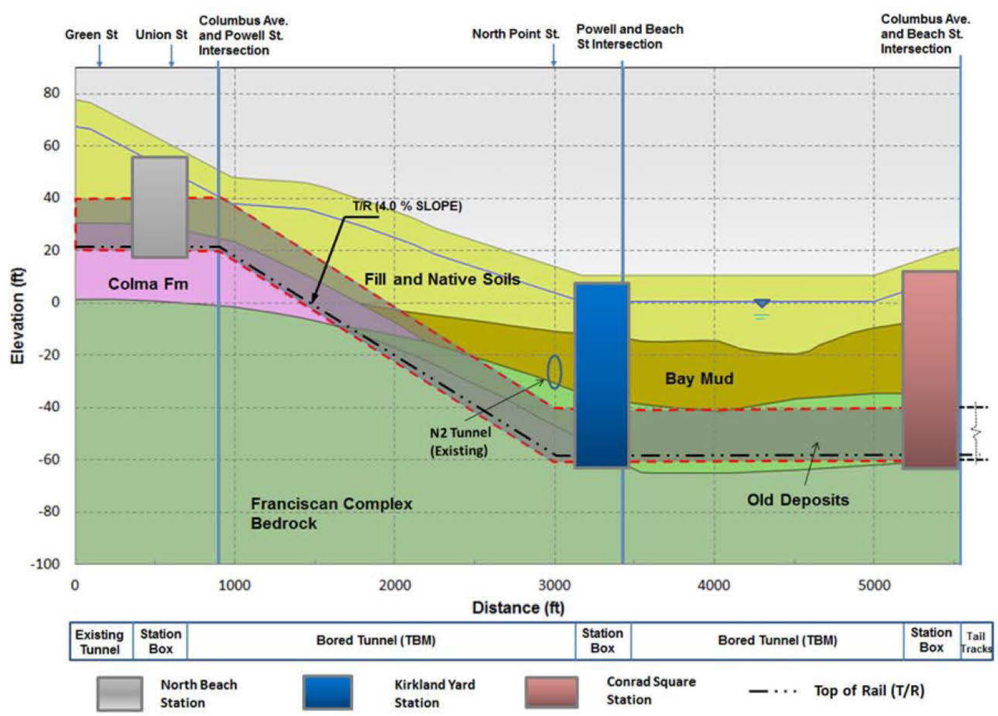
Alt. No.	PLAN AND PROFILE	SCORE
		2
2A-4		

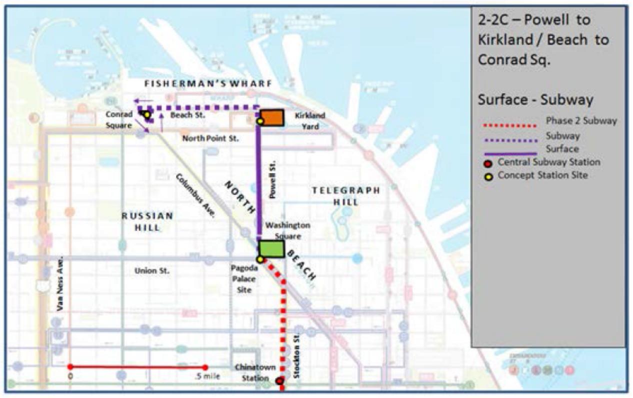
Summary: In terms of tunneling using TBM methodology, alternative not feasible due to anticipated sudden grade change at Kirkland Yard Station and the fact that the tunnel need to be beneath the existing N2 sewer tunnel to avoid impacts. Shallow cut and cover or SEM construction along the entire Powell Street may be possible and needs to be investigated due to limited cover available at northern part of Powell street; it would entail (C&C)--decked construction, relocation and support of utilities and increase of street construction impacts; for (SEM)—ground improvement would need to be implemented extensively to control the excavation from the street impacting traffic, utilities. Monitoring program would be extensive.

Alt. No.	PLAN AND PROFILE	SCORE
		3/4
2A-5		
Summary: Alternative similar to 2-1A for constructability aspects. Traffic feasibility of northern surface loop not considered.		

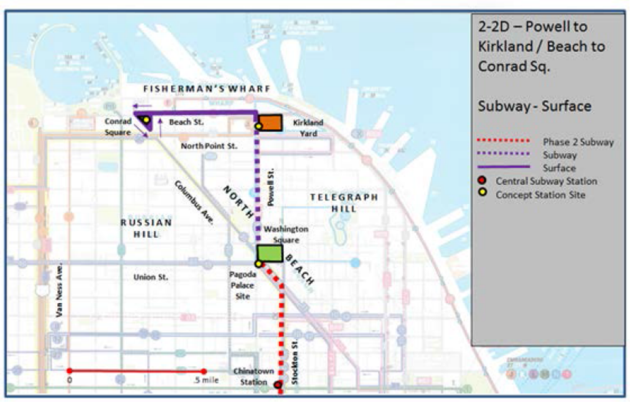
Alt. No.	PLAN AND PROFILE	SCORE
		2
2A-6		
Summary: In terms of tunneling using TBM methodology, alternative not feasible due to anticipated sudden grade change at Kirkland Yard Station and the fact that the tunnel need to be beneath the existing N2 sewer tunnel to avoid impacts. Shallow cut and cover or SEM construction along the entire Powell Street may be possible and needs to be investigated due to limited cover available at northern part of Powell street; it would entail (C&C)--decked construction, relocation and support of utilities and increase in street construction impacts; for (SEM)—ground improvement would need to be implemented extensively to control the excavation from the street impacting traffic, utilities. Monitoring program would be extensive.		

<table>
<tr><td rowspan="2">Alt. No.</td><td rowspan="2">PLAN AND PROFILE</td><td>SCORE</td></tr>
<tr><td>3/4</td></tr>
<tr><td>2B-1</td><td colspan="2">
</td></tr>
<tr><td colspan="3">**Summary:** Alternative similar to 2-1A for constructability aspects. Traffic feasibility of Conrad Square surface loop not considered.</td></tr>
</table>

Alt. No.	PLAN AND PROFILE	SCORE 4
2B-2	 	
Summary: Alternative similar to 2-1B for constructability aspects. Conrad Station is similar to Kirkland Yard station for constructability aspects. Better machine utilization (tunnel cost is less per linear foot), possibility to extend the alignment further west. Providing for tail tracks would require an additional machine retrieval shaft at the western end of the alignment. Subsurface obstructions north of Kirkland Yard Station were not evaluated and shall be part of a further study.		

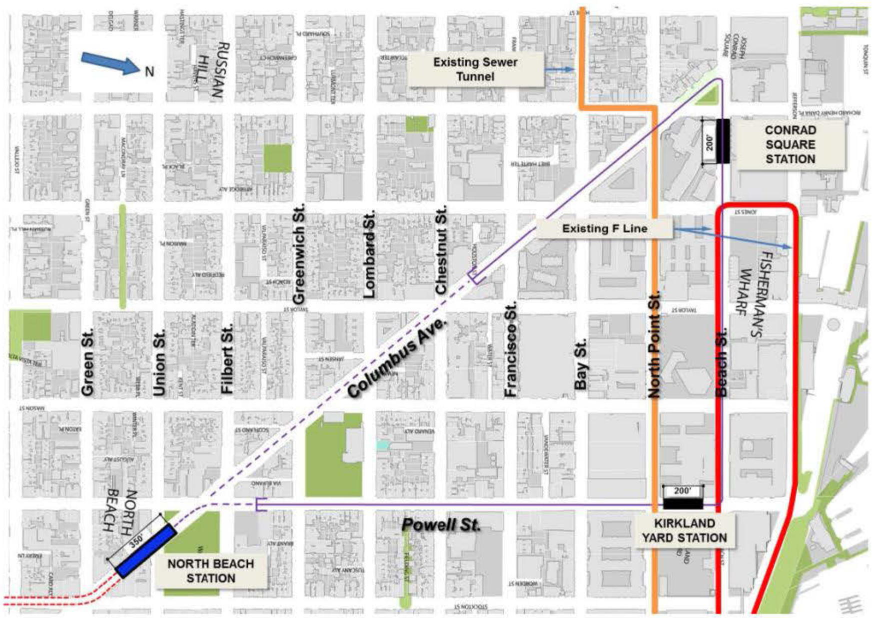
Alt. No.	PLAN AND PROFILE	SCORE
		1
2B-3		

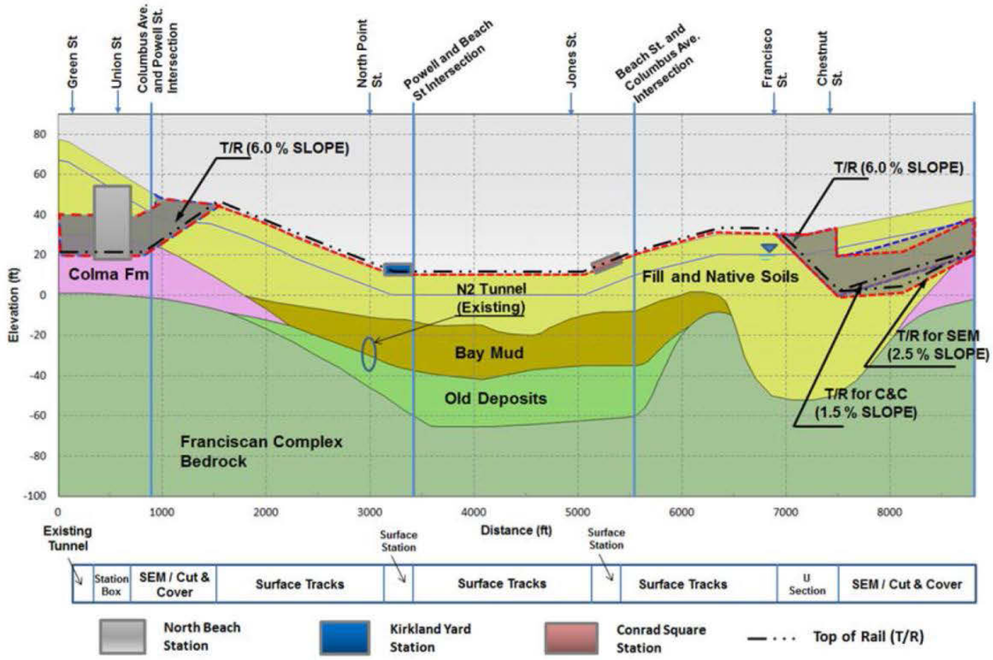
Summary: In terms of tunneling using TBM methodology, alternative not feasible due to anticipated sudden grade change at Kirkland Yard Station. Shallow cut and cover or SEM construction along the entire Beach Street may be possible and needs to be investigated; however, the alignment would need to transition into a subsurface alignment south of Kirkland Yard station causing grade separation at North Point and possibly Bay Street intersections. The construction would entail: (C&C)--decked construction, relocation and support of utilities and increase in street construction impacts; for (SEM)—ground improvement would need to be implemented extensively to control the excavation from the Beach Street impacting traffic, utilities. Monitoring program would be extensive. To provide for an underground loop under Conrad Square the entire zone would need to be excavated and decked over causing the extensive traffic/ utility impacts and monitoring program.

Alt. No.	PLAN AND PROFILE	SCORE
		2
2B-4		

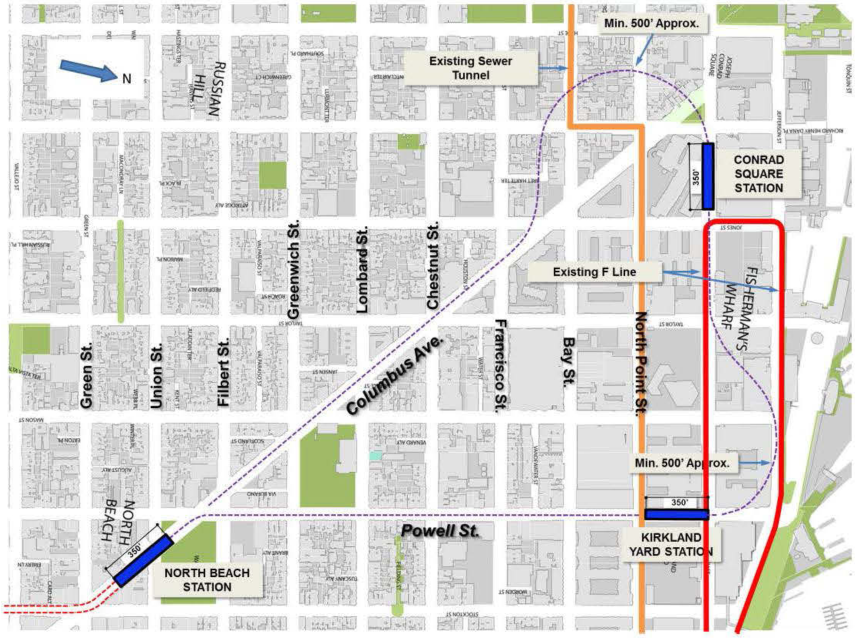
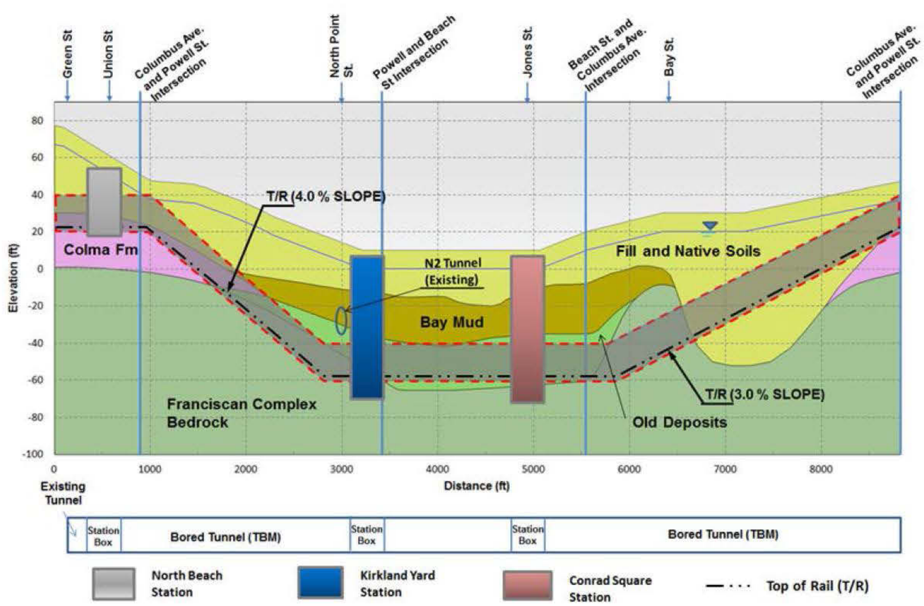
Summary: In terms of tunneling using TBM methodology, alternative not feasible due to anticipated sudden grade change at Kirkland Yard Station and the fact that the tunnel need to be beneath the existing N2 sewer tunnel to avoid impacts. Shallow cut and cover or SEM construction along the entire Powell Street may be possible and needs to be investigated due to limited cover available at northern part of Powell street; it would entail (C&C)--decked construction, relocation and support of utilities and increase in street construction impacts; for (SEM)—ground improvement would need to be implemented extensively to control the excavation from the street impacting traffic, utilities. Monitoring program would be extensive.

Alt. No.	PLAN AND PROFILE	SCORE
		3
3-1		

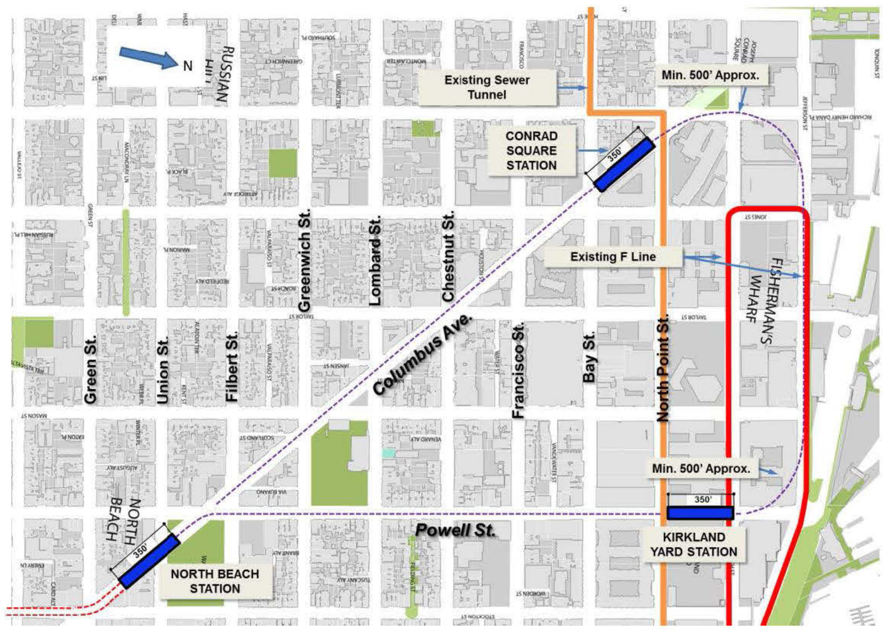


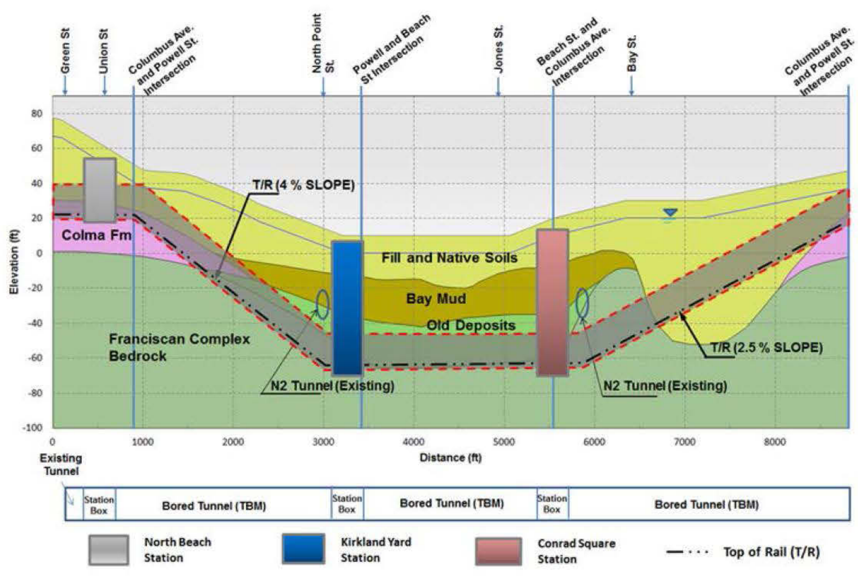


Summary: Constructability impacts similar to alternatives 1-1 and 2-1A. Surface station location at Conrad Square needs to be investigated further. 20-30% of the northern surface alignment would be flooded during 100-year flood event.

Alt. No.	PLAN AND PROFILE	SCORE 3/4
3-2A	 	
Summary: Constructability impacts similar to alternatives 1-2 and 2-1B. TBM machine utilization is better and possibly could be retrieved at Pagoda site leaving a connection tunnel to be excavated by SEM. Providing flood protection measures are implemented at station entrances at Conrad and Kirkland Yard stations, no 100-year flood impact is anticipated. Limited opportunity to extend northern alignment to the west. Subsurface obstructions beneath existing buildings were not evaluated and shall be part of a further study.		

Alt. No.	PLAN AND PROFILE	SCORE
		4
3-2B		





Summary: Constructability impacts similar to alternatives 1-2 and 2-1B. TBM machine utilization is better and possibly could be retrieved at Pagoda site leaving a connection tunnel to be excavated by SEM. Providing flood protection measures are implemented at station entrances at Conrad and Kirkland Yard stations, no 100-year flood impact is anticipated. Limited opportunity to extend northern alignment to the west. Subsurface obstructions along Jefferson Street were not evaluated and shall be part of a further study.