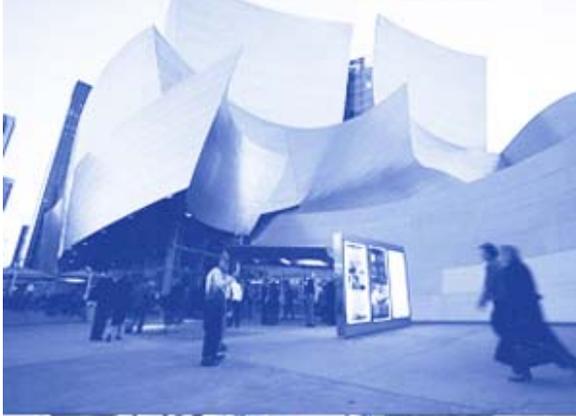


**APPENDIX A**

**DRAFT FLOWER STREET TUNNELING METHOD  
ALTERNATIVES REPORT**



# REGIONAL CONNECTOR TRANSIT CORRIDOR PROJECT

## Draft Flower Street Tunneling Method Alternatives

Prepared for:



**Metro**

Prepared by:

**The Connector Partnership  
432 East Temple Street  
Los Angeles, California 90012**

The Connector Partnership



### Review Copy

	Date	Initials
Originator	7/2/2014	JC/DD/XY
Checker	8/19/2014	WHH
Back checker (for Final)		JC/DD/XY
Approved by		JSP

August 19, 2014

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## **1.0 PREFACE**

The Connector Partnership Joint Venture (CPJV), engaged by Los Angeles County Metropolitan Transportation Authority (LACMTA), conducted a tunnel feasibility and environmental assessment for Flower Street construction methods and alignment alternatives for the Regional Connector Transit Corridor Project. This effort was undertaken to evaluate feasibility of tunneling along Flower Street in response to community concerns about cut-and-cover construction impacts in this area.

This report builds on previous analysis to evaluate tunneling alternatives along Flower Street and supports preparation of a Supplemental Environmental Impact Statement (SEIS) for the Regional Connector Transit Corridor Project. The environmental assessment of the tunneling alternatives is conducted and discussed in the SEIS.

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Revision\Development for 8-19-2914\FlowerStreetTunnelingMethodAlternatives Updated Draft  
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## **2.0 EXECUTIVE SUMMARY**

In an effort to address concerns from the Financial District, regarding the potential construction impacts along Flower Street, the LACMTA Board, in April 2012, directed staff to examine various value engineering and cost saving methods to determine if certain specific construction methods and design features could be incorporated, to mitigate potential construction impacts along Flower Street, without causing an increase to the Life of Project (LOP) budget. The Board further directed staff that, if the analysis determined that the methods exceeded the LOP budget, the construction methods and design features should be included, as bid options, during the construction procurement to allow design-build proposers a process to include each feature and determine if it could be accomplished within the LOP budget.

At the time of the April 2012 Board Meeting, the Flower Street mitigation method under consideration was referred to as the “Low Alignment.” This alignment, with a deeper segment between 4<sup>th</sup> and 5<sup>th</sup> Streets, would extend pressurized-face TBM tunneling from the Baseline termination, at south of 4<sup>th</sup> Street, to a point south of 5<sup>th</sup> Street, which would subsequently reduce the length of the cut-and-cover section with street decking system along Flower Street. The Low Alignment was considered as Alternative B in this study.

The Baseline and two alternatives have been evaluated in this study in order to fully respond to stakeholders concerns for tunneling alternatives along Flower Street. The Baseline consists of earth pressure balance machine (EPBM) tunneling to south of 4<sup>th</sup> Street and the cut-and-cover with street decking system to the 7<sup>th</sup>/Metro Center Station along the Locally Preferred Alternative (LPA) vertical profile. Alternative A would extend tunneling south to the 7<sup>th</sup>/Metro Center Station along the LPA profile through the use of a combination of EPBM, open-face shield tunneling, and sequential excavation method (SEM) construction techniques in series. Alternative B would extend tunneling south toward the 7<sup>th</sup>/Metro Center Station along a lower profile (Low Alignment) through the use of a combination of EPBM and SEM construction technique. Both Alternatives A and B would minimize cut-and-cover construction, limiting it to the tie-in with the 7<sup>th</sup>/Metro Center tail tracks and street-surface exit shafts.

It was determined based on this study that it is not feasible to use pressurized-face tunnel boring machines (Earth Pressure Balance Machines [EPBM]) for tunneling where tiebacks are present. Unacceptable risks of excessive subsidence from ground loss are associated with open-face shield and SEM tunneling in mixed face geologic conditions with the tieback obstructions. The substantial amount of drilling from the ground surface for ground improvement by grouting that would be required to mitigate the hazard of mixed-face conditions and tiebacks would negate the benefit intended of avoiding street surface impacts by tunneling.

This study supports the environmental assessment presented in the Supplemental Environmental Impact Statement (SEIS). Based on this environmental assessment, no changes to the Project are being recommended. The assessment demonstrates that there are a variety of construction, operation, cost, and schedule concerns that make the tunneling alternatives infeasible, and that while some environmental impacts may be reduced along Flower Street, other impacts are similar along Flower Street and/or shifted to the other end of the alignment, in Little Tokyo area, which is an environmental justice community.

## 3.0 DEVELOPMENT OF PROJECT CONFIGURATION

The project configuration on Flower Street between 2<sup>nd</sup>/Hope Station and the existing Blue Line tail tracks at 7<sup>th</sup>/Metro Center Station has progressed from preparation of the Draft Environmental Impact Statement/Draft Environmental Impact Report (DEIS/DEIR) through the Final Environmental Impact Statement/Final Environmental Impact Report (FEIS/FEIR). From the engineering perspective, the work encompassed Conceptual Engineering, Advanced Conceptual Engineering, and Preliminary Engineering.

### 3.1 Conceptual Engineering and DEIS/DEIR October 2010

The project went through a number of design iterations, which have been significantly influenced by mitigation measures in the environmental process. This section presents the design and construction methods carried in the project at the conclusion of Conceptual Engineering and preparation of the DEIS/DEIR.

The DEIS/DEIR alignment under Flower Street included a pocket track between 3<sup>rd</sup> and 4<sup>th</sup> Streets and an underground station between 4<sup>th</sup> and 5<sup>th</sup> Streets. Both elements would require large cut-and-cover excavation over long sections of the alignment along Flower Street. The combined length and arrangement of these major structures and the cut-and-cover connection to the existing 7<sup>th</sup>/Metro Center structure left only short construction sections deemed not practical or cost effective to construct by tunneling. This left no practical section of the alignment to be constructed by tunneling, either by conventional tunneling techniques or pressurized-face Tunnel Boring Machines (TBM). See Sections 4.3, 4.4, and 4.6 for the descriptions of different tunneling techniques. Therefore, a cut-and-cover construction scheme was developed for this part of the Regional Connector project as has been typical for the underground station sites on the Los Angeles Metro system, including the existing 7<sup>th</sup>/Flower Street Blue Line tail tracks.

An additional construction consideration along Flower Street at the time of the DEIS/DEIR preparation is the existence of tiebacks that were abandoned in place after construction of many of the adjacent buildings along the Flower Street portion of the alignment. Use of tiebacks that extend into the public right-of-way was permitted upon approval by the City of Los Angeles for construction of the buildings. The tiebacks were used to temporarily support the ground for excavations required to construct the building foundations, or other underground structures, such as the ARCO Plaza (505 and 515 South Flower Street), 444 South Flower Street, Bank of America, Westin Bonaventure Hotel, and the Library Parking Garage.

Cost of transit structure is minimized by having the stations and tunnels deep enough to avoid existing utilities and to permit construction of the station in accordance with LACMTA standards with a concourse (mezzanine). However, in the case of Flower Street, the tunnel profile (depth below street) was dictated by the tie-in elevation to existing track at 7<sup>th</sup>/Metro Center Station and the minimum depth required for the 5<sup>th</sup>/Flower Station to be under the existing utilities. Also, the foundations for 4<sup>th</sup> Street ramps (bridge structures) placed a limit on tunnel depth to avoid impacting the existing drilled shaft bridge foundations. Alternative construction methods were not credible for this area, i.e. tunneling by pressurized-face TBMs at this shallow depth would encounter numerous tieback obstructions; and tunneling by SEM (see Section 4.4) would have greater risks.

Tunnel construction using a pressurized-face TBM was identified in conceptual engineering to be used only between the 2<sup>nd</sup>/Hope Station and the 1<sup>st</sup>/Central Station. Direction of tunneling

and associated environmental impacts had not been determined at that time. The direction of the tunnel drive would be either from west to east from 2<sup>nd</sup>/Hope Station or east to west from a shaft in 2<sup>nd</sup> Street between Central and San Pedro Streets.

In summary, during the conceptual engineering, the cut-and-cover method was considered to facilitate removal of existing tiebacks that are known to be present on Flower Street with the least cost and schedule impacts. Alternative construction methods, such as open face shield tunneling, were reviewed but rejected. See Section 4.8 for more description of tiebacks and their relevance to feasible construction methods on Flower Street. Cut-and-cover was determined to be the most appropriate construction method for the alignment between 3<sup>rd</sup> Street (2<sup>nd</sup>/Hope Station) and the tie in to the 7th/Metro Center Station.

On October 28, 2010, the LACMTA Board accepted the Draft EIS/EIR for the Regional Connector Transit Corridor and designated the Locally Preferred Alternative (LPA) as the Fully Underground LRT Alternative, which was used in the Baseline and Alternative A alignments described in this report. At that time the 5<sup>th</sup>/Flower Street Station was eliminated from the project definition due to cost considerations. However, the Board further stipulated the design and alignment should not preclude future construction of a 5<sup>th</sup>/Flower Street station.

### **3.2 Advanced Conceptual Engineering March 30, 2011**

Implementing LACMTA Board direction, the Advanced Conceptual Engineering design was revised to eliminate the 5<sup>th</sup>/Flower Street Station, but did not preclude its construction in the future. The track alignment through the 2<sup>nd</sup>/Hope Station was refined to use larger radius curves that would improve rail operations and also allow for TBM tunneling through the station area. At the same time, the pocket track was moved to south of 4<sup>th</sup> Street. This allowed the TBM tunneling to be extended south to 4<sup>th</sup> and Flower Streets, thereby reducing the amount of cut-and-cover construction and increasing tunneling to reduce cost by optimizing usage of the pressurized-face TBM.

The continuation of pressurized-face TBM construction south of 4<sup>th</sup> Street was precluded by the presence of abandoned tiebacks south of 4<sup>th</sup> Street, the need for a box structure for a crossover, and the fixed elevation of the existing rail at the 7<sup>th</sup>/Metro Center tail tracks. As was the case for Conceptual Engineering (Section 3.1), the combined length and arrangement of these major structures left only short construction sections deemed not practical or cost effective to construct by tunneling.

During Advanced Conceptual Engineering, the presence of tiebacks on Flower Street continued to be recognized as a hazard for pressurized-face tunneling. As stated above, extending pressurized-face TBM tunnel to just south of 4<sup>th</sup>/Flower Streets was limited by the presence of tiebacks associated with construction of the Westin-Bonaventure Hotel. Had there been no tiebacks, or if tiebacks would have not been encountered by pressurized-face TBM tunneling (the tiebacks being either below or above the tunnel), the tunnel would have been extended. Such was not the case. See Section 4.8 for the full discussion of tiebacks and how their presence negatively affects the feasibility of tunneling and the great risks if attempting to tunnel through tiebacks.

In summary, a result of the refinements during Advanced Conceptual Engineering, major project configuration changes were:



- No station at 5<sup>th</sup>/Flower (but did not preclude future station construction)
- Pocket Track moved to south of 4<sup>th</sup> Street
- 2<sup>nd</sup>/Hope Station track geometry revised (horizontally and vertically) for operations and tunneling
- Pressurized-face TBM tunneling extended to south of 4<sup>th</sup> Street bridge (south of 4<sup>th</sup> and Flower Street intersection)

### **3.3 Draft (June 29, 2011) and Pre-Final (September 29, 2011) Preliminary Engineering (PE) Submittals**

Project advancements and value engineering (VE) further refined the project configuration. As a specific VE recommendation to reduce costs, the rail elevation and station platform were raised at the 2<sup>nd</sup>/Hope Station by approximately 14 ft. The station depth reduction saved construction cost with shorter construction time, less excavation support, and significantly less station structure with one less flight of long escalators for this deep station.

LACMTA also determined that a pocket track for car storage was not required within the subsurface area of the project alignment. A possible storage track location was identified at Division 21, which is located north of the Metro Gold Line Chinatown Station. Eliminating the pocket track narrows the width of cut-and-cover construction from 4<sup>th</sup> Street to the 7<sup>th</sup>/Metro Center Blue Line tail tracks by several feet thus reducing potential construction impacts on Flower Street. LACMTA considered reducing construction impacts further by eliminating the underground cross over. However, crossovers are still required within the Flower Street section of the project to mitigate service delays to allow LACMTA to manage the operational impacts of disabled trains and track maintenance.

During this time, to address the cost, construction duration, and impact on the community, a raised deck over the cut-and-cover excavation was reviewed to minimize relocations of existing utilities. In addition in response to community concerns, LACMTA limited the height to approximately 10 inches that the “raised deck” could be constructed above the existing roadway. The low raised deck has less impact to adjacent properties and maintenance of street use. At the same time, design development eliminated construction work areas on private properties and work staging was restricted to the public right-of-way. Some work on adjacent properties would be needed to construct and maintain access at driveways and entryways, but by temporary easements, or rights of entry, rather than permanent “takes.”

The Pre-Final PE Submittal of September 29, 2011 was the project configuration that LACMTA issued for Industry Review on October 20, 2011.

In summary, changes incorporated in the Pre-Final PE September 29, 2011 were as follows:

- Pocket track no longer on Flower Street
- Crossover (previously part of pocket track) on Flower Street located south of 5<sup>th</sup> Street
- Raised 2<sup>nd</sup>/Hope Station by 14 ft



- “Raised decking” along Flower Street limited in height, which reduced overall Flower Street construction impact and activity, while maintaining significant reduction in utility relocations and associated impacts.
- Modified construction staging areas to reduce private property easement requirements

### **3.4 Draft Final PE December 20, 2011**

Station designs were refined to site-specific conditions, which included establishing street and traffic layouts in the 2<sup>nd</sup>/Hope Street Station area. Design/build technical requirements (performance specifications) were drafted. Characterization of existing utilities and utility relocations were refined. No changes were made to the project configuration on Flower Street.

### **3.5 Final PE March 30, 2012**

The Final documents submitted March 30, 2012 did not change the configuration on Flower Street from the December 20, 2011 Draft.

### **3.6 PE and FEIS/FEIR**

During Preliminary Engineering and preparation of the FEIS/FEIR, four major changes established the project configuration and tunneling limits. LACMTA’s actions listed below document the fact that LACMTA considered and implemented changes that fine tuned the project configuration to further mitigate the construction impact to the public. This would result in the least public impact possible within the available budget.

First, the tunnel alignment was refined through Little Tokyo, resulting in a relocated station at 1<sup>st</sup>/Central Avenue. This new station site was initially proposed for the pressurized-face TBM tunnel shaft. In parallel with preparation of the FEIS/FEIR, the “Mangrove Site” at the northeast corner of 1<sup>st</sup> and Alameda Streets became available for a TBM tunnel work shaft when a development rights lease expired. As a mitigation of impact on the Little Tokyo community, the commitment was made by LACMTA that the Mangrove Site would be the main site for staging of tunneling operations. The pressurized-face TBMs would be assembled and launched from that site and tunneling would proceed to the west.

Second, two major structures, 5<sup>th</sup>/Flower Street Station and the pocket track, were not included in the preliminary design. As cost saving actions, the LACMTA Board eliminated the 5<sup>th</sup>/Flower Street Station when approving the Locally Preferred Alternative (LPA) (with the stipulation to not preclude future construction) and the pocket track was eliminated during PE. Deletion of these major structures reduced construction impact with a much narrower structure and reduced property takes or temporary construction easements along Flower Street.

Third, tunneling was extended south from the 2<sup>nd</sup>/Hope Street Station to 4<sup>th</sup> and Flower Streets where the TBMs would be removed through a shaft south of 4<sup>th</sup> Street. In addition to the mitigation of less construction impact, cost savings resulted from efficiencies with longer length of tunneling and avoiding the deep cut-and-cover construction between 3<sup>rd</sup> and 4<sup>th</sup> Streets. Tunneling also eliminated the impact of cut-and-cover construction to the community and reduced the construction impact to the 4<sup>th</sup> Street bridge foundations.

Fourth, during PE, LACMTA continued to search documentation of all tiebacks on Flower Street. LACMTA confirmed that hundreds of tiebacks currently exist in Flower Street that are

obstructions to tunneling, especially pressurized-face TBM tunneling. Existing records show the number of tiebacks along this segment as over 500 and potentially up to 800. (See Section 4.8 for more description of tiebacks and their relevance to feasible construction methods on Flower Street.) The major impacts from tieback obstructions for tunneling south of 4<sup>th</sup> Street were avoided by specifying construction by cut-and-cover. Due to the confirmed presence of numerous existing (abandoned) tiebacks along Flower Street south of 4<sup>th</sup> Street, the need for a box structure for a crossover, and the fixed elevation of the existing rail at the 7<sup>th</sup>/Metro Center tail tracks, pressurized-face TBM tunneling could not be extended farther south under Flower Street for the FEIS/FEIR alignment. This profile is presented in the FEIS/FEIR and in the Preliminary Engineering documents.

### **3.7 Record of Decision/ Procurement Documentation Pre-Construction Activities**

In June 29, 2012, the FTA issued a Record of Decision (ROD) for the project. The ROD includes further commitments to mitigate adverse effects of the project as it proceeds and are described in the Mitigation Monitoring and Reporting Plan (MMRP). Contract documentation was initiated to procure a design build contractor. Subsequent to the ROD, three parties along Flower Street submitted challenges to the EIS/EIR for the Regional

### **3.8 Procurement and Start of Construction**

Metro started procurement for a Request for Qualifications (RFQ) in 2012. Qualified teams were issued a Request for Proposals (RFP) on January 7, 2013. Construction Contract No. C0980 was Awarded May 6, 2014 and Notice to Proceed was July 7, 2014 and has started Final Design. Current construction activities include utility relocation by Contract No. C0981R along the project alignment. Mitigations are being implemented as appropriate per the MMRP to help minimize construction impacts.



## **4.0 MAJOR CONSIDERATIONS FOR CONSTRUCTION METHOD**

This section presents several engineering and practical construction topics addressed during development of the Regional Connector Transit Corridor Project configuration in general and specifically on Flower Street. Mitigation of environmental impacts is addressed in the FEIS/FEIR/SEIS.

Major factors considered were:

- Geologic Conditions (Section 4.1)
- Transit Structure Configuration (Operations) (Section 4.7)
- Underground Obstructions to Tunneling – Tiebacks (Section 4.8)
- Schedule (Section 6.0)
- Cost (Section 7.0)
- Risk (Section 8.0)

### **4.1 Geologic Conditions**

Along Flower Street, alluvium and fill materials overlie the Fernando Formation consisting primarily of weak to very weak clayey siltstone. The alluvial deposit consists of interlayered silty clays, sandy silts, clayey sands, and silty sands with some sand layers containing variable gravel and few cobbles. The fill consists of mixtures of gravel, sand, silt, and clay with construction debris. The depth of fill material varies along Flower Street with maximum fill depth estimated to be about 40 ft below ground surface. Occasional boulders are also present in the alluvium. The principle geologic conditions on Flower Street that control tunneling feasibility and risk are groundwater, geologic interface of different soil or weak rock strata, and hazardous gases.

Groundwater seepage at relatively shallow depths that ranged from approximately 15 to 35 ft below ground surface was encountered in historical borings drilled for many building sites adjacent to Flower Street between 5<sup>th</sup> and 7<sup>th</sup> Streets. Groundwater within the lower portion of the alluvial deposits, most probably perched above the Fernando Formation, has been reported at depths from approximately 18 to 27 ft below ground surface adjacent to Flower Street in the area between 2<sup>nd</sup> and 5<sup>th</sup> Streets, which is close to or within the tunnel horizon. Groundwater problems will be magnified at the Alluvium–Fernando interface. Before development of downtown Los Angeles, Flower Street was more recognizable as a natural drainage path (stream during rainfall) with seasonal variations of groundwater in the Alluvium. In present day, development has affected the groundwater regime as a result of cuts and fills altering the topography, paving streets, and constructing buildings with deep basements. However, groundwater is still anticipated to follow the ancient underground water course and pose problems for stability of open-face tunnel excavations.



Along Flower Street, the geologic interface of alluvial soils over the Fernando Formation (weak rock) is a recognized geologic tunneling hazard. If tunneling is fully below the geological interface and there is adequate Fernando Formation (one tunnel diameter, which is about 22 ft) between the tunnel and interface, there exists a reduced potential hazard. On the other hand, if the interface is just above the tunnel or within the face of the tunnel being excavated, the major hazard is the alluvial materials running uncontrolled into the tunnel. In the presence of ground water, this could cause an uncontrolled flow into the tunnel under construction. Both conditions are unacceptable risks that must be mitigated by grouting to create non-running/non-flowing ground conditions, or mitigated by using another method, such as pressurized-face TBM, which inherently can safely deal with such conditions.

Methane and hydrogen sulfide (H<sub>2</sub>S) are expected as described in the Geotechnical Baseline Report (GBR). Several sections of the tunnels are to be constructed through Methane Buffer Zones. Cal/OSHA has classified all of the underground construction for the Regional Connector as “potentially gassy.” Metro requires specific designs where gassy conditions are present. The use of EPBMs for tunneling and installation of a double gasketed segmental precast tunnel lining provides a robust barrier to resist entry of methane into the tunnels. SEM or open-shield tunneling would increase risks of hazardous gas for construction and likely require significant additional measures to mitigate these safety issues. An open-face shield allows hazardous gasses into the tunnel at the tunnel face. SEM has greater safety risk of gas on account of greater exposure to the excavated ground. Hazardous gases in a cut-and-cover excavation also need to be safely handled, but open excavation allows easier control of hazardous gases.

## **4.2 Cut-and-Cover Construction Method**

Cut-and-cover is the usually preferred method of constructing relatively large underground transit structures such as stations, crossovers, and pocket tracks. Becoming less so in current times, cut-and-cover has also been used extensively to construct relatively shallow running tunnels. The type of cut-and-cover construction along Flower Street is recognized to be a suitable method and has extensive precedent with construction of all major modern buildings in downtown Los Angeles, as well as transit stations.

On past LACMTA rail projects, the excavation support system consisted of braced soldier piles and lagging which minimized settlement of adjacent ground and facilities and accommodates utilities and traffic control requirements. An additional benefit of this method, which installs soldier piles in drilled holes at 6 to 8 ft spacing, is that the system can be revised to adapt to circumstances during construction, for instance, by changing soldier pile spacing. Cut-and-cover is the basis of construction on Flower Street in the FEIS/FEIR and for Preliminary Engineering.

The soldier piles are structural steel members placed in pre-bored (vertical) holes, which are then filled with concrete such that piles are encased in concrete. As excavation takes place, lagging is placed horizontally between the soldier piles. Traditional local Los Angeles practice is to use timber lagging. Lateral support is either by tiebacks where real estate conditions permit or by structural steel struts across the excavation.

Regardless of type of excavation support system, to minimize public disruption on the street surface, a precast concrete deck is installed over the excavation to maintain street traffic and allow construction activities beneath. The excavation support system provides temporary support for the adjacent ground until the permanent structure is constructed. After the

permanent cast-in-place concrete structures are completed, the deck beams are removed, the excavation is backfilled and the street is restored.

Cut-and-cover is relatively unaffected by the variations and uncertainty regarding the presence of man-made and natural obstructions and geologic conditions. Obstructions, in the form of abandoned tiebacks, can be dealt with directly as they are encountered during excavation. The geologic conditions along Flower Street are known to have perched groundwater and a distinct change in geologic strata consisting of fill and alluvium over weak rock. For cut-and-cover construction, past experience in downtown Los Angeles indicates groundwater can be managed by pumping from sumps in the excavation or, in rare instances, from dewatering wells. The presence of “weak rock,” which is generally stiffer than the alluvium, can be considered a positive condition for excavation stability where soldier piles would be founded within the relatively stiff Fernando Formation (the “weak rock”).

In summary, the existing tiebacks and geologic conditions pose no extraordinary challenges for cut-and-cover construction, whereas for tunneling, the variations and uncertainty regarding the presence of man-made obstructions (tiebacks) and geologic conditions pose substantial construction hazards as elaborated subsequently in this document.

### **4.3 Open-Face Shield Tunneling**

Tunnel construction with open-face machines (also called a “digger shield”) was considered for the Regional Connector but was rejected as not being a satisfactory method of construction to mitigate risks of uncontrolled settlement in this mixed face geologic profile (condition) along Flower Street (and anticipated in Little Tokyo).

Ground control hazards are always present when an open tunnel face is in alluvium and where water is present, or where a mixed face heading is present (alluvium over Fernando Formation). The ground at the heading of the open-face shield could become unstable and subject to unacceptable loss of ground, raveling, running, or flowing of disturbed soil uncontrolled into the tunnel face, all of which could result in surface subsidence. This was the case during the construction of the Metro Red Line A146 contract when the tunnel was constructed using the digger shield shown in Figure 4-1. In much of the alignment, the upper part of the tunnel encountered cohesionless sand which ran uncontrolled into the tunnel face and created a void ahead of and over the tunnel shield. A number of ground losses occurred during tunneling with volumes as great as 36 cubic yards, or more than the size of a full-size automobile. Significant surface settlement was avoided by a soil stabilization program consisting of holes drilled from the ground surface to backfill with concrete the voids created by the ground losses. The Red Line case serves as an example of what methods and risks LACMTA will not accept for future projects: Open-face tunnel shields and any project that would have to rely upon grouting from inside the tunnel for safe construction are now deemed to have unacceptable risk. To avoid this geologic hazard, ground improvement by grouting from the ground surface (“preconditioned ground” in the Tunnel Advisory Report) would be required as a risk mitigation measure. Such grouting is costly, time consuming to undertake, and would create substantial construction impacts at the surface (street level) that were intended to be avoided with tunneling.



Figure 4-1: Digger Shield Used to Construct Metro Red Line Contract A146 Tunnels



A characteristic of a digger shield is that, when an obstruction such as a tieback is encountered during tunneling, the tunnel face is accessible and the tieback can be removed in pieces manually by torch cutting or metal cut-off saw. Special powered equipment operated remotely by miners would likely be used to assist in tieback removal to some extent. Regardless of possible mechanized assistance, manual labor would be required and job-specific safety hazards would exist for tieback removal.

The heading of an open-face shield would need to remain stable for sufficient time without sloughing and raveling into the tunnel face to permit workers to safely remove some tiebacks. Generally, tiebacks are installed on a downward angle and are expected to run downward across the face of the tunnel shield. Where the tunnel face is in uniform ground conditions, a portion of a tieback that intersects in the upper part of the tunnel would be relatively easy to remove, compared to tiebacks at lower depth, on the basis there being the least amount of soil to excavate. On the other hand, any part of the tieback that intersects the open-face shield at the lower part of the tunnel would be buried; gaining safe access for miners would be difficult. To do so would require stopping tunneling and then manually excavating and supporting the tunnel face until the tieback can be manually dug out. The tunnel shield would be about 22 ft in diameter and the tunnel face requiring support would be as high as a two-story building.

A very difficult condition would exist where an open-face shield encounters the mixed-face condition of the Alluvium-Fernando geologic contact with perched water in the face of the tunnel. In this case an attempt to remove a tieback that intersects in the upper part of the tunnel would likely lead to an uncontrolled loss of disturbed soil and water into the tunnel, settlement, and possibly a sinkhole at the ground surface. Tunneling safely in such condition requires mitigation



by ground improvement of the Alluvium by grouting or other measures to create firm ground conditions. See Section 4.8.3 Tieback Hazard for Open Face Shield or SEM Tunneling.

Although open-face shield construction may be technically feasible, this method likely require soil stabilization from the street surface causing major disruption along Flower Street to locate a grout plant and manage (control) the grouting spoils. This would further complicate traffic management, have major impact on existing utilities, and potentially limit building access and have impacts similar to cut-and-cover construction.

Grouting from inside the tunnel is much more costly and is not considered to be a viable alternative to pre-grouting from the ground surface along Flower Street. Moreover, grouting from the tunnel face could not reliably provide the needed ground improvement beneath utilities, particularly the large storm drain, leaving “windows” of ungrouted soil which would become potential zones of unstable soil. Grouting from the tunnel face (from inside of the tunnel) will simply not provide the adequate ground improvement to ensure control of settlement for utilities and roadway surface.

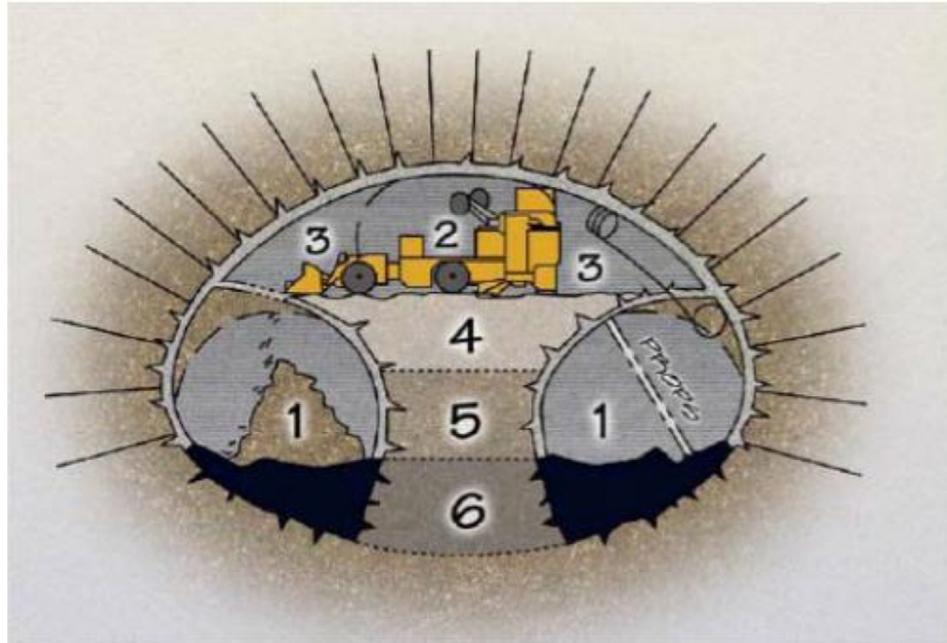
The above describes difficulties typically experienced when the soil in the face of the TBM is mostly loose water-bearing alluvium. Generally a mixed face condition (water bearing alluvium over Fernando Formation) is even more difficult to control because the alluvium tends to ravel and flow into the face on top of the more stable Fernando Formation. However, a much more risky situation is created when any unfavorable soil condition is encountered unexpectedly because the ground control measure being implemented cannot be changed quickly enough. It should be noted that the crown of the tunnel alignment discussed in this report is very close to the alluvium/Fernando interface creating a significant risk of hazardous conditions with uncontrolled soils coming into the tunnel resulting in excessive settlement and possibly creation of a sinkhole at the ground surface.

#### **4.4 Sequential Excavation Method (SEM)**

Another tunneling technique is the Sequential Excavation Method (SEM), which is used globally for underground construction. The excavation is performed by mechanical excavators in a prescribed sequence with the initial ground support typically consisting of sprayed-on concrete (shotcrete). Figure 4-2 shows a typical SEM excavation sequence.



Figure 4-2: Sequential Excavation Method (SEM) Tunneling



For safe SEM operations, it is desirable to have a competent layer of good ground as thick as the width of the tunnel over the tunnels, i.e., 20 ft of good ground above a 20 ft diameter transit (running) tunnel. Less cover and weaker soils greatly increase the risk of settlement and large ground loss resulting in runs and flowing of ground that rapidly rise to the surface and form sinkholes. In order to mitigate this risk, tunneling would require more ground modification and a greater number of excavation sequences with slower advance rates. Such situations typically also require the use of extensive pre-support measures, which include ground improvement and/or forepoling or spiling. Forepoling is a conventional, ground pre-support method to advance tunnels in loose, caving, or running ground by driving pipes, timbers, steel sections, or concrete slabs ahead of the tunnel excavation. Similarly, spiling is a ground pre-support method by installing untensioned reinforcement (spiles) in drilled holes. Spiles consist of deformed steel reinforcing bars, steel pipe, or self-drilling bars, grouted in place. They are typically installed without end hardware in a row or multiple overlapping rows above the tunnel crown at a low angle to the longitudinal axis of the tunnel. See Figure 4-6 showing an SEM excavation with a canopy of spiles created by jet grouting.

As shown in cross-section in Figure 4-9, Flower Street SEM excavation for the crossover may be as wide as 60 ft but will only have about 20 ft thickness or less of poor soil cover combined with close proximity to utilities and ground water in potentially gassy conditions making it a very high risk for excessive settlement, uncontrolled subsidence, or collapse. SEM relies upon the natural arching effect of the ground. Not much arching can be expected in Flower Street because of the low ground cover, poor ground, and existing utilities. Use of SEM would require major ground improvements and/or forepoling or spiling work, which would have major impacts on both Flower Street and the construction schedule.

Compared to constructing the Metro guideway tunnels by cut-and-cover on Flower Street, SEM construction has more risk. It is preferable to use SEM in deep alignments with adequate ground cover and favorable ground conditions, and where extensive ground modification is not



required. Typically, machine bored tunneling is chosen because of its rapid advance rates and efficiency in long runs; whereas, the slower SEM method is considered for short runs and excavation of non-circular shapes. In another area of the Regional Connector project along 2<sup>nd</sup> Street, the track crossover cavern is fully within the Fernando Formation (with Fernando cover of approximately 35 ft above the tunnel crown), which makes use of SEM for construction at that location possible with acceptable risk.

## **4.5 Ground Improvement and Tunneling**

Ground improvement is the general term used for the construction methods that make poor soil conditions stronger and/or less pervious. Poor soils include pervious soils below the ground water table and weak or loose soils. Where poor soils conditions are present, successful tunneling often relies on various methods to “improve the ground” in order to reduce or eliminate many risks associated with tunneling in such conditions. Implemented before tunneling, the ground improvement methods are either grouting or freezing:

- Permeation Grouting
- Jet Grouting
- Ground Freezing

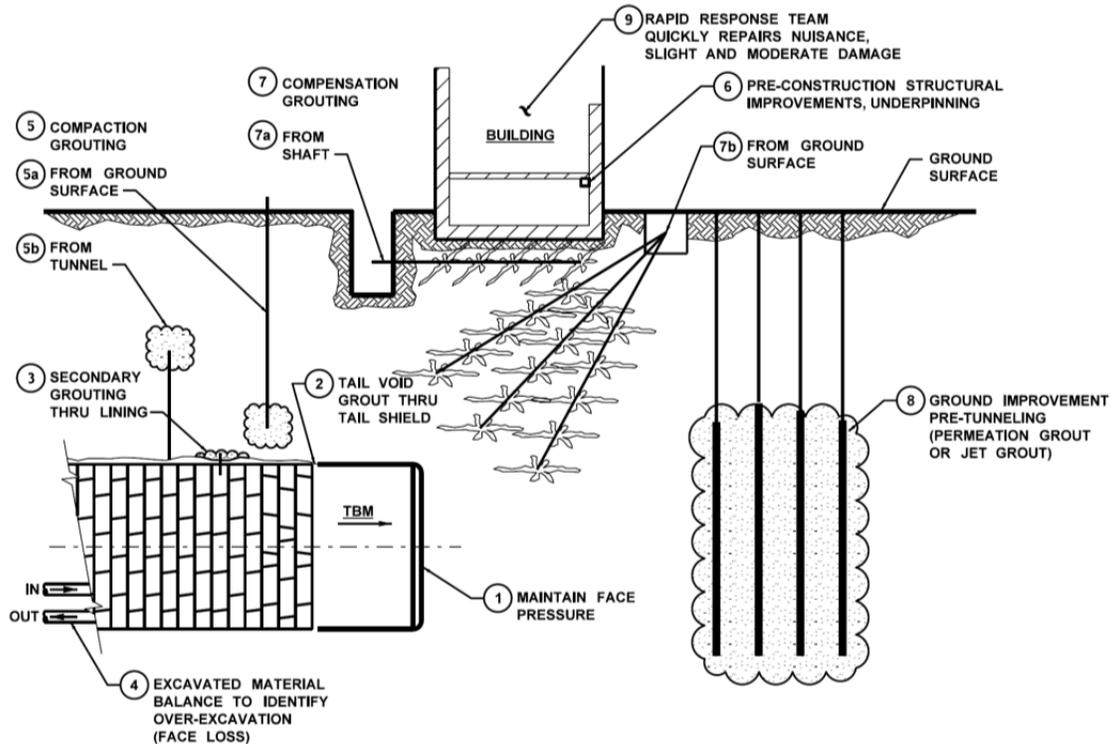
Grouting techniques implemented during tunneling are:

- Compensation Grouting
- Compaction Grouting

As a guide to where and how ground improvement is implemented for tunneling, Figure 4-3 shows various methods. As can be seen on the figure, some methods are done well in advance of tunneling and some during tunneling. A closed, pressurized-face TBM is shown. In the detailed descriptions of each method below, use of various grouting techniques associated with open-faced TBMs and SEM tunneling are addressed, where applicable.



Figure 4-3: Grouting Methods for Tunneling



In the broad scope of geotechnical engineering and ground improvement, other methods exist that are not typically used in tunneling or the Regional Connector site conditions, such that they are not remotely applicable. They are mentioned here for the record, but are not elaborated further in this report. These other methods include vibro-compaction (insertion of vibrating probe in sands below water table, commonly used in marine construction), dynamic compaction (dropping very large weight to compact loose soils), wick drains (insertion of geotextile filters to increase rate of consolidation of poorly consolidated soils below the ground water table), and use of explosives to density loose soils. Dewatering is often considered a type of ground improvement where tunneling is below the ground water table. However for the Regional Connector, much of the tunnel alignment has little to no groundwater or groundwater is perched groundwater. Any tunneling scheme will have to accommodate groundwater. On its own, dewatering in the absence of other mitigating measures would not result in an improvement of site conditions that would make a specific tunneling method constructible, where it was not constructible before.

#### 4.5.1 Permeation Grouting: Chemical or Cement

Permeation grouting involves filling the soil pore spaces with chemicals or fine cement, while individual soil grains are not disturbed or moved. The structure and dimension of the soil pore spaces dictate the type of grout that can be effectively used. Generally, permeation grouting is suitable for sandy soils containing less than 10 to 20% silt or clay.

For tunneling application, permeation grouting is done from the ground surface or, when unusual or extreme conditions dictate, from the tunnel face. Permeation grouting performed from the ground surface in most cases is the only practical scheme compared to grouting at the

tunnel face. Permeation grouting requires drilling and injecting grout to the targeted ground. The drilling pattern depends on the soil pore space structure. Typical spacing of the drilling pattern is two to six feet between grout holes. See Figure 4-4 for a drill hole pattern for grouting from the ground surface. Working from the ground surface permits control of the grouting and provide substantial assurance of the targeted tunneling ground being improved. The inherent and unavoidable impact is the ground surface disturbance by grouting from surface.

**Figure 4-4: Permeation Grouting from Surface**



On the other hand, permeation grouting from tunnel will have essentially no impact on the ground surface; however, working from the confines of the tunnel face, it is difficult to assure satisfactory improvement of the soils targeted for ground improvement. In addition, when grouting from the tunnel face, the tunnel advance rate will be significantly reduced with the introduction of the drilling and grouting operations to the tunneling cycle. Grouting from the tunnel face is only possible with open-face TBMs or SEM tunneling.

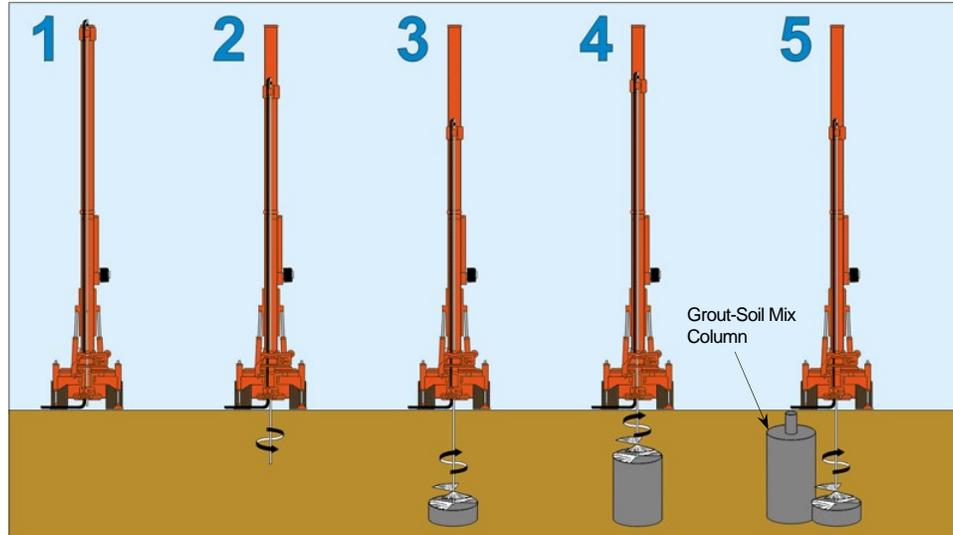
Regardless of where the permeation grouting is done, the alluvial deposits along South Flower Street would be difficult to be improved by permeation grouting. The content of fines (silt and clay) would limit the extent of grout permeation and would require closer drill hole spacing. The interlayered nature of the sands and fine soils would also make it difficult to achieve a uniformly grouted condition. Some zones would be not groutable or marginally groutable. Particularly, the horizontal and sub-horizontal grout holes drilled from tunnel face could easily miss the targeted pervious layers and would not be able to achieve the ground improvement intended. Overall for grouting from the tunnel face, it would be difficult to control the quality of a zone intended to be grouted, which in turn creates a tunneling hazard.

#### **4.5.2 Jet Grouting**

Jet grouting mixes cement grout with the in-situ soil to result in a mixed grout-soil material. With jet grouting, weak soils would be changed to a stronger grout-soil mixture and create “firm”

ground conditions. Figure 4-5 shows the jet grouting procedure creating series of grout-soil mix columns in the ground.

**Figure 4-5: Jet Grouting Sequence**



The technique requires drilling grout holes on a 5 to 10 ft spacing throughout the area to be grouted such that the neighboring grout-soil mix columns would overlap or touch each other. Grout holes would typically extend from the ground surface creating vertical grout-soil mix columns. In rare cases, horizontal jet grouting is used to create grout-soil material canopy over a tunneling course to provide pre-supported tunneling ground in front of the face (see Figure 4-6). On account of its brute-force approach of replacing weak soils with grouted soil, jet grouting is a method that has control over achieving a high degree of improvement of the targeted ground, and achieving the required strength of the soils. However, the surface disturbance would be significant requiring a large staging area and a messy grouting operation. Figure 4-7 shows the jet grout plant set up on the street, and Figure 4-8 shows a jet grouting operation on urban streets.



Figure 4-6: Jet Grouting Canopy by Horizontal Drilling

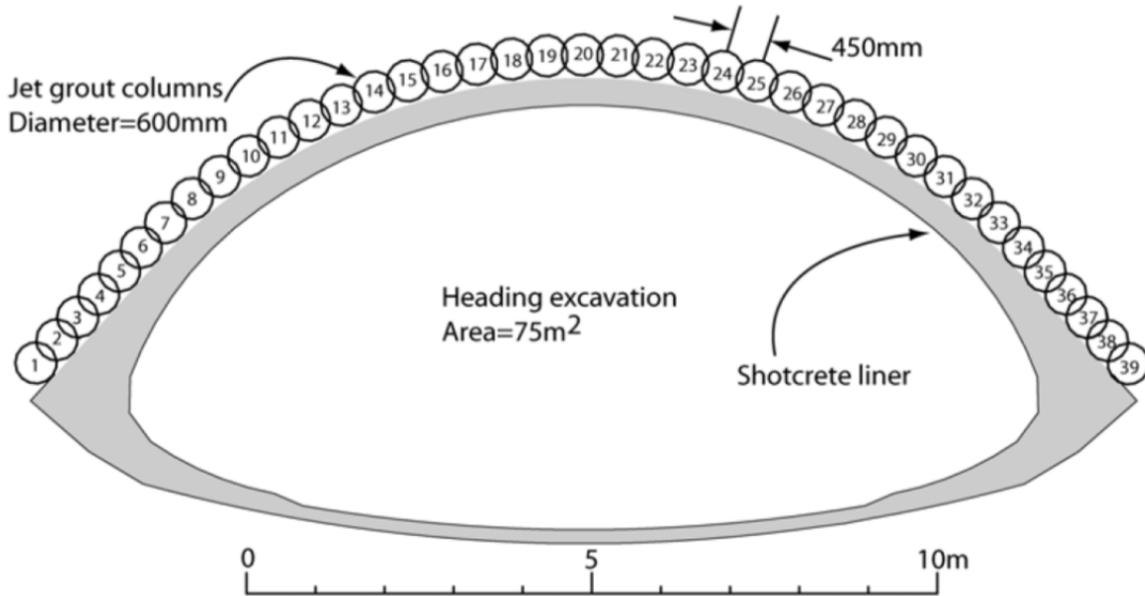
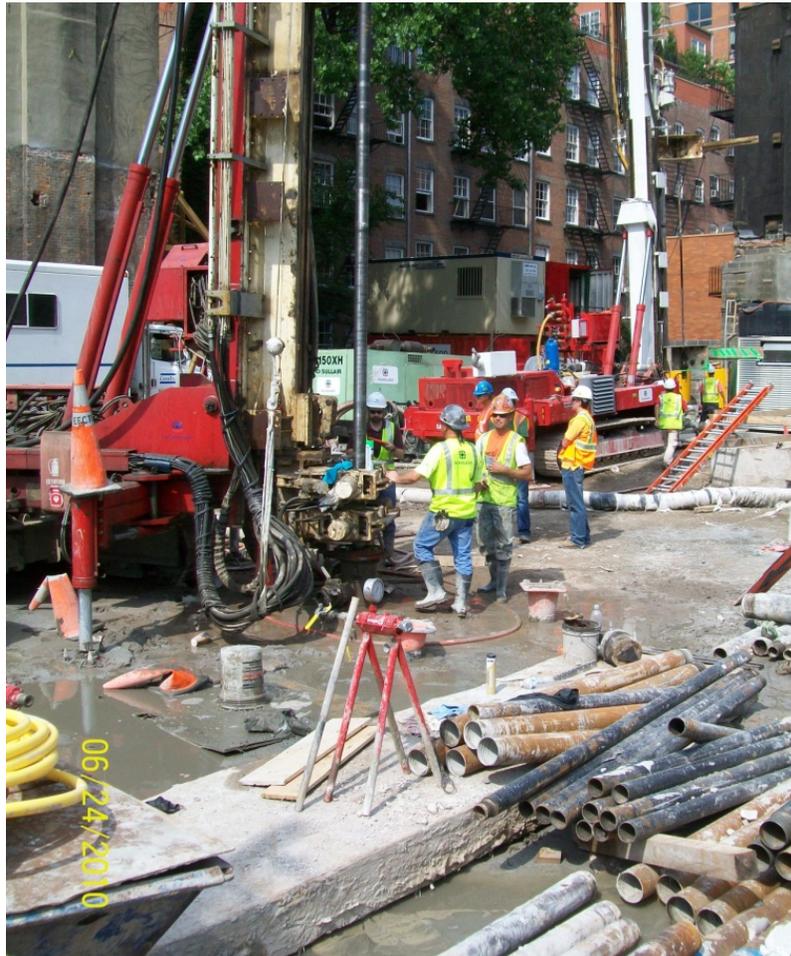


Figure 4-7: Staging for Jet Grouting Operation



Figure 4-8: Surface Jet Grouting Operation

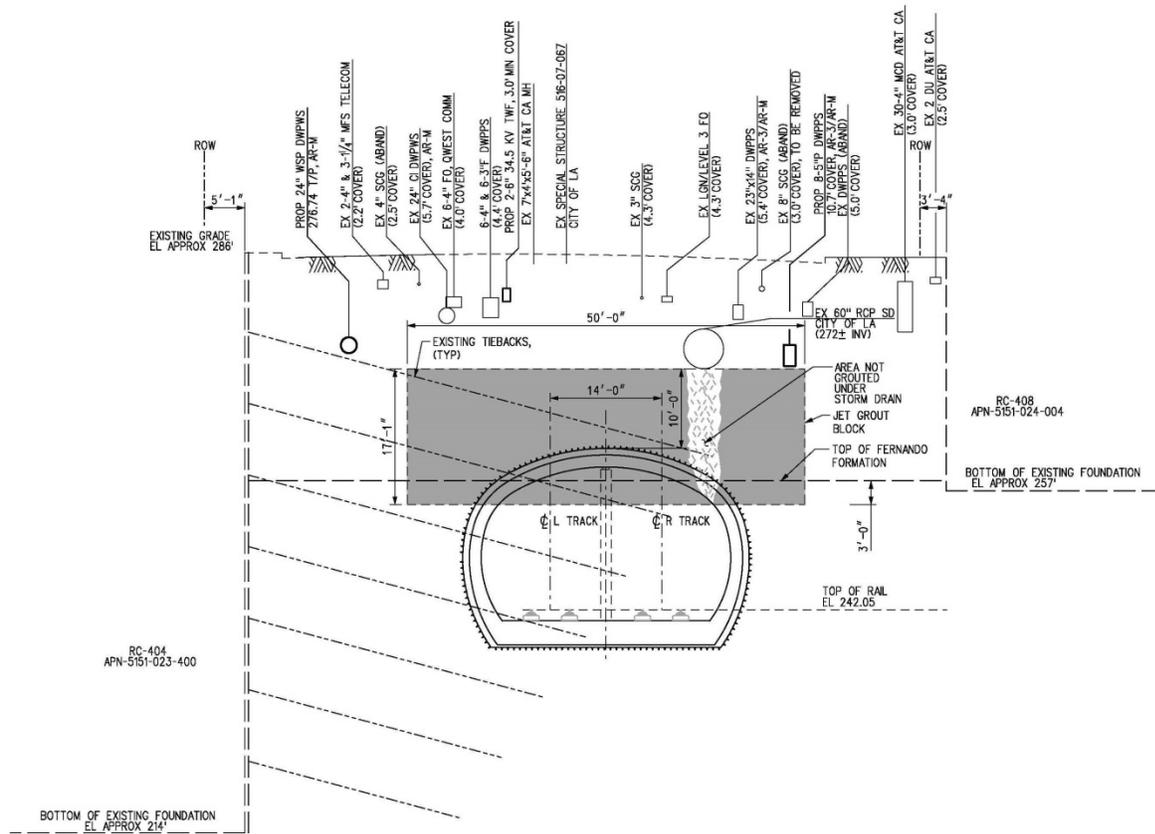


Along the Flower Street, vertical jet grouting would be the most effective technique to improve the ground conditions to permit tunneling with open-face shields or SEM. Jet grouting is considered the most suitable for the soil conditions in this area and would provide adequate strength and size of the grout-soil mix block above the tunnel crown. The method has relatively good control over assuring the quality of grouted soil blocks. Yet, the extensive environmental impacts on the street, the risk of utility damages, and the risk of incomplete ground improvement remain. Figure 4-9 shows typical jet grout zone that could be installed from the street above SEM tunneling section with abandoned tiebacks intersecting the tunnel and various utilities within the subsurface. A major risk is the interference created by utilities that prevent full coverage by jet grouting. As can be seen in Figure 4-9, it would not be possible to fully jet grout below the 60 inch diameter storm drain and a “window” of ungrouted ground would be present above the tunnel. The ungrouted ground would tend to transmit groundwater, and if intersected by the tunneling, would be the point where an uncontrollable run or flow of soil into the tunnel would start, which in turn can progressively lead to a sinkhole at the street surface.

The use of jet grouting canopy by horizontal drilling alone (see Figure 4-6). would not be considered feasible for the tunnel under the Flower Street. This technique is rarely used in North

America. As tunneling takes place, it would be necessary to drill the holes out at an angle from the heading every few rounds over the length of the tunnel drive. This process is a very slow and difficult operation in order to achieve and ensure adequate coverage and full support of the ground.

**Figure 4-9: Jet Grout Zone above SEM Tunnel on Flower Street**



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### 4.5.3 Ground Freezing

Ground freezing is based on withdrawing heat from the soil. The process converts in-situ pore water into ice. The ice binds the soil particles imparting strength to the frozen soil mass. For the creation of a frozen soil body, a pattern of vertical (in very special instances horizontal or inclined) freeze pipes have to be installed in drill holes. Each freeze pipe (or freeze “pile: as

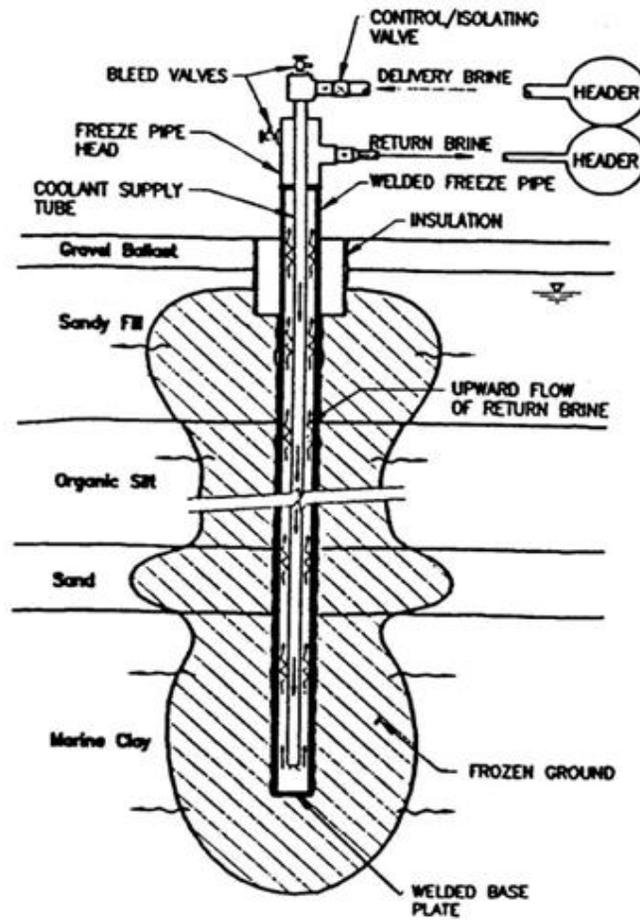


referred to in the industry) consists of the open-end inner pipe and the closed-end freeze pipe. The inner pipe is used for the supply of a cooling medium, usually brine, or liquid nitrogen. The inner pipe is connected to the supply line and the outer pipe to the return line (when brine is used) or the exhaust line (when liquid nitrogen is used). The coolant flows through the inner pipe. On its way back through the annulus, the coolant picks up heat from the soil. The freeze takes place over time as the frost penetrates the soil and a ring of frozen soil grows around the pipes. Figure 4-10 shows the individual freeze pipe arrangement.

The freeze pipes are arranged to achieve the required shape of frozen soil mass. The initial setup and freezing time of ground freezing operation must be considered for significant schedule impact. Figure 4-11 and Figure 4-12 show freeze pipe installation and ground freezing operation in an urban area. Setting up for the freeze, establishing the freeze, tunneling, and finally demobilizing the freeze would take months of time and occupy at least two to three traffic lanes.

Along the Flower Street section of the Regional Connector, feasibility of ground freezing has a fatal flaw of the being substantially dry and, in a sense, “not freeze-able,” and thus not suitable to mitigate unstable ground conditions during tunneling. The groundwater within the alluvium along the Flower Street is perched groundwater. Once the limited perched groundwater is frozen, the freeze would not continue. In this situation, the freeze would be incomplete as non-uniform and discontinuous, and would not provide the sufficient ground stability for tunneling under Flower Street. Also, as can be seen in Figure 4-13, ground freezing would block off several lanes of the traffic for months of time in order to set up for the freeze, tunnel, demobilized, and restore the street. In addition, were there enough groundwater present, ground freezing from the surface would have extensive surface impacts and problems getting full coverage with utilities in the way. To freeze from underground, pipes installed horizontally would need to be drilled large distances from a large excavation (shaft) in order to position them properly around the tunnel. Such a scheme is impractical and ineffective.

Figure 4-10: Individual Freeze Pipe Arrangement



**Figure 4-11: Ground Freezing Pipe Installation in New York City, Prior to Starting Freeze**



**Figure 4-12: Ground Freezing Operation**



**Figure 4-13: Freeze Pipe Array**

#### **4.5.4 Compensation Grouting**

Compensation grouting is known as correctional measures, rather than a preventive measure to mitigate ground settlement due to the excavation or tunneling. For compensation grouting, steel or plastic grout pipes with sleeve ports are installed in the holes drilled from the ground surface or grout pits prior to tunneling. Typical application for protection of buildings is shown in Figure 4-3, items 7a and 7b. Compensation grouting displaces the surrounding soils at grouting points along the grout pipe to compensate for settlement caused by construction activities, such as tunneling. A fluid grout mix is used to hydro-fracture the ground, and fills any pre-existing discontinuities and the fractures created in the process. As the grout penetrates the ground it forms a network of wedges and displaces/heaves the ground, “compensating” for settlement. As tunneling advances and settlement occurs, compensation grouting is activated to keep the settlement within the acceptable limit. Once the ground movement is stabilized, the grouting pipes and equipment are typically abandoned in place. Grout pipes are typically limited to a maximum length of 200 ft. Compensation grouting would be only suitable for mitigation of settlement of utilities by open-faced TBM tunneling or SEM tunneling along Flower Street. Implementation would require shafts in the street required to install grout pipes. Compensation



grouting would be completely ineffective in avoiding excessive ground loss and collapse of the tunnel face leading to a sinkhole in the street.

#### **4.5.5 Compaction Grouting**

Compaction grouting involves injection of very stiff grout with low mobility at high pressure creating grout columns and densifying surrounding soils at the injection points. Grout holes are usually vertical and spaced on a grid of 6 to 12 ft. The grout bulbs are not designed to overlap or contact with each other, as the soils left in place between grout columns are presumed to be densified. Inclined holes if required to avoid utilities, should be no more than about 20 degree from the vertical line. An inclined or horizontal hole provides a greater horizontal effective area resulting refusal at low grout pressure due to surface/utility heave and resulting incomplete ground improvement. In general, a vertical column of grout and the resulting compacted soil provide the better support than inclined. Key to successful compaction grouting is deposition of the grout in such a manner that it remains in a globular mass at the injection point such that the surrounding soil can be radially densified.

Compaction grouting is a technique developed in the 1970's and has had limited use. Subsequent development of compensation grouting provided a more manageable and effective technique for tunneling applications. Compaction grouting is seldom a preferred choice in today's practice, or even considered at all, as a tunneling settlement mitigation method. Also, the advent of pressurized face tunneling, which has reduced tunneling ground losses, has decreased the need. Compaction grouting is shown in Figure 4-3 for completeness to illustrate the various methods. For the specific case shown, use from inside a very large tunnel (54 foot diameter Alaskan Way Tunnel) is proposed to mitigate settlement for a very specific situation where grouting from the ground surface would not be possible (under existing railway tunnel at depth of over 100 ft). However, the compaction grouting for the referenced tunnel has not yet taken place.

The alluvial deposits along South Flower Street would be difficult to improve by compaction grouting. Keeping the deposition of the grout in a globular mass would be difficult because of the interlayered nature of the soils. The high pressure grout may just crack the weak soil layers creating thin lenses of grout. Also, trying to grout effectively at high pressures above a wide SEM excavation cannot be done ahead of the face, and would not prevent running ground. Essentially, compaction grout would only be used at low pressures to fill voids that have already developed. The SEM tunnel depth along the Flower Street is too shallow and there is no arresting layer above the tunnel that would stop a void so that the void could be filled before it reached the surface. Thus this technique is considered to be not effective for preventing large ground loss and reducing the risk of surface subsidence if Flower Street were to be tunneled.

#### **4.5.6 Summary and Conclusions on Ground Improvement for Tunneling**

Ground improvement using jet grout, compaction grout, permeation grout, compensation grout, or ground freezing would have to be employed from the ground surface for tunneling with an open face shield or by SEM under the Flower Street. However, as was the case on LACMTA's construction along Lankershim Street for the Red Line, the grouting operations will create extensive environmental impacts involving lane closures and multiple equipment operations. There is also significant possibility for damage to utilities, basements, and at the street level due to grout pressure and grout flowing into unplanned or undesirable locations. Similarly, the ground freezing operations will also create extensive environmental impacts on the street and may cause damage to utilities, basements, and at the street level. In fact, the numerous utilities



will be obstructions to the grouting and ground freezing operations increasing the risk of incomplete ground improvement. The existing utilities along the Flower Street include an 84-in diameter reinforced concrete storm drain which has the invert level as deep as 18 ft below ground surface. Additionally, extensive geotechnical instrumentation and monitoring points will need to be installed and monitored for any ground improvement operation.

### 4.5.7 Summary of Feasible Ground Improvement Methods

The following Table 4-1 summarizes the evaluation of various ground improvement methods discussed above.

**Table 4-1: Summary of Evaluation of Ground Improvement Techniques**

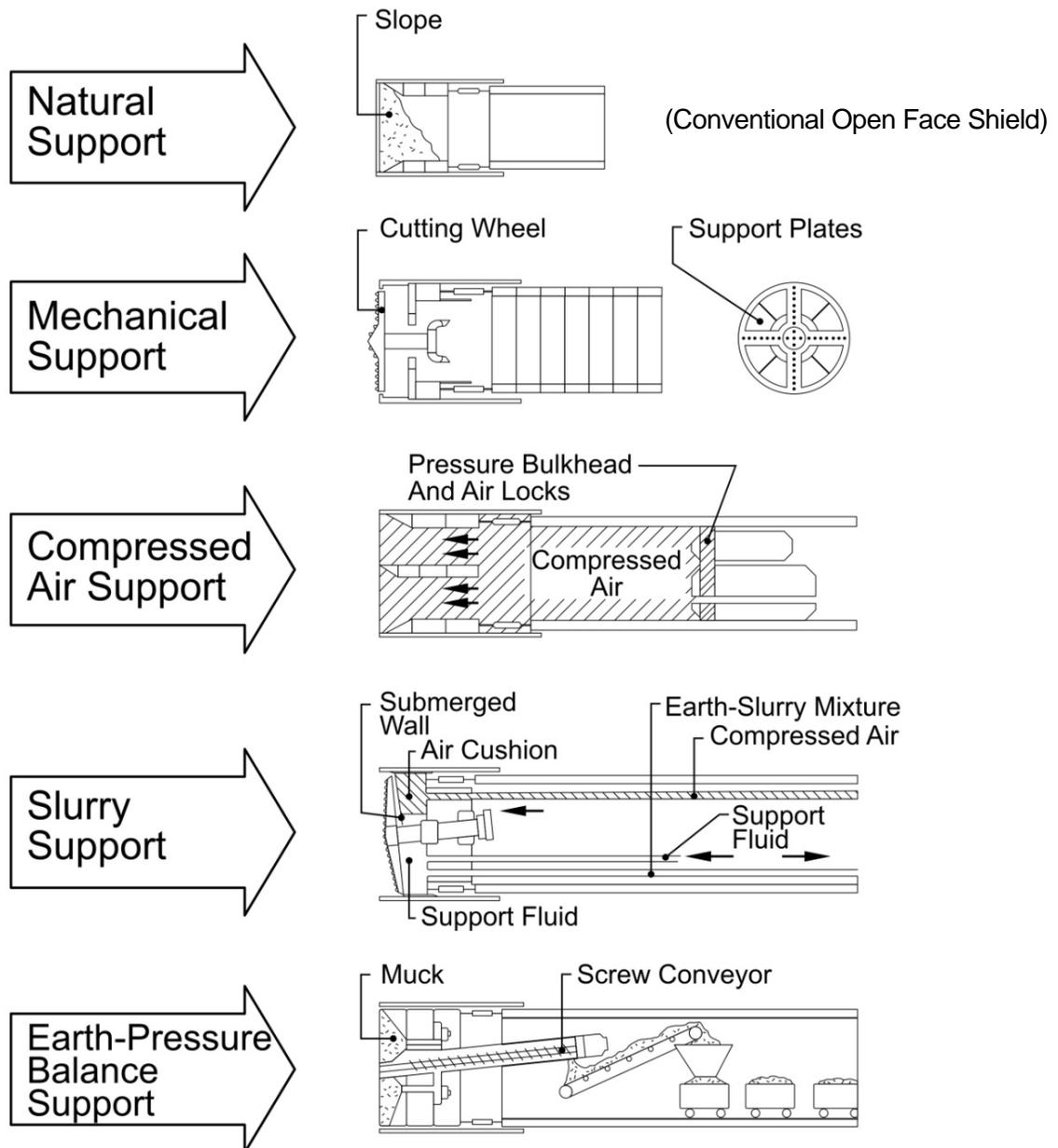
Ground Improvement Technique	From Ground Surface	From Inside Tunnel
Permeation Grouting	<ul style="list-style-type: none"> <li>• Difficult to permeate grout through the soil because of fine contents</li> <li>• Non-uniform grout block because of the interlayered soil structure</li> <li>• Difficult to control QAQC</li> <li>• High surface disturbance</li> <li>• Low tunneling schedule impact</li> </ul>	<ul style="list-style-type: none"> <li>• Difficult to permeate grout through the soil because of fine contents</li> <li>• Non-uniform grout block because of the interlayered soil structure</li> <li>• Very difficult to control QAQC</li> <li>• Low surface disturbance</li> <li>• High tunneling schedule impact</li> </ul>
Jet Grouting	<ul style="list-style-type: none"> <li>• Widely applicable for soil conditions</li> <li>• Relatively uniform grout block</li> <li>• Better control on QAQC</li> <li>• High surface disturbance</li> <li>• Low tunneling schedule impact</li> </ul>	<ul style="list-style-type: none"> <li>• Widely applicable for soil conditions</li> <li>• Insufficient grout block size</li> <li>• Better control on QAQC</li> <li>• Low surface disturbance</li> <li>• High tunneling schedule impact</li> </ul>
Ground Freezing	<ul style="list-style-type: none"> <li>• Insufficient quantity of groundwater</li> <li>• Non-uniform frozen mass because of the interlayered soil structure and perched groundwater condition</li> <li>• Difficult to control QAQC</li> <li>• High surface disturbance</li> <li>• High tunneling schedule impact</li> </ul>	<ul style="list-style-type: none"> <li>• Insufficient quantity of groundwater</li> <li>• Non-uniform frozen mass because of the interlayered soil structure and perched groundwater condition</li> <li>• Difficult to control QAQC</li> <li>• Low surface disturbance</li> <li>• High tunneling schedule impact</li> </ul>
Compensation Grouting	<ul style="list-style-type: none"> <li>• Extensive set up before tunneling</li> <li>• Correctional measures rather than prevention measures</li> <li>• Not recommended for high riser buildings</li> <li>• High surface disturbance</li> <li>• Low tunneling schedule impact</li> </ul>	<ul style="list-style-type: none"> <li>• Not applicable: Must be prepared and ready prior to tunneling.</li> </ul>
Compaction Grouting	<ul style="list-style-type: none"> <li>• Correctional measures rather than prevention measures</li> <li>• Difficult to control QAQC</li> <li>• High surface disturbance</li> <li>• Low tunneling schedule impact</li> </ul>	<ul style="list-style-type: none"> <li>• Difficult to control QAQC</li> <li>• Moderate surface disturbance (heave)</li> <li>• High tunneling schedule impact</li> </ul>



### 4.6 Pressurized-Face (Closed-Face Shield) Tunneling

Tunneling with a shield refers to use of a circular tunnel shield with either an open face or a closed face (“pressurized face”). Types of tunnel shields are shown in Figure 4-14.

Figure 4-14: Types of Shield Machines



The cylindrical shield provides ground support and permits safe installation of a tunnel lining. Open-face shield tunneling is discussed in Section 4.3 of this report. Closed-face tunnel shields

are the modern-day evolution of a tunnel shield that once used compressed air to stabilize the ground and control groundwater. A closed-face tunnel boring machine, also generically termed “pressurized-face,” has a rotating cutter head inside a sealed chamber at the front of the machine. There are two general types: slurry type, where the excavated soil is removed by mixing with slurry injected into the cutterhead chamber and pumped out of the tunnel as slurry, and earth pressure balance type, where pressure is maintained on the soil itself and the soil is removed as a semi-solid in muck cars by rail or by a conveyor. These two types of machines are known as Slurry Machines and Earth Pressure Balance Machines (EPBM).

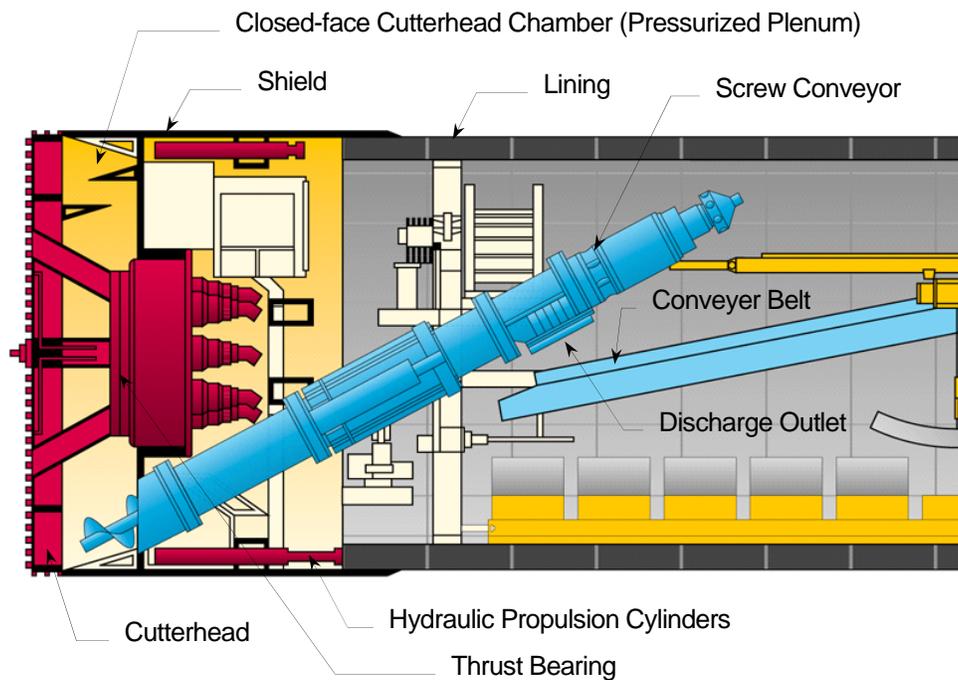
In recent decades, pressurized-face TBMs have become the tunneling method of choice for projects in the Los Angeles area. The recent Eastside Extension project was successfully constructed using pressurized-face TBMs. The use of pressurized-face TBMs for LACMTA projects follows the recommendation in the 1995 report of a specially convened Tunneling Advisory Panel (TAP) entitled “Report on Tunneling Feasibility and Performance,” wherein it is recommended that “[LACMTA] for future tunneling, consideration be given to application of earth pressure balance tunnel boring machines...” The report further states “The choice of whether to permit an open face shield in preconditioned ground or require an earth pressure balance machine will depend on the degree of risk [Metro] wishes to share and on the overall cost.” Preconditioned ground assumes the use of specific grouting techniques whereby soil stabilizing material such as cement is injected to reinforce the strength of the earth where tunneling may occur. Such preconditioning is used where ground conditions are less than desirable for TBM activity such as open face tunneling. The LACMTA Board accepted TAP’s recommendation and LACMTA has instituted the policy to reduce or avoid construction risk of excessive settlement with open face tunnel shields by requiring pressurized-face tunneling. Since the Eastside Extension project, LACMTA’s practice for soft ground tunneling has been to use pressurized-face tunneling equipment to control ground and prevent subsidence. Figure 4-15 shows the EPBMs used for tunneling of the LA Metro Eastside Extension Project Contract No. CO800. Figure 4-16 shows a typical EPBM in cross section.



Figure 4-15: EPBMs Used for Constructing Los Angeles Eastside LRT Tunnels



Figure 4-16: Cross-Section of Typical EPBM





## **4.7 Transit Structure Configuration**

The design of underground structures along Flower Street has gone through various design iterations including double-track box for line track sections (close track centers of 14 ft), double crossover for operational purposes, 5<sup>th</sup>/Flower Street Station, and a pocket track. As stated in Section 4.2, practical construction of these structures is by cut-and-cover. Although the pocket track has been eliminated, a crossover is still needed between 2<sup>nd</sup>/Hope and 7<sup>th</sup>/Metro Center Station and is located at 6<sup>th</sup> & Flower Street, immediately North of the existing Blue Line tail tracks.

### **4.7.1 Deferred 5<sup>th</sup>/Flower Street Station**

The DEIS/DEIR alignment included the underground 5<sup>th</sup>/Flower Street Station between 4<sup>th</sup> and 5<sup>th</sup> Streets under Flower Street. According to Metro's Design Criteria, the future station should be constructed on a 370 ft long tangent alignment with maximum vertical grade of one percent. The 5<sup>th</sup>/Flower Street Station, however, was eliminated due to cost considerations with LACMTA Board's direction for the design and alignment not to preclude future construction of a 5<sup>th</sup>/Flower Street station. The Advance Conceptual Engineering and the FEIS/FEIR documented the Locally Preferred Alternative (LPA) and the elimination of the future station with LACMTA Board's direction. Deletion of the future station resulted in a reduction of construction impact along Flower Street. The Baseline alignment using cut-and-cover construction allows the construction of a station in the future from the street surface. Discussion on each alternative with respect to the future 5<sup>th</sup>/Flower Street station is presented in Section 5.

### **4.7.2 Pocket Track**

LACMTA Rail Operations at the onset of the project indicated a need to have a pocket track within the Regional Connector system to accommodate trains going out of service, systems disruption, or peak service. A pocket track permits a managed, quick recovery of the system when a train has to be taken out of service, so the required level of service can be maintained. The pocket track was deleted from the subsurface project area configuration and will be provided elsewhere in the system. The elimination of the pocket track enabled narrowing the width of cut-and-cover along Flower Street, thereby reducing construction impacts.

### **4.7.3 Profile Requirements for Rail Operations**

Metro Design Criteria limits the grade of the track profile for 3-car trains. The ruling (maximum) grade is 5% for grade length of 500 to 1,000 ft between vertical points of intersection and 6% for grade length of less than 500 ft between vertical points of intersection. Simultaneous horizontal and vertical curves further reduce the maximum allowable grades, as can other operational considerations. Also the track profile can result in a reduced design speed that may not meet Metro Design Criteria requirement for operating headway. The grade constraints limit the track profile and the depth that can be considered for tunneling.

### **4.7.4 Crossovers**

LACMTA Rail operations require a double crossover on Flower Street for operational flexibility. The project includes a double crossover with standard No. 10 turnouts, which will allow higher operating speed through the crossover during single track operations.



#### **4.7.5 Tie-in at 7<sup>th</sup>/Metro Center Station**

The Regional Connector must meet the existing tail tracks at the north end of the 7<sup>th</sup>/Metro Center Station. The existing tail track location and elevation is a control point for the project. The end wall of the existing 7<sup>th</sup>/Metro Center Station structure has a “knock-out panel” (a section of wall with minimal or no steel reinforcing). The knock-out panel facilitates extending the transit line by making it easy to demolish the panel without compromising the integrity of the structural tunnel walls. With the shallow cover over the existing structure, of about 20 ft, the future connection was expected to be made from a cut-and-cover excavation.

It is not possible to change the existing tail track elevation without reconstructing the entire existing structure, significantly and unacceptably impacting the active rail operations of the Blue and Expo Lines and likely closing down 7<sup>th</sup>/Metro Center Station. When the Expo Line is extended to Santa Monica in late 2015, LACMTA will operate two of the heaviest ridership LRT lines in the country. Re-configuration of 7<sup>th</sup>/Metro Center Station on a long-term basis of a year or more would not be acceptable. Reconstruction of the existing tail track was not addressed in the EIR and is outside the limits of the Regional Connector project. If this were proposed it would have major environmental, cost, and schedule impacts.

#### **4.7.6 2<sup>nd</sup>/Hope Street Station**

The 2<sup>nd</sup>/Hope Street Station in the northern end of the Flower Street section of the project is fixed in its horizontal plan location. The alignment proposed at this station has physical and right-of-way constraints. The minimum radius of curvature at both ends of the station is 583 ft for both right and left track centerline, which is the minimum radius a tunnel boring machine can operate. Curve radii cannot be increased because of the horizontal alignment and right-of-way constraints. Within certain limitations, vertical adjustments are possible.

#### **4.7.7 4<sup>th</sup> Street Bridge Foundations**

The existing 4<sup>th</sup> Street bridge foundations are on both sides of Flower Street, beneath the sidewalks and partially within the street footprint. It is understood that a seismic retrofit has been performed on the bridge structure.

In the LPA, the tunnels pass between the bridges’ drilled shaft and battered pile foundations. During Preliminary Engineering an analysis was performed to evaluate the Regional Connector’s pressurized-face TBM tunnel impact to the bridge foundations. As a result of this analysis, it was determined that there would be no significant impact to the bridge foundations.

The Low Alignment, discussed in details in Section 5.0, requires the pressurized-face TBMs to pass beneath the pile foundations. Further engineering analysis would be required to assess the impacts and design requirements for possible temporary support of the bridge foundations during construction, for example installation of foundation underpinning. The structure may also require permanent foundation modifications due to possible changes in foundation soil support. Temporary and permanent bridge modifications would require extensive coordination with and approvals by the City of Los Angeles. It is concluded based on the above discussions that there is substantial risk of mitigations being more costly with the Low Alignment than with LPA.



## **4.8 Underground Obstructions to Tunneling – Tiebacks**

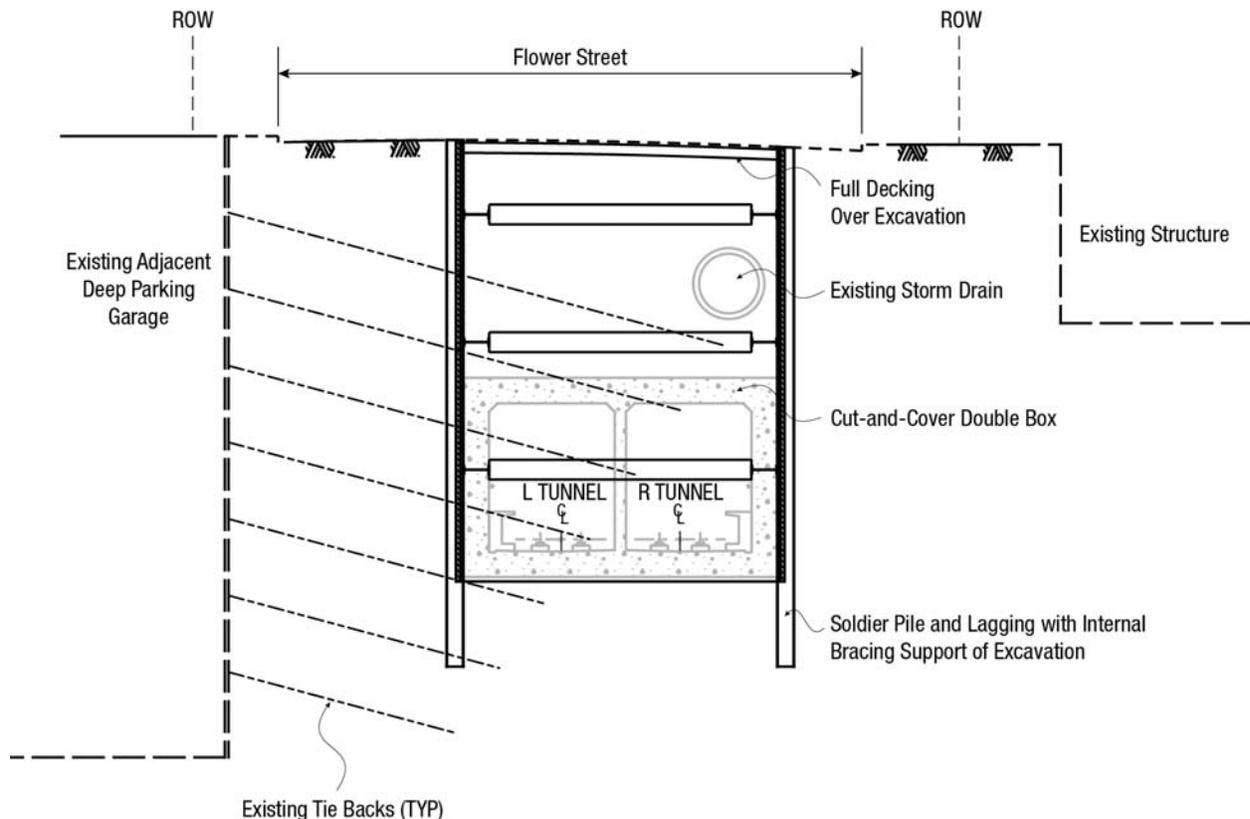
### **4.8.1 Tiebacks on Flower Street**

The existing deep basement/parking garages along Flower Street used tiebacks (steel bars or cables grouted in the ground) to laterally support the original excavations during construction. The steel tiebacks extend deep below ground across the width of Flower Street from both sides along the alignment and have been abandoned in place. Tiebacks exist every six to eight feet in this reach of the project. There are hundreds of tiebacks that impact the alignment, particularly south of 4th Street and even more so south of 5th Street. Existing records show the number of tiebacks along Flower Street segment of the Regional Connector as over 500 and potentially up to 800. Figure 4-17 shows a typical arrangement of existing tiebacks under the Flower Street.

It is commonly considered an unnecessary effort to remove the tieback and industry practice is that tiebacks are left beneath the streets but untensioned. Also, where removal is intended for construction reasons or required by regulations, removal is not assured since the force required for removal has to overcome the tieback bond with the ground. Failure of the tieback tendon can occur, leaving the tieback irretrievably in the ground.

Use of tiebacks for temporary support of excavations came into practice in Los Angeles in the 1970's. The initial method of construction was to drill a large-diameter drill hole (12 inches, possibly larger), similar to that used to construct drilled-shaft foundations with or without an enlarged end, commonly called a belled end. In Los Angeles, the "Old Alluvium" and Fernando Formation constitute firm ground conditions, and resulted in stable drill holes without casing. The tieback tendon was cast in the concrete filled drill hole. Later developments in the construction industry led to smaller diameter drill holes (6 inch or less) and a pressure-grouted anchorage.

It has been found that exposed tiebacks can be pathways for water to flow into excavations or tunnels. Also, it should be noted that many of the existing tiebacks were installed relatively soon after tieback technology developed when quality control of drilling and concreting the holes was likely not well developed, thus adding to the numbers of leaky tiebacks. When encountered during tunneling, groundwater seepage along the periphery of the tieback could erode the soil, bringing soil and water into the tunnel. If uncontrolled, this can progressively lead to excessive settlement, which if allowed to continue can create a sinkhole at the ground surface.

**Figure 4-17: Existing Tiebacks on Flower Street**


#### 4.8.2 Tieback Hazard for Pressurized-face Tunneling

In either the tensioned or untensioned state, tiebacks are a hazard to closed-face (pressurized-face) tunneling as the cutter head will be entangled in the tiebacks which can damage the machine, stall advancement of the excavation, and create excessive ground loss. Uncontrolled efforts to extract the tiebacks would lead to excessive ground loss (more soil excavated than tunnel size), which in turn leads to unacceptable settlements beneath utilities, roadway surfaces and overlying structures. If tiebacks were entangled with the cutterhead, the entangled and displaced tiebacks could disturb surrounding soils and raveling of the adjacent ground could occur, causing settlement and potential damage to overlying structures.

The TBM cutterhead is not capable of “chewing-up” or otherwise processing a steel tieback. The TBM will need to stop advancing and substantial down time will be required to work within or ahead (in front) of the TBM cutterhead to manually remove a tieback which could lead to ground loss. As can be seen in the photo of typical pressurized-face TBMs in Figure 4-15, the cutterhead is a huge barrier between tunnel workers and a tieback that would have to be removed. The pressurized-face machine is designed to control excavation of the soils, which in reverse, practically prohibits tunnel worker access ahead of the machine. The machines are designed with sectional doors in the cutterhead and/or a man-way hatch that can be used to access the ground and cutterhead interface to find, cut and remove a tieback. This design feature is to make access possible, but does not make the process easy or automatically safe.

Working through the spokes of the cutterhead (see Figure 4-15) or ahead of the cutterhead will add significant delay to the construction schedule, even if firm ground conditions are present. If ground water is present and soils are unstable, grouting would be required to create firm ground conditions or the work would have to be done under compressed air (hyperbaric conditions) with appropriate safety cautions instituted. Removal of one tieback would likely have to be done in several sections to free the steel tendon from the ground and cutterhead. Dealing with one or two tiebacks in this manner might be practical. The result would still be a substantial delay and significant cost increase. Encountering hundreds of tiebacks, which is the case here in this section of Flower Street, renders the use of a pressurized-face TBM not viable.

#### **4.8.3 Tieback Hazard for Open Face Shield or SEM Tunneling**

Tiebacks in the face of an open-face shield can be removed in a more direct manner compared to the pressurized-face TBM since the ground is directly accessible. However, instability of the face and potential for soil runs poses unacceptable risks and makes the method unsuitable for use in alluvial and fill materials without complete soil stabilization or ground treatment. An open-face shield to get access to tiebacks requires removing the soil from the tunnel face in the shield, thus there is no protection from the hood and breasting or from the excavated soils sloping on the breast tables or in the pan at the front of the shield. This can lead to runs in the sandy silty soils. Another complication is that the tiebacks would cross the tunnel face at an angle. Removal of a tieback in the top heading (upper part of the tunnel face) would be relatively straight forward in comparison to the remaining portion of the tieback that went fully across the tunnel face. In the latter case, the tunnel heading would have to be excavated; the ground would have to be supported to exhume the tieback; and the tieback would be cut off at the tunnel shield periphery. A time consuming effort, including ground improvement for the unstable soil conditions, will be required. During construction of the Seattle Bus Tunnel, hundreds of tiebacks were removed from an open shield but there was substantial loss of ground and two sinkholes. See also discussion of risks associated with open-face shield tunneling in Section 4.3.

For SEM construction, tiebacks would be directly removable from the tunnel face. Absence of a shield, however, has consequences of increased risk of creating unstable conditions, where mixed-face soil conditions are present and any complications resulting from removal of tiebacks.

#### **4.8.4 Advance Tieback Removal to Mitigate Tunneling Hazard**

Removal of tiebacks in advance of tunneling can be done by constructing tieback removal pits or trenches to mitigate the tieback hazard. In practice, the location of tiebacks would need to be identified. Where their location is fairly well known, a few tiebacks encountered by TBM tunneling can be removed in advance where the value of more tunneling greatly outweighs the cost of proactive advance removal. This situation exists along Flower Street next to the Bank of America building (tunnel reach between Sta 19+00 and Sta 28+00). In this area, up to twenty tiebacks can be extracted by trenching, which allows tunneling a block further to the south. In this specific instance, mitigation by excavation and removal in advance of tunneling is planned.

A complicating condition is that as-built records may not be available or not reliably documented to be able to plan and execute such temporary works for advance tieback removal. Geophysical techniques, such as a magnetometer survey performed in the tunnel might be able to find some tiebacks, but if used in drilled holes, would be like “looking for a needle in a haystack.” A geophysical method at the ground surface is not known to exist that can reliably and simply find the tiebacks at depths of possibly 40 to 80 ft below the ground surface. Thus even with rigorous study of records and field investigation, the risk of not finding and removing all the tiebacks to eliminate the tieback



hazards would remain. Also, even if the tunnel profile were to be established to avoid existing tiebacks with a specific clearance of several feet, there would still be the risk of encountering during tunneling a tieback that was installed longer than indicated by available records. The only feasible direct method to remove tiebacks for the substantial extent that are known to exist for safety on Flower Street would require an independent excavation, a trench with suitable ground support to explore, cut, and remove tiebacks. The task of digging trenches along Flower Street would have significant impacts to traffic and pedestrian disruption and may require utility relocations. In effect, it would have impacts like cut-and-cover construction.

## **5.0 ALTERNATIVE ALIGNMENTS AND TUNNELING METHODS**

In February 2012, stakeholders on Flower Street requested LACMTA to investigate extending the bored tunnels further south, along Flower Street, and reduce the length of the cut-and-cover construction. To address the stakeholder concerns, an alternate lower tunnel profile (“Low Alignment”) was developed to allow continuation of tunneling south of 4<sup>th</sup> Street, to a point south of 5<sup>th</sup> Street, which simultaneously reduced the overall length of the cut and cover construction. Based on then available existing building tieback information, the lower profile was developed to permit the extension of bored tunnels, at a Low Alignment, avoiding potential conflict with these tiebacks.

In the April 2012 LACMTA Board meeting, the Board approved the Project definition (the “Base Design” referred to herein as “Baseline”) for the Regional Connector Transit Corridor Project. At this meeting, the Board directed staff to examine various value engineering and cost saving methods to determine if certain specific construction methods and design features could be incorporated to mitigate potential construction impacts along Flower Street, without causing an increase to the Life of Project (LOP) budget. If it can be completed within the current LOP budget then amend the Locally Preferred Alternative (LPA) of the Regional Connector Transit Corridor Project to include the design features. The Board further directed staff that if the analysis determined that the methods exceeded the LOP budget, the construction methods and design features shall be included during construction procurement, as bid options, to allow design-build proposers a process to include each feature and determine if it could be accomplished within the LOP budget.

At the time of the April 2012 Board Meeting the Flower Street mitigation method under consideration was the “Low Alignment”. This alignment would extend tunneling from the termination of tunneling at south of 4<sup>th</sup> Street, to a point south of 5<sup>th</sup> Street, and would subsequently reduce the length of the cover and cut section along Flower Street. Construction impacts in the block between 4<sup>th</sup> and 5<sup>th</sup> Streets would be further mitigated by limiting the construction ingress and egress to points south of 5<sup>th</sup> Street.

Two tunneling Alternatives, A and B, have been advanced to determine if they reduce or mitigate construction impacts or lower the risks to construction safety, cost, and schedule compared to the Baseline. The Baseline consists of EPBM tunneling to south of 4<sup>th</sup> Street and the cut-and-cover with street decking system to the 7<sup>th</sup>/Metro Center Station along the LPA profile. Alternative A (“EPBM/Open Face Shield/SEM LPA Profile”) would extend tunneling south to the 7<sup>th</sup>/Metro Center Station through the use of a combination of EPBM, open-face shield, and SEM tunneling along the LPA profile. Alternative B (“EPBM/SEM Low Alignment”) would extend tunneling south of the 7<sup>th</sup>/Metro Center Station through the use of a combination of EPBM and SEM tunneling along the Low Alignment. Both Alternatives A and B would minimize cut-and-cover construction, limiting it to the tie-in with the 7<sup>th</sup>/Metro Center tail tracks and street-surface exit shafts.

In summary, the types of construction for the Baseline and these two tunneling alternatives are shown in Figure 5-1.

Figure 5-1: Baseline and Tunneling Alternatives

