WESTSIDE SUBWAY EXTENSION PROJECT

Century City Tunneling Safety Report

Metro

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Acronyms and Abbreviations

ACE	Advanced Conceptual Engineering
API	American Petroleum Institute
APTA	American Public Transportation Association
bgs	below ground surface
BHHS	Beverly Hills High School
BHUSD	Beverly Hills Unified School District
Cal/OSHA	California Occupational Safety and Health Administration
dB	decibels
DOGGR	California Division of Oil, Gas, and Geothermal Resources
EIS/EIR	environmental impact statement/environmental impact report
EM	electromagnetic
EPBM	earth pressure balance machine
FTA	Federal Transit Administration
GPR	ground penetrating radar
HDPE	high-density polyethylene
I-405	Interstate 405
LEL	lower explosive limit
LPA	Locally Preferred Alternative
MGLEE	Metro Gold Line Eastside Extension
mph	miles per hour
NEIS	North East Interceptor Sewer
NOS-ECIS	North Outfall Sewer—East Central Interceptor Sewer
PE	Preliminary Engineering
ppm	parts per million
PPV	peak particle velocity
Project	Westside Subway Extension Project
RMS	root mean square
SFM	slurry face machine
SPT	standard penetration test
TBM	tunnel boring machine
TAP	Tunnel Advisory Panel
VA	Veterans Affairs
VdB	vibration decibels

EXECUTIVE SUMMARY

On October 28, 2010, the Metro Board approved the Draft Environmental Impact Statement/ Environmental Impact Report (EIS/EIR) for the Westside Subway Extension Project (the Project), which included two tunnel alignment options through the Century City area. The proposed station locations would be on either Constellation Boulevard or Santa Monica Boulevard, but both would be centered on the Avenue of the Stars. During the October 28 meeting, Metro staff expressed concerns related to the potential impact of the Santa Monica fault zone on the proposed Santa Monica Boulevard Station. (Additional investigations were being planned to locate the fault zone near the station.) Concerns were also expressed at the meeting regarding the safety of tunneling under Beverly Hills High School (BHHS), which would be required for the proposed Constellation Boulevard Station.

To address the tunneling safety concerns, the Metro Board approved the following motion from Supervisor Yaroslavsky to be undertaken during preparation of the Final EIS/EIR. Specific items in the Board motion included the following:

> *… that in the West Beverly Hills to Westwood area:*
>
> - *Staff fully explore the risks associated with tunneling under the [Beverly Hills] High School, including but not limited to the following: risk of settlement, noise, vibration, risks from oil wells on the property, impact to use of the school as an emergency evacuation center, and overall risk to student faculty and community;*
> - *"Staff analyze the possibility of moving the subway tunnel in order to avoid all school buildings and avoid any future plans to remodel BHHS.*

In addition, Metro staff was directed to fully investigate the nature and location of faults in the Century City area and their potential impact on the proposed station locations. The resulting conclusions from both the tunnel safety and fault studies would provide a basis for the Board to make a decision on which station option to adopt. The resulting studies have been completed and presented in two separate reports: the *Century City Area Fault Investigation Report*—addresses the issues surrounding the safety of tunneling under and near BBHS, West Beverly Hills, Century City, and Westwood—and this report, the *Century City Area Tunneling Safety Report.*

Risk of Settlement

Pressurized closed-face tunnel boring machines (TBMs) will be used to excavate the tunnels for the Project. These machines provide immediate support of the ground and use proven systems for monitoring and controlling machine functions. These machines were successfully used on the Metro Gold Line Eastside Extension (MGLEE) where ground movements were always held to very small values. Along most of the alignment there was no measureable settlement.

The alignment under BHHS would pass under portions of a structure consisting of masonry walls and concrete floor beams and columns. Analysis of these structures, as well as experience gained from other tunnel excavations in the U.S. and worldwide where tunneling occurred under similar structures, show that building distortions from tunneling will not result in structural or functional impairment of the buildings. A comprehensive monitoring program will be implemented to ensure that ground movements from tunnel excavation are controlled below a level that could cause structural or functional damage and are in a range where cracking of finishes does not occur or is very minor.

Noise and Vibration

Metro constructed and now operates 18 miles of Red and Purple Line tunnels through downtown Los Angeles, Hollywood, and North Hollywood. The tunnels run directly under a number of buildings. Metro reports that, to date, no complaints about noise or vibration during service operations have required mitigation. Vibration and noise tests were recently performed in boreholes during the environmental studies. On the campus of BHHS, study results predict that ground-borne vibration from the trains would be no greater than 64 decibels (dB), which is less than the vibration criterion of 72 to 75 dBs established by the Federal Transit Administration (FTA) for residential and institutional uses respectively. The predicted noise level would be no greater than 33 dBs, which is also lower than the FTA criteria of 35 and 40 dBs for residential and institutional use. Monitoring of noise and vibration above existing Metro tunnels has shown no detectible noise or vibration above normal background levels.

During construction low levels of noise and vibration may be experienced for a day or two as each of the two TBMs pass under a given location. In addition, as the tunnels are driven, construction trains bring supplies to and from the tunnel heading. These underground sources of will also be controlled to be within Metro criteria. Metro construction specifications also provide requirements to monitor and limit construction noise at the surface worksites, such as at Century City Station. Metro will address and mitigate any substantiated complaints related to noise and vibration, however there were no substantiated noise-level complaints made during MGLEE tunneling.

Risk from Gassy Ground and Oil Wells

Century City and much of Beverly Hills are located within the Methane Zone identified by the City of Los Angeles in 2003. In fact, almost the entire Project corridor lies within the current Methane Zone. However, the Century City Project area is not within the former Potential or High Potential (methane) Risk Zone created in 1986, which is centered in the Wilshire/Fairfax area. For the Project, methane and hydrogen sulfide gas sampling and monitoring were conducted in the Century City and Beverly Hills areas, including the BHHS campus. The results of this testing in the ground indicate that these gases are present in the area of Constellation Boulevard. In some areas, the concentrations were at or above levels that could be explosive under unfavorable conditions, but the measured concentrations were less than those encountered along the Red Line in downtown Los Angeles. The hydrogen sulfide levels in the Century City area (for both alignment options) area were either low (measured in parts per billion) or not detectable.

The State of California has pioneered the development and implementation of regulations for safe tunneling in gassy ground. Moreover, the tunneling industry in Los Angeles has much experience successfully driving miles of tunnels in gassy ground. These tunnels were constructed using the strict state tunnel safety regulations, as would the tunnels constructed under West Beverly Hills, Century City, and Westwood. Accordingly, it has been demonstrated many times that tunnels can safely be constructed and operated in soils containing subsurface gases.

The hazard or risk during tunneling depends on the volume, concentration, and pressure in the surrounding soil, and can vary between borings. Conditions in the tunnel are not directly related to those in the soil because the presence of the tunnel lining limits the flow into the tunnel and because ventilation is provided to dilute and remove gases that enter the tunnel. During tunneling, the pressurized closed-face TBM can be thought of as a submarine. The volume of gas (or water containing dissolved gas) released from the soil during TBM tunneling is confined to the excavated material chamber because of the closed-face and gas-tight lining that is installed immediately behind the TBM. There are a number of oil wells (active and abandoned) on the BHHS campus and in the vicinity. A comprehensive study of all available information found that there was one mapped abandoned oil well within the proposed tunnel alignment. According to the state's records, the location of this well is beneath a parking structure on Century Park East and does not lie within the BHHS campus. The magnetic survey program indicated that the mapped locations of abandoned oil wells could be inaccurate by 50 to 200 feet.

A geophysical (magnetic) survey was performed on the BHHS campus to detect metal, which would indicate the presence of an abandoned oil well casing. The survey identified only one anomaly on the BHHS campus that is close to the alignment. It is on the west edge of the lacrosse field and is located 5 to 10 feet north of the tunnel envelope. The anomaly may or may not be a well casing, but it will be further investigated and addressed appropriately as described below.

For exploration beneath the BHHS buildings during the next phases of design, horizontal directional drilling (HDD) investigation will be conducted along the alignment at tunnel level. A magnetometer probe survey will be conducted in the drilled hole to detect metal casings so that if found, they can be re-abandoned properly below the tunnel depth prior to tunneling. Moreover, during tunnel construction in Los Angeles, magnetometer surveys have been conducted in probe borings extending in front of the TBM to ensure that obstructions, such as well casings, are detected before they are reached by the TBM. In suspected oil field areas, probing of the tunnel zone will be carried out by HDD either before tunneling or ahead of the face during tunneling.

Abandoned oil wells have been encountered in the past during tunneling in Los Angeles. Procedures have been developed to evaluate the well conditions and safely re-abandon them. Metro has experienced no gas incidents related to encounters with oil well casings during tunnel excavation.

Tunneling through Fault Zones

To construct the Project, it will be necessary to pass through at least two active fault zones. There are numerous proven designs and construction means and methods to safely build a tunnel through fault zones. Design methods include building a larger diameter tunnel and/or a very strong but flexible lining to withstand several feet of movement without collapse and still be repairable. As for tunneling in unfaulted ground, there are construction techniques to assure safe tunneling through faults while minimizing ground settlement. Additionally, there are proven procedures to monitor and control ground movements and protect overlying structures as the tunnels are advanced through the fault zones. These construction techniques could include closed-face TBM tunneling and special water- and gas-tight lining segments made with steel and compressible concrete. Additional investigations will be needed to more accurately define the extent and nature of the fault zones.

Since the tunnels will be designed to not collapse during an earthquake, the tunnels will affect neither the threat to buildings above active faults during an earthquake nor the severity of shaking.

Impact to Use of School as Emergency Evacuation Center

The tunnel will be designed so that it will not collapse even during the Maximum Design Earthquake (MDE). Accordingly, the Project will not reduce the availability of BHHS for use as an emergency shelter or impact the operations of its use as an emergency shelter.

Potential of Shifting Tunnel Alignment to Avoid All School Buildings and Any Future Plans to Remodel BHHS

Many considerations are analyzed in determining a tunnel alignment and station location for a project such as this. To minimize impacts to BHHS structures as well as to achieve maximum safe train speeds between stations (by minimizing curves and grade differentials), several alignments were studied for the Century City—Constellation Boulevard alignment. The current alignment minimizes tunneling under buildings to the east and west of the Century City—Constellation Boulevard Station. The station position on Constellation Boulevard requires the tunnel alignment to be under the south portion of BHHS Building B in order to reach the station location. There is no reasonable tunnel alignment that does not pass under structures within the school campus.

The vertical alignment of the tunnel would be 55 to 70 feet below the ground surface (to the top of the tunnel), which would allow for construction of an underground structure over the tunnel at a later date. Foundations for a future structure, including deep underground parking, could be safely set above the tunnel, while deep foundations, if necessary, could extend down so they are adjacent to or between the tunnels. Coordination would be required between Metro and BHHS to ensure compatible designs.

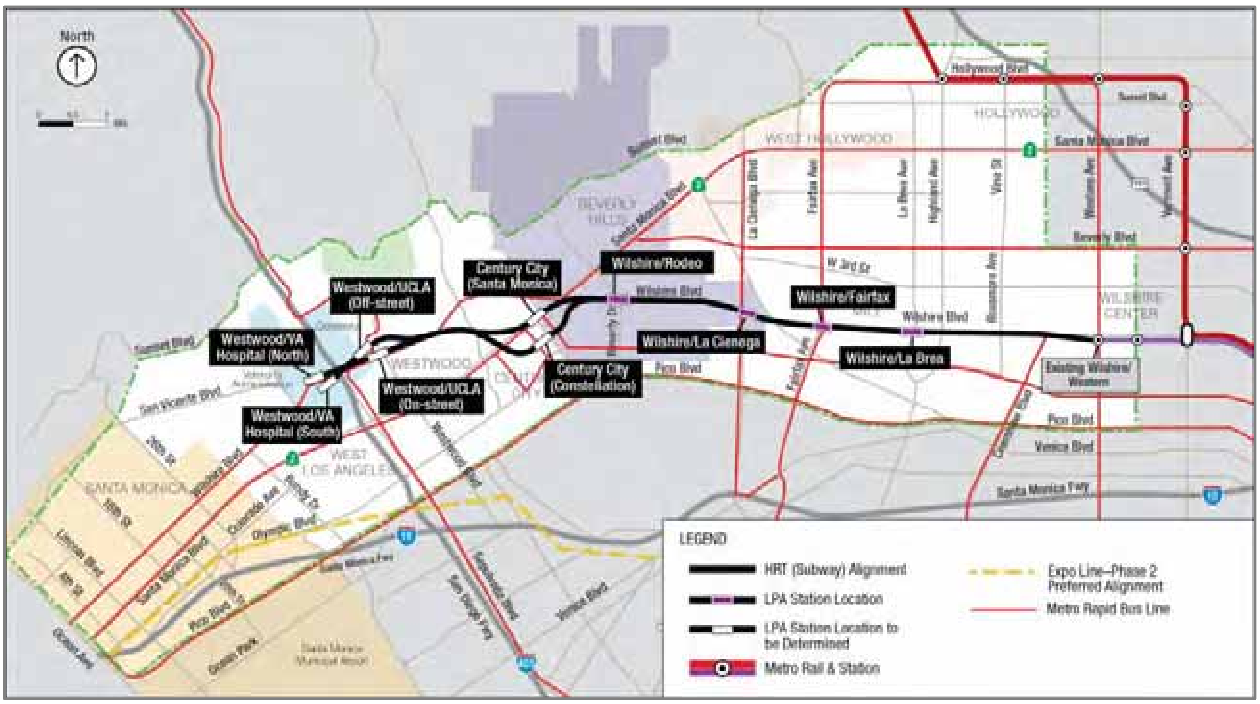
Overall Risk to Students, Faculty, and Community

On most transit tunnel projects, significant portions of the alignment are constructed adjacent to or beneath buildings. The capability of tunneling beneath structures without damage has resulted in large part from the use of pressurized closed-face TBMs, with systems and protocols to monitor and control their operation. The American Public Transportation Association (APTA) prepared a report in 2006 that concluded that tunnels could be safely constructed and operated in the Wilshire Corridor. Furthermore, Metro has followed up and built on the recommendations of the APTA report through analysis of more detailed geotechnical information and their experience gained in successfully completing the tunnels for the MGLEE that was constructed through the former Boyle Heights oil field. The construction and operational safety measures used for that project will be incorporated into the Project’s designs and specifications. The Project is not expected to pose new threats to the students, faculty, or community as a result of its construction and operation.

1.0 INTRODUCTION

Planning and engineering studies for the Westside Subway Extension Project (the Project) are considering two options for the location of a Century City station: Constellation Boulevard and Santa Monica Boulevard (both centered on the Avenue of the Stars) and associated tunnel alignments. These two options remain after an analysis of more than 17 alternatives in the Alternatives Analysis[1] study and further consideration of the remaining options after circulation of the Draft Environmental Impact Statement/Environmental Impact Report (EIS/EIR). The recommendation for the station location will be based primarily on planning and engineering technical studies. This report presents results of engineering studies for, and an assessment of, tunneling safety along the proposed Constellation Boulevard Station route. Figure 1-1 shows a schematic plan of the Project and the options remaining for station locations. Other technical reports document studies for fault analyses, ridership forecasting, land use, and other environmental studies, and are presented in the technical reports supporting the Administrative Draft Final EIS/EIR.

Figure 1-1: Westside Subway Extension Project Planned Alignment



1.1 Supervisor Yaroslavsky's Motion to Metro Board of Directors

The Alternatives Analysis identified potential station locations on both Santa Monica and Constellation Boulevards. Based on existing geologic and topographic evidence and fault maps, the station location on Santa Monica Boulevard was expected to be outside of the Santa Monica fault zone, a feature that has been studied in detail to the west of the Interstate 405 (I-405) freeway, but not until recently in the Century City area.

[1] Los Angeles Metropolitan Transportation Authority Alternatives Analysis and Study, Los Angeles Westside Extension Transit Corridor, January 2009

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To address the tunneling safety concerns, the Metro Board approved the following motion from Supervisor Yaroslavsky to be undertaken during preparation of the Final EIS/EIR. Specific items in the Board motion included the following:

> *… that in the West Beverly Hills to Westwood area:*
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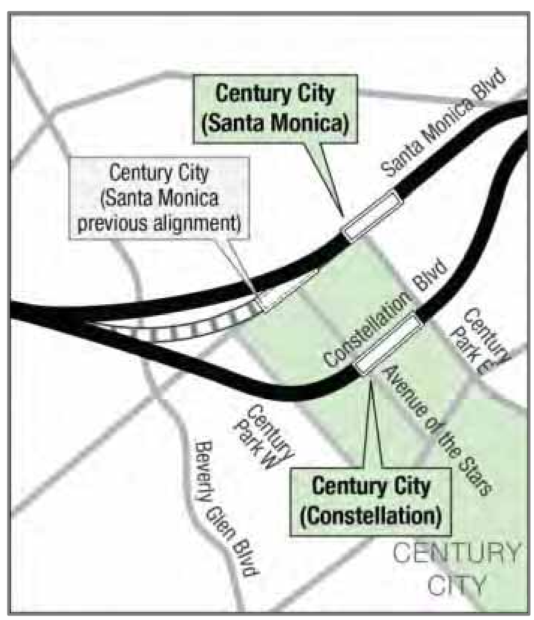
> - *Staff fully explore the risks associated with tunneling under the [Beverly Hills] High School, including but not limited to the following: risk of settlement, noise, vibration, risks from oil wells on the property, impact to use of the school as an emergency evacuation center, and overall risk to student faculty and community;*
> - *"Staff analyze the possibility of moving the subway tunnel in order to avoid all school buildings and avoid any future plans to remodel BHHS.*

In addition, Metro staff was directed to fully investigate the nature and location of faults in the Century City area, and their potential impact on the proposed station locations. The resulting conclusions from both the tunnel safety and fault studies would provide a basis for the Board to make a decision on which proposed station to adopt. The resulting studies have been completed and presented in two separate reports: this report, the *Century City Area Tunnel Safety Report*—which addresses the issues surrounding the safety of tunneling under and in the vicinity of BHHS, West Beverly Hills, Century City, and Westwood—and the *Century City Area Fault Investigation report.*

Figure 1-2: Century City Station Options



Subsequent geotechnical studies for the Project during the final environmental studies revealed that the initially proposed location of the Santa Monica Boulevard Station was within the (active) Santa Monica fault zone and, hence, not suitable for a public transit station. To avoid a station located within the Santa Monica fault zone, the Century City Santa Monica Boulevard Station was shifted to the east with an entrance near Century Park East (Figure 1-2) to allow for continued study of a station on Santa Monica Boulevard. Recommendations for the Century City station location with respect to fault locations are reported in the *Century City Area Fault Study Report*.

The location of the Century City—Constellation Boulevard Station would require that the incoming tunnel from

Beverly Hills pass beneath the BHHS buildings and some residences. The tunnels will also pass beneath numerous residences and some commercial properties as they proceed west from Century City to Westwood. To assist in decision making for the station location, County Supervisor Zev Yaroslavsky (Metro Board member) proposed a motion that Metro conduct a special study of both station locations and tunnels and report back to the Metro Board. This Board motion was passed along with approval of the Draft EIS/EIR.

This report summarizes and evaluates current tunneling technology and addresses the following important issues surrounding the safety of tunneling:

- Alignment studies to minimize impact on BHHS
- Risk of settlement from tunneling
- Effect of proposed tunnels on future development of BHHS
- Risks from gas conditions and oil wells in the vicinity
- Noise and vibration impacts
- Impact on use of the school as an emergency evacuation center
- Overall risk to BHH students, faculty, and the communities of West Beverly Hills, Century City, and Westwood
- Tunneling through fault zones

1.2 Status of Design and Environmental Documents

The current environmental study to extend the subway to the Westside was initiated in June 2007, and the Alternatives Analysis was completed in January 2009. After a review of many alignment and modal options, five Build Alternatives, a No Build Alternative, and a Transportation System Management Alternative were carried forward for further environmental analysis in the Draft EIS/EIR. The Draft EIS/EIR contains the technical analysis to form the basis for selection of a Locally Preferred Alternative (LPA), which is the project that will be carried forward for final environmental clearance. The Draft EIS/EIR can be accessed at the following link: http://www.metro.net/projects/westside/draft-eis-eir-sept-2010/. The Final EIS/EIR will also be available on Metro's website at http://www.metro.net/projects/Westside/.

The location for each of the stations and related alignment options will be determined by the Metro Board at the time final action is taken on the Project. On October 28, 2010, the Metro Board authorized preparation of the Final EIS/EIR to further evaluate the No Build Alternative and the LPA. The Final EIS/EIR will incorporate findings from this report and other studies.

In support of the environmental documents, engineering design has progressed through the Advanced Conceptual Engineering (ACE) phase and is currently in Preliminary Engineering (PE) phase. Entry into PE was approved by the Metro Board on October 28, 2010, and by the FTA in January 2011.

The following sections present a review of the Project's tunnel alignment and tunneling methods, an assessment of impacts to property over the tunnel, risks from tunneling in oil field areas, and conclusions about the overall safety of tunneling in the Century City area.

2.0 TUNNELING CONDITIONS

2.1 Alignment and Profile

The tunnel design for the Project will be similar to the existing Red and Purple Lines that currently provide service to the Wilshire/Western and North Hollywood Stations. The system has twin tunnels—inbound and outbound—each with an excavated diameter of about 21 feet. Typical subway depths are between 40 and 60 feet to the top of the tunnel, but are generally shallower as the tunnels approach the stations. This section describes the tunnels' horizontal alignments and profiles in the reach between the Wilshire/Rodeo Station and the Westwood area where the tunnels approach Wilshire Boulevard north and west of Century City.

During ACE and PE phases, alignments are revised as more detailed information on utility locations and station appendages (e.g., entrances and vent shafts) is added. During PE, other design refinements are in progress, such as deepening the tunnel profile in the areas of Crenshaw and Manning Boulevards, where the mid-line ventilation shafts were removed. Appendix A contains the plan and profile drawings for the West Beverly Hills, Century City, and Westwood areas as included in the Final EIS/EIR.

2.1.1 Horizontal Alignment

To place a station in Century City at the Constellation Boulevard location, the tunnels running east-west along Wilshire Boulevard must turn to the south-southwest at about McCarty Drive and run under private property (Appendix A for street locations). Relatively large radius curves are needed for the TBMs and to allow for sufficient train operating speeds. From Wilshire Boulevard, the tunnels curve about 600 feet before they turn south under Lasky Drive and run about 300 feet, where they curve to align again in an east-west orientation and reach Constellation Boulevard and the location of the Constellation Boulevard Station. Moving west from this station, there is a short, required, tangent (straight) section from the station and then a curve to the north under the Westfield Century City Mall. Again, this radius is tight (less than 1,000 feet) to reduce the length of the tunnels under private property in the area. After the tunnels cross Santa Monica Boulevard, they continue in a straight alignment until just south of Wilshire Boulevard, where they curve to the west. Figure 2-1 compares the Constellation Boulevard alignment with the Santa Monica Boulevard alignment.

2.1.2 Profile

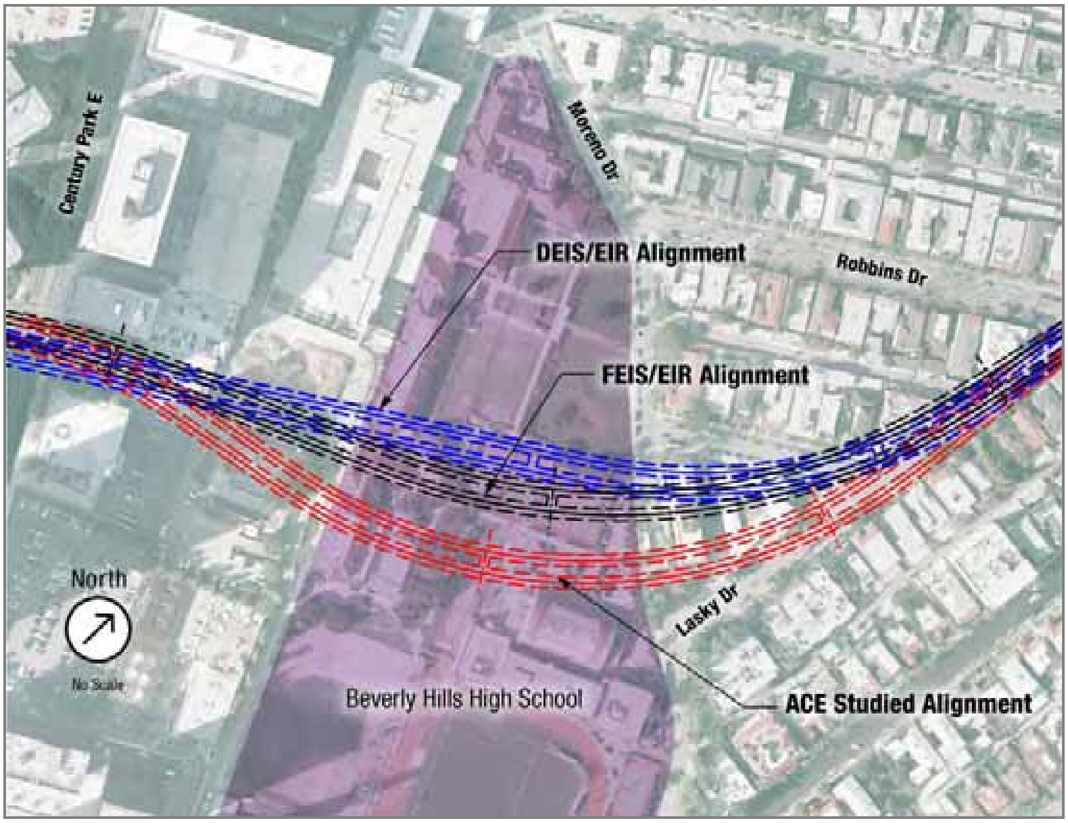
In south West Beverly Hills, the depth to the top of the tunnel increases from about 65 feet below the ground surface at Wilshire Boulevard and McCarty Drive to 70 feet along Lasky Drive (refer to Appendix A for engineering drawings). Because the ground surface elevation rises between Lasky Drive and Century Park East, the tunnel also rises. In addition, there is a steep change in ground surface elevation on the BHHS property; a hill rises to the west of Moreno Drive beyond the front lawn of the school. Thus, the BHHS's main building (Building B) sits atop this hill such that the depth to the top of the tunnel under the building is 55 to 70 feet, and the average depth is about 85 feet at the proposed Constellation Boulevard Station. The depth to the bottom of the tunnel is 90 to 95 feet, with the top of the train rails being at about 90 feet. West of the Constellation Boulevard Station, the tunnel deepens again to a minimum depth of 85 feet at South Beverly Glen Boulevard. Continuing back to Wilshire Boulevard from Beverly Glenn, the tunnels reach greater depths, over 100 feet in some areas.

Figure 2-1: Century City Area Alignments

2.1.3 Alignment Studies

During the ACE phase, alignment studies of the tunnels under the BHHS property were undertaken to minimize the length of the tunnel under buildings. Further evaluation was completed to address the Board's motion to study alignments to avoid tunneling under BHHS. Figure 2-2 shows three study alignments: the alignment presented in the Draft EIS/EIR (north), an alignment studied in ACE (south), and the proposed alignment for PE (central). The Draft EIS/EIR alignment presented a longer tangent section into the station but runs directly under Building B of BHHS. Moving the alignment to the south (ACE) avoids tunneling under the two-story portion of Building B, but is closer to the school's historic swimming pool building. Tighter curves on this alignment would also mean slower operating speeds. A more central alignment presents smoother curves in the high school area, eliminates the influence on the swimming pool, and passes beneath the south part of Building B. The current alignment provides the optimal layout for train operations and impacts on the BHHS buildings. Further discussion on the building analyses is presented in Section 4.3.

Figure 2-2: Alignment Studies in Beverly Hills High School Area



2.2 Geologic Conditions

The Southern California region is composed of several tectonomorphic provinces characterized by distinct structural orientations and geomorphic elements. The tunnel alignment is located near the boundary between the northwestern end of the Peninsular Ranges geomorphic province and the southern margin of the Transverse Ranges geomorphic province. The Peninsular Ranges province is characterized by elongated northwest-southeast trending geologic structures such as the nearby Newport-Inglewood fault zone. In contrast, the Transverse Ranges geomorphic province is characterized by east-west trending geologic structures such as the Santa Monica Fault, the Hollywood Fault, and the Santa Monica Mountains. The Santa Monica and Hollywood Faults are considered the boundary between the two geomorphic provinces within the area of the alignments under study.

The tunnel alignment for the Project is located in the northern portion of the Los Angeles Basin, approximately 0.5 to 3 miles south of the Santa Monica Mountains. This sedimentary basin occupies the northernmost portion of the Peninsular Ranges geomorphic province. The Los Angeles Basin is a major elongated northwest-trending structural depression that has been filled with sediments up to 13,000 feet thick since the Middle Miocene Epoch.

The La Brea and Santa Monica Plains comprise the primary geomorphic surfaces along the study alignments. These two gently sloping alluvial surfaces extend from the Santa Monica Mountains to the alignments and were formed by accumulation of sediments that had been shed from the mountain front over the course of the Late Pleistocene Epoch. This process was accelerated by tectonic uplift along the eastern portion of the Santa Monica Mountain range front, which has resulted in relatively high rates of erosional down-cutting in the mountain range. Repeated tectonic uplift and base level changes caused varying rates of channel incision and aggradation of sediments to areas of gentler topographic gradient. The net result of periodic tectonic uplift was the formation of alluvial surfaces at varying elevations and ages adjacent to the mountain front. Tectonic uplift has caused older alluvial surfaces to be located at generally higher elevations and show greater dissection by stream channels with respect to younger alluvial surfaces. The areal distribution of surficial geologic units and major Quaternary Faults in close proximity to the study alignments are shown in Figure 2-3.

Holocene- and Late Pleistocene-age sediments form the surficial cover along the study alignments. The Holocene-age materials, where present, are underlain by variably thick, older alluvial deposits of the late-Pleistocene age, which in turn are underlain by semi-consolidated, continental and marine sediments of the late Pleistocene-age Lakewood Formation. The Lakewood Formation materials are underlain by sediments of the early Pleistocene-age San Pedro Formation. Tertiary-age sedimentary rocks of the Fernando and Puente Formations underlie the Pleistocene sequence of sediments.

2.2.1 Subsurface Conditions

Beneath the Century City (West Beverly Hills to Westwood) area, several geologic units were encountered, ranging from Pleistocene to Holocene ages. The units, from youngest to oldest, are the Holocene younger alluvium, Pleistocene older alluvium, and the Lakewood and San Pedro Formations. Artificially placed fill soils form a surface layer of variable thickness in many portions of the study area.

A profile showing subsurface conditions in the BHHS area is shown on Figure 2-4. Descriptions of geologic formations anticipated to be encountered during tunnel and station excavations within the study area are summarized below. Boring locations and more detailed geologic profiles are contained in Appendix B.

Artificial Fill

Artificial Fill (**af** symbol on Figure 2-4) materials consist primarily of variable silts and clays with occasional sand layers. The fill contains scattered man-made debris such as concrete, asphalt, and glass. Thickness of fill materials encountered in exploratory borings within the Century City area varies from about 4 feet to a maximum of 43 feet.

Younger Alluvium

The Younger Alluvium (**Qal** symbol on Figure 2-4) sediments were encountered primarily within the north-south trending ravines that intersect the study area. These sediments were deposited by alluvial fan processes and by streams of low to moderate energy, and consist predominantly of soft to medium-stiff sandy to silty clays and clayey sand with subordinate layers and lenses of sandy silt and gravelly sand. The thickness of Younger Alluvium within the study area ranges from about 4 feet to a maximum of 28 feet.

Figure 2-3: Regional Geologic Map

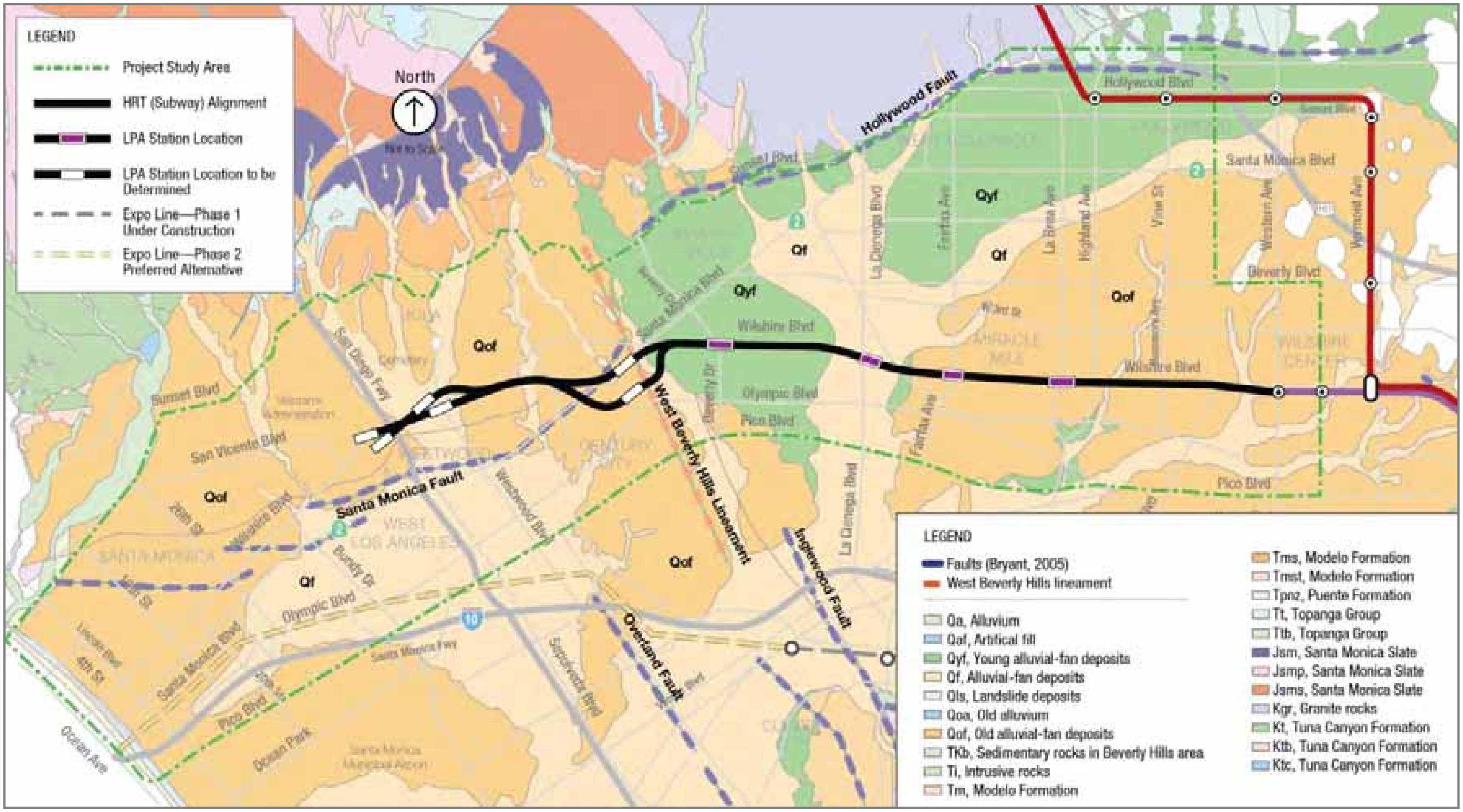
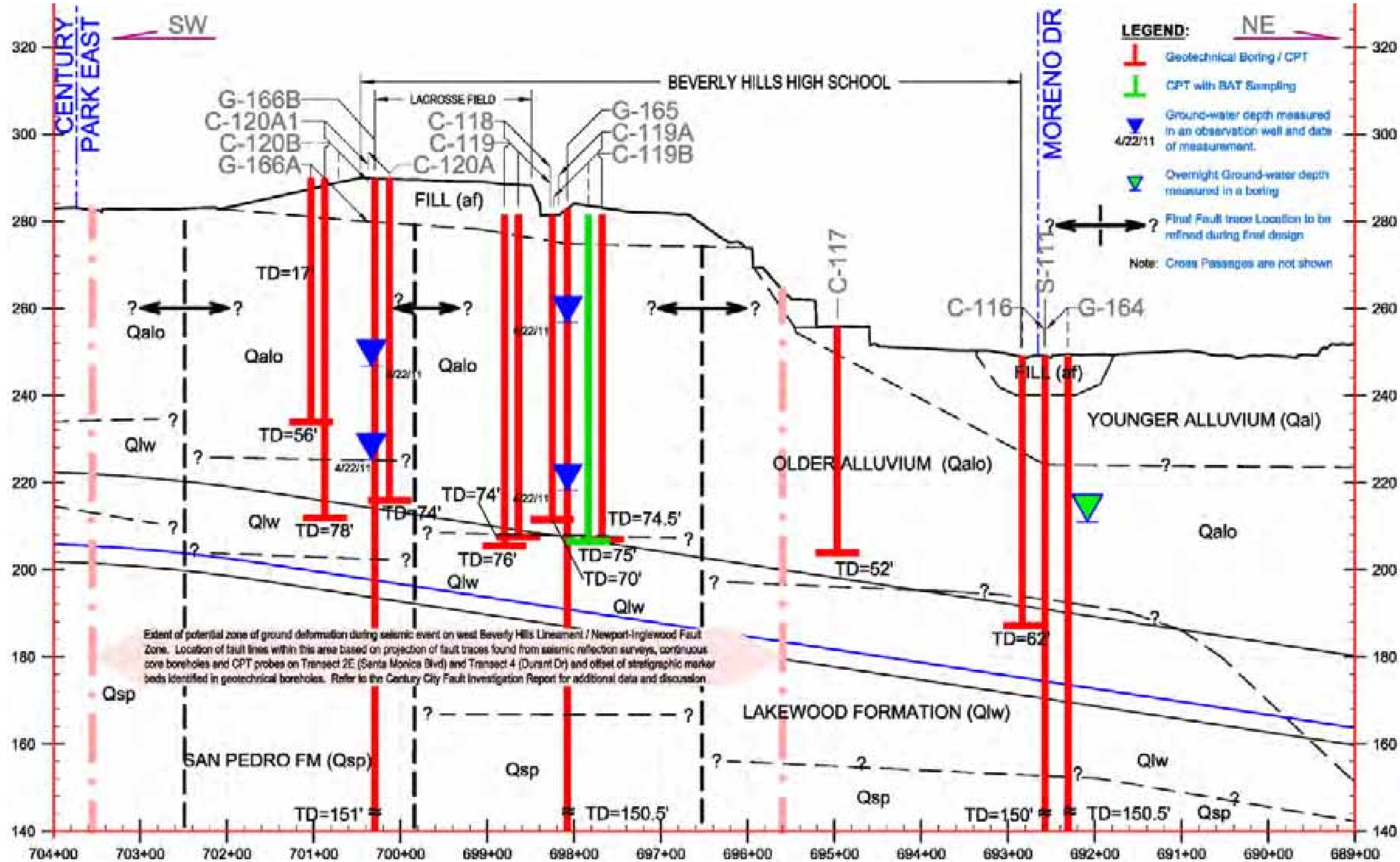


Figure 2-4: Subsurface Conditions BHHS



Older Alluvium

The Older Alluvium (**Qalo** symbol on Figure 2-4) encountered in the study area consists primarily of alluvial fan materials deposited by sheet flow, small stream channels, and other alluvial fan processes during the Late Pleistocene time. The Older Alluvium fan deposits within the study area are relatively heterogeneous. The majority of these deposits consist of stiff and very stiff to hard silts, clays, and silty/clay mixtures with layers of dense to very dense sands, gravelly sands, and fine gravel. Thickness of these sediments varies from about 80 feet in the area east of South Moreno Drive to about 20 feet in the area west of the BHHS campus. Boulders and cobbles have not been observed in the Century City area within the Older Alluvium.

Lakewood Formation

Shallow marine deposits that appear to be associated with the Late Pleistocene age Lakewood Formation (**Qlw** symbol on Figure 2-4) were encountered in the study area underlying the Older Alluvium. These sediments consist predominantly of light colored medium to very dense silty sands and poorly graded sands, with infrequent stiff to hard sandy silts and gravelly beds. Some layers containing bivalve shell fragments were encountered near the base of the Lakewood Formation. The lateral continuity of the Lakewood Formation beds and the presence of distinct marker beds, such as a shell bed and thin clay layer, allow the stratigraphy to be mapped with a high degree of confidence over relatively large distances. Thickness of the Lakewood Formation within the study area varies from 40 feet to a maximum of about 68 feet.

San Pedro Formation

Marine deposits of the Middle to Late Pleistocene age San Pedro Formation underlie the Lakewood Formation and Older Alluvium in the eastern portion of the study area. The San Pedro Formation (**Qsp** symbol on Figure 2-4) materials consist of interbedded gray to dark gray to greenish-gray, poorly graded, dense to very dense sand, silty sand, and sandy silt and variable clay/silt mixtures with occasional gravelly beds. A number of fossiliferous beds containing bivalve shell fragments were encountered within the San Pedro Formation, as well as local concretionary beds with calcium carbonate cement. Sands are generally fine grained and micaceous.

2.2.2 Groundwater

In the Century City area, groundwater levels, where observed, vary considerably. Along Century Park West and Avenue of the Stars, a groundwater barrier is present just south of the intersection with Santa Monica Boulevard. Groundwater was measured at depths as shallow as 5.4 feet below ground surface (bgs) in borings and cone penetration tests performed close to Santa Monica Boulevard, whereas groundwater is not present to the southeast in borings drilled as deep as 94 feet. This groundwater barrier is reflected in the historic geotechnical borings and in deep excavations for office structures south of Santa Monica Boulevard in the Century City area where rare groundwater inflows were encountered.

To the east of Avenue of the Stars, groundwater levels vary widely. East of Century Park East, depth to groundwater ranged from around 17 to around 85 feet, and the distinct groundwater barrier to the west is more diffuse or not present.

2.2.3 Geotechnical Exploration Program

To date, two geotechnical field investigations have been carried out for the Project. The first, during ACE, was conducted in 2009-2010 (Mactec 2010), and the second, which began in November 2010, and completed in September 2010. The current investigation, which started also during the ACE phase of design, is continuing into the PE phase of design and is referred to as the ACE/PE phase.

Field investigation for the current ACE/PE phase in the western portion of the City of Beverly Hills and Century City area consists of the following explorations:

- 12 rotary wash borings
- 2 sonic core borings
- 9 cone penetration tests
- 2 BAT® groundwater/gas samplings
- 4 pressure meter tests
- 3 monitoring wells for groundwater-level measurements
- 4 noise and vibration tests in boreholes
- Surface magnetometer scans in designated areas for abandoned oil well detection

In the tunnel reach between Century City and Westwood (to Westholme Avenue and Wilshire Boulevard), 7 rotary wash borings and CPTs were placed at about 500-foot spacings along the alignments.

In addition, a detailed geotechnical and geophysical investigation was performed to evaluate the location and extent of faulting in the area. The geotechnical results are presented in the *Century City Area Fault Investigation Report*.

2.2.4 Geologic Structural Features

The Los Angeles Basin is a seismically active area. Figure 2-3 shows regional fault locations. The known documented active faults that are close to the alignment include the Santa Monica Fault, the Hollywood Fault, and the West Beverly Hills Lineament (WBHL), now considered the Newport-Inglewood Fault. The Century City Area Fault Study Report separately presents faulting with respect to the Century City alignments.

As can be seen in Figure 2-4, the tunnels will be driven through very dense to hard soils of the Older Alluvium, Lakewood, and San Pedro formations. As a result of a comprehensive fault investigation conducted in parallel with the tunneling safety study, it has been determined that the WBHL is an extension of the Newport-Inglewood fault. The detailed results of this fault investigation have been considered with the geotechnical data obtained for the tunnel safety study to present the data in the soil profile in Figure 2-4. The interpretation is that in this area there are multiple strands of fault traces, which are identified by offsets in marker beds between adjacent borings.

In Figure 2-4, the extent of potential zone of ground deformation during seismic events is shown by pink vertical lines; the western boundary is at about Century Park East and the eastern boundary is at about the bluff on the BHHS campus grounds. Marker beds between borings essentially line up to the west and to the east of these lines and thus there is no indication of active faulting to the west or east of the zone. There are three potential fault strands (shown as vertical black dashed lines within the pink zone of deformation). The location of each fault strand was determined by a combination of boring data and geophysical fault transect (study lines) conducted in the vicinity. The horizontal arrows crossing these lines indicate that the precise location and orientation of the fault strand is not known and there may be other unknown strands within the zone. A description of the methodology and the backup for these interpretations are given in the *Century City Area Fault Investigation Report*.

Within the faulted area, the geotechnical data indicate that the soils will be dense and will not be unfavorable conditions for tunneling. There is no evidence of cobbles and/or boulders in the soils. Variability in soil conditions may exist to some extent, but a pressurized closed-face tunnel boring machine should not have difficulty in these soils. Further exploration to confirm the actual tunneling soils and conditions, including fault offsets, will be conducted.

Additional investigations during final design will be necessary to more accurately define the extent and nature of the fault zones that must be crossed and to provide details to determine and design the most suitable excavation and lining methods.

3.0 BUILDINGS ALONG THE CENTURY CITY ALIGNMENTS

Protection of buildings above tunnels is analyzed during design phases. Over much of the Project's alignment, the tunnels are within public rights-of-way and are not directly beneath buildings. For the Century City Constellation alignment, between about Wilshire Boulevard and McCarty Drive to Wilshire Boulevard and Manning in Westwood, the alignment requires some tunneling under buildings. For the Santa Monica Alignment, the reach between Club View Drive and Manning in Westwood requires tunneling under buildings.

Constellation Option

- For the reach within Southwest Beverly Hills from the intersection of McCarty Drive and Wilshire Boulevard to ~~the intersection of Young and Lasky~~South Moreno Drive, the tunnel corridor passes beneath ~~12 properties~~21 buildings, comprising the following:
  - ~~10 single-family homes~~12 one or two story buildings
  - ~~2 buildings with apartments or multiple-occupancy residences~~9 three or more story buildings
- For the BHHS campus and associated Beverly Hills Unified School District (BHUSD) buildings that are off campus and to the north of South Moreno Drive, the tunnel corridor passes beneath two off-campus buildings and one building on the school campus.
- Commercial building (AAA building) and parking garage between BHHS and Century Park East Boulevard.
- The Westfield Century City Shopping Center in the heart of Century City is a multiple-building shopping center accessed by outside walkways. The shopping center sits on approximately 18.7 acres and is bordered by Santa Monica Boulevard to the north, Avenue of the Stars to the east, Constellation Boulevard to the south, and Century Park West to the west. The tunnel corridor passes beneath the three following commercial properties in the southwest portion of the shopping center:
  - 3-story AMC movie theater
  - 2-story Macy's department store
  - 5-story, 48,417-square-foot office building on a 0.75 acre parcel
- For the reach through Century City and Westwood from Century Park West Boulevard to the intersection of Wilshire Boulevard with Manning Avenue, the tunnel easement corridor passes directly beneath 73 properties comprising the following:
  - ~~56 single-family homes~~61 one or two story buildings
  - ~~16 buildings with apartment or multiple-occupancy residences~~12 three or more story buildings
  - ~~1 office building~~

Santa Monica Option

- For the reach between Club View Drive, Santa Monica Boulevard and Manning in Westwood, the tunnel corridor passes beneath 77 ~~properties~~ buildings comprising the following:
  - 67 ~~single-family homes~~one or two story buildings
  - 10 ~~buildings with apartment or multiple-occupancy residences~~three or more story buildings

In addition to the tunnels within this area, a subway station serving Century City could be located on Constellation Boulevard just west of the BHHS campus.

3.1 Proposed Alignment beneath BHHS

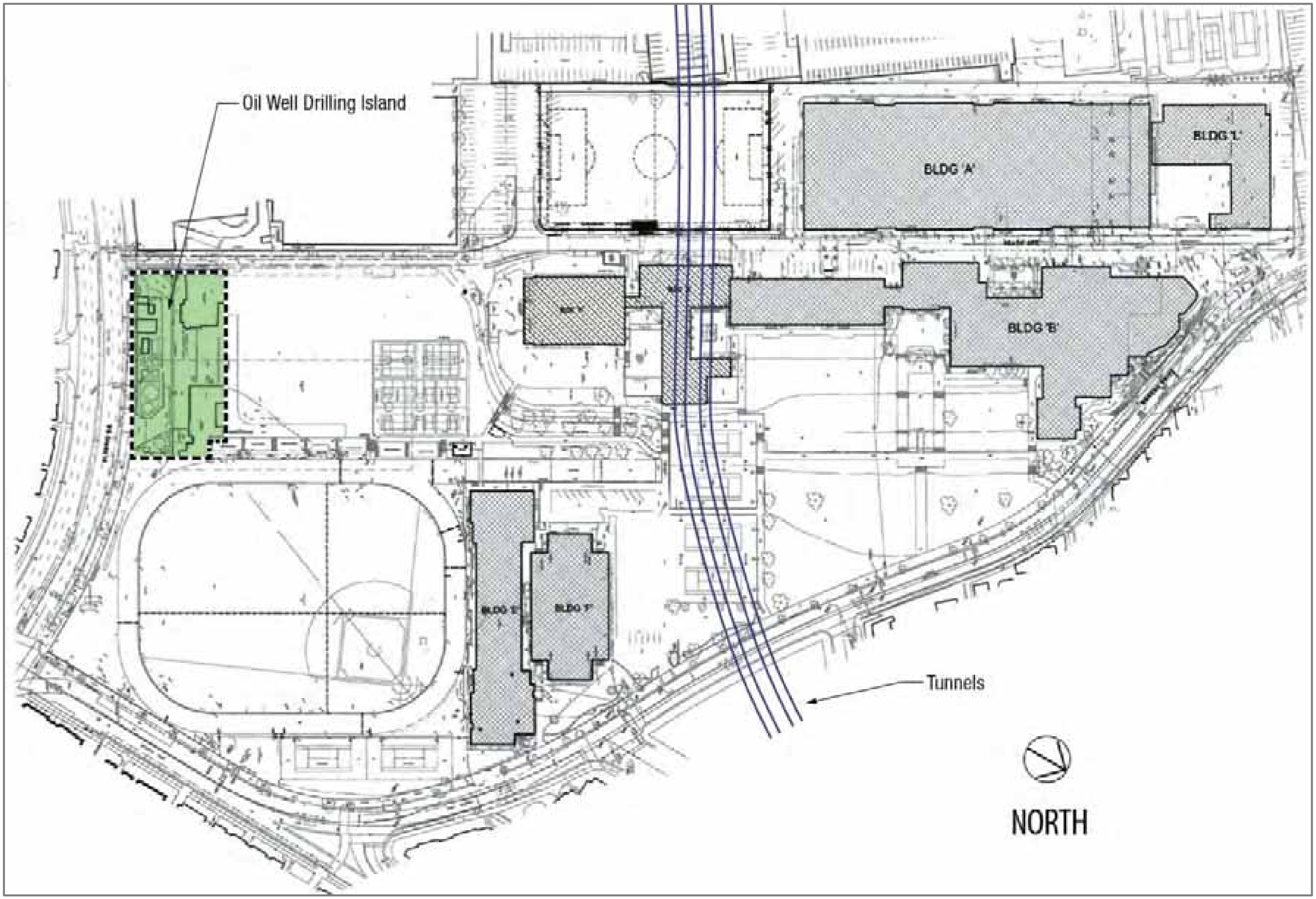
BHHS is the only major public high school for the City of Beverly Hills. It is part of the BHUSD and was founded in 1927. The BHHS campus also includes Moreno High School, a small alternative school that is the only other high school in Beverly Hills. Site visits were made to the high school property for geotechnical investigations as well as to observe the property. Appendix C contains notes from the site visit.

BHHS is located on 19.5 acres on the west side of Beverly Hills, at the border of Century City. Figure 3-1 shows a photo of the High School in 1928, and a schematic plan of the school campus showing the layout of existing structures is provided in Figure 3-2.

Figure 3-1: Beverly Hills High School (1928)

Photo credit: Security Pacific National Bank Collection/Los Angeles Public Library

Figure 3-2: BHHS Campus and Layout of Buildings



The land on which the campus is located was previously part of the Beverly Hills Speedway board track, which was torn down in 1924. The original buildings, which are still standing and used as classrooms, were designed by Robert D. Farquhar in the French Normandy style.

The tunnel alignment alternative passes beneath the BHHS campus as follows:

- The alignment approaches the campus from the northeast following beneath South Lasky Drive. It passes under the BHUSD Administration Building at 255 South Lasky Drive and then the Adult Learning Center operated by the district on the east side of South Moreno Drive.
- After crossing beneath South Moreno Drive, the alignment enters the high school campus (street address 241 South Moreno Drive), passing beneath the existing tennis courts and about 100 feet northwest of the Athletic Facility (i.e., Swim Gym—Building F).
- The alignment then passes beneath building wing south of Building B, part of the original school facilities built in the late 1920s.
- The alignment then crosses beneath Heath Drive, a public right-of-way that transects the campus.
- On the southwest side of Heath Avenue, the alignment crosses beneath the existing lacrosse playing field south of Building A, a newer structure.
- West of the playing field, the alignment exits the school campus and the jurisdiction of the City of Beverly Hills, crossing into Century City, a neighborhood within the City of Los Angeles.

The tunnels approaching South Moreno Drive from South Lasky Drive would be approximately 60 feet deep to the tunnel crown. This depth would be reduced to about 50 feet beneath the tennis courts. As the tunnels continue southwest, passing beyond the steep scarp slope, the depth to the tunnels would increase, and beneath Building B, the tunnel depth to top of tunnel would approach over 70 feet, 90 feet to top of rail.

4.0 TUNNELING AND GROUND MOVEMENT

The subway will consist of two parallel bored tunnels serving eastbound and westbound tracks. As currently configured, each tunnel will be circular with an 18-foot 10-inch inside diameter. The tunnel will be lined with pre-cast concrete segments bolted together to form a ring and dowelled to the previously installed ring. Each ring will be installed after the tunnel has advanced 5 feet.

The installed concrete segment lining is the initial support during construction and permanent support over the life of the tunnel. The segments are gasketed to provide watertight and gas-tight joints between segments. For the Project, a double-gasket system will be used that provides a robust seal against water and gas and a positive means for isolating and sealing any leaks. This system was used on the MGLEE and is described further in Section 5.5.3.

4.1 Tunneling Methods

On most transit tunnel projects, significant portions of the alignments are constructed adjacent to or beneath buildings. The ability to control and limit ground movements allows this to be done safely. The primary safeguard for the protection of buildings is the selection of an appropriate tunneling method—one that minimizes ground loss and the ground movements that could affect buildings. Over the past 10 to 15 years in the U.S., pressurized, closed-face soft ground TBMs have been used to provide immediate support of the ground and use proven systems for monitoring and controlling machine operations. As a result, excavated volumes can be controlled, which reduces the risk of ground loss and allows timely response to the conditions encountered during tunneling. These machines provide a safer work environment than open-face shields and minimize ground loss and settlement of the ground surface.

The project tunnels will be constructed using these state-of-the-practice soft-ground TBMs. The machine is contained within a circular shield that supports the ground behind the face and provides protection for the erection of the tunnel lining. It has a closed chamber behind the cutting wheel filled with the excavated soil and/or slurry. The chamber is pressurized to support the ground ahead of the tunnel and prevent inflows of soil and water. The bulkhead allows a positive pressure to be applied to the tunnel face while allowing tunnel workers to work in free air (atmospheric pressure) behind the bulkhead.

Two types of pressure face TBMs are used worldwide: Slurry Face Machines (SFMs) and Earth Pressure Balance Machines (EPBMs).

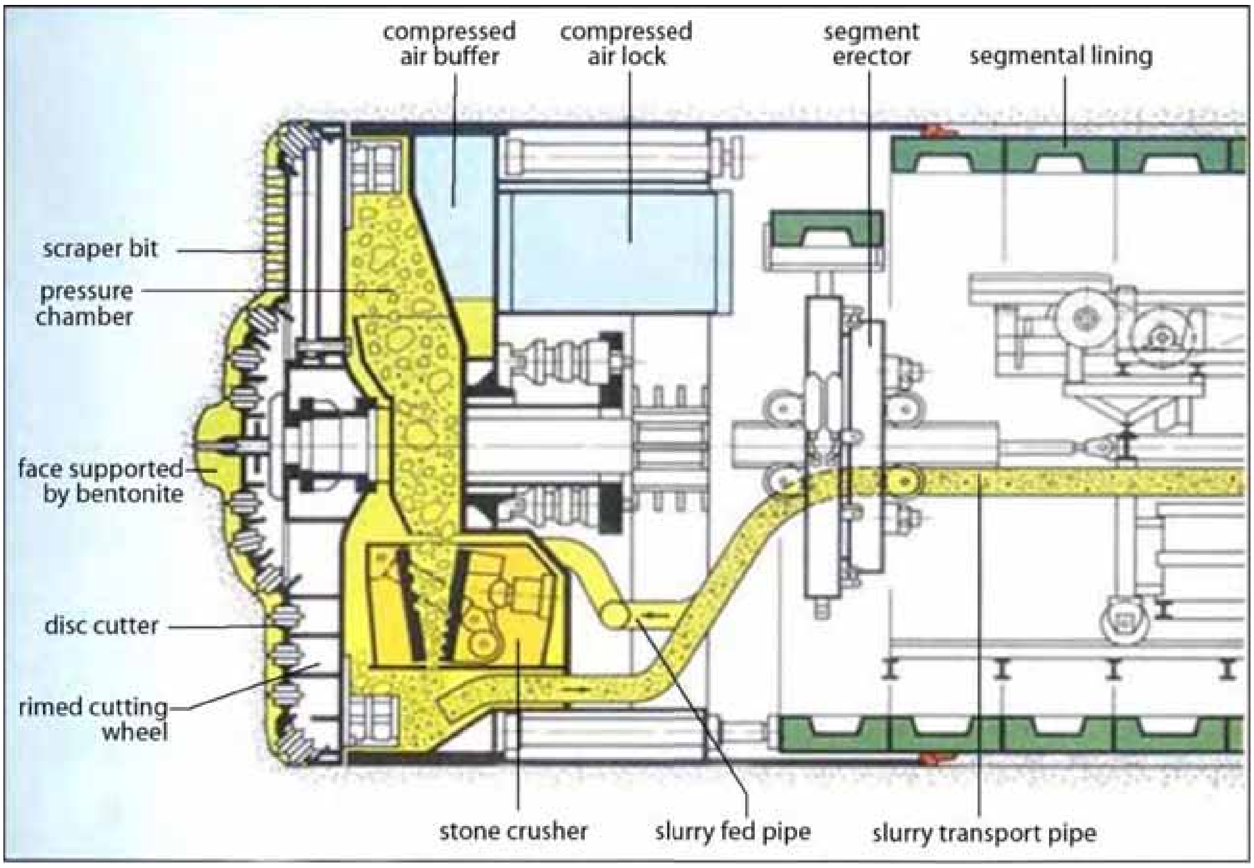
Using SFMs and EPBMs, tunnel construction is a cyclic process that advances the tunnel in increments (typically 4 to 5 feet) and with the following primary operations:

- Excavation of the tunnel face by a rotating cutterhead and advancement of the TBM by propel jacks that react against the installed tunnel lining.
- Erection of the pre-cast concrete segments to form the circular tunnel lining within the tail section of the TBM shield.
- Continuous backfilling of the annular space between the lining and the excavated perimeter with grout injected through the tail of the TBM shield as the TBM is advanced.

4.1.1 Slurry Face Machine

The SFM, shown in Figure 4-1, applies fluid pressure to the tunnel face through the excavation chamber through pressurized bentonite slurry. Other fluid conditioners may be added, depending on the soil conditions encountered. While the fluid maintains positive pressure at the tunnel face, the slurry is continually circulated through the excavation chamber to facilitate removal of excavated material (i.e., spoils) from the face as the tunnel progresses. Suspended in slurry, the spoils are pumped from the chamber to a separation plant at the ground surface where they are separated from the slurry, allowing the treated slurry to be returned and reused in the excavation chamber.

Figure 4-1: Schematic Section of a Slurry Face Machine



Since the slurry system is always enclosed in the TBM's cutting chamber and in pipelines into and out of the tunnel, exposure of workers to the excavated soil is eliminated. Thus, the slurry system is well suited for ground that contains contaminants and hazardous gases. These materials can be removed at the surface where ventilation can be more easily provided.

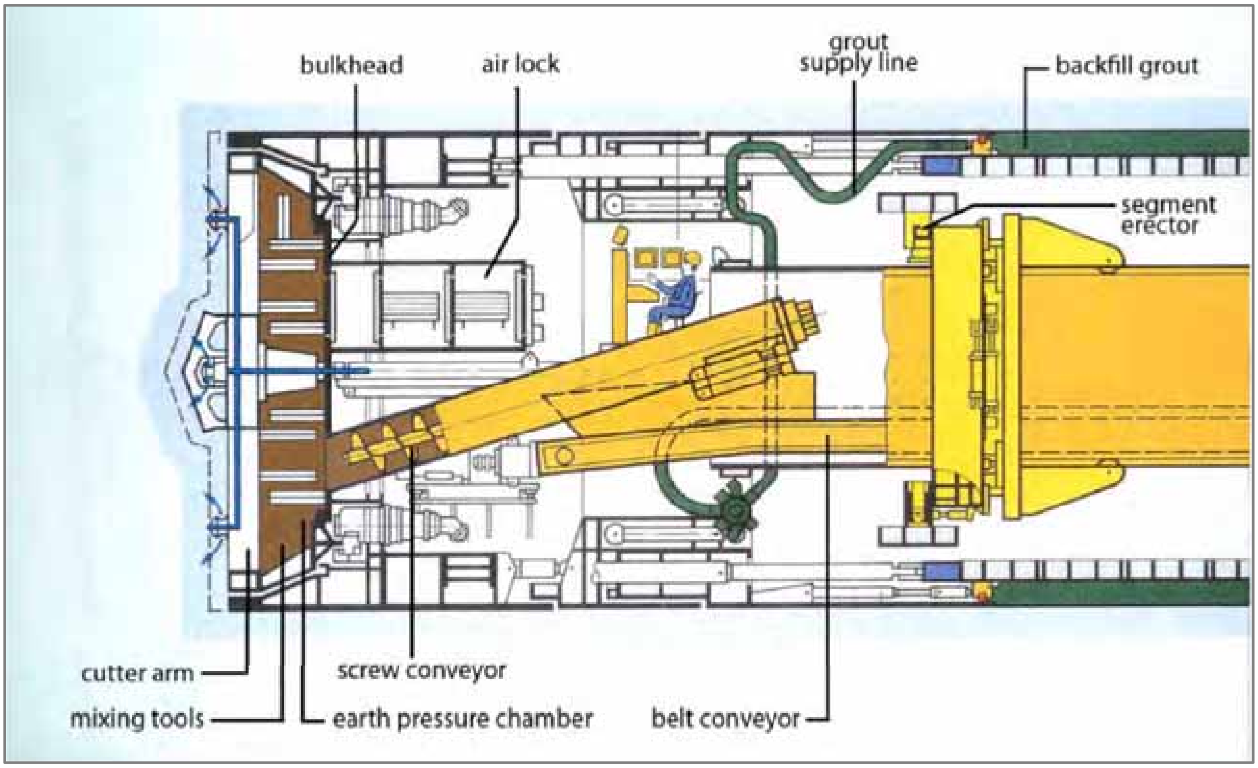
Soil conditions in which an SFM are best suited are coarser-grained soils (sands and gravels). However, with advances in soil/slurry separation techniques, the range of grain sizes that can be excavated using SFMs has increased to include finer-grained materials. The separation equipment required and the cost of treatment increases for the finer-grained materials.

4.1.2 Earth Pressure Balance Machine

With an EPBM, excavated material is allowed to fill the excavation chamber as the tunnel advances. Face pressure is controlled by balancing the rate of advance of the EPBM with the rate of discharge of the excavated material.

Soil conditioners, such as bentonite, foam, and polymers, are added to the chamber to improve workability and reduce wear on the machine. Excavated material emerges from the screw conveyor as a thick paste and is emptied onto a conveyor belt or into muck cars for transport to the surface. Figure 4-2 shows a schematic of an EPBM.

Figure 4-2: Schematic Section of an Earth Pressure Balance Machine



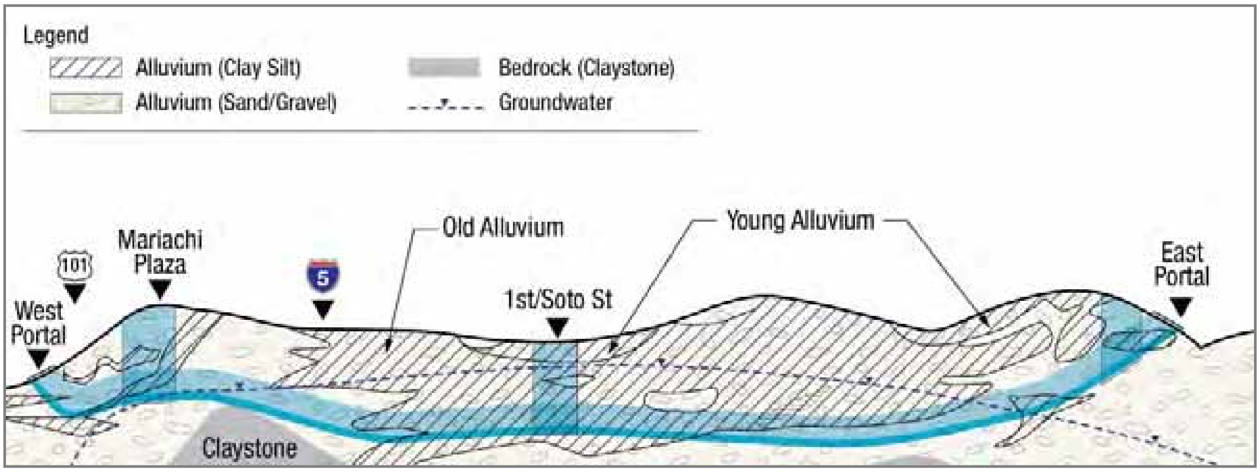
The soil conditions for which the EPBM is best suited are finer grained (sand, silt, and clay) materials. However, with advances in methods for conditioning soils, the range of grain sizes that can be excavated using EPBMs has increased to include coarser-grained materials.

4.2 Tunneling Experience from MGLEE

Metro recently completed 1.8-miles of twin tunnel for the MGLEE. This was the first Metro project on which pressure-face TBMs were specified and used. The twin tunnels were driven with two EPBMs, the most widely used type of pressure-face TBM. Procedures were in place and were used to control the tunneling operation and limit settlement throughout the two tunnel drives.

The tunnels were advanced through Old Alluvium, consisting of layers of sand and clay (an alluvial deposit also to be encountered in the Westside tunnels). Figure 4-3 shows a longitudinal profile of soil conditions.

Figure 4-3: Metro Gold Line Eastside Extension—Geologic Profile



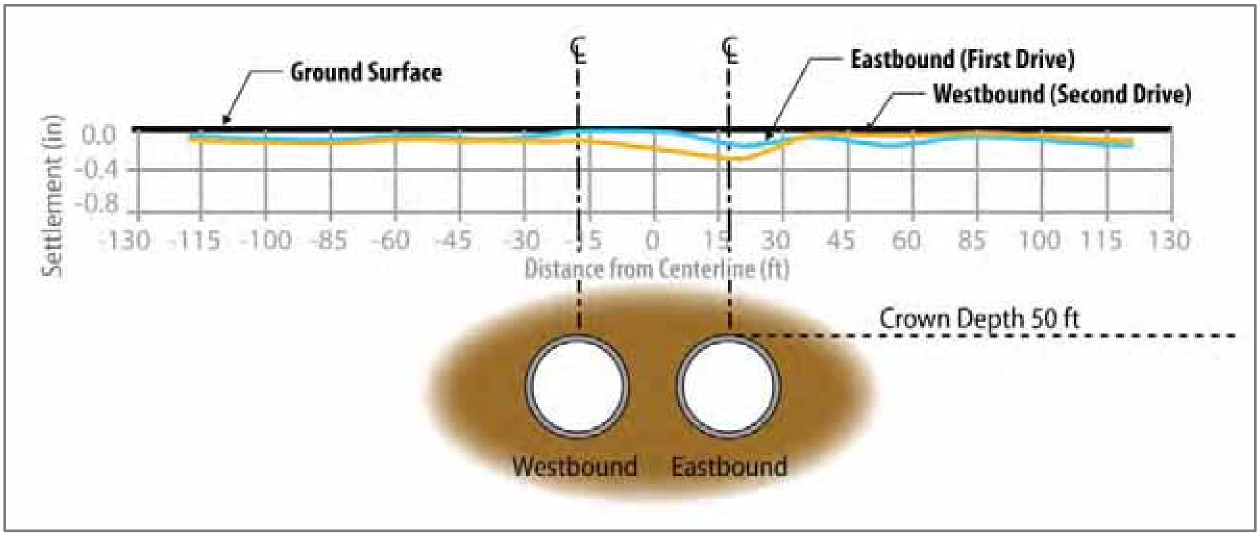
A comprehensive program of instrumentation and surveying was conducted to monitor ground movement around and above the MGLEE tunnels during and after construction. Surface settlement points were established at 25-foot intervals along both tunnel centerlines. The data showed surface settlements were very small, typically in the range of 0 to 0.4 inch; the values were often less than survey accuracy. Settlement points placed on the sides of buildings located above and adjacent to the tunnels also recorded little or no displacement.

There were no substantiated damage claims from settlement. Figure 4-4 is a cross section showing a surface settlement profile with maximum settlement of approximately 0.3 inch after mining of both tunnels. During driving of the first (eastbound) tunnel, settlements were less than 0.2 inch, which was in the range of survey accuracy. Settlements increased to 0.3 inch during driving of the second (westbound) tunnel. The percentage volume loss for the settlement profile has been estimated to be in the range of 0 to 0.3 percent, which is well below the 0.5 to 1.0 percent values that have been used to estimate ground loss for Metro projects.

Seventy-seven extensometers were installed in vertical borings along the two tunnel centerlines to measure ground movement near the crown of the tunnels and at mid-depth between the tunnel and the surface. Continuous readings were recorded, plotted, and compared to established Action and Maximum levels. Throughout the tunnel drives, the extensometers recorded displacements that were typically less than 0.1 inch and an order-of-magnitude less than the Action and Maximum levels, confirming that the EPBM operation was effective in minimizing ground movement.

At the extensometer locations, settlement cross sections, consisting of a series of settlement points anchored below the pavement, were placed to measure surface settlement. Measurement and reporting of the settlement data were conducted as the tunnels were advanced beneath the instrument and settlement point array. Surface settlements ranged from 0.0 to 0.4 inch, and averaged 0.1 inch. Settlements dropped off in magnitude with distance from the tunnel centerlines.

Figure 4-4: Typical Settlement Profile, MGLEE



4.3 Anticipated Ground Movements for the Project

For the Project, including the section beneath BHHS, the design of the Project's tunnels will build on experience gained from tunneling on the MGLEE and other projects throughout the world. Pressurized-face TBMs will be used to advance the tunnels and will limit ground movement by using systems and procedures for controlling face pressure and immediately and continuously grouting annular gaps around the tunnel lining as the shield is advanced and the tunnel lining is installed.

The evaluation of ground movements for the Project considers soil properties, tunnel depth, and the systems and procedures that will be employed during tunneling to control ground movement. Surface settlements along the Project's alignment have been analyzed for surface volume losses of 1 percent and 0.5 percent.

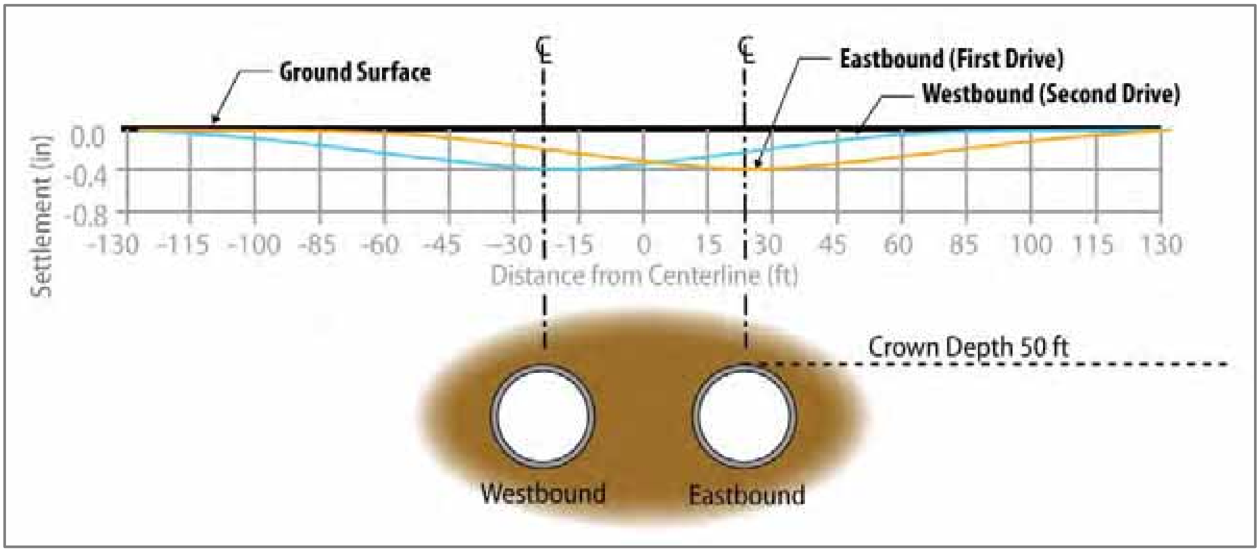
Recent experience of pressurized closed-face TBMs tunneling through dense alluvial deposits indicate that ground loss in the field will be less than 0.5 percent. This has been the experience on the following recently completed projects:

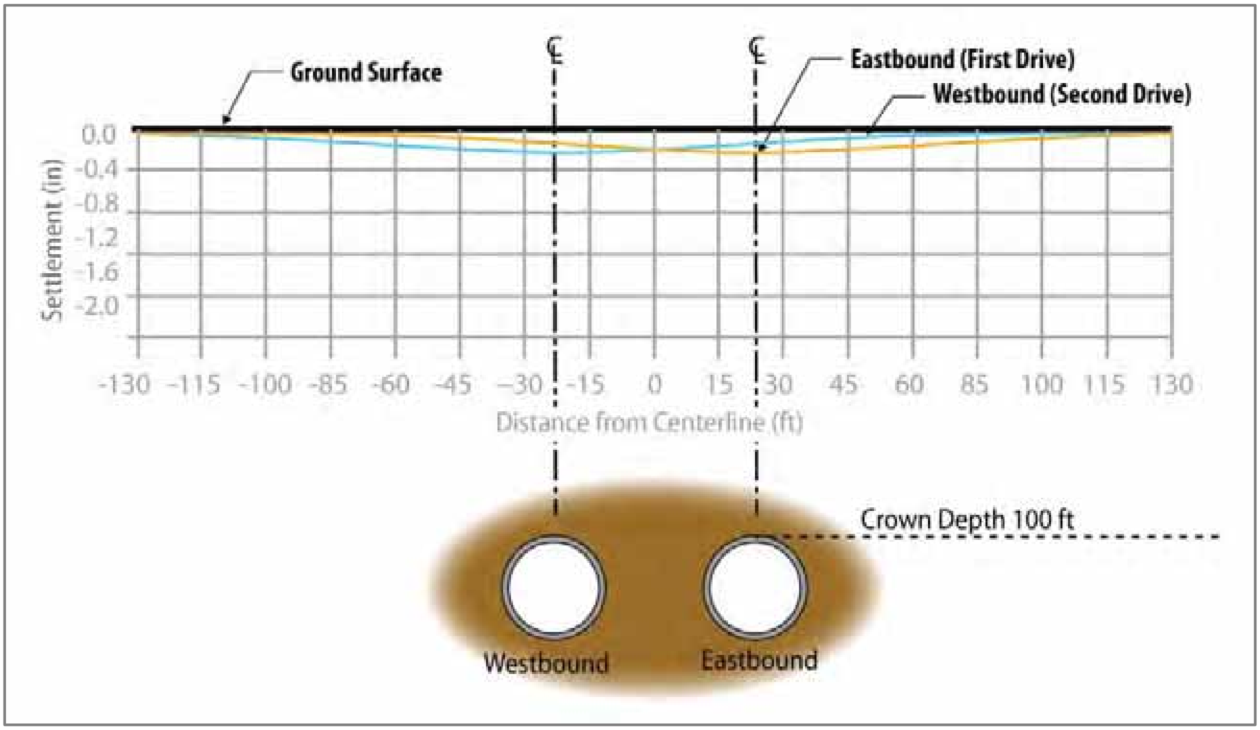
- MGLEE Tunnel, Los Angeles, California—Ground loss back-calculated from ground surface, measurements at more than 50 cross sections, ranged from 0.0 to 0.4 percent and was typically less than 0.25 percent, essentially not detected.
- West Side Combined Sewer Overflow Tunnel, Portland, Oregon—Ground loss over much of the alignment was less than 0.5 percent.
- East Side Combined Sewer Overflow Tunnel, Portland, Oregon—Ground loss over much of the alignment was less than 0.5 percent.

Ground loss appears at the ground surface as a three-dimensional trough that advances with the tunnel and can be estimated in a cross-section by a Gaussian distribution as developed by Birger Schmidt and Ralph Peck (Peck 1969)—an inverted Bell curve.

Figure 4-5 illustrates the estimated settlement for 50- and 100-foot tunnel depths (to crown) at 0.5 percent ground loss.

Figure 4-5: Estimated Settlements for 50- and 100-Foot Tunnel Depth (to crown) at 0.5 Percent Ground Loss





Once the anticipated settlement patterns, such as shown in Figure 4-5, have been determined, the level of distortion and damage can be assessed for buildings located within the potential settlement zone. Burland et al., 1977, developed a classification that used three general categories—architectural (or cosmetic), functional, and structural damage—to describe the effects of progressive amounts of strain (Figure 4-6). This approach was further refined by Boscardin and Cording, 1989, and Cording et al, 2001, who considered both the angular distortion that results from settlement and lateral strains that develop in buildings located within the settlement zone (Table 4-1). For design purposes, a conservative (high) estimate can be obtained by assuming angular distortion is equal to the average settlement slope. A more accurate determination of the angular distortion is obtained by subtracting the building tilt and sidesway from the settlement slope, and by reducing the angular distortion to take into account the effect of building stiffness on the shape of the settlement curve.

Figure 4-6: Damage Categories

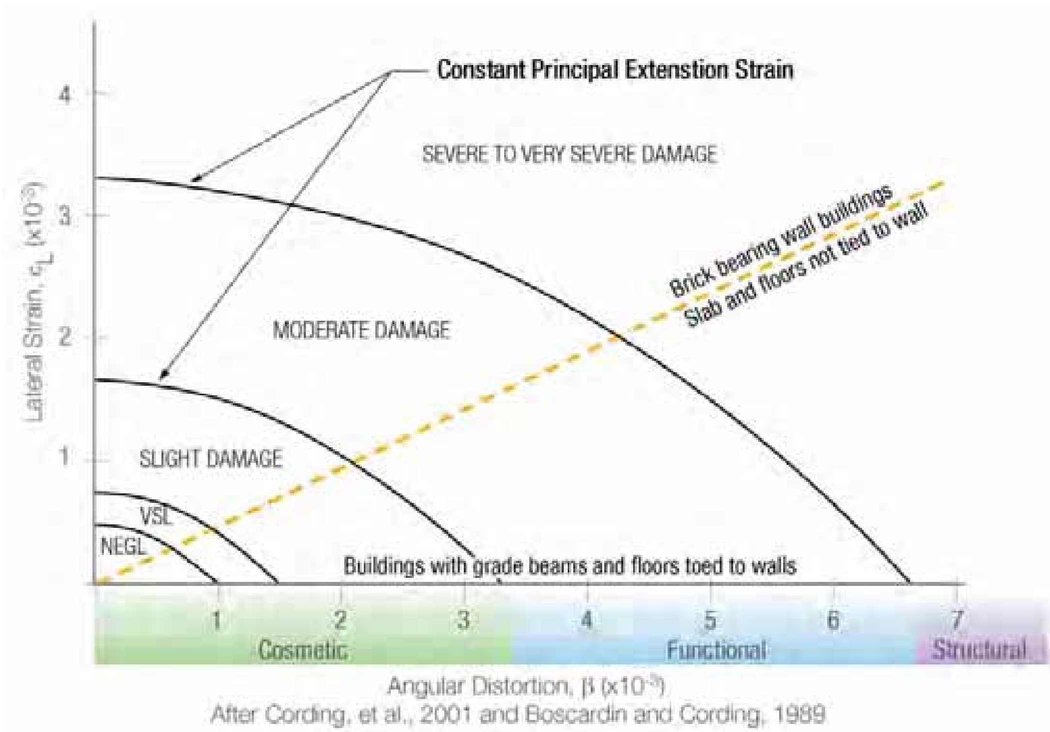


Table 4-1: Building Damage Classification[1]

Risk Category	Degree of Damage	Description of Typical Damage and Likely Forms of Repair for Typical Masonry Buildings	Approx. Crack Width (in)
0	Negligible	Hairline cracks	< 0.004
1	Very Slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior brickwork visible upon close inspection.	0.004 to 0.04
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible: some repointing may be required for weather-tightness. Doors and windows may stick slightly.	0.04 to 0.2
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Re-pointing and possibly replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather-tightness often impaired.	0.2 to 0.6; or number of cracks greater than 3
4	Severe	Extensive repair involving removal and replacement of sections of walls, especially over doors and windows required. Windows and frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted.	0.6 to 1.0; also depends on number of cracks
5	Very Severe	Major repair required involving partial or complete reconstruction. Beams lose bearing. Walls lean badly and require shoring. Windows broken by distortion. Danger of instability.	> 1.0; also depends on number of cracks

The table is based on the work of Burland et al (1977), as reproduced in Cording and Boscardin (1989). Crack width is only one aspect of damage and should not be used on its own as a direct measure of it.

Figure 2-4 showed the profile of soil conditions at BHHS along the proposed tunnel alignment. The tunnel crown is located at a depth ranging from 55 to 70 feet bgs. At the tunnel level, very dense sands predominate, with stiff to hard clays above the tunnel crown.

The alignment avoids the central section of the school and passes beneath the wing south of Building B (Section 2.2, Geologic Conditions, Figure 2-2). The portion of the structure beneath which the tunnel passes has masonry walls on the exterior with interior concrete columns and with concrete floor beams tied into the walls.

In Century City, the tunnel would pass directly below foundations for the Westfield Mall. Existing foundation plans are currently being obtained such that an evaluation of the structure with respect to the tunnel depth can be performed.

Volume losses of less than 0.5 percent are expected along the alignment, which, at BHHS for a tunnel crown at a depth of 50 feet, would result in surface settlements of less than 0.5 inch and an average surface settlement slope (angular distortion) of 0.75×10^{-3}. As shown in Figure 4-6, this value is in the range of negligible damage for buildings with floors and slabs tied to walls (such as brick bearing-wall buildings with reinforced concrete beams tied into the walls) and negligible to very slight for buildings that are not laterally tied. Distortions are well below the levels of structural or functional damage and in the range where cracking of finishes does not occur or is very minor.

5.0 TUNNELS CONSTRUCTED IN GASSY SOILS

Transit tunnels constructed in gassy ground conditions pose concerns for both construction and operating conditions. The Los Angeles area has a long history of oil production and its ground contains related subsurface gases—mostly methane and hydrogen sulfide—but other heavier hydrocarbons such as Ethane (C_2H_6) and Pentane (C_7H_{16}) have also been encountered in areas with tar seeps. Tunnels constructed through these areas are subject to regulation by the State of California's Occupational Safety and Health Administration (Cal/OSHA). The safety provisions were developed in the 1970s after an explosion during construction of the Sylmar tunnel. Federal OSHA contains similar provisions, some adapted from California and mining industry experience.

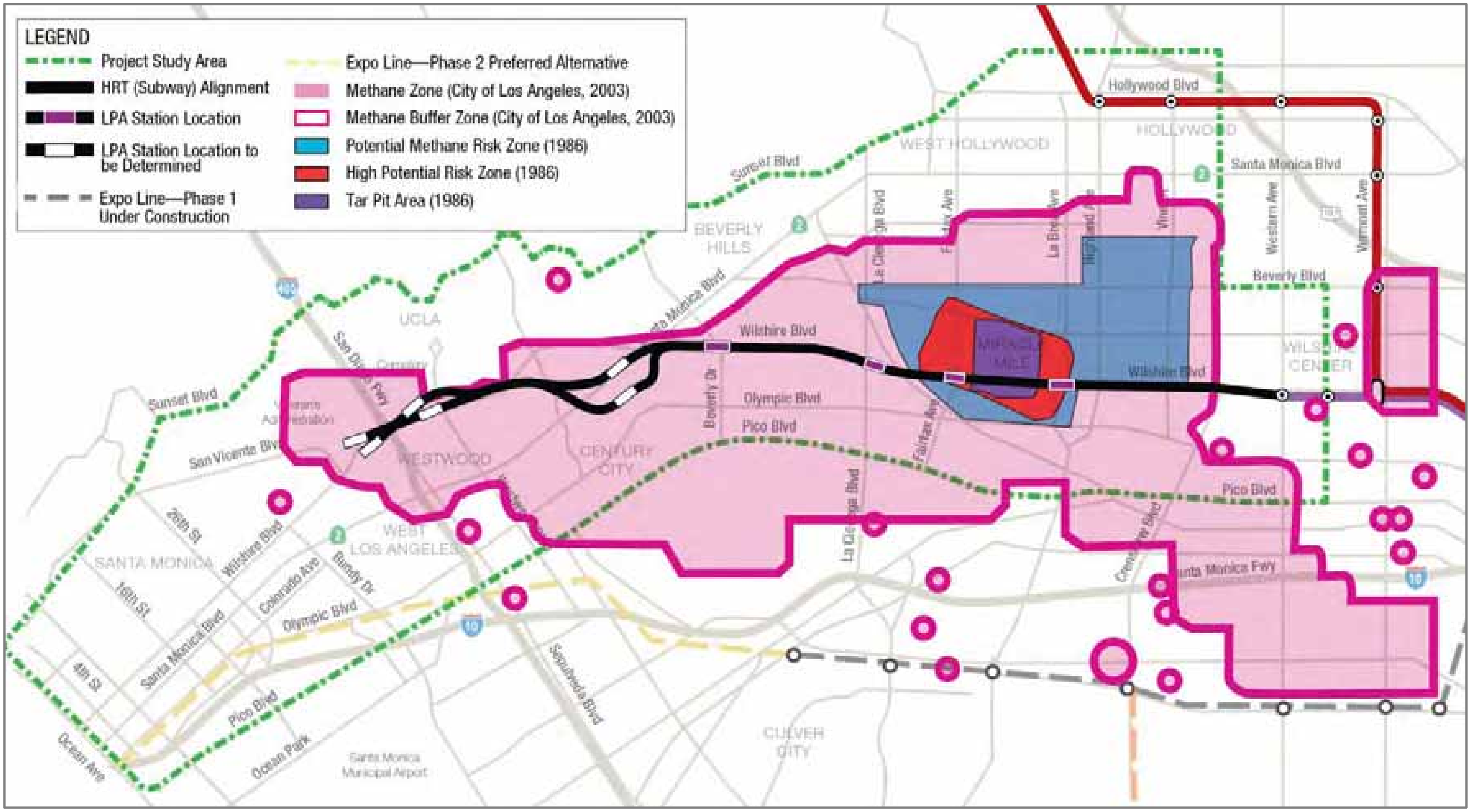
Metro has developed designs and operating procedures for its existing subways in these types of ground conditions and is currently designing tunnels for the Project (and other projects) in gassy ground conditions, including the area around the La Brea Tar Pits. This section provides background on gassy ground conditions in Los Angeles, tunnel design for and construction methods in gassy ground conditions, and a description of tunnel design and operational provisions envisioned for the Project.

5.1 City of Los Angeles Methane Zone

The presence of gassy ground in the project area is well known and was brought to the public's attention after the 1985 explosion of the Ross Dress for Less Store on Third Street and Fairfax Avenue area in the La Brea Tar Pits area. After this event, the City of Los Angeles assembled a task force that recommended creation of a Methane Risk Zone and special requirements for buildings to be constructed in this zone. Figure 5-1 shows that the Potential and High Potential Methane Risk Zones, extend along Wilshire Boulevard from east of Vine Street to about San Vicente Boulevard, centered in the Wilshire/Fairfax area around the La Brea Tar Pits. In 1986, after the creation of the Methane Zone, the U.S. Congress enacted legislation (HR3244) that funded Metro's initial Red Line segment but prohibited use of federal funds for subway construction in the potential methane zone. In 2007, Congress repealed the 1986 legislation given subsequent advances in technology and demonstrated successes in underground construction projects, including those in Los Angeles. Key in the repeal of this legislation were conclusions by a panel of experts assembled by the American Public Transportation Association (APTA). The panel reviewed new data and prepared the November 2006 Peer Review Panel Report on tunneling safely along Wilshire Boulevard. The focus of the APTA study was on the conditions at the Wilshire/Fairfax area. Building code provisions for methane zones and methane buffer zones within the city address the natural occurrence of gas and provide mitigation. These building measures include proper investigation of gases, construction of methane barriers or liners under buildings, gas venting systems beneath building slabs, and methane detection equipment. Although Metro explorations in the Century City area have not encountered the level of gases found in the Fairfax Avenue area, it is now included in the City of Los Angeles' 2003 Methane Zone, expanded in area since 1986 (Figure 5-2).

Figure 5-1: City of Los Angeles Methane Zone: 1986

Figure 5-2: Current Methane Zone



5.2 Review of APTA Study

The overall objective of the APTA peer review was "to conduct an independent evaluation and report on gas related safety issues associated with the proposed extension of the Metro Red (now Purple) Line Subway along Wilshire Boulevard, taking into account currently available technologies." The evaluation included both tunnel- and station-construction methods and the long-term performance of these structures. The panel was also asked to provide conclusions as to whether tunnel and station construction and operation along Wilshire Boulevard could be implemented safely in view of available tunnel construction and gas mitigation technologies.

Summary conclusions of the panel were that tunnels could be safely constructed and operated in the Wilshire Boulevard corridor given changes since 1985, which include the following:

- Advances in TBM technologies such as use of pressure face TBMs (as described in Section 4.1)
- Increased local and international tunneling experience with pressure-face tunneling
- New knowledge about methods to mitigate gas risks
- Local experience with subterranean construction along Wilshire Boulevard and within Century City
- Improvements in gas measurement instrumentation technology
- Successful operation of the existing Metro system with its gas monitoring and mitigation measures
- Improved attitudes with regard to safety in the industry

Metro has followed up and built on recommendations of the APTA panel, given the more detailed geologic information obtained during conceptual and preliminary engineering, as well as through experience gained in Metro construction since the APTA study—in particular, successful completion of the MGLEE tunnels and its cross-passages constructed in the former Boyle Heights oil field.

5.3 Tunneling in Gassy Ground Conditions

Gases from the ground can mix with air in an excavation to form an atmosphere that can explode, or can irritate, poison, or asphyxiate the occupants. For an explosion to occur, the gas concentration in air must be within its explosive range (percentage in air) and a source of ignition (spark) must occur. Gases occur in a variety of geologic conditions, and when unanticipated, may have negative consequences. Methane is common in the Los Angeles geology and is explosive in air in concentrations of 5 to 15 percent. Hydrogen sulfide, while also explosive in concentrations of 5 to 45 percent in air, is highly toxic in much lower concentrations. Safe levels for the working environment have been established at 10 percent of the lower explosive limit for methane and 10 parts per million (ppm) for hydrogen sulfide. Other gases, typically heavier hydrocarbons, have been known to evolve from the tar materials encountered in open excavations. California Tunnel Safety regulations (Section 5.4) provide minimum requirements for tunnel safety during construction.

Traditional geotechnical exploration for soil and soil gases measures the concentration of hazardous gases such as methane and hydrogen sulfide in the groundwater and/or in the vapors that seep into the borings. These exploration results indicate the presence and intensity of the gas in the soil and/or groundwater. However, the gas hazard during tunneling and operations is not always related directly to the measurements in borings during exploration. The hazard or risk during tunneling depends on the volume, concentration, and pressure in the surrounding soil, and can vary between borings. Conditions in the tunnel are not directly related to those in the soil because the presence of the tunnel lining limits the flow into the tunnel and because ventilation is provided to dilute and remove gases that enter the tunnel. During tunneling, the pressurized closed-face TBM can be thought of as acting like a submarine. The volume of gas (or water containing dissolved gas) released from the soil during TBM tunneling is confined to the excavated material chamber because of the closed-face and gas-tight lining that is installed immediately behind the TBM.

Much information about gas conditions has been collected in Los Angeles with development of commercial facilities and their deep foundations, buried infrastructure, as well as from the oil field data. Tunnels in the area were built and operated—in the case of the Red/Purple line subway—with full consideration of the gassy conditions, and provisions were made to control gases to safe levels and exclude them from the operating system. Studies for construction of the Project have focused on geologic and subsurface conditions and an evaluation of construction technologies and operational procedures appropriate for these conditions. The safety of tunneling for the Project can best be assessed based on past and current experience in Los Angeles, other cities around the U.S., and worldwide. This experience has shown that the proper combination of design, modern tunneling equipment and methods, and a supply of sufficient ventilation leads to successful tunnel construction and operations. Evidence of this is found in the operating MGLEE tunnels, Metro Red Line tunnels and in similar projects in the U.S. Of these success stories, the MGLEE is most applicable as it demonstrates that tunnels can be constructed and operated in local conditions, including the Boyle Heights oil field.

5.4 California Tunneling Regulations

Regardless of the TBM, all underground construction must comply with Cal/OSHA regulations, which have been developed to address safety in the underground work place. Tunnel classifications are determined by Cal/OSHA based on the findings of the geotechnical investigation, previous land use (e.g., oil fields). and other local experience. Classifications can be non-gassy, potentially gassy, gassy, and extra-hazardous. Most tunnels in the Los Angeles Basin have been classified as gassy.

For underground construction classified as gassy by Cal/OSHA (California Code of Regulations, Title 8, Tunnel Safety Orders), specific requirements are as follows:

- All equipment used in the tunnel must be approved. For example, internal combustion engines and other equipment such as lighting must meet approval standards of the U.S. Mine Safety and Health Administration. These approvals require verification that equipment is safe (i.e., does not produce sparks or emit gas into the tunnel).
- Smoking is not allowed in the tunnel, nor is standard welding, cutting, or other spark-producing operations. Special permits and additional air monitoring are required if welding or cutting operations are essential for the work. In addition, welding is only allowed in stable atmospheres containing less than 10 percent of the Lower Explosion Limit (LEL) and under the direct supervision of qualified personnel.
- A fixed system of continuous automatic monitoring equipment must be provided for the heading (working area of the tunnel), spoils handling transfer points, and return air sources. Monitors must be equipped with sensors situated to detect anticipated gas to be encountered. Monitors must automatically signal the heading, give visual and audible warnings, and shut down electric power in the tunnel—except for acceptable ventilation, lighting, and pumping equipment necessary to

evacuate personnel—when 20 percent or more of the LEL is encountered. In addition, a manual shut down control must be provided near the heading.

- Tests for flammable and hazardous gas and petroleum vapors are to be conducted in the return air and measured a short distance from the working surfaces.
- Whenever gas levels in excess of 10 percent of the LEL are encountered, Cal/OSHA will be notified immediately. After the approval to proceed by Cal/OSHA, any work will then be conducted with required precautionary measures such as increased ventilation.
- The main ventilation systems must exhaust flammable gas or vapors from the tunnel, must be provided with explosion relief mechanisms, and must be constructed of fire-resistant materials. This exhaust requirement means that only rigid (metal) fan lines (as opposed to flexible), and two-way fan systems that operate in both directions by blowing exhaust from the tunnel and drawing air into the tunnel, may be used in gassy tunnels.
- A refuge chamber or alternate escape route must be maintained within 5,000 feet of the face of a tunnel classified as gassy or extra-hazardous. Workers must be provided with emergency rescue equipment and trained in its use. Refuge chambers (typically pre-fabricated) will be equipped with a compressed air supply, a telephone, and means of isolating the chamber from the tunnel atmosphere. The emergency equipment, air supply, and rescue chamber installation must be acceptable to Cal/OSHA.
- Special health and safety training and procedures will be implemented because of the health and safety issues associated with tunneling through a zone known to have elevated methane, hydrogen sulfide, and oil seeps. These procedures may require basic hazardous waste and emergency response training (29 CFR 1926 Subpart M), as well as training for excavations in a hazardous atmosphere (29 CFR 1926 Subpart P).
- The tunnel must have adequate ventilation to dilute gases to safe levels.
- Tunnel classifications may be changed as new data is obtained during tunneling. For example if heavier than air hydrocarbons are detected, an “extra hazardous” classification may be applied to require additional gas detection methods.

Strict application of the California Tunnel Safety Orders is required for all Metro underground construction projects and referenced in all contract provisions.

5.5 Los Angeles Tunneling Experience

Los Angeles’ geology has presented major tunneling challenges because of seismic conditions and the presence of naturally occurring subsurface gases. These challenges require additional provisions, such as application of the California Tunnel Safety Orders for design, construction, and operations. Methane and hydrogen sulfide and their impacts on tunneling have been studied extensively by Metro during planning and design phases for all subway projects. This section provides a review of Metro’s tunnel construction experience and studies performed for the Mid-City Extension and Eastside Extension (Mid-City projects suspended in 1997). Other Los Angeles tunnel projects have been reviewed for lessons learned and applicable technology.

The Metro Red Line tunnels were built with open-face (Digger Shield) machines in Los Angeles geology, including ground with methane and some hydrogen sulfide present. More modern tunneling practice (i.e., the use of EPBMs) has demonstrated even better success in the gassy ground of the Boyle Heights area of Los Angeles. The previous experiences have been applied to the evaluation of tunneling safety for the project area, including Century City.

5.5.1 Metro Red Line—Existing System Design and Construction

In 1984, before the creation of the Methane Zone by the City of Los Angeles, Metro's engineers prepared the *Alerting Report on Tunneling Liners*. This report presented expected tunnel construction methods, recommended lining methods and ventilation requirements for each tunnel between stations along the 1983 alignment (extending west along Wilshire Boulevard and north on Fairfax Avenue). Design assumptions from this report are the basis for the existing Metro Red/Purple Line. Portions of the Red Line were constructed through the Los Angeles city oil field.

To exclude gas (and water) inflow, all Metro Red Line tunnels (with the exception of the rock tunnels under the Hollywood Hills) were designed with a "two-pass" tunnel lining system that included a high-density polyethylene (HDPE) water and gas barrier. Early contracts used steel ribs and wood lagging boards for initial support, and subsequent contracts used precast, expanded (non-gasketed) segments for initial support. Open-face shields were used for all soft-ground tunnels, as this was the traditional tunneling method used in Los Angeles until about 1995. This method would allow gas into the tunnel face, and to some extent through the initial tunnel liner.

Lining design for the Metro tunnels takes into account concentration and pressure of the gas in the ground that were obtained during geological exploration. The contribution to total estimated inflows from each tunnel reach is then estimated. When that is done, the airflow required to dilute the gas to an acceptable level is calculated. For the Red Line, gas could be diluted to safe levels; however, Metro added an HDPE barrier to add a level of redundancy to protect against gases. This is backed up by gas detection instrumentation to detect gas and send an alarm if the concentration is higher than 10 percent of the LEL. Emergency ventilation fans are then activated.

Several occurrences of gas alarms were reported during construction of the Metro Red Line. One of the most notable experiences was an encounter with tar seams in the tunnel reach of Red Line Contract B-201, 1,000 feet west of MacArthur Park. Contractors adjusted tunnel ventilation rates while mining in these areas to dilute gases to safe levels.

5.5.2 Mid-City Studies

During the Mid-City planning studies, for an alignment circumventing the Methane zone along Crenshaw Boulevard, west to Pico Boulevard and then Northwest along San Vicente Boulevard, high levels of hydrogen sulfide were found south of Wilshire Boulevard along Crenshaw and Pico Boulevards. Subsurface conditions producing high gas readings occurred in the San Pedro Formation, generally in unsaturated zones capped by a less permeable Lakewood Formation (alluvial) soil. Hydrogen sulfide concentrations in test borings measured more than 10,000 ppm (with a high of 15,000 ppm), and extensive testing programs were undertaken to evaluate tunneling and station construction under these conditions.

Mid-City studies (LACMTA 1994 included soil-gas monitoring and testing programs to locate the gas-bearing formations, determine the extent of the gas reservoir(s), examine methods of gas treatment—both pre-tunneling and during tunneling—and recommend tunnel and station configurations to avoid the gassiest ground. As with the APTA panel conclusions, the Mid-City studies concluded that safe tunneling could be accomplished if pressure face TBMs, in particular the enclosed SFM system, were used for worker protection.

5.5.3 Eastside Extension Tunnels

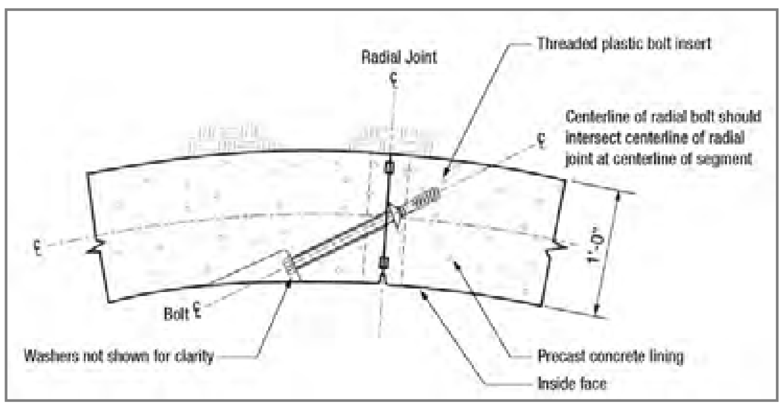
At the same time that the Mid-City area was being studied, design began for the Metro Red Line Segment 3 Eastside Extension. This line later became the MGLEE, a light rail project with about 2 miles of underground guideway. Designs for both of these projects are applicable for the Westside Subway Extension Project.

Portions of the original Red Line alignment (now referred to as the Suspended Project) west of the Los Angeles River had high levels (above the LEL) of hydrogen sulfide and methane. Other contaminants in the ground included man-made Volatile Organic Compounds. In this reach, the water table was mostly above the proposed tunnel crown, conditions similar to those along Wilshire Boulevard.

As planned for the Mid-City segment, SFMs were to be specified for the tunnel segment in the contaminated ground. Metro developed final specifications for slurry treatment and monitoring at the treatment plant, as well as pre-treatment of the ground prior to emergency exit shaft excavation. Because of the configuration of the existing yard-lead tunnels, the (suspended) Eastside tunnel separation required exit shafts to the surface, as opposed to cross-passages between tunnels, in some locations.

Given the risks of hydrogen sulfide and methane leakage into the tunnel, designers (and Metro’s Tunnel Review Panel) recommended use of a double-gasketed tunnel liner (a “one-pass” system) for use with the pressure face TBMs in gassy areas. Seismic conditions led to the design of a convex-to-convex shape on radial joints, principally to flex during earthquakes so that the tunnels remain sealed from gas. Figure 5-3 illustrates the double-gasket system. This sealing system was believed to be the first of its kind, and thus Metro undertook a six-month, nearly full-scale, laboratory testing program conducted at the University of Illinois to verify the design. The testing program evaluated the structural capacity of the segments under seismic and ground loads, and included gas leakage testing through gaskets and gasket material testing.

Figure 5-3: Schematic of Convex-to-Convex Double-Gasketed Segment Joint



As required for all Metro subways, the design also called for continuous gas detection in the operating tunnels and emergency ventilation. Subway operations are further described in Section 5.9.

Although testing provided a high level of confidence in a single-pass system using double gaskets, additional redundancy was designed for the Eastside heavy rail Red Line (suspended project) tunnel section designed for a highly contaminated reach west of the Los Angeles River. This called for design of an oversized tunnel, such that a second lining could be added in the event of leakage. This case was thought to be most likely after a significant earthquake.

The first Eastside project was suspended because of lack of funding in 1997, and the design was not field tested until construction of the MGLEE, where the tunnels were successfully completed in December 2006, and Revenue Operations began in November 2009. Figure 5-4 shows the current Metro rail system map, including the MGLEE and planned extensions (shown as dashes).

Figure 5-4: Current Metro Rail System Map

The MGLEE project tunnels were not constructed in the contaminated area west of the Los Angeles River (that portion of the alignment is now at-grade). However, the tunnels do pass through the abandoned Boyle Heights oil field, and methane and hydrogen sulfide were anticipated. No hydrogen sulfide gas was measured in soil borings, but hydrogen sulfide odor was reported on boring logs. Methane was measured with a maximum reading of 1,700 ppm. Cal/OSHA ultimately issued a “gassy” tunneling classification. As with the suspended project, Metro specified pressure face TBMs and a pre-cast concrete, bolted, gasketed lining for the MGLEE.

EPBMs were used successfully for the MGLEE. For that project, the contractor designed a long EPBM screw conveyor to discharge soil a distance away (more than 200 feet) from the tunnel’s working face. A 72-inch vent line was located over the end of the screw conveyor to deliver or evacuate high volumes of air to dilute and remove any gases being discharged with the soil. A 40-inch vent extended forward to ventilate the front of the tunnel. Figure 5-5, Figure 5-6, and Figure 5-7 show the double gaskets at the tunnel heading, and long conveyor used for MGLEE.

The MGLEE project has demonstrated successful tunneling in gassy ground conditions above and below the water table. Inflows of water have been well below specifications, and no gas leakage through the tunnel lining has been measured. That the tunnel lining segments are operating as planned is apparent from observation and from all available measurements. It is noted that low levels of hydrogen sulfide were encountered (smelled) in some construction areas that were excavated without the use of the EPBM (e.g., cross-passages), but these were readily, safely, and handled with an increase in local ventilation, which was no longer needed after completion of the tunnel lining.

5.5.4 North East Interceptor Sewer Tunnels, City of Los Angeles

Other Los Angeles tunneling projects were studied for issues related to tunneling safety. During excavation of the North East Interceptor Sewer (NEIS), which was constructed for the City of Los Angeles between 2003 and 2005, high levels of hydrogen sulfide and methane were encountered. This tunnel had been classified “Potentially Gassy” by Cal/OSHA, but the encounters prompted Cal/OSHA to reclassify the tunnel as “Gassy.”

For the tunnel’s upper reach (San Fernando Road east of the Los Angeles River), none of the project borings along the alignment encountered gas, liquid oil, or tar within the Puente Formation or overlying alluvial soils. However, naturally occurring hydrocarbons were found in that formation at several other locations along the alignment.

Shortly after tunneling began from the Humboldt Street shaft (east of the Los Angeles River just south of the I-110 Freeway), hydrogen sulfide gas was encountered. It was determined that the gas was emitted into the atmosphere from groundwater flowing into the TBM’s cutting chamber. Methane concentrations in excess of 20 percent of the LEL was also encountered early on, and additional ventilation was provided to dilute the gas to acceptable levels.

The upper reach segment of the NEIS continued to produce gassy conditions. Ultimately, the project was successful, and the contractor attributed the ultimate success to additional ventilation, strict adherence to California’s Tunnel Safety Orders, careful crew training, and a knowledgeable staff (Zernich, 2005).

Figure 5-5: Double-Gasketed Segments at Tunnel Heading

Figure 5-6: EPBM Screw Conveyor for MGLEE

Figure 5-7: Schematic of EPBM with Extended Screw Conveyor for MGLEE

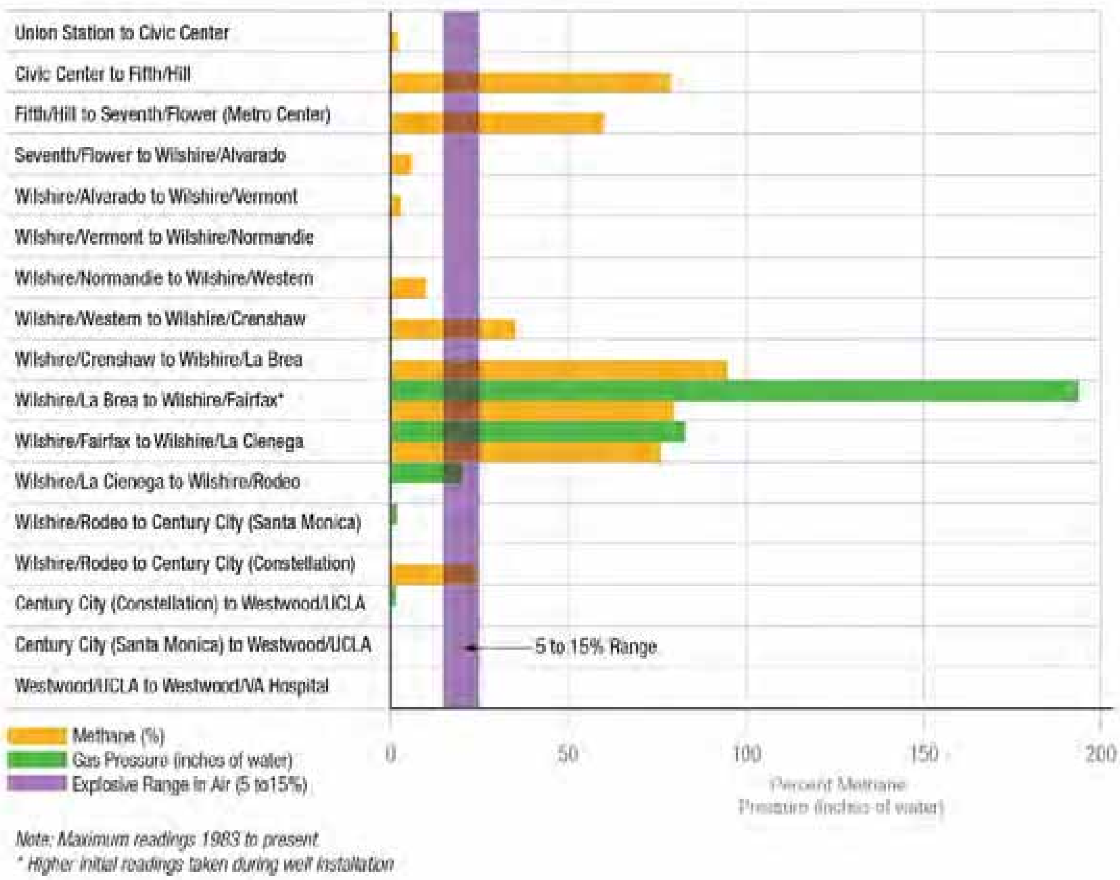
5.6 Subsurface Gas Conditions in Century City Area

Gas conditions in the Century City area were evaluated from new borings installed for the Project and existing data from nearby projects. Maximum methane readings in the Constellation Boulevard Station area were 12 to 24 percent at depths of 75 and 40 feet, respectively, and traces (less than 1 ppm) of hydrogen sulfide were noted. In the Metro borings placed for the tunnel under BHHS, maximum methane readings were 0.012 percent in soil borings using field equipment and laboratory testing of samples. More detail on gas data for the Project's subsurface gas data is presented in Appendix B.

For perspective, methane levels detected along both the existing and planned Red/Purple Line route are plotted in Figure 5-8. This figure shows methane levels in soil boring above 90 percent in the Civic Center to 5th/Hill Station reach and more than 50 percent in the 5th/Hill to 7th/Metro Center reach. Tunneling within these reaches downtown was accomplished safely, and is discussed in more detail in Section 5.5.

Methane levels in the Century City area are in the range of the levels tunneled within in previous Metro tunnel projects, even those using older open-shield tunneling methods, and they are substantially below the levels measured in the ground between Civic Center and Seventh and Flower Streets.

Figure 5-8: Maximum Gas Concentrations: 1983–2011 Readings in Gas Probes



Sources: Geotechnical and Environmental Report 2011

5.7 Tunnel Lining Design—Westside Subway Extension

Concrete rings formed from precision-made pre-cast segments commonly provide structural support of tunnels in soft ground (as opposed to rock) excavated by EPBMs. Figure 5-9 shows the completed MGLEE tunnel, prior to rail installation, with pre-cast segments.

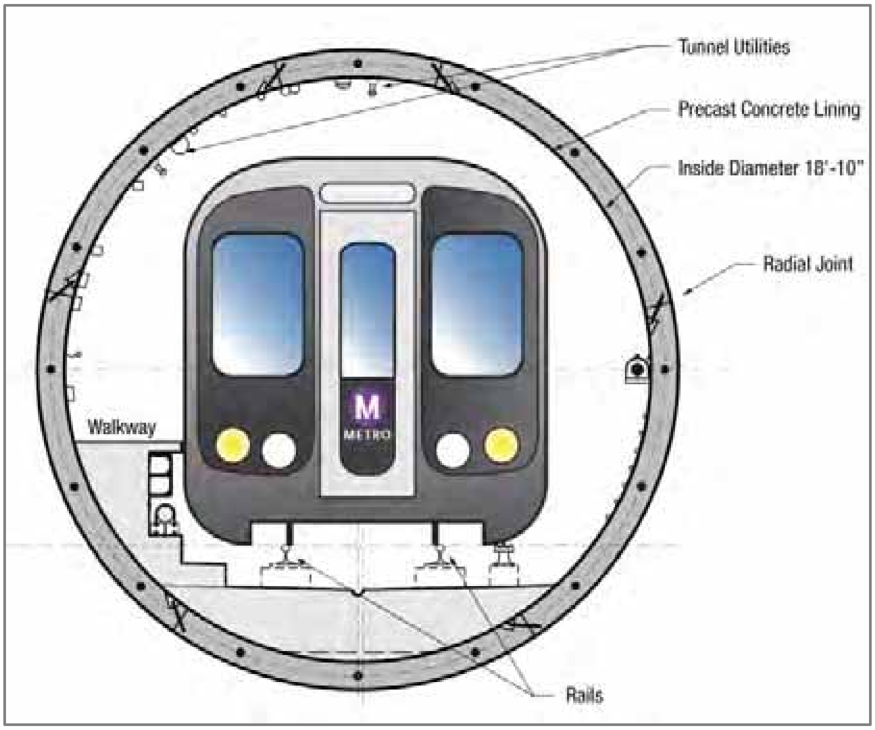
Figure 5-9: Segmental Lining

Tunnel linings are installed after soil excavation to limit the inflow of groundwater and/or gas along the length of the tunnel, support appurtenances and utilities in the tunnel, and provide a base for the final tunnel invert for placement of the train rails. Tunnel linings can be used for initial stabilization of the excavation, permanent ground support, or both.

Precast concrete linings will be used as both initial and final ground support. Circular arc segments are assembled inside the shield of a TBM to form a ring. When the TBM-installed lining forms the final or (permanent) ground support, it is called a “single-pass” or “one-pass” lining. If necessary, the rings can be part of a two-pass system, with the precast rings acting as the structure supporting the ground loads and a secondary lining (and an added membrane) functioning as an additional gas and water barrier.

As currently configured, the tunnels for the Project will have a minimum 18-foot 10-inch inside diameter and have a lining about 12 inches thick. (The actual thickness will depend on structural analysis.) It is anticipated that five segments with a key will form the ring. Figure 5-10 shows the tunnel segment lining under design at the PE phase for the Project.

Figure 5-10: Tunnel Segment Configuration



The lining will be designed to provide the following primary requirements over its service life:

- Handle structural loads, including the permanent and temporary dead (ground loads), live, and seismic loads
- Be impermeable to groundwater inflows
- Be impermeable to gas inflows
- Be fire resistant

Pre-cast concrete gasketed segmental linings have a proven record of structural and groundwater control in the tunneling industry worldwide. In addition, Metro has in-house experience from several years of service of the MGLEE light-rail system, which runs its transit cars through about 1.7 miles of tunnel with single-pass linings. These tunnels also consider water and gas intrusion and were designed as a pre-cast concrete bolted segmental lining with a double-gasketed system to prevent intrusion of gas and water between the segment joints. This experience provides a sound basis for using a single-pass final lining for the Project's tunnels. The single-pass tunnel lining will provide structural support, be the primary barrier to water and gas, and provide an effective means into the tunnel should it be necessary to check and repair any leakage.

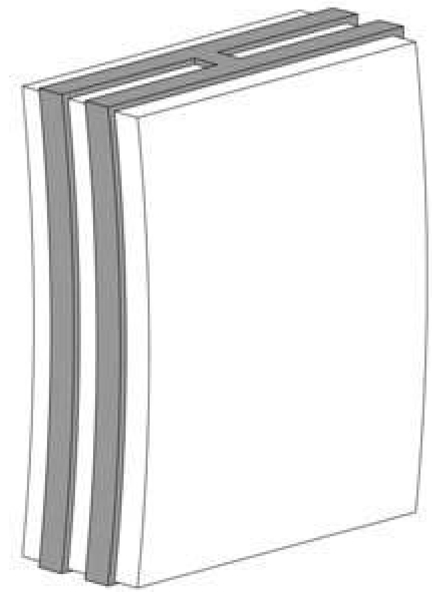
To be effective as a barrier to groundwater and gas intrusion, concrete for the segments should be highly impermeable and should not degrade over the long-term because of the presence of hydrocarbons. To achieve this, specifications for the concrete for the segments will require high strength, ductility, low permeability, and be durable to resist spalling in fires. Since the tunnels are in a seismic area, the lining must have sufficient ductility such that it does not fail when subject to distortions caused by ground motions. The segmental tunnel linings designed for the Project will be capable of accepting distortions imposed by seismic loads without failing (refer to Section 7-1).

5.7.1 Design Redundancy for Water and Gas Exclusion

Based on the performance of the MGLEE, the Project tunnels should be supported and lined by a one-pass system of precast concrete segmental liners; however, the following levels of redundancy will be added to prevent gas leakage into the tunnel as well as to have the ability to repair the lining should leakage occur:

- The system should have double gaskets with the use of additional gasket bulkheads or cross-gaskets (Figure 5-11) to further reduce the potential for “ring-to-ring” transmission of water.
- The tunnel ventilation system must be designed to dilute gases to safe levels and to exhaust smoke.
- Segments should have the ability to be easily repaired (using grout) should leakage occur between gaskets. The double-gasket system provides backing for confinement of grout.

Figure 5-11: Schematic Double-Gasketed Tunnel Segment with Cross-Gaskets



5.8 Cross-passages

Cross-passages between tunnels perform two basic functions: they allow passengers to move from one tunnel to the other any time that it becomes necessary, such as egress in the event of an emergency on a train, and they allow emergency personnel to pass from one tunnel to the other when necessary. In addition, they provide space for train operations equipment and sump structures. Metro’s criteria require adherence to the National Fire Protection Association’s code for cross-passage spacing every 800 feet along the tunnel.

Excavation of cross-passages is typically a “hand” operation because they are too short for the use of large construction equipment or tunneling shields. Thus, some pre-treatment of the ground is usually necessary to allow for safe construction of cross-passages. Such pre-treatment is determined on a case-by-case basis, depending upon the local geology and geometry, and thus there is no single design that suits all situations. Pretreatment may include any of the following, either singly or in combination:

- Permeation grouting (single or multiple stages), jet grouting, or soil mixing with a variety of materials—cement (including micro fine and ultra fine), colloidal silica, and others—depending on soil properties
- Pre-treatment of ground and/or groundwater by such techniques as dewatering, local draining, or freezing

Relocating cross-passages for improved ground should be evaluated; however, fire/life safety requirements must also be strictly adhered to. Sealing cross-passages against tunnel liners will require special details to be developed during design. Similar to tunnel segment design, this may include swelling materials to seal joints, adding gaskets and plates at connections, and post-construction grouting to maintain seals at cross-passages to tunnel connections.

Cross-passage linings have traditionally been “two-pass” systems where initial ground support may consist of ribs and lagging or shotcrete and lattice girders. Installation of the final cast-in-place lining must take into account protection of the HDPE (or other methane-resistant barrier) during installation and placement of concrete. Waterproofing products continue to improve, and composite materials with felt or other protective backings are now common. Final design details should include the investigation of new products for ease of installation and reduced leakage.

5.9 Subway Tunnel Operations for Gassy Conditions

One of the most important systems for use during both construction and subway tunnel operations is ventilation. Ventilation and closed-face tunneling technology make it feasible to construct and operate the subway system. This is a guiding principle throughout the design stages.

All subway systems include ventilation systems for passenger comfort and safety, but the Project is unusual in that provisions must include the potential for hazardous gas intrusion as well as for the usual requirement of clearing smoke in the event of fire. Thus, the normal ventilation system must be evaluated in this context.

In addition, the Project’s system features emergency ventilation provisions designed specifically to counter any release of gas that might be triggered by a seismic or other event. It is envisioned that, just as with the Red Line, this emergency system will be high volume for quick and safe removal of gas release or for short-term backup in the event of a malfunction of the normal ventilation system.

The typical Metro tunnel with adjoining stations has ventilation equipment located within the stations to control smoke from a train fire and potential methane and hydrogen sulfide gas, as well as for environmental control. Each station has two fan plant rooms—one located at each end of the station. These plant rooms each have two emergency fans that are connected to the trainway via ventilation shafts (starting at street level and ending in the tunnel), as well as the associated fan and track dampers to direct fire smoke away from occupied areas.

The ventilation equipment will consist of fully reversible axial fans (emergency), station air handling units, smoke exhaust fans, and under-platform exhaust fans. A similar system is currently operating for the Metro Red Line. There are two distinct hazardous gas purge scenarios: one for the tunnels and another for the stations. For the tunnels, it is usually a push/pull mode where fans in two stations operate in conjunction. One station will be in the exhaust mode and the other in the supply mode (push/pull), creating the longitudinal air velocity to purge the tunnels. For the stations, the required air velocity is provided in public areas by having all fans in the exhaust mode in the incident station as well as the adjoining stations.

The typical ventilation analysis for gas purging is aimed at predicting tunnel/station air velocities during non-revenue operations since the piston action of moving trains aids in the gas dispersal and purging functions during normal train operations.

For Metro tunnels, a dedicated gas monitoring system has been implemented for the existing system and is planned for the Project. Usually hydrogen sulfide and methane detectors are placed in the cross-passages and at the tunnel/station box area. Methane detectors are placed throughout the station along the outside perimeter walls, and hydrogen sulfide detectors are placed in low level-areas (e.g., under the platforms and near sumps). This system monitors methane and hydrogen sulfide, and the alarm settings are below permissible exposure or explosive limits for methane and hydrogen sulfide, as follows:

- Methane gas—Alarm at 10 percent of LEL and major alarms at 20 percent and 25 percent of LEL
- Hydrogen sulfide—Alarm at 8 ppm and major alarm at 10 ppm

Most gases are purged from the tunnels simply by the action of trains running through the tunnels. During non-revenue operations, air velocity must be maintained at a minimum of 100 feet per minute. This air velocity is the minimum that the ventilation system must achieve to direct hazardous gases toward the nearest point of extraction and prevent gases from accumulating during the hours when the trains are not operating.

5.10 Summary

Metro considers its existing system and operations a success, and therefore a similar approach to operations will be designed for the Project. Because of the existence of the Methane Risk Zones, construction and operation of this Project will be approached with caution and an added degree of conservatism. Tunneling and station construction in the Methane Risk Zones is a challenging but entirely possible construction operation. As discussed in this report, major advances in technology, materials, and design have occurred in the last 25 years. The APTA panel, upon review of the available information, supported this conclusion. In summary, the Project's approach to the successful accomplishment of construction and operation in the higher gas risk areas will involve the following:

- State-of-the-art design and construction for tunnels and stations
- Multi-levels of redundancy in design
- Contract documents and contracting methods to ensure best quality construction
- State-of-the-art normal ventilation, instrumentation for leak detection, and activation of emergency operating procedures
- Emergency ventilation system
- Rapid repair procedures

Two decades of operation have shown the current systems to be quite safe and reliable. In addition, it is well known that technology has continued to improve. The detection and operations system ultimately designed for the Project will be a marriage of the existing system(s) and appropriate modifications and advancements as indicated by current technology at the time of design.

6.0 ACTIVE AND ABANDONED OIL WELLS

The geology beneath Los Angeles County consists of a deep sedimentary basin that is a known source of hydrocarbon deposits. These deposits have been commercially explored and exploited starting in the late 1800s. As a result, the Los Angeles Basin is the site of a number of active and inactive oil fields with tens of thousands of exploratory and production oil wells drilled throughout the basin. A great number of these wells are now idle or have been abandoned.

The Project will cross portions of the active South Salt Lake, Beverly Hills, and Sawtelle Oil Fields. These are shown in Figure 6-1. In the Beverly Hills and Century City areas, the alignment will cross over the western portion of the Beverly Hills Oil Field.

The California Division of Oil, Gas, and Geothermal Resources (DOGGR) maintains a database of active and expired (abandoned) wells. However, data on oil well abandonment in the late 1800s and early 1900s can vary in accuracy and completeness. Thus, it is possible that undocumented oil well casings might be encountered along the route of proposed tunnels in Los Angeles. This has been dealt with successfully on other tunneling projects in the area, including the North Outfall Relief Sewer, Metro's Red Line, the City of Los Angeles East Central Interceptor Sewer, and MGLEE.

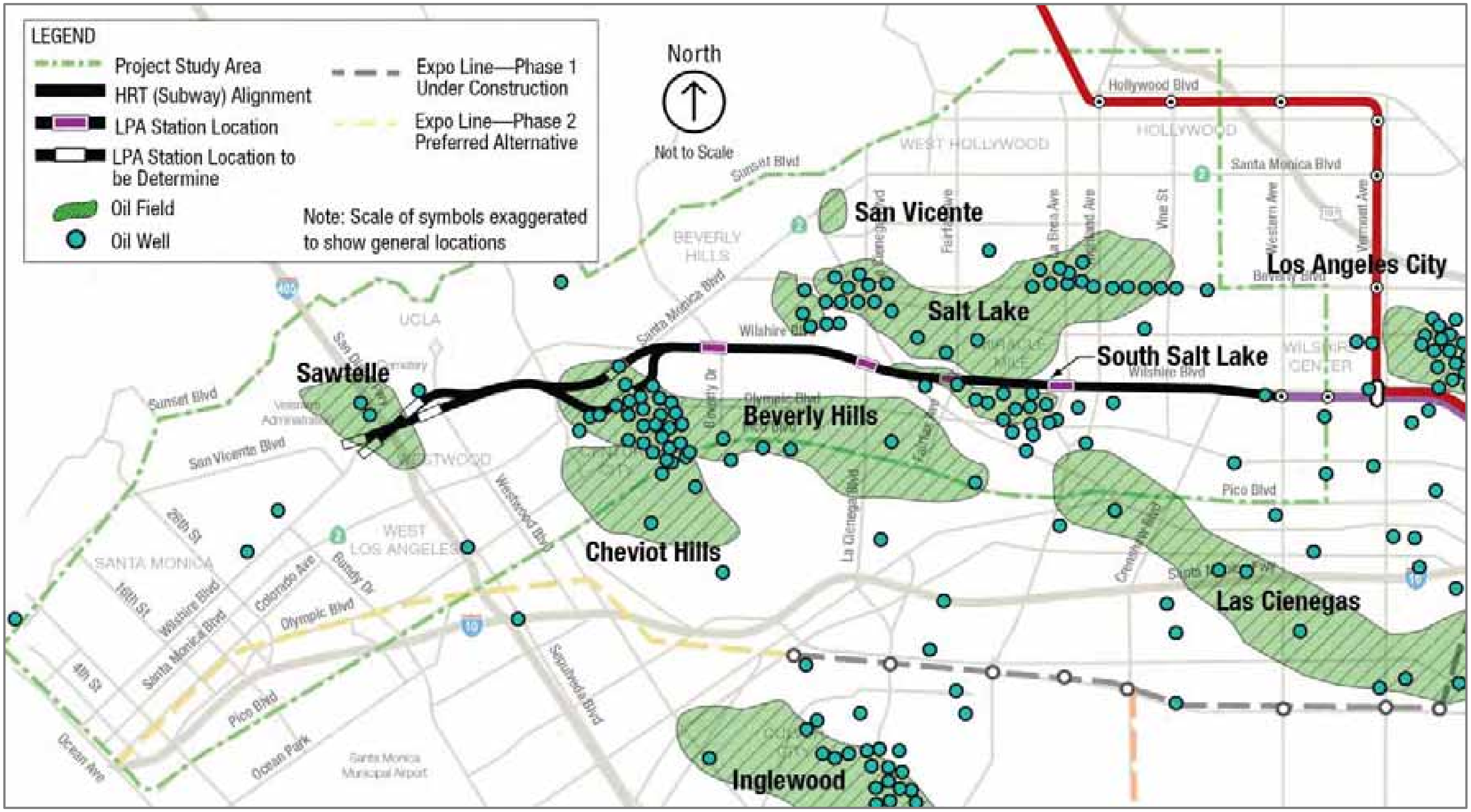
Known and undocumented abandoned oil wells could contain residual accumulations of pressurized and potentially explosive gases, which could pose a threat to worker safety when encountered within the proposed tunnel envelope if they were released into the tunnels. In addition, steel casings pose difficulties for TBM tunneling. Mining through any kind of steel obstruction is not a regular or planned operation. Detection prior to construction and either mitigation (by removal of obstructions before tunneling reaches them) or interventions (at the face to remove the obstructions) should be the preferred methods for dealing with such obstructions.

6.1 Beverly Hills Oil Field

The Beverly Hills Oil Field is about 4 miles long by 0.5 to 1 mile across. The total productive area of the field, projected to the ground surface, covers about 1,200 acres. It is large and currently active, and is underneath part of Beverly Hills and portions of the adjacent City of Los Angeles. Discovered in 1900, it has produced more than 150 million barrels of oil and ranks 39th by size among California's oil fields. All drilling, pumping, and processing operations for the 97 active wells (DOGGR 2007) has been done from within four large drilling islands visible on Pico and Olympic Boulevards as large windowless buildings. From these islands, wells slant diagonally into different parts of the producing formations directly underneath residences and commercial structures.

The active drilling island located on the grounds of BHHS, just north of Olympic Boulevard is owned and operated by Venoco Inc. It is a landmark feature, covered in a sound-absorbing jacket and decorated with a floral design. The wells drilled from this island are essentially vertical to about 1,000 feet, at which point some transition to an angled orientation.

Figure 6-1: Oil Fields in the Los Angeles Area



6.2 Investigation of Alignment within Beverly Hills Oil Field

A review of DOGGR's Online Mapping System (DOMS 2010) for the Beverly Hills and Century City areas identified a number of oil wells within 100 feet of the outer edge of the tunnel or station alignments, and one possibly within the tunnel zone. These are mapped as abandoned wells. Their approximate locations and their relationship to the proposed alignments are shown on Figure 6-2. Information on these wells—including oil well name, operator name, well-specific American Petroleum Institute (API) number, and well status—is provided in Table 6-1.

As a result of a review of the information shown on Figure 6-2, a data search and geophysical field investigations were performed to address the following issues:

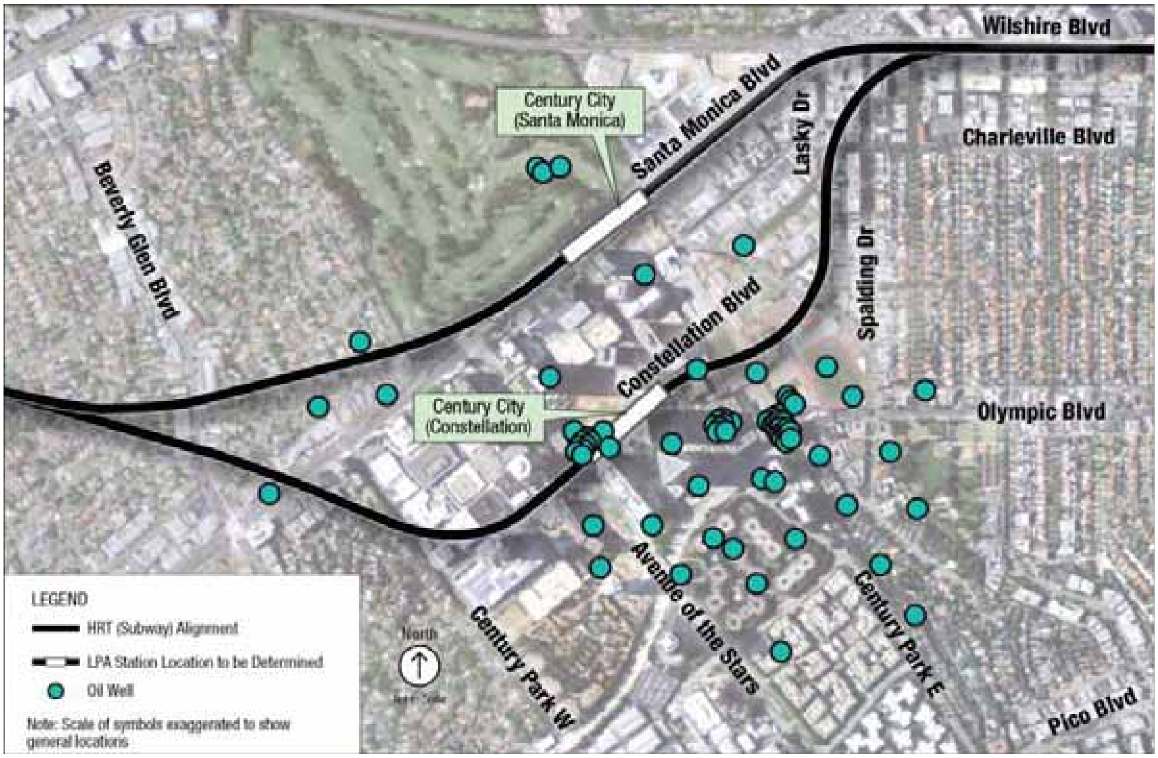
- The cluster of wells indicated to be at the southwest end of the Century City—Constellation Boulevard Station that included four abandoned oil wells on the northeast corner of Constellation Boulevard and Avenue of the Stars that were suspected of being located within the proposed right-of-way for the subway extension
- The abandoned well—"Wolfskill" 23—indicated to be directly on the tunnel alignment west of BHHS and suspected of being located beneath the AAA Building Parking Garage
- The possible presence of unknown, abandoned wells on the BHHS campus

6.2.1 Data Search

The following efforts were undertaken to search for information on the location of existing and abandoned oil wells along the Project's alignment:

- Available DOGGR Online Mapping System (DOMS 2010) maps, data, and reports were reviewed.
- DOGGR's office was visited to obtain additional records and information on specific oil wells in the project area and to obtain records that may not be included in the available online database.
- DOGGR's staff were consulted by telephone regarding general and well-specific information pertaining to the well location and abandonment procedures/records.
- Tunnel safety experts were consulted on previous experience and procedures used for detecting and treating oil wells encountered during the excavation of previous tunnels in the Los Angeles area.
- Available historic aerial photographs from 1922 to 1956 were reviewed for possible correlation of oil drilling rigs with the locations of abandoned oil wells indicated on available maps. Examples of these photographs are shown on Figure 6-3 and Figure 6-4.
- The City of Los Angeles Department of Building and Safety was consulted for records about location of abandoned oil wells on selected properties.
- Petroleum industry experts were consulted on their experience in oil and gas field development and well closures.
- Available historical maps were researched and reviewed for information pertaining to existence of abandoned oil wells on selected properties.
- Companies operating existing wells in the area were contacted regarding maps and information about their facilities.

Figure 6-2: Oil Wells in the Century City Area



Source: California Department of Oil, Gas, and Geothermal Resources

Table 6-1: Oil Wells Identified from DOGGR Records—Beverly Hills, Century City and Westwood Area

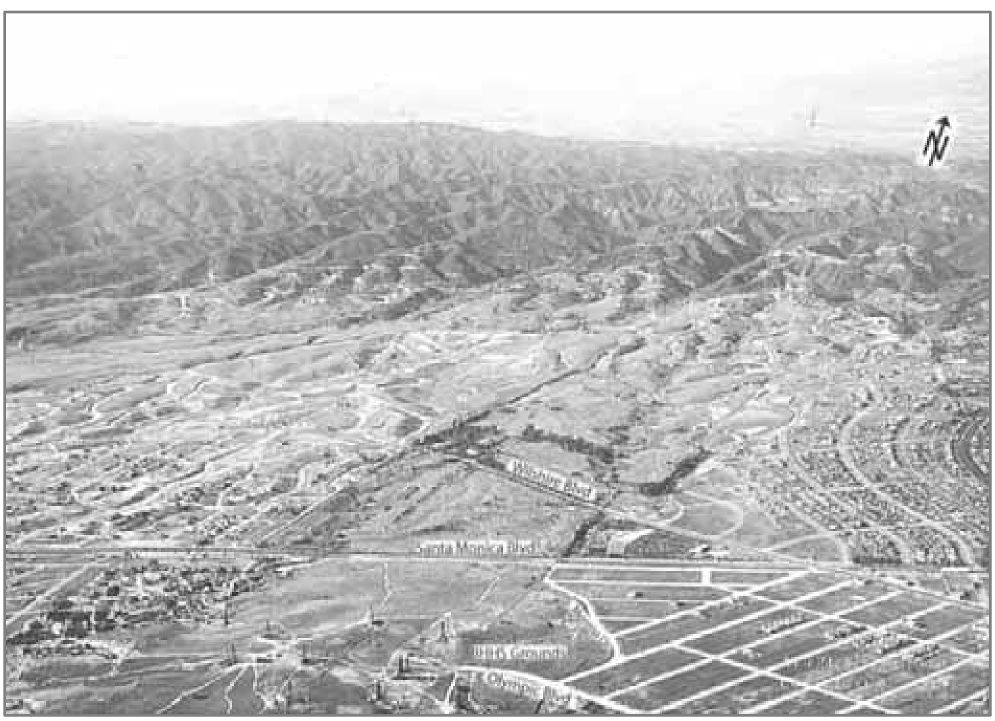
Well Name/API No.	Location	Approximate Station[1]	Well Status
Chevron USA "Wolfskill" 23 API: 03701104	Potentially within footprint of tunnel, approximately 150 feet east of Century Park East	701+00 to 702+00	Abandoned
Chevron USA Aladdin 28 API: 03716549	100 feet north of Constellation Boulevard at northeast corner of Constellation Boulevard and Avenue of the Stars	710+00 to 714+00	Abandoned
Chevron USA Aladdin 26 API: 03716453	100 feet north of Constellation Boulevard at northeast corner of Constellation Boulevard and Avenue of the Stars	710+00 to 714+00	Abandoned
Chevron USA Aladdin 23 API: 03716547	100 feet north of Constellation Boulevard at northeast corner of Constellation Boulevard and Avenue of the Stars	710+00 to 714+00	Abandoned
Chevron USA Aladdin 25E-1 API: 03716548	100 feet north of Constellation Boulevard at northeast corner of Constellation Boulevard and Avenue of the Stars	710+00 to 714+00	Abandoned
Kansas Crude Co 2 API: 03700992	100 feet north of the Santa Monica Boulevard alignment and 30 feet east of Ensley Street	718+00 to 719+00	Abandoned
Union Oil Gabel 2 API: 03701113	150 feet west of the Constellation Boulevard alignment on Santa Monica Boulevard	738+00 to 739+00	Abandoned

[1] Within 100 feet of alignment

Figure 6-3: Aerial Photo Century City Area (View 1)

Dick Whittington Studio, 1954, USC Library

Figure 6-4: Aerial Photo Century City Area (View 2)



Spence Airplane Photos, 1926, University of California, Los Angeles Geography Department

6.2.2 Geophysical Field Investigations

Because the location of oil wells obtained from the DOGGR/DOMS 2010 maps are approximate and intended for general information use, geophysical investigations were performed to locate any existing abandoned oil wells along the project alignment or those located within approximately 100 feet on either side of the alignment.

The geophysical techniques used during these investigations were magnetic and electromagnetic (EM) methods. These methods complement one another as each responds to different physical properties and has different strengths and limitations.

- The magnetic method is the most commonly used geophysical technique for locating abandoned oil wells because the magnetic anomalies associated with oil wells have very high amplitudes, large spatial dimensions, and a different signature from many other types of buried metallic objects. The magnetic scan performed by GEOVision, Inc. on the grassy lacrosse field of BHHS is shown on Figure 6-5.
- The EM method was used to scan selected areas for metallic pipes and to further characterize anomalies found in the magnetic data. The geophysical survey was designed to map abandoned oil wells with ferrous metallic pipe (casing) in the upper 15 feet.

Figure 6-5: Geophysical Survey at BHHS Grounds

Detailed descriptions of these geophysical techniques, the field procedures used, data processing and interpretation, and the results of the geophysical surveys are provided in the referenced GEOVision, Inc. reports.

The areas designated for scanning were selected based on the findings of the data search, a review of the DOGGR maps and areas above the proposed tunnel available for surveying.

Geophysical investigations were conducted between February and July 2011 by GEOVision, Inc. on:

- BHHS grounds (Figure 6-5 and Figure 6-6) to identify possible undocumented wells along the alignment
- AAA Building Parking Garage, to find the location of the abandoned "Wolfskill" 23 well (Figure 6-6)
- The northeast corner of the Avenue of the Stars and Constellation Boulevard to identify the location of the wells clustered near the southwest end of the Century City—Constellation Boulevard Station (Figure 6-7)

The findings from the geophysical investigations are as follows:

- **Within the BHHS grounds**
  - In the tennis court area and the front lawn, there was no indication (within 15 feet of surface) of abandoned oil wells from the geophysical data.
  - In the area of the football field, where the suspected location of abandoned oil well "Rodeo" 114 was marked, there was no indication of abandoned oil wells.
  - Four anomalies were detected by geophysics in the vicinity of the lacrosse field. In the northern half of the lacrosse field (Figure 6-6), one anomaly, A-1, was detected at a location about 5 to 10 feet north of the tunnel envelope. It is reported that A-1 "…may be related to a pipe segment or previous building infrastructure. However, it cannot be fully discounted that this anomaly is related to an abandoned oil well or its infrastructure" (GeoVision, 2011). Accordingly, further investigation will be conducted by Horizontal Directional Drilling (HDD) and associated magnetometer surveys during the next phase of design. This will determine the location, nature, and characteristics of the anomaly. Should this anomaly be determined to be an abandoned oil well, it will be safely addressed according to DOGGR regulations.
  - Anomalies A-2, A-3 and A-4 may be related to abandoned oil wells, infrastructure, or other buried metallic debris, but the closest, A-2, is at least 80 feet south of the tunnel alignment and thus sufficiently far from the tunnel to avoid interception during tunneling.

- **Within the AAA Building Parking Garage Area** (Figure 6-6)
  - The at-grade parking garage, part of the alley east of the structure and part of the asphalt road west of the structure, were included in the survey.
  - No well-like anomalies were interpreted for the AAA Building parking garage from the geophysical data despite the fact that DOGGR maps show the abandoned "Wolfskill" 23 well should be within the footprint of the garage. Accordingly, further investigation will be conducted by HDD and associated magnetometer surveys during the next phase of design. This will provide the location, nature, and characteristics of any anomaly, which, if determined to be an abandoned oil well, will be safely addressed according to DOGGR regulations.

Figure 6-6: Geophysical Survey at BHHS and "Wolfskill" 23

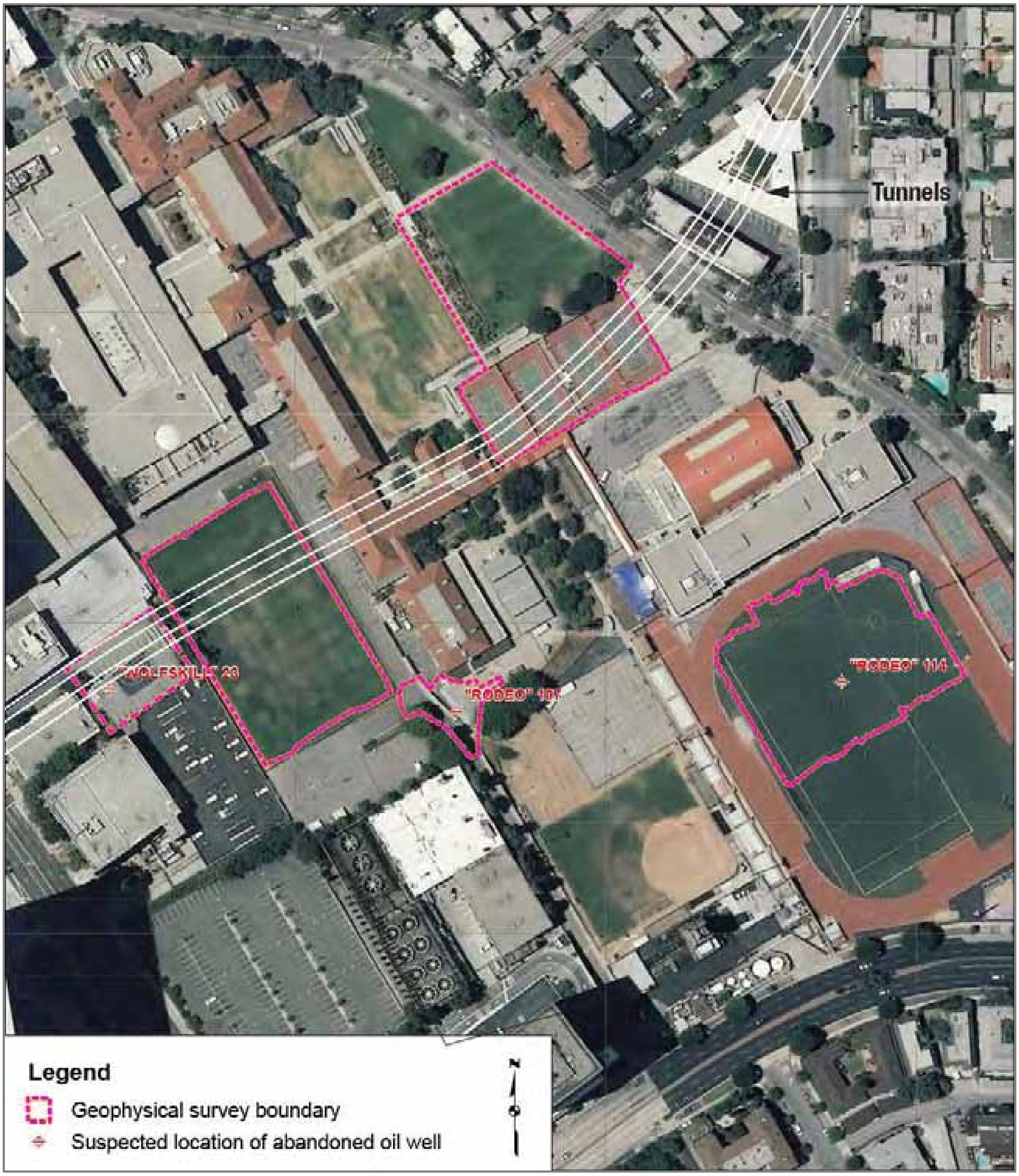
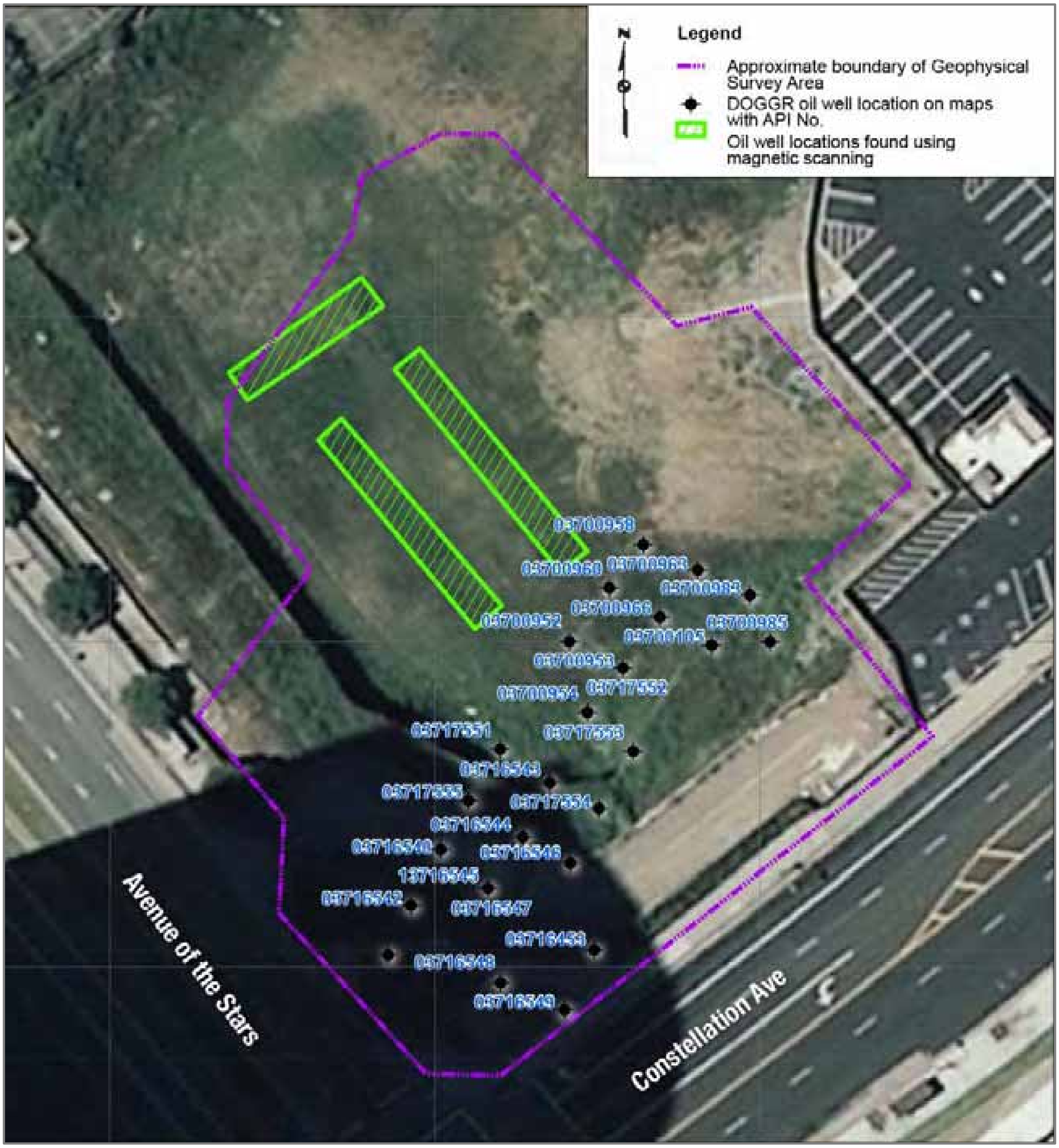


Figure 6-7: Geophysical Survey of Constellation Boulevard Area



- **Northeast corner of the Avenue of the Stars and Constellation Boulevard** (Figure 6-7)
  - No significant well-like anomalies located in the proposed right-of-way of the Project were identified from the geophysical data in the vacant lot north of Constellation Boulevard.
  - Several oil-well anomalies were interpreted to be located in the geophysical survey area within the empty lot but not at the locations predicted by the DOGGR record or in the proposed right-of-way of the Project.
  - The location of anomalies identified from the geophysical data vary significantly from the well locations shown on the DOGGR maps, indicating the importance of geophysical scanning and physically locating of oil wells rather than relying on the mapping records (Figure 6-7).

6.3 Summary of Findings

6.3.1 Tunnel Alignment

With the exception of the mapped abandoned "Wolfskill" 23 well and possibly Anomaly A-1, there is no evidence of oil wells existing directly under the planned tunnel alignment for the Constellation Boulevard option. Since the abandoned well casings at the Constellation Boulevard and Avenue of the Stars (northeast) corner were detected through magnetic scanning to be some 100+ feet from their predicted mapped locations, "Wolfskill" 23 could also be outside the mapped location on the alignment.

Where there are suspected abandoned wells, investigation at the tunnel level by magnetometer probing will be conducted either before or during tunneling to locate any well casing before encountering them in the tunnel. Additional precautions will be exercised, and further discussions of these precautions are described in the next sections.

6.3.2 "Wolfskill" 23 Well and Anomaly A-1

A review of available documents for the "Wolfskill" 23 well indicates that it was drilled to a depth of 2,745 feet in 1909. It was constructed with casing that was cemented in place, but the casing collapsed at 2,500-foot depth in 1912, and the well was abandoned in 1916 due to lack of production. DOGGR records from 1916 show that the well was likely abandoned by "shooting" its casing at depths of 2,203, 2,201, and 420 feet below the ground surface, and plugging it with cement. This indicates that the top portion of the well is sealed from pressure. The hole was filled with miscellaneous materials and tampered to the surface. There is no information on whether the casing in the upper portion of the well was pulled out or left in place. It is understood that most casings are left in place and only the upper several feet are removed.

Given the degree of uncertainty regarding its location and the state of Wolfskill's "left-in-place" casing and of Anomaly A-1, additional investigations will be carried out during the design phase to permit detection and treatment of any oil well casings in the path of the tunnel.

6.3.3 Century City—Constellation Boulevard Station

There is no evidence of oil well drilling directly within the zones that would be tunneled into and out of the Constellation Boulevard Station.

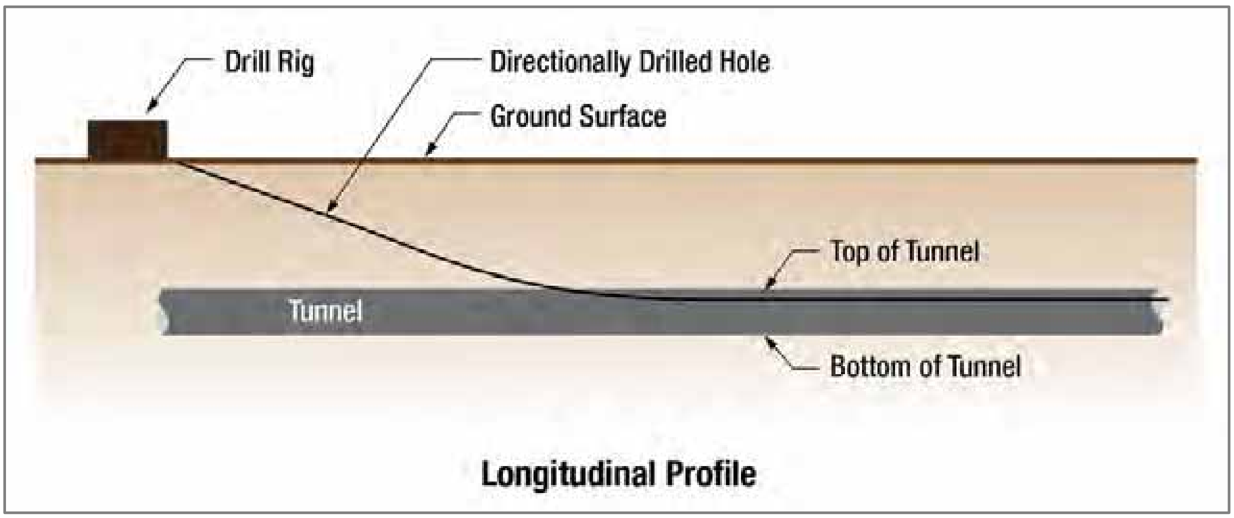
The cluster of wells mapped by DOGGR near the station and entrance area was found by the geophysical investigation to be well within the current vacant lot. However, it is necessary to make contingency plans to abandon wells within the station and entrance area should they be encountered. Given that abandonment of wells at the station area would be conducted in an open excavation, this can be performed using DOGGR procedures that have been developed previously and implemented where surface access is available.

6.4 Proposed Investigations during Design

6.4.1 Horizontal Directional Drilling with Magnetometer Probe

Horizontal directional drilling with a magnetometer probe survey will be performed over the proposed tunnel alignment in areas that are not accessible for surface magnetometer scanning (underneath existing structures, and other obstacles or restricted areas) or where detection of suspected abandoned oil wells by other methods is inconclusive. A schematic figure showing directional drilling is shown on Figure 6-8.

Figure 6-8: Directional Drilling Schematic



6.5 Proposed Procedures during Construction

6.5.1 Investigations using Magnetometer Probe Hole from the Tunnel Heading

To identify abandoned metallic oil well casings ahead of the excavated tunnel heading, a probe hole with magnetometer survey can be performed in front of an advancing tunneling machine. The magnetometer survey involves drilling a horizontal probe hole as much as 200 feet ahead of the tunnel face, testing the hole for gases with a portable gas sniffer, and pushing the magnetometer probe through a stainless-steel (non-magnetic) or polyvinyl chloride casing inserted into the probe hole. Readings from the magnetometer probe are taken in fixed, usually 1-foot intervals, both on the way in and the way out of the probe hole. The collected data are reduced and interpreted by an engineering geophysicist. Following data collection with the magnetometer probe, the same basic procedure is repeated but with the insertion of an inclinometer to the probe hole casing. The inclinometer provides information to determine deviation of the probe hole from the TBM to the end of the probe hole.

Magnetometer probe holes have been performed on past tunneling projects by Metro. Tunnels for the Metro Red Line were excavated using open-face TBMs, thus providing easy access for the probe hole to be drilled from the tunnel heading. Magnetometer probe holes were carried out in front of advancing TBMs in selected locations west of downtown, where abandoned wells were suspected to be present. With the exception of magnetic anomalies attributed to nearby tieback anchors and extensometer anchor heads close to the tunnel crown, anomalies related to possible oil wells were not detected by the probing during tunneling (Stirbys et al., 1999).

The tunnel for the North Outfall Sewer—East Central Interceptor Sewer (NOS-ECIS) driven in the Baldwin/Blair Hills area oilfields was excavated by an EPBM. Contract specifications required the contractor to probe ahead of the TBM in a portion of the alignment to locate possible abandoned oil well casings or other buried pipelines. When anomalies were present, the speed of the EPBM was to be reduced and the mining operation to proceed ahead carefully. Mining of the tunnel was successfully completed, and no abandoned wells were encountered (Keller, E., Crow, M. 2004). The contractor developed procedures for well abandonment should they be encountered, which were approved by the City of Los Angeles and DOGGR.

The twin tunnels for the MGLEE were also excavated by EPBMs. Considering that the ground to be encountered was classified by Cal/OSHA regulations as “gassy,” and due to the possibility of encountering abandoned oil wells along the tunnel alignment, one of the specification requirements for the EPBM was provision for drilling a probe hole ahead of the tunnel face. However, on review of the project data, the contractor’s proposed EPBM, tunnel ventilation system, and muck handling procedures by representatives of Cal/OSHA’s Division of Mines and Tunnels, the requirement for the probe hole from the face was reduced to an “as needed” basis. The tunnels were never evacuated because of gas intrusions during time of mining, and no abandoned oil wells were encountered.

6.5.2 Investigations using Ground Penetrating Radar from the Tunnel Heading

Ground penetrating radar (GPR) is a high frequency electromagnetic method commonly used for engineering and geotechnical applications and has been proven effective in locating both metallic and non-metallic buried objects. GPR technology was used in tunneling through the former Los Angeles City Oil Field on the Metro Red Line Project, Segment 2, to search for undocumented, abandoned oil wells. The GPR method was implemented after studies indicated that the abandoned oil wells on the tunnel alignment could be wood-cased or concrete abandonment plugs without casing, and thus not detectable by the probe hole magnetometer survey methods outlined above. Oil wells were not encountered during tunneling; however, the GPR surveys did detect anomalous radar reflections that the machine operator was alerted to as possible oil well casing. Careful mining in the areas of anomalies and detailed tunnel face mapping by the geologist indicated that changes in ground conditions, rather than oil well casings, were being detected, such as transition from soft to hard ground materials and zones of oil-bearing formations (Hebert, Olson, 1995).

A GPR survey is performed by moving a hand-held radar antenna across a smoothed tunnel face. Thus, easy access and ample space in front of the tunneling machine, as is the case with an open-face tunneling method, is required. It is understood that in order to drill thousands of feet for oil, oil well casings were made of steel not wood.

Considering that tunnels for the Project will be excavated by close-faced TBMs, the use of GPR for detection of wood casings or uncased concrete plugs may not be practical but also not necessary. It should be noted that there is no known record of encountering either a wood casing or concrete plug during previous tunneling experience in Los Angeles. No matter what, the tunneling machine will have the tools, power, and excavation techniques to tunnel through wood casings and even un-cased non-metallic (i.e., concrete) plugs. Hazardous gases cannot accumulate in abandoned wooden or un-cased well shafts at a pressure higher than the surrounding gas or water pressure and thus are not a significant risk, especially since the closed-face machine fully controls and minimizes inflow of gases into the tunnel.

6.5.3 Oil Well Removal/Abandonment

If a casing from an abandoned oil well is confirmed to be on the tunnel alignment, the exact location must be confirmed, the upper casing well must be removed, and the well must be properly re-abandoned.

If an undocumented or improperly abandoned oil well is found to be within the envelope of the proposed tunnel, sealing or plugging of the well must be both functionally and environmentally acceptable based upon sound technical principles accepted in the oil and gas industry and in accordance with State and local requirements and regulations. Every effort will be made to locate the well prior to tunnel construction through a surface magnetometer survey or a horizontal directional drilling method. If an abandoned oil well is found prior to starting construction of the tunnel, and the access to the top of the well is available at the ground surface, the re-abandonment of the well will proceed in accordance with California Laws for Conservation of Petroleum and Gas (1997), Division 3 Oil and Gas, Chapter 1 Oil and Gas Conservation, Article 4, Sections: 3228, 3229, 3230, and 3232. The requirements include written notification of DOGGR, obtaining surface rights (if/as necessary), providing access for the necessary equipment, excavation for the well head, protection of adjacent property, and, before commencing any work to abandon the well, obtaining approval by DOGGR. In case surface access is not available or limited, or the well is found to be underneath a building, the use of directional drilling to locate and investigate the well in advance may be required. Once the well is located and the casing is exposed, abandonment work, including well re-drilling, sealing off oil/gas-bearing units, filling the well with cement grout, casing removal, etc., must be performed by a State-licensed contractor under the regulatory oversight and approval of DOGGR.

Undocumented abandoned oil wells have been found during tunnel and shaft excavations on previous projects in the Los Angeles area. An oil well was encountered during early stages of construction of the tunnel access shaft for the NOS-ECIS. The well had originally been cut off below grade and buried, and was detected and exposed while excavating for the guide walls for the perimeter slurry wall of the shaft. It was subsequently successfully removed and abandoned (Keller, Crow, 2004).

If an abandoned oil well is detected underground ahead of an advancing tunnel heading, special procedures must be used to ensure that all operations associated with evaluation of the existing condition of the well, and the implementation of appropriate well-abandonment procedures, can be conducted safely with minimal risk to construction workers and to the public. Oil well casings were encountered during tunnel excavation of the Los Angeles County Flood Control Project No. 1102 in the Mid-City Area and during the Metro Red Line, in Downtown Los Angeles (Figure 6-9). For both of these projects, tunnels were excavated using open-face TBMs.

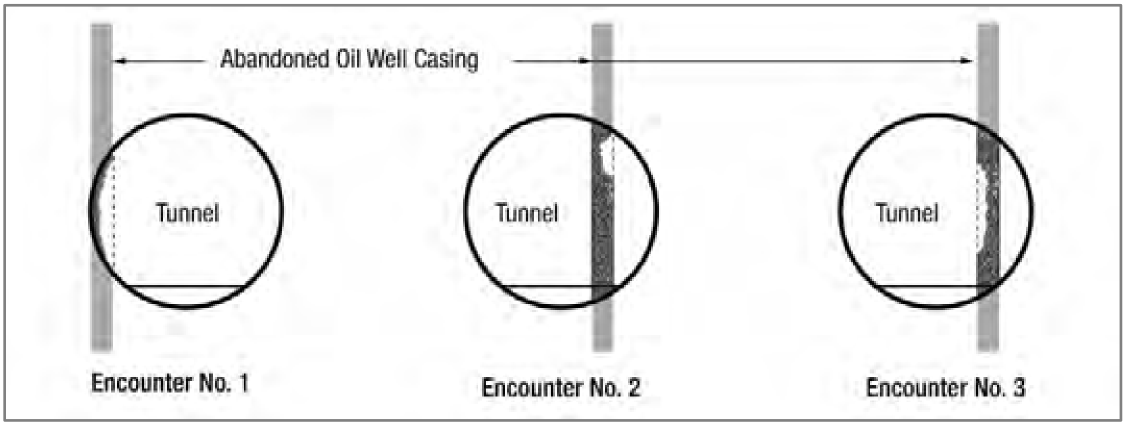
Figure 6-9: Probing of Oil Well Casing, Metro Red Line, Downtown Los Angeles

These encounters of oil well casings in the tunnel headings led to development of general procedures to be implemented on future projects in case oil well cases are encountered. During all of the following procedures, the environment must be monitored., which consists of the following basic steps:

1. Clear the area in the tunnel around the encountered casing.
2. Inspect the casing to determine the original purpose and use of the casing. Continue gas testing around the exposed casing.
3. Drill a small probe hole into the casing near the tunnel crown to assess gas conditions in the well.
4. Neutralize and control oil and gas released from the drilled hole.
5. Take gas readings continuously in the drilled hole and the surrounding tunnel area.
6. With the gases and liquid hydrocarbons neutralized, cut the casing or piping strings exposed at the crown and invert, and remove the piping.
7. After cutting and removing the casing, if it is determined that it is indeed an oil or gas well, call DOGGR for further instructions, including use of DOGGR-approved contractors and additional procedures.
8. Pump cement grout into the cut-off pipe at the invert.
9. After the abandonment procedures are completed, cut additional portions of the pipe at the crown and invert to ensure clearance of the tunnel advance.

The above procedure was used three times on the Los Angeles County storm sewer project (Figure 6-10).

Figure 6-10: Oil Wells Encountered in L.A. Flood Control Tunnels



Considering that the tunnels for the Project will be excavated by closed-face TBMs (EPBMs/SFMs), removal and/or abandonment of oil well casing from the tunnel will be more difficult than is the case with the open-face tunneling method. Where access from the ground surface is available, a shaft from the surface would be used to access the oil well casing and safely abandon it according to the developed procedures and methods approved by DOGGR. If ground surface access is not possible, ground treatment (stabilization by grouting, freezing, or other methods) of the area around the well casing would likely be needed to be conducted to allow for safe well removal/abandonment by working from inside of the tunnel in front of the tunneling machine.

7.0 TUNNELING IN SEISMIC AREAS

Southern California is a seismically active region, well known for its active faults and historic seismicity. For seismicity, tunnel design must consider two related, but distinctly separate, phenomena:

- Ground shaking (the vibration of the ground) during an earthquake on any active fault within the influence zone of the proposed underground facilities
- Actual fault rupture along a fault crossing the alignment of the proposed tunnel

These challenges are not without precedent, however, and practical technical solutions are available.

7.1 Tunnel Design for Ground Shaking

Metro design criteria use a probabilistic seismic hazard analysis that takes into account the combined effects of all nearby faults to estimate ground shaking. U.S. Geological Survey probabilistic seismic hazard analysis computations are used as the basis for evaluating the ground motion levels along the alternative alignments. Ground motions induced by a seismic event are typically characterized by a value of horizontal peak ground acceleration, which is expressed as a fraction (or multiple) of the acceleration due to gravity.

Metro, being an important transit facility, follows a two-level ground motion approach outlined in the *Recommended LRFD Guidelines for the Seismic Design of Highway Bridges* (ATC-49), which is published by the Applied Technology Council and the Multidisciplinary Center for Earthquake Engineering Research.

The two different levels of ground shaking hazard are denoted as the following:

- The Operating Design Earthquake—Is used to check functionality and is based on a 50-percent chance of exceedance during the life of the facility. This translates into a return period of about 150 years with peak ground acceleration along the alignment ranging from 0.26g to 0.32g.
- The Maximum Design Earthquake—Metro structures should meet the life safety performance level equivalent to “no collapse.” At the Maximum Design Earthquake level, the service would be disrupted for general traffic, but some limited access for light emergency vehicles would be available. The Maximum Design Earthquake is based on a 4 percent probability of exceedance in 100 years. This is equivalent to an average return period of about 2,500 years, with a peak ground acceleration along the alignment ranging from 0.81g to 0.98g.

Experience in California and worldwide shows that tunnels perform well during earthquake ground shaking, and do not suffer significant damage or collapse. Since they are embedded in the ground, they move with the ground, and thus, their motion is not magnified by the pendulum effect that occurs when an above ground structure is shaken by an earthquake. As an example, during the Northridge Earthquake, in 1994, Metro’s Phase 1 Red Line tunnels, which were then in operation, received ground motions at the level of Operating Design Earthquake without damage. Inspection was performed and the system was reopened for service the following day, with greatly increased ridership because highways were closed due to earthquake damage to bridge structures. Another example is the 1989 Loma Prieta earthquake (6.9M) that shook San Francisco, collapsing key elevated highways but leaving the Bay Area Rapid Transit tunnel system unaffected. Subway tunnels in Mexico City in 1985 were also in service within hours after the 8.1M earthquake.

7.2 Fault Crossings for the Westside Subway Extension Project

Of particular significance to tunneling within the Century City area are the Santa Monica Fault and the West Beverly Hills Lineament, both of which cross the project alignments. The recent investigation of faulting in the Century City area, as reported in the *Century City Area Fault Investigation Report* (2011), describes the West Beverly Hills Lineament as a part of the active Newport-Inglewood Fault system.

The active Santa Monica Fault is part of the Transverse Ranges Southern Boundary Fault System, a west-trending system of reverse, oblique-slip, and strike-slip faults that extends for more than 124 miles along the southern edge of the Transverse Ranges. Dolan et al. (2000) suggest that the Santa Monica fault zone consists of a combination of high-angle, near-surface strike-slip faults, deeper reverse faults, and low-angle, near-surface thrust faults.

The West Beverly Hills Lineament is a northwest-trending geomorphic lineament that crosses Santa Monica Boulevard near Moreno Drive and extends to the south in the vicinity of Moreno Drive and the BHHS property. It is delineated by discontinuous east-facing scarps that mark the boundary between two distinct geomorphic provinces. The investigations reported in the *Century City Area Fault Investigation Report* (2011) show that the lineament is part of the active Newport-Inglewood fault zone, which consists predominantly of right lateral strike slip faults.

7.3 Tunnel Design through Fault Zones

To construct the Project, it will be necessary to pass through at least two active fault zones. There are numerous proven designs and construction means and methods to safely build a tunnel through fault zones. Design methods include building a larger diameter tunnel and/or a very strong but flexible lining to withstand several feet of movement without collapse and still be repairable. There are also many construction techniques to assure safe tunneling through faults while minimizing ground settlement. Additionally, there are proven procedures to monitor and control ground movements and protect overlying structures as the tunnels are advanced through the fault zones. These construction techniques could include closed-face TBM tunneling, special water, and gas-tight lining segments made with steel and compressible concrete. Additional investigations will be needed to more accurately define the extent and nature of the fault zones and their soil properties.

Since the tunnels will be designed to not collapse during an earthquake, the tunnels will affect neither the threat to buildings above active faults during an earthquake nor the severity of shaking.

Special design measures are employed where the tunnel alignment crosses an active fault zone. The alignment is selected so that stations are not built in active fault zones. Tunnel alignments should be selected so that the tunnel does not run along the fault zone but crosses at a relatively sharp angle to the zone to minimize the length of tunnel that must be designed to accommodate fault displacements or would have to be repaired if faulting did occur. The tunnel in the fault zone would be designed to accommodate fault displacement without collapse due to fault displacement and to prevent large inflows of water or gas. Both the amount of fault displacement and the distance over which it takes place is assessed. For the same amount of fault movement, displacement spread out over a long distance is easier to accommodate than displacement over a short distance. Designs have been developed for both types of movement. Another consideration in the design is the effort required to repair the tunnel and resume service after an earthquake.

The individual faults within a fault zone contain sheared and altered geologic materials that have lower shear strength than the undisturbed material. Changes in groundwater and gas conditions can also occur in or adjacent to a fault. In soils, such as the dense alluvial soils in the Century City area, faults in fault zones also have sheared surfaces but the differences between the fault surface and the surrounding undisturbed soil is less pronounced than in rock.

The most appropriate means of tunneling through fault zones in soils is through the use of pressurized closed-face TBMs—the type of TBM proposed for the Project and described in more detail in Section 4.1. Such a TBM applies positive pressure to the face that supports the ground and prevents sudden inflows of water and/or gas through the face, even in variable ground such as in a fault zone. In addition, the gasketed segmental lining, which is installed as the TBM shield advances, prevents inflow of water and gas along the length of the tunnel. This type of TBM and lining installation system also has capabilities for installing a lining that can accommodate fault displacements, as described in the following paragraphs. During tunneling through the fault zones, procedures will be in place for monitoring and controlling ground movements and protecting overlying structures as described in Section 4.0. The presence of the tunnel will not affect the ground shaking or fault displacement imposed by an earthquake on overlying structures.

In some cases, such as in the rock tunnel crossing the Hollywood Fault by the Red Line, the tunnel is oversized through a fault zone to accommodate future fault displacement. This is not always practical, particularly when TBMs with segmental linings are used. Designs for the MGLEE called for short-length steel segments when passing through potential fault zones. For potentially large anticipated tunnel deformations in fault zones, articulated joint designs have been developed as a means to satisfactorily and economically mitigate the seismic risk, providing that sufficient ductility can be provided in the lining at the fault (Russo et al., 2002). Other solutions include backpacking the segments with a stiff but crushable material. Similar solutions were used when a few tunnels in Los Angeles crossed the Newport-Inglewood Fault.

These and other solutions will be considered for applicability during detailed design. One design under development includes a segmental lining consisting of a composite of a ductile steel lining and crushable material that will accept the fault displacements without collapse and can be installed through the fault zone with the same procedures and equipment used for installing the segmental concrete linings in the remainder of the tunnel. The space between the ground and the tunnel lining would be pumped full of cellular (crushable) concrete to allow controlled deformation of the tunnel. In addition, the tunnel linings for the Project tunnels are being designed with additional clearances that will allow placement of a double lining with a membrane (as described in Section 5.7), or can be used as space to accommodate some of the fault offset.

Lining designs to accommodate fault displacements will be developed for both the Santa Monica fault zone and the Newport Inglewood/WBHL fault zone. The design fault displacements and requirements for developing the lining designs location and length of required lining will be further defined during the final design period.

7.4 Fault Zone Crossings in Los Angeles

Fault zones have been tunneled through previously in the Los Angeles area. These have included the following faults.

7.4.1 Metro Tunnels through the Hollywood Fault

The Hollywood Fault was investigated for the Hollywood Hills Metro tunnels. The investigations indicated that the fault dips to the north at 60 to 70 degrees and displays vertical and left slip movement. The width of the fault zone was estimated to be 120 feet and was found to act as an effective barrier to water (aquitard), resulting in an abrupt change in groundwater level across the fault.

For the section of the Metro Red Line tunnels through the Hollywood Fault, both running tunnels were enlarged vertically and laterally to a 28-foot excavated span using drill and blast methods, as these tunnels were constructed in rock. The objective of enlarging the tunnels within the fault zone is to minimize the amount of re-excavation needed to realign the tracks after fault movements have occurred. The enlarged tunnels allow for up to a 6-foot vertical and a 6-foot lateral slip across the fault zone.

7.4.2 North Outfall Sewer—East Central Interceptor Sewer Tunnel through the Newport Inglewood Fault

The City of Los Angeles Department of Public Works built the NOS-ECIS in the early 2000s. This tunnel, a deep interceptor sewer constructed for the City of Los Angeles sewer system, crosses the Newport-Inglewood Fault near the intersection of La Cienega Boulevard and Coliseum Street. The fault was estimated to be 10 feet wide and contained sheared clays, silts, and sands within the siltstone formation. The fault was anticipated to be a trap for groundwater, methane, and hydrogen sulfide.

For the section of tunnel through the fault zone, the space between the sewer's carrier pipe and the initial ground support (a precast concrete segmental lining) was backfilled with cellular (light weight, compressible) concrete to accommodate ground movements.

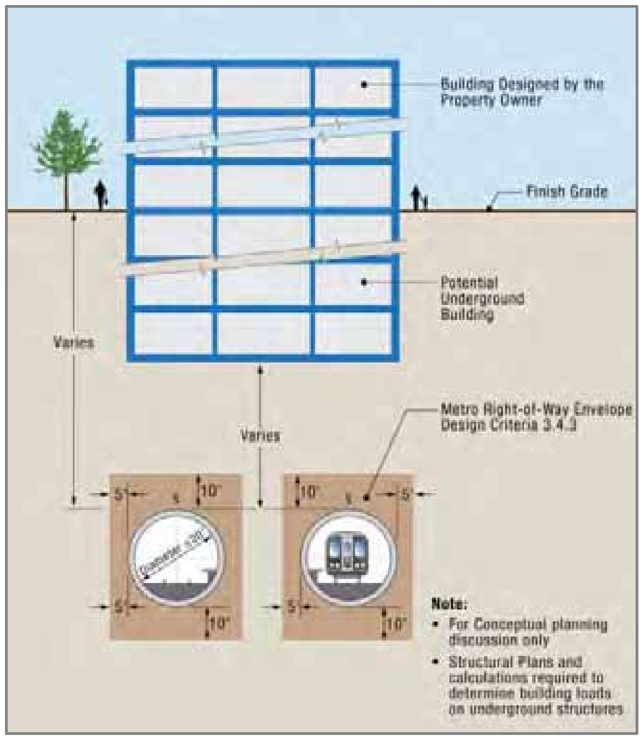
8.0 IMPACT ON BEVERLY HILLS HIGH SCHOOL FACILITIES

8.1 Future Development over Metro Tunnels

At the BHHS property, the proposed tunnel crown is approximately 55 to 70 feet beneath the ground surface. Future BHHS development can occur above the tunnels. Multiple levels of underground parking can be placed over the tunnel and foundations for future structures and can be constructed above the tunnel or can extend down between and adjacent to the tunnels. If the tunnels are constructed first, excavation for foundations and underground parking levels can be constructed above the tunnels. The effect of construction on the existing tunnels would be analyzed, but major bridge structures to support the building are not required. The floor spans and any related foundations would be within typical building practice, on the order of that required to extend across the 21-foot-width of a single tunnel.

If the tunnels were to be constructed before future BHHS development, the tunnels would be constructed taking into consideration the effects of any future construction. In fact, the construction of deep basements over a tunnel would not create additional load but may even reduce the load on the tunnel. This is a fact used in foundation engineering to construct a so-called “floating foundation” since the weight of the building is less than the weight of the soil removed.

Figure 8-1: Right-of-Way Envelope for Metro Tunnels



If the tunnels are constructed after future development, foundations for these structures would be designed as necessary to span the future tunnels. During tunneling, specific procedures to ensure control of ground movement would be in place to prevent damage to the existing structures.

A typical easement for Metro twin tunnels is shown in Figure 8-1. Clearances to the Metro tunnels can be small. Metro tunnels have been designed to pass less than 10 feet below existing structures, including existing tunnels.

The design of the building structures and their foundations should take into consideration future tunnel construction through close cooperation between Metro and BHHS designers.

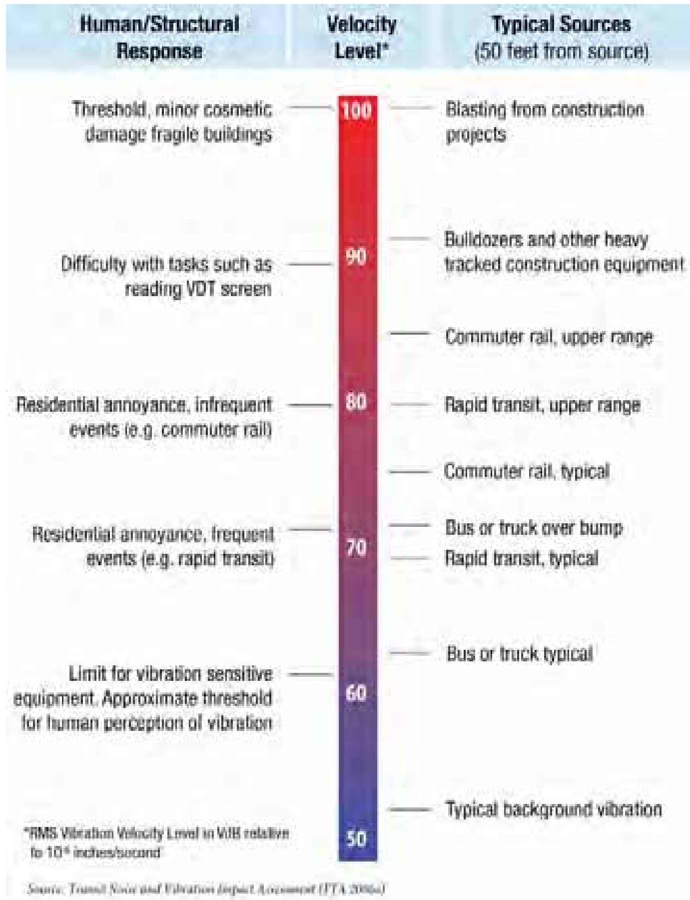
8.2 Noise and Vibration from Operating Trains

8.2.1 Vibration and Its Effect on People

Vibration generated by operating trains may be transmitted from the subway tunnels through the ground to at-grade structures. This is referred to as ground-borne vibration. When evaluating human response, ground-borne vibration is usually expressed in terms of dBs using the root mean square (RMS) vibration velocity. RMS is defined as the average of the squared amplitude of the vibration signal.

To avoid confusion with sound dBs, the abbreviation VdB is used for vibration decibels. All vibration dBs in this section use a dB reference of 1 micro-inch/second (μin/sec.). Typical vibration levels from different sources are presented in Figure 8-2. The potential effects of rail transit ground-borne vibration are defined as follows:

Figure 8-2: Typical Vibration Levels



- Perceptible Building Vibration—This occurs when building occupants feel the vibration of the floor or other building surfaces. Experience has shown that the threshold of human perception is around 65 to 70 VdB, and that vibration that exceeds 75 to 80 VdB may be intrusive and annoying to building occupants. Beyond 80 VdB, vibration levels are generally considered unacceptable.
- Rattle—The building vibration can cause rattling of items on shelves and hanging on walls, and various different rattle and buzzing noises from windows and doors.
- Reradiated Noise—The vibration of room surfaces radiates sound waves that may be audible to humans. This is referred to as ground-borne noise. When audible ground-borne noise occurs, it sounds like a low-frequency rumble.
- Damage to Building Structures—It is extremely rare that ground-borne vibration from transit systems results in building damage, even minor cosmetic damage. The primary consideration therefore is whether vibration will be intrusive to building occupants or will interfere with interior activities or machinery. The vibration from a rail system, such as the Metro Red Line, is significantly lower than the most restrictive thresholds for preventing damage to fragile buildings. Hence, the vibration effect criteria focus on human annoyance, which occurs at much lower amplitudes than does building damage.

8.2.2 Federal Transit Administration Vibration Criteria

The FTA has developed impact criteria for acceptable levels of ground-borne noise and vibration (Table 8-1 and Table 8-2). Ground-borne vibration from transit vehicles is characterized in terms of the RMS vibration velocity amplitude. A 1-second RMS time constant is assumed. This is in contrast to vibration from construction activities that could cause building damage typically characterized by the peak particle velocity (PPV). In addition to units of inches per second, the amplitude or strength of vibration may be expressed as a velocity level in units of VdB. VdB is obtained in a manner similar to sound level dBs by logarithmically comparing measured or predicted vibration amplitude to reference amplitude of 1 micro-inch/second. When assessing the potential for building damage, ground-borne vibration is usually expressed in terms of the PPV, using units of inches per second but may also be expressed using VdB values.

Table 8-1: FTA Ground-borne Vibration and Ground-borne Noise Impact Criteria

Land Use Category	Ground-borne Vibration Impact Levels (VdB re: 1 micro-inch/sec)			Ground-borne Noise Impact Levels (dB re 20 micro Pascals)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where vibration would interfere with interior operations	65 VdB[4]	65 VdB[4]	65 VdB[4]	N/A[4]	N/A[4]	N/A[4]
Category 2: Residences and buildings where people normally sleep	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

Source: Transit Noise and Vibration Impact Assessment (FTA 2006)
1 “Frequent Events” are defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2 “Occasional Events” are defined as between 30 and 70 vibration events of the same source per day. Most commuter rail lines have this many events.
3 “Infrequent Events” are defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4 This criterion limit is based on levels that are acceptable for most moderately sensitive equipment, such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the heating, ventilation and air conditioning (HVAC) systems and stiffened floors.

Table 8-2: FTA Ground-borne Vibration and Ground-borne Noise Impact Criteria for Special Buildings

Land Use Category	Ground-borne Vibration Impact Levels (VdB re 1 micro-inch/sec)		Ground-borne Noise Impact Levels (dB re 20 micro Pascals)	
	Frequent Events[1]	Occasional or Infrequent Events[2]	Frequent Events[1]	Occasional or Infrequent Events[2]
Concert halls	65 VdB	65 VdB	25 dBA	25 dBA
TV studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

Source: Transit Noise and Vibration Impact Assessment (FTA 2006)
1 “Frequent Events” are defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2 “Occasional Events” are defined as between 30 and 70 vibration events of the same source per day. Most commuter rail lines have this many events.

Table 8-1 summarizes the FTA impact criteria for ground-borne vibration and ground-borne noise caused by a project’s operations. The criteria are applicable as measured or calculated at a point just outside the building’s foundation using the shortest distance from the activity (construction or operations). Some buildings, such as concert halls, television and recording studios, and theaters, can be very sensitive to vibration but do not fit into any of the three standard categories. Along the Project’s alignments, special-use buildings that may be especially sensitive to vibration have been noted and evaluated individually. Because of the sensitivity of these buildings, they usually warrant identification during the environmental review of a transit project and special attention during the Project's engineering design phase. Table 8-2 provides criteria for acceptable levels of operations-based ground-borne vibration and ground-borne noise for various types of special buildings.

8.2.3 Studies of Existing Red Line

Metro successfully operates a large mass transit system comprising traditional bus service, Bus Rapid Transit (BRT), Light Rail Transit (LRT), and Heavy Rail Transit. LRT lines include both surface, aerial, and subway lines. Because of the plans to extend the subway to the west—into new areas that have no experience with a subway—a study was performed to objectively evaluate and document any train-related perceptible vibration at the ground surface above representative Metro subway tunnels. Results were reported in the *Final Metro Red Line Vibration Study* (December 2008).

The objectives of this study were the following:

- Select four locations on an existing subway line where train type and depth of the tunnel below ground would be similar to what is planned for the Project;
- Measure the existing ambient ground-level vibration without a train passing underneath the measurement point but with other typical local activity present;
- Measure vibration from a representative sample of passing underground trains to determine if there are measurable vibrations from the existing Metro Red Line operations; and

Noise and vibration specialists measured ground vibration during periods of no subway train activity and periods with subway train activity. They found that vibration levels during no subway train activity (ambient) are slightly higher than what FTA (Figure 8-2) shows as "typical background" vibration levels. This is expected, given that Los Angeles is a busy urban environment with substantial movement of heavy motor vehicles, and distant construction and/or mechanical equipment activity.

The vibration specialists conducting the measurements could not distinguish the train vibrations from the ambient vibration generated by the nearby traffic of heavy trucks and buses. Additionally vibration specialists preparing the study did not themselves perceive ground vibration at any time during the measurements at any of the locations. This includes the nearby movement of heavy trucks and busses on adjacent streets, the passage of underground trains, and one occasion when a compact car entered a driveway apron about 20 feet away with enough speed and force to temporarily overload the vibration measurement system.

The vibration from Metro heavy rail subway trains is not perceptible above the ambient levels even directly above tunnels at depths ranging from 56 feet to 99 feet below ground. Measured ground vibration levels during operation of the Metro Red Line subway did not exceed the FTA criterion of 72 VdB for residential buildings and other structures where people normally sleep (Category 2) at any residential location. Metro has not received noise or vibration complaints that have required mitigation.

The vibration levels likely to be generated by the future extension of the subway is expected to be very similar to vibration from the existing Metro Red Line, assuming similar operational and design parameters of locomotives and railcars, speeds, track type, crossover/turnout type, curve radii, and tunnel depth. Thus, it is believed that the tradition of vibration-complaint-free operation of the Metro subway system will continue.

8.2.4 Methods Used to Predict Train Vibrations

The process used to evaluate potential impacts from ground-borne vibration and ground-borne noise follows that outlined in *Transit Noise and Vibration Impact Assessment* (FTA 2006). The projections are based on characterization of the magnitude of the vibration forces generated by a transit train in terms of a force density and characterization of the propagation through the soil with a transfer mobility function. The force density is assumed to represent the combined effects of the vehicle suspension, the wheel and rail condition, and the track support system, and is assumed to be independent of the local geologic conditions. Force density level measurements of the Breda type vehicle, currently operating on the Metro Red and Purple Lines, which would likely be the heavy rail vehicle used for the Project, was conducted by Metro in 1996. The force density levels were measured at 40 miles per hour (mph) and, based on the different trackwork geometries were adjusted to the projected train operating speeds in the range of 40 to 70 mph following the FTA Detailed Vibration Analysis methodology in the FTA Transit Noise and Vibration Impact Assessment Report.

The combination of the force density and measured transfer mobility functions provides an estimate at the ground surface as a function of distance from the tracks, the horizontal distance, and the depth of the subway tunnels. All estimates of ground-borne vibration are calculated in one-third octave bands. The overall vibration level in VdB is calculated from the individual one-third octave bands and compared to the FTA criteria. The predicted vibration levels are at the foundation of each building. and do not include any estimates of building coupling loss. These projections are representative of first-floor vibration levels for buildings constructed as a concrete slab on grade. In addition, a 5-dB safety factor has been incorporated into all of the ground-borne vibration and ground-borne noise projections. The purpose of the safety factor is to account for normal fluctuations in ground-borne vibration due to normal wheel and track wear, and unexpected differences in the local soil and geology that were not represented by the transfer mobility tests. Ground-borne noise was calculated by converting the one-third octave band vibration levels to sound pressure levels and applying an A-weighted adjustment using the FTA Detailed Vibration Analysis procedures.

The ground-borne vibration and ground-borne noise were calculated at BHHS and at 10 other locations along the Century City—Constellation Boulevard Station alignment.

8.2.5 Field Tests Conducted at BHHS

Borehole vibration tests were performed on the BHHS campus to directly determine the vibration propagation characteristics for subsurface vibration sources at this site. The test method consists of generating ground vibration at the bottom of a borehole using the exploratory drill rig penetration drop hammer. The impulsive forces transmitted into the soil at the bottom of the borehole are measured using a special load cell and the resulting surface acceleration measured at varying distances from the hole. The resulting measurements are digitally processed to obtain the transfer mobility, which characterizes the relationship between the exciting force and the resulting ground motion.

Testing was performed on March 5, 2011, at test depths of 55, 65, and 75 feet. Three indoor accelerometers were installed and mounted roughly center-span inside classrooms 107, 123, and 201. For the outdoor measurements, the accelerometers were located at distances of 25, 37, 50, 75, 100, and

150 feet, extending north from the borehole location. Figure 8-3 and Figure 8-4 show the drill rig used and the accelerometers in the classroom tested, respectively.

8.2.6 Results of Vibration Modeling

Table 8-3 presents the predicted and FTA impacts criteria and Figure 8-5 shows the locations of the receivers. Vibration-sensitive receiver sites V-A through V-C represent a hotel, medical offices, and residents in Beverly Hills to the east of the school campus. Sites V-D and V-E represent the classroom and offices at the high school directly over the subway tunnel. Site V-F is the site of a future residential building near the Constellation Boulevard Station. Sites V-G and V-H are the residential land uses east of Santa Monica Boulevard. Site V-I is Pacific Crossroads Church. Sites V-J through V-L represent the single- and multi-family residences between Eastbourne and Kinnard Avenues. Included in Table 8-3 is the tunnel depth and horizontal distance to each receiver site, predicted ground-borne vibration and ground-borne noise, FTA impact criteria, and train speed. The results of the vibration modeling are that no exceedances of the FTA ground-borne vibration or ground-borne noise criteria would occur at BHHS or any other receiver sites presented in Table 8-3.

8.2.7 Tunnel Construction Noise and Vibration Levels

Whether or not equipment used for underground construction, such as the TBM and mine trains, generate audible ground-borne noise levels in surface buildings depends on the mechanical characteristics of the equipment, tunnel depth, and soil conditions. Metro has substantial experience with noise control and allows slightly higher criteria for noise and vibration during construction. Control measures exist for construction-induced vibration that have been implemented in previous Metro tunnels, including the MGLEE tunnels. The MGLEE required that ground-borne noise levels caused by all underground construction operations (including supply train [muck car] operations, TBM excavation, and other construction activities) be limited to 40 dBA for residential buildings and 45 dBA for schools. The MGLEE specifications required the tunneling contractor to provide vibration isolation of the muck train rail system to mute noise levels from muck car movement, should levels exceed the specified levels. There were no substantiated noise-level complaints made during MGLEE tunneling. While it is not expected that Metro will receive any construction-related noise complaints, if substantiated, Metro will address and mitigate them.

Tunneling in the Century City area will be undertaken with the same noise- and vibration-level limits and mitigation measures used during MGLEE construction. It should be noted that the MGLEE tunnels were at relatively shallow depths (less than 50 feet to the top of rail) where they passed near underground stations. In comparison, the tunnels under West Beverly Hills, BHSS, and Westwood would vary from 60 to more than 100 feet, thus providing a significantly higher level of attenuation of ground vibration than that at the MGLEE tunnels.

Previous studies by Metro of tunneling-induced vibrations for the Metro Red Line construction showed that vibration affecting overlying buildings was unlikely to be perceived. The findings were substantiated during actual construction; vibration was well-below the most conservative damage thresholds. Moreover, exposure of buildings to vibration and ground-borne noise from the TBMs was confined to short periods of time (a day or two at most) as the TBM passed beneath surface structures.

Table 8-3: Predicted Ground-borne Vibration and Ground-borne Noise at Vibration-Sensitive Receivers on the Century City (Constellation Boulevard) Station Option Alignment

ID #	Receiver	Tunnel Depth (feet)	Horizontal Distance (feet)	Predicted Ground-borne Vibration Level (VdB)	FTA Ground-borne Vibration Criteria (VdB)	Predicted Ground-borne Noise Level (dBA)	FTA Ground-borne Noise Criteria (dBA)	Train Speed (mph)
V-A	Beverly Hills Mosaic Hotel	93	0	62	72	32	35	65
V-B	Medical Office	91	0	62	75	32	40	65
V-C	Apartments	86	15	63	72	34	35	45
V-D	BHHS Offices and Classrooms	77	0	64	75	33	40	45
V-E	BHHS Classrooms	85	0	63	75	30	40	45
V-F	Future Office Buildings	78	40	59	75	29	40	40
V-G	SFR	96	0	63	72	33	35	70
V-H	Apartments	88	0	64	72	35	35	70
V-I	Pacific Crossroads Church	87	0	64	75	35	40	70
V-J	SFR	92	0	63	72	33	35	70
V-K	Apartments	120	0	61	72	30	35	70
V-L	SFRs	121	0	61	72	30	35	70

1. SFR = Single-family residence
2. The ID numbers are shown on Figure 8-5: Location of Vibration-Sensitive Receivers
3. Tunnel Depth to top of rail

Figure 8-3: Drill Rig Outside BHHS Classroom Building

Figure 8-4: Vibration Transducer in Classroom 123

Figure 8-5: Location of Vibration-Sensitive Receivers

Given (1) that Metro will adopt specifications similar to those enacted during MGLEE tunneling that enforce limits on noise and vibration levels affecting overlying buildings; (2) the absence of noise complaints during MGLEE construction; and (3) the more favorable conditions for attenuation of ground borne noise and vibration at locations such as BHHS, Century City and Westwood, it is not anticipated that vibration from tunneling will affect residences, schools, or commercial buildings in the study area. Moreover, noise levels produced by a TBM will be confined to a narrow window of time (generally less than 24 hours) as the tunnel is advanced beneath overlying buildings. Metro construction specifications also provide requirements to monitor and limit construction noise at the surface worksites, such as at a Century City Station.

8.3 Impact on Use of BHHS as Emergency Evacuation Center

The question of whether to use BHHS as an emergency evacuation center was addressed in the Metro Board motion. Background on the school's function as an operation center was gathered from public information, such as the City's website and Emergency Operations Plan, and then reviewed against configuration and operation of the proposed Metro tunnels. It is known that schools are often used to provide shelter during an emergency. However, the American Red Cross notes that because it is important that a community return to normal activities as soon after a disaster as possible, schools should be used in shelter operations only when other resources are unavailable. The BHUSD states in its Hazard Mitigation Plan of March 2006 that all of its schools are required by both federal and state regulation to be available for shelters following a disaster. The Emergency Plan for the Department of Education does not require the use of schools in California as shelters during disasters, but rather promotes the use of those facilities.

The BHUSD states in its Hazard Mitigation Plan of March 2006 that all schools are required by federal and state regulations to be available for shelters following a disaster. Background on the BHHS's function as an emergency evacuation center was obtained from multiple sources, such as the Beverly Hills Emergency Operations Plan and city web site, and then reviewed against configuration and operation of the proposed Metro tunnels. Metro's review shows that neither the construction nor the presence of tunnels beneath BHSS will affect adversely its use as an emergency evacuation center.

It has been demonstrated many times that tunnels behave well during earthquakes. At BHHS the tunnels will have linings that are gas and water tight. Moreover, there are existing Metro policies and procedures for safe shutdowns during earthquakes with subsequent inspections and necessary repairs. According to existing Metro seismic criteria, the tunnels will be designed so they will not collapse even during a large earthquake with several feet of movement across a fault. Accordingly, the tunnels will affect neither the behavior of BHHS structures nor the severity of earthquake shaking, and thus will not affect the ability to use BHHS as an Emergency Evacuation Center.

9.0 SURVEY OF EXPERIENCE WITH TUNNELING UNDER AND ADJACENT TO BUILDINGS

9.1 Background

With urbanization, much infrastructure has been placed underground not only to achieve the shortest and least slope alternative, but also to allow the ground surface to be used for other purposes. For instance, tunnels may be used for transportation of people or materials while at the surface, parks, residences, and commercial and industrial facilities can be built and operated independently of the underground operations.

Within the last 20 years, improvements in technology, management, and workmanship have resulted in tunnels being built with minimal effects on surface structures. This section summarizes selected cases where tunnels have successfully been driven under surface structures or utilities. Many of these cases involve tunneling beneath an existing structure or utility of special significance—for instance, historic or sensitive with respect to the building use. Others involve the construction of facilities over existing tunnels. Issues considered mostly involve tunneling-induced ground movement.

9.2 Los Angeles Metro Experience

The Los Angeles Metro's Red Line tunnels began construction in 1991. Construction was carried out in three segments:

- Segment 1 consisted of tunneling between Union Station and Westlake/MacArthur Park Station, a distance of about 12,250 route feet.
- Segment 2 consisted of:
  - Tunneling between Westlake/ MacArthur Park Station and Wilshire/Western Station (including through Wilshire/Vermont Station), a distance of about 3,800 route feet.
  - Tunneling between Wilshire/Vermont Station and Hollywood/Vine Station, a distance of about 10,200 route feet.
- Segment 3 consisted of:
  - Tunneling between Hollywood/Vine Station and North Hollywood Station, a distance of about 13,450 route feet.

Tunneling was primarily within the soft ground sedimentary and alluvial deposits of Los Angeles Basin except for the section of tunnel between Hollywood/Highland Station and Universal City Station in Segment 3 that passed beneath the Hollywood Hills and was tunneled through rock.

The soft-ground tunnels for Segments 1, 2 and 3 were constructed using open-face shield tunneling methods (Figure 9-1), which was the standard practice for tunneling in Los Angeles' geology and groundwater conditions at that time. This method of tunneling is an efficient means for excavating soft ground consisting of sands, silts, and clays, and gives high rates of tunnel progress under ideal conditions. However, the method does not control groundwater inflows and these must be dealt with by other means. It also can result in large settlements at the surface as the method provides only limited capability to control the tunnel face.

Figure 9-1: Tunnel Shield Used for Metro Segment 1

As the subway tunnels were being constructed in Los Angeles, they passed beneath existing buildings at a number of locations, particularly where they curved to change alignment, as shown in Figure 9-2 through Figure 9-5. Locations include the following:

- Downtown Los Angeles Hill Street to 7th Street (6 buildings)
- Union Station to Civic Center (4 buildings)
- From Wilshire/Vermont station to both Wilshire/Western and Vermont Avenue
- Vermont Avenue to Hollywood Boulevard
- Hollywood Boulevard to Highland
- Curves to align tunnels to Lankershim Boulevard

The potential damage to buildings was studied during design, and in some instances, where the tunnels were shallow, grouting programs were implemented to reduce settlement of buildings. In all cases, tunneling was accomplished safely and successfully.

Figure 9-2: Tunnel Reach—Union Station to Civic Center

Figure 9-3: Tunnel Reach—Hill Street to 7th Street

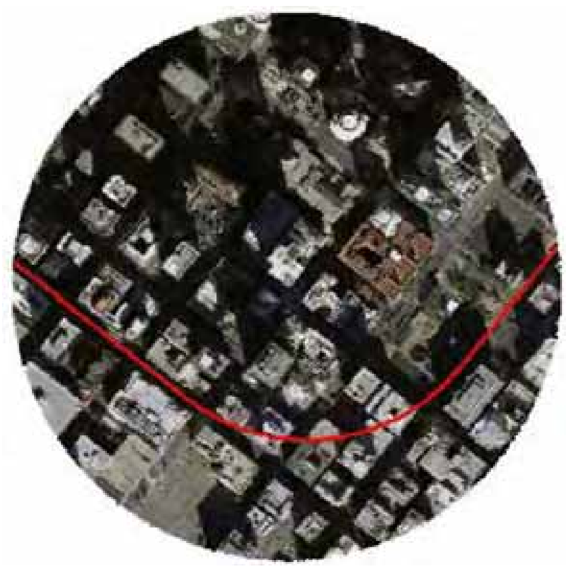


Figure 9-4: Tunnel Reach—Wilshire/Vermont

Figure 9-5: Tunnel Reach—Vermont/Sunset to Hollywood/Western

During the initial stages of subway construction, although most of the tunneling was undertaken without any problems, a series of unfavorable incidents associated with tunnel construction did occur:

- Excessive surface settlement (up to 9 inches) occurring in August 1994 above the twin tunnels along Hollywood Boulevard near Hudson and Whitely Avenues
- Sinkhole above a tunnel along Hollywood Boulevard west of Vermont in June 1995
- Excessive settlements (up to 3 inches) occurring along Lankershim Boulevard in North Hollywood

These led Metro to commission a panel of advisors (known as the Tunnel Advisory Panel or TAP) to evaluate the feasibility and safety of tunneling within the Los Angeles area. The findings from the panel were presented in a report submitted in November 1995 titled *Los Angeles County Metro Rail Project Report on Tunneling Feasibility and Performance.* As indicated by the report, there were unique and different conditions leading to the unsatisfactory performances for each of these incidents. What they had in common were defects related to tunneling procedures rather than geologic conditions. As a result, the TAP pointed out that they could be addressed for future projects by rigorously specifying improved means and methods of tunneling.

The findings from the TAP's 1995 report are quoted from the Executive Summary:

> *The geological and geotechnical environment along the existing and proposed corridors of Los Angeles Metro is clearly compatible with safe and economical underground construction. Dozens of cities in various countries have successfully developed underground transportation systems in similar or even more difficult ground conditions.*

And the TAP went on to recommend that:

> *… ground control be established as the governing design and construction criterion on the existing and future tunneling contracts, with firmly set rules about monitoring and interpreting ground deformation data as well as practical steps to be taken immediately where deformations exceed the permissible limits. MTA should consider that cost and benefits of specifying less risky construction methods and methods which minimize construction impacts to the public, even if their initial cost may be more expensive.*

The TAP demonstrated that Los Angeles performance was in line with performance from other urban tunneling projects worldwide.

With these recommendations in place, Metro revised its approach to construction contracts. It became more proactive in specifying tunneling means and methods. For example, closed-face pressurized TBMs—EPBMs or SFMs—were specified for the MGLEE. The contractor selected EPBMs. They proved highly successful (see Sections 3 and 4), and 1.7 miles of twin tunneling was completed with surface settlements of less than 0.4 inch.

9.3 Other Los Angeles Tunneling Experience

9.3.1 North Outfall Sewer—East Central Interceptor Sewer

NOS-ECIS was an approximately 16-foot-diameter excavation, about 11.5 miles long. It was excavated using four EPBMs and a temporary precast concrete segmental lining with a final reinforced concrete carrier pipe installed inside the temporary support. This was one of the first applications of EPBMs in the U.S, with the TBM used in its closed pressurized face mode in order to control ground movements.

The east-west ECIS alignment through west Los Angeles roughly parallels parts of the Wilshire corridor of the Project a couple of miles to its south. Over 800 structures were identified within the zone of influence of tunneling, and several were tunneled directly beneath, including single-family dwellings and commercial buildings. The tunnel also passed beneath the Los Angeles River, as well as the Harbor Freeway (110 Freeway) and the I-10 Freeway. Geotechnical monitoring of the structures along the alignment took place, but no damage was reported.

10.0 CONCLUSIONS

This report addresses the issues surrounding the safety of tunneling under and in the vicinity of BHHS, including West Beverly Hills, Century City, and Westwood. A companion report, the *Century City Area Fault Investigation Report*, presents the results of a comprehensive study on the earthquake faults in the vicinity of Century City and West Beverly Hills. The findings of both reports should be read and evaluated concurrently as they both are needed to establish the preferred alignment alternative through this area and the location of the station to serve Century City.

The conclusions from this report are as follows.

- **Tunneling can be safely carried out beneath the BHHS campus and the West Beverly Hills, Century City, and Westwood neighborhoods.**

  The use of state-of-the-art pressurized closed-face TBMs for soft-ground tunneling has greatly improved the control of ground movements such that tunneling can be done with minimal surface settlements that would cause distress in the form of functional or structural damage to buildings. This has been successfully achieved on a number of recent projects using these TBMs, including Metro's MGLEE tunnels.

  Although it is not possible to select an alignment to the proposed Constellation Boulevard Station location that would avoid all BHHS buildings, the selected alignment would minimize potential impact and tunneling for the twin bores and could be carried out without causing structural or functional damage. Any effects on buildings would be in a range where cracking of finishing does not occur or is very minor.

- **Tunneling would not prevent future development of the BHHS campus.**

  The crown of the tunnels has been set 55 to 70 feet below the ground surface, which is sufficient depth for the future construction of multiple levels of underground parking above the tunnels. Foundations for such a structure could either be set above the tunnel or extended down so they are adjacent to or between the tunnels.

  New building development, particularly foundation plans, should be coordinated with future tunnels. The floor spans would be within typical building practice, on the order of that required to extend across the 21-foot-width of a single tunnel.

- **Tunneling would not impact the use of the BHHS campus as an emergency evacuation center.**

  The presence of the tunnels would not affect the behavior of any structures during an earthquake. The tunnels would not interfere with the use of the school as an emergency evacuation center or adversely impact its operation as a shelter.

- **Tunneling through fault zones can be done safely.**

  To construct the Project, it will be necessary to pass through at least two active faults. There are numerous tools, designs, and construction means and methods that have been used elsewhere that can be used to safely tunnel through these fault zones. Risks due to tunneling (e.g., settlement) would be similar to those in unfaulted areas.

  Presence of the tunnels will neither affect the risk to buildings above them during an earthquake nor change the severity of shaking.

- **Vibration and noise levels are within the FTA requirements and tunnel operation is not anticipated to have adverse impacts. The tunnel construction may cause some low levels of noise and vibration for a day or two.**

  Metro has been operating its subway system for almost 20 years and has not received complaints requiring noise and vibration mitigation. In some locations, the tunnels are shallower than proposed in Beverly Hills, Century City, and Westwood. Metro will address and mitigate any substantiated complaints related to noise and vibration, however there were no substantiated noise-level complaints made during MGLEE tunneling.

  Should future underground construction be considered that would place a school building foundation closer to the tunnel, mitigation measures could be implemented to reduce ground-borne noise and vibration impacts. To mitigate such noise impacts, a high-compliance direct-fixation resilient rail fastener can be incorporated into the track work.

- **Tunnelling can be constructed and operated safely in gassy ground.**

  The Century City and Beverly Hills areas, as with most of west Los Angeles, are within a Methane Zone identified by the City of Los Angeles but are not areas with the highest gas levels. These are to be found in the Wilshire/Fairfax area.

  Since the 1970s, the State of California has pioneered the development and implementation of regulations on safe tunneling in gassy ground. Moreover, the tunneling industry in Los Angeles has since had very successful experiences in driving many miles of tunnels in gassy ground. The tunnels have been constructed using the strict Cal/OSHA tunnel safety regulations, as would the tunnels constructed under BHHS, Century City, and Westwood. Accordingly, it has been demonstrated many times that tunnels can safely be constructed and operated in gassy ground.

- **Oil wells do not pose an unmitigatible risk to tunneling. Should they be encountered, procedures will be in place for their safe removal and re-abandonment.**

  Tunnels, through known oil well fields, have been safely constructed with no adverse incidents with either hazardous gas or oil casings. In recent Los Angeles tunneling history, there have been no oil well incidents related to tunneling, and oil well casings have been safely removed and re-abandoned. Where oil wells are suspected, magnetometer probing will be conducted either prior to tunneling or during tunneling to assure that there are no steel casings in the path of the TBM.

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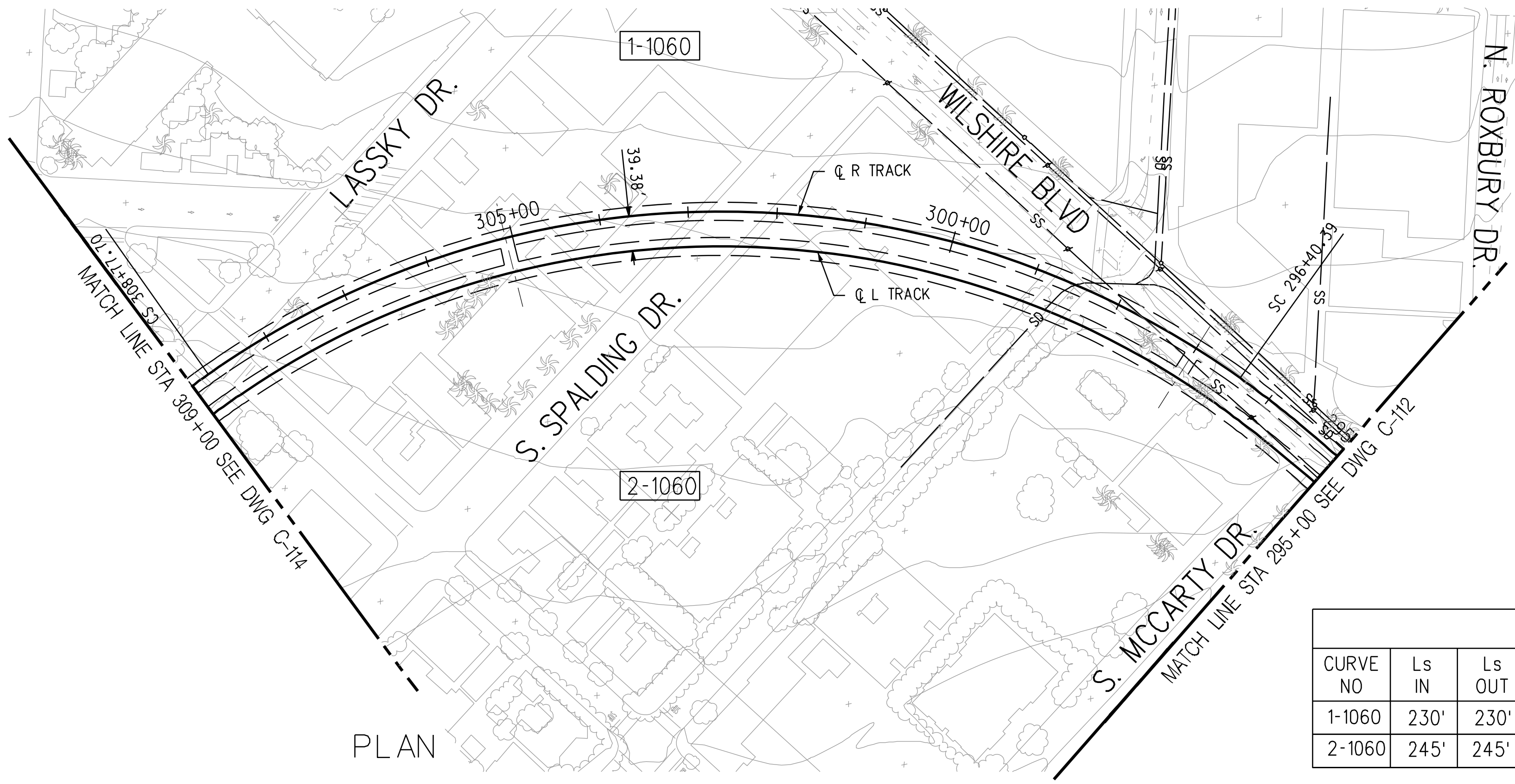
Appendix A
Plan and Profile Drawings



PLAN

CURVE DATA									
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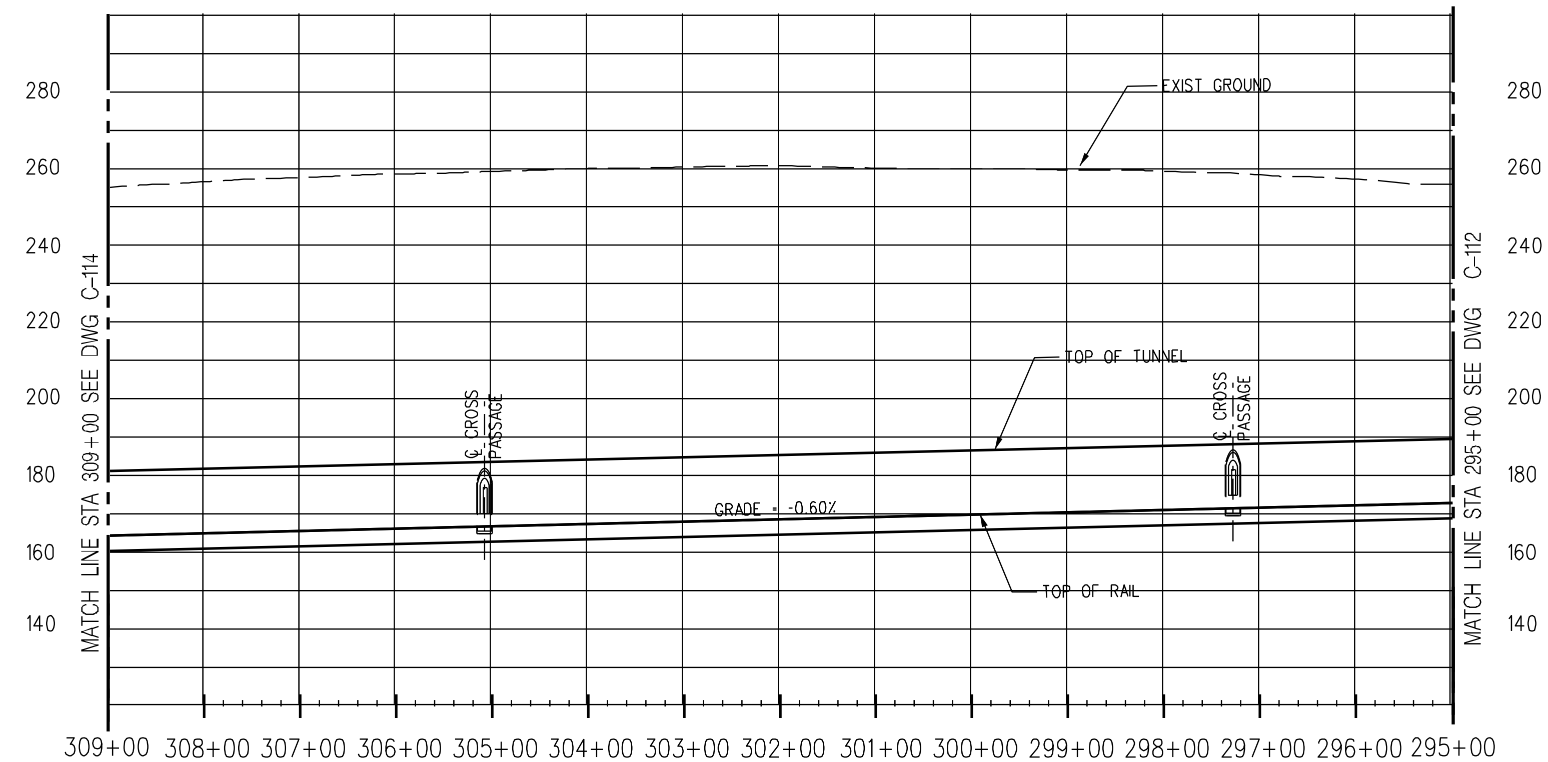
1-1060	230'	230'	84° 04''14''	1000'	1237.31'	8.12''	4''	4.12''	45
2-1060	245'	245'	84° 04''14''	961.20'	1165.38'	8.45''	4''	4.45''	45



CONCEPTUAL ONLY - SUBJECT TO CHANGE DURING PE AND FINAL DESIGN.

PROFILE

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DESIGNED BY W. GUO
DRAWN BY W. GUO
CHECKED BY S. ALDRETE
IN CHARGE R. CHOY
DATE MAY 18, 2011

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

Metro

PROJECT MANAGER ____________

WESTSIDE SUBWAY EXTENSION
FINAL EIS/EIR APPENDIX A
CENTURY CITY CONSTELLATION BLVD
ALIGNMENT OPTION
PLAN & PROFILE
STATION 295+00 TO 309+00

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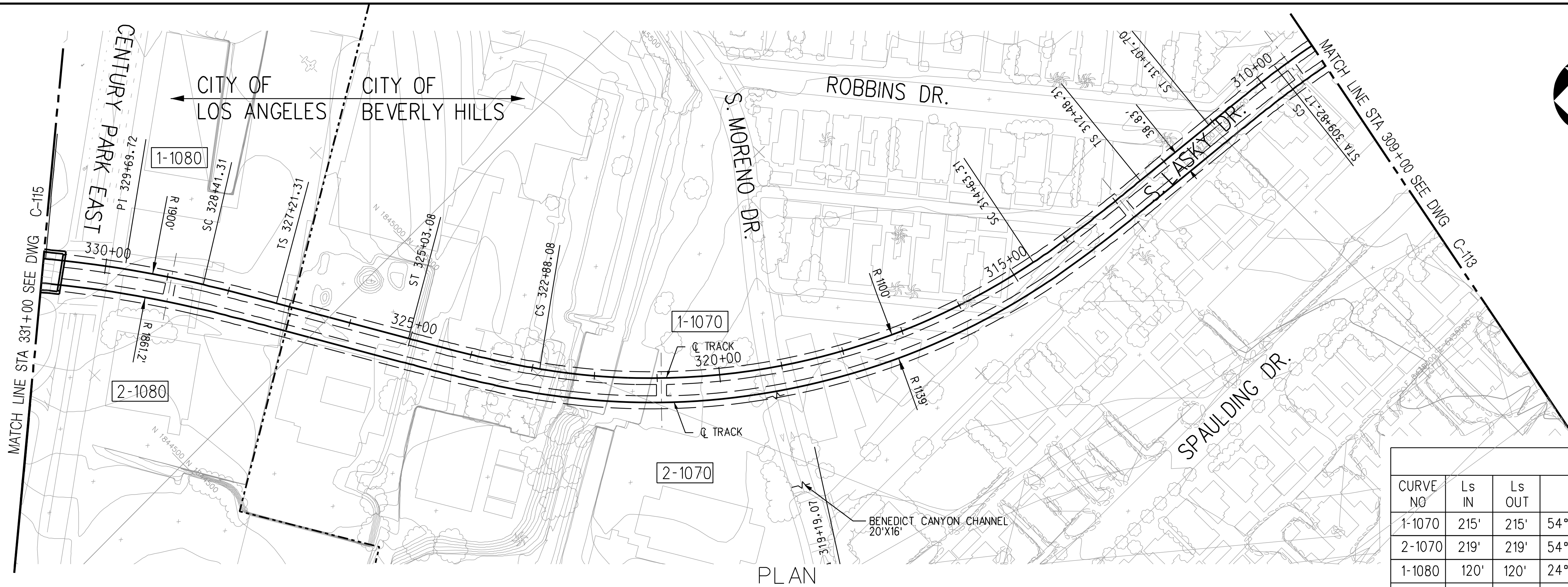

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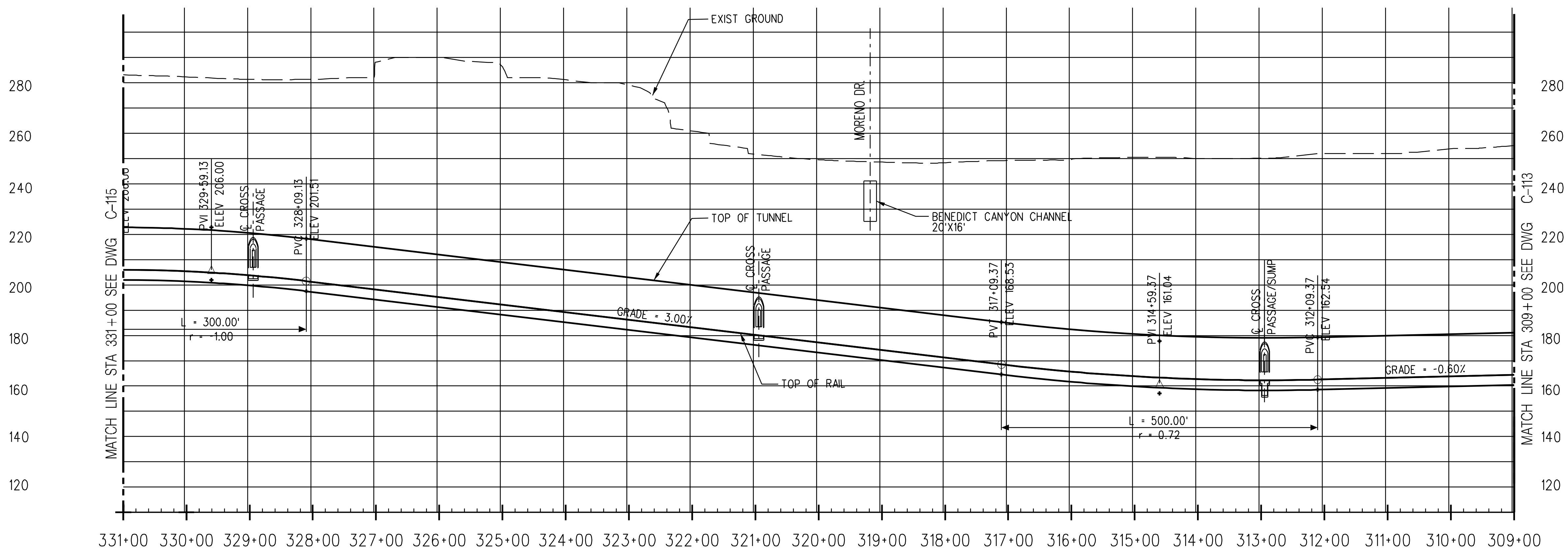
2-1070	219'	219'	54° 09' 32"	1139'	857.64'	7.13"	4"	3.13"	45
1-1080	120'	120'	24° 18' 48"	1900'	255.53'	4.27"	2.25"	2.02"	45
2-1080	119'	119'	24° 18' 48"	1861.2'	248.68'	4.36"	2.25"	2.11"	45



CONCEPTUAL ONLY - SUBJECT TO CHANGE DURING PE AND FINAL DESIGN.

REV	DATE	BY	APP	REG NO	EXPIRES	SEAL HOLDER	DESCRIPTION

DESIGNED BY W. GUO
DRAWN BY W. GUO
CHECKED BY S. ALDRETE
IN CHARGE R. CHOY
DATE MAY 18, 2011

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

Metro

PROJECT MANAGER

WESTSIDE SUBWAY EXTENSION
FINAL EIS/EIR APPENDIX A
CENTURY CITY CONSTELLATION BLVD
ALIGNMENT OPTION
PLAN & PROFILE
STATION 309+00 TO 331+00

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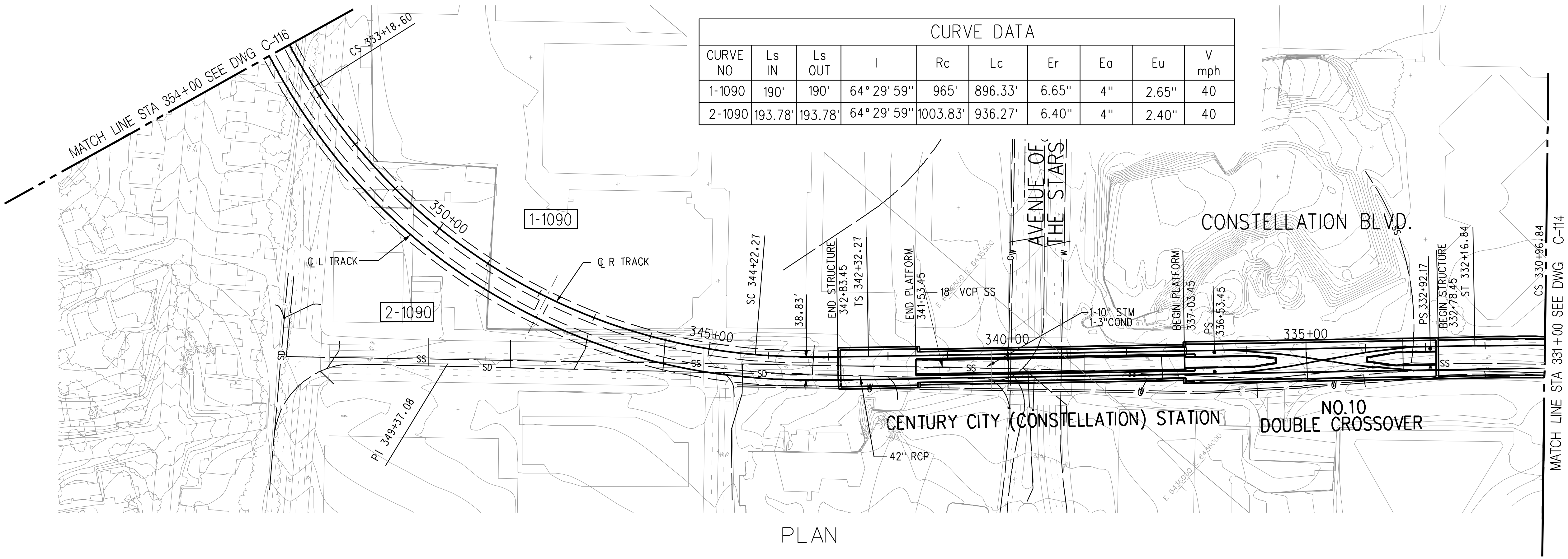
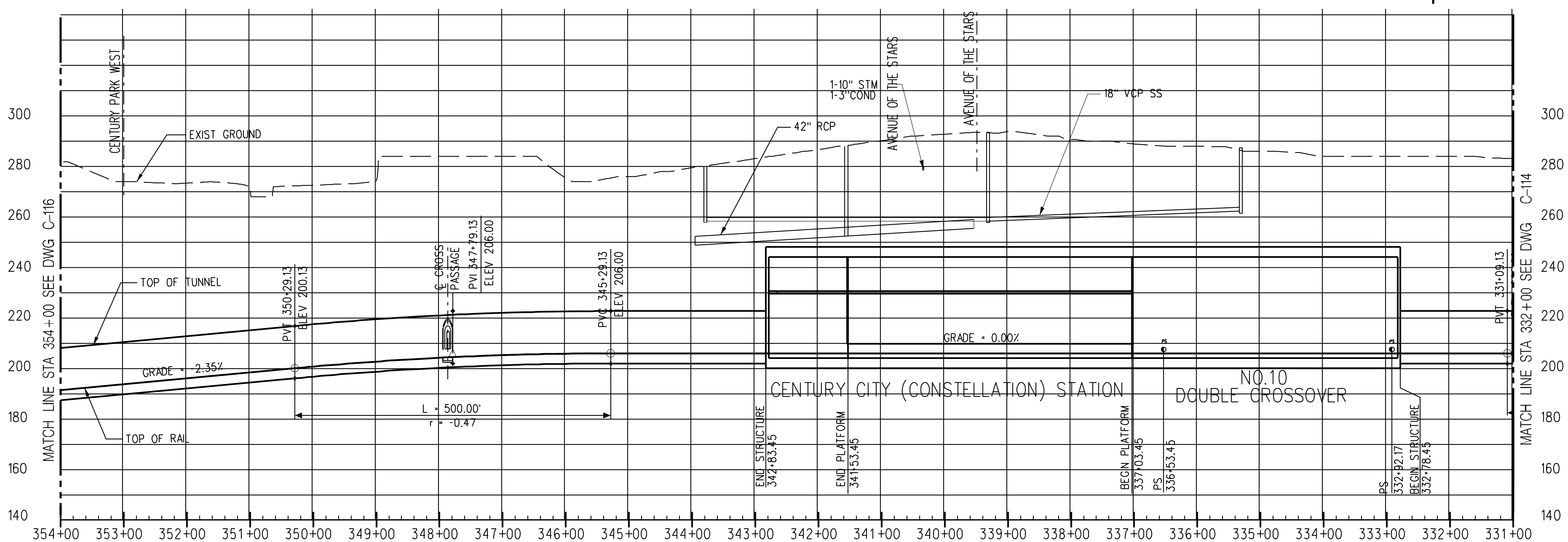
1-1090	190'	190'	64° 29' 59"	965'	896.33'	6.65"	4"	2.65"	40
2-1090	193.78'	193.78'	64° 29' 59"	1003.83'	936.27'	6.40"	4"	2.40"	40



PLAN



PROFILE

CONCEPTUAL ONLY - SUBJECT TO CHANGE DURING PE AND FINAL DESIGN.

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DESIGNED BY W. GUO
DRAWN BY W. GUO
CHECKED BY S. ALDRETE
IN CHARGE R. CHOY
DATE MAY 18, 2011

Metro

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

PB

PROJECT MANAGER

WESTSIDE SUBWAY EXTENSION
FINAL EIS/EIR APPENDIX A
CENTURY CITY CONSTELLATION BLVD
ALIGNMENT OPTION
PLAN & PROFILE
STATION 331+00 TO 354+00

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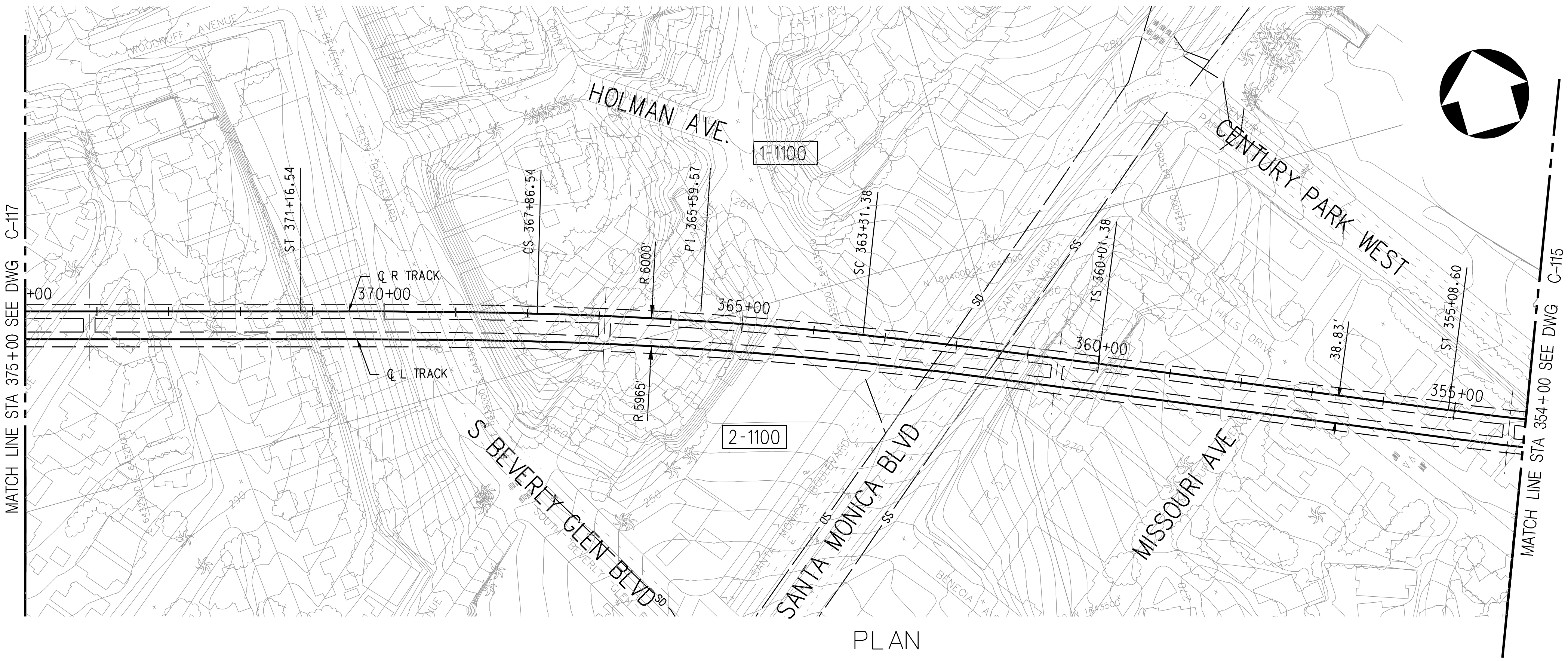
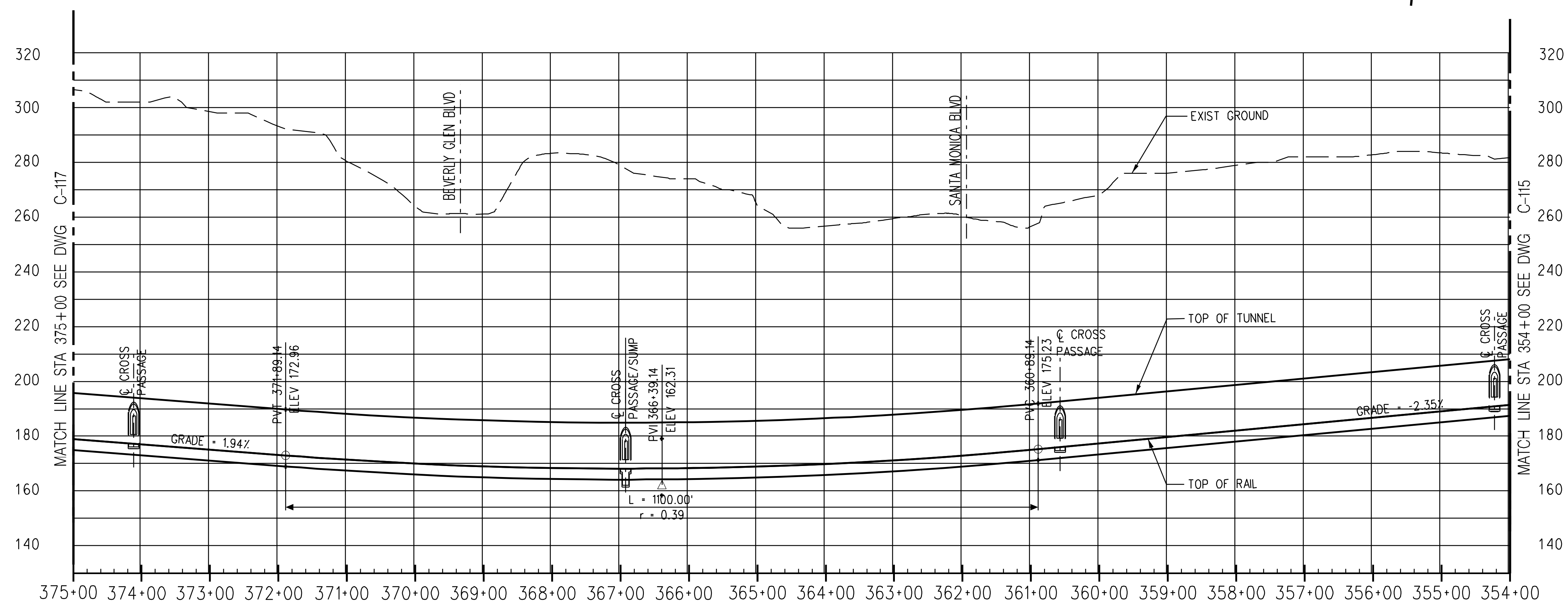


PLAN

CURVE NO	Ls IN	Ls OUT	I	Rc	Lc	Er	Ea	Eu	V mph
1-1100	330'	330'	7° 29' 52"	6000'	455.16'	3.76"	3.75"	0.01"	75
2-1100	330'	330'	7° 29' 52"	5965'	450.59'	3.78"	3.75"	0.03"	75

CURVE DATA



CONCEPTUAL ONLY - SUBJECT TO CHANGE DURING PE AND FINAL DESIGN.

PROFILE

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DRAWN BY C. GRIFFITH
CHECKED BY S. ALDRETE
IN CHARGE R. CHOY
DATE MAY 18, 2011

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

Metro

PROJECT MANAGER

WESTSIDE SUBWAY EXTENSION
FINAL EIS/EIR APPENDIX A
CENTURY CITY CONSTELLATION BLVD
ALIGNMENT OPTION
PLAN & PROFILE
STATION 354+00 TO 375+00

CONTRACT NO
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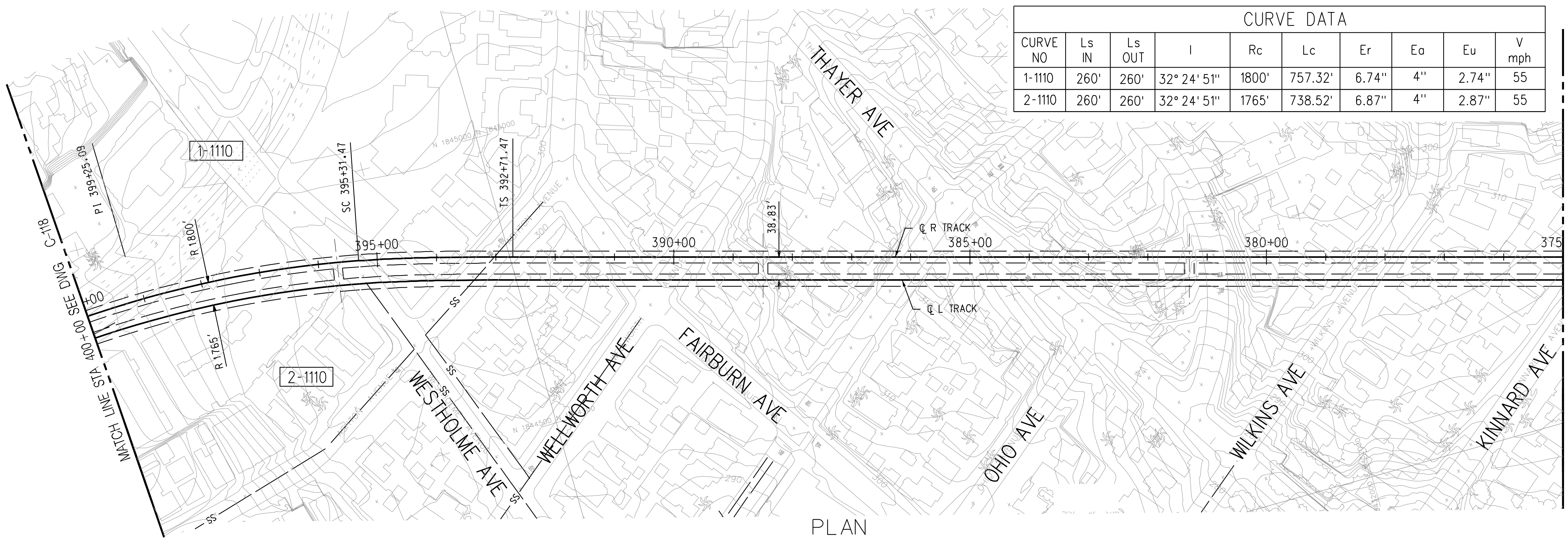
1-1110	260'	260'	32° 24' 51"	1800'	757.32'	6.74"	4"	2.74"	55
2-1110	260'	260'	32° 24' 51"	1765'	738.52'	6.87"	4"	2.87"	55



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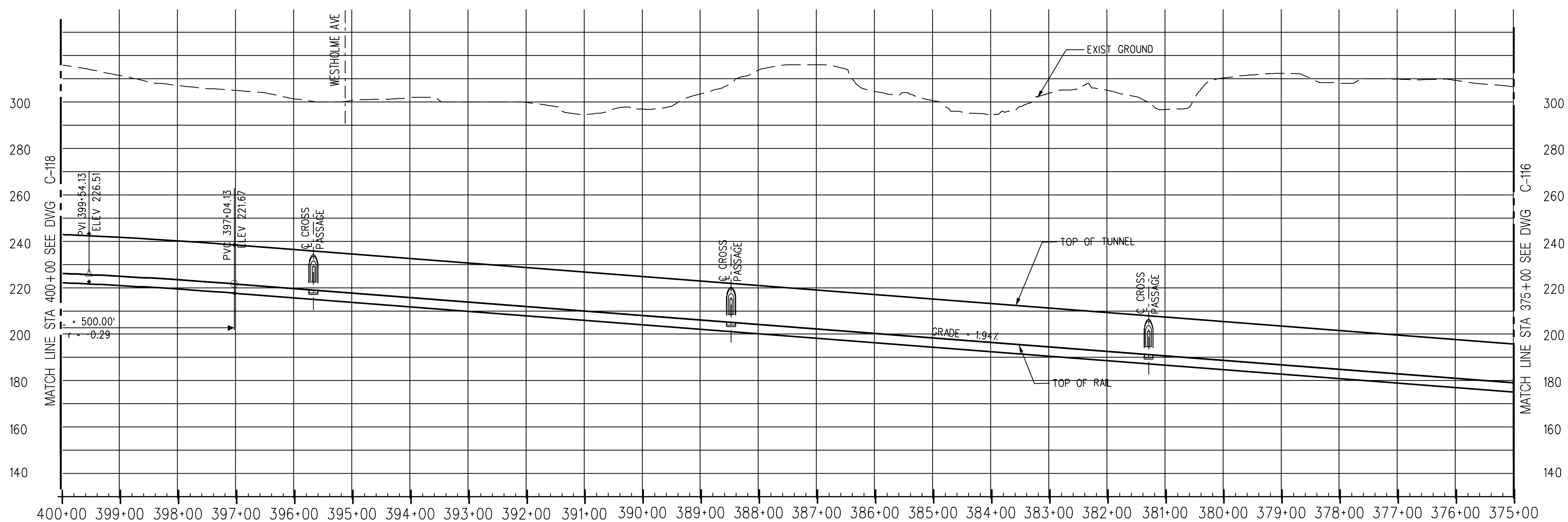

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PROFILE

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DESIGNED BY C. GRIFFITH
DRAWN BY C. GRIFFITH
CHECKED BY S. ALDRETE
IN CHARGE R. CHOY
DATE MAY 18, 2011

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

Metro

PB

PROJECT MANAGER

WESTSIDE SUBWAY EXTENSION
FINAL EIS/EIR APPENDIX A
CENTURY CITY CONSTELLATION BLVD
ALIGNMENT OPTION
PLAN & PROFILE
STATION 375+00 TO 400+00

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Appendix B
Geologic Profiles

Gas Conditions Century City Area

1. Boring Plan, Moreno Drive to Century Park East (Rev 1)
2. Soil Profile, Moreno Drive to Century Park East
3. Legend Sheet, Geotechnical Investigation
4. Soil Profile with Detailed Boring Data (Rev 1)
5. Soil Profile with Gas Data (Rev 1)

Gas Conditions Century City Area

This Appendix summarizes subsurface gas data collected during Advanced Conceptual Engineering (ACE) and the Preliminary Engineering (PE) Phases. Gas monitoring wells were installed by AMEC (formerly MACTEC Engineering and Consulting) in Century City in 2009 as part of the ACE phase. Well M-18 was installed on Santa Monica Boulevard near Century Park East, and well M-19 was installed on Avenue of the Stars between Constellation Boulevard and Santa Monica Boulevard. These wells were installed as nested gas probes screens set so that measurements could be taken at variable depths. As part of the PE phase, additional gas wells were installed in the Century City and West Los Angeles areas between January and June 2011. Monitoring well M-119 was installed on Constellation Boulevard between Century Park East and Avenue of the Stars. The following figures display the plan location of exploratory borings between Moreno Drive and Century Park East, and soil profiles of the same area. The full Project geologic profile will be presented in the Geotechnical and Hazardous Materials Technical Report (2011).

Wells M-18 and M-19 were sampled in August 2009 and May 2011. Results in 2009 indicated that methane was not present at any depths, with the exception of M-19 at 70 feet where 0.7 percent methane was detected (7,000 ppm) using a field instrument (i.e., a CES Landtec meter). The only detection of hydrogen sulfide was from well M-19 at a depth of 70 feet, and the concentration of hydrogen sulfide was very low, 0.030 ppm. In 2011, the results were very similar, with no detection of methane and less detection of hydrogen sulfide in M-18 at 65 feet (0.001 ppm) and M-19 at 40 feet (0.017 ppm). The geologic profile shown in this Appendix present the gas data from well M-19. The data from M-18 is not shown on the profile due to its distance from Constellation Boulevard.

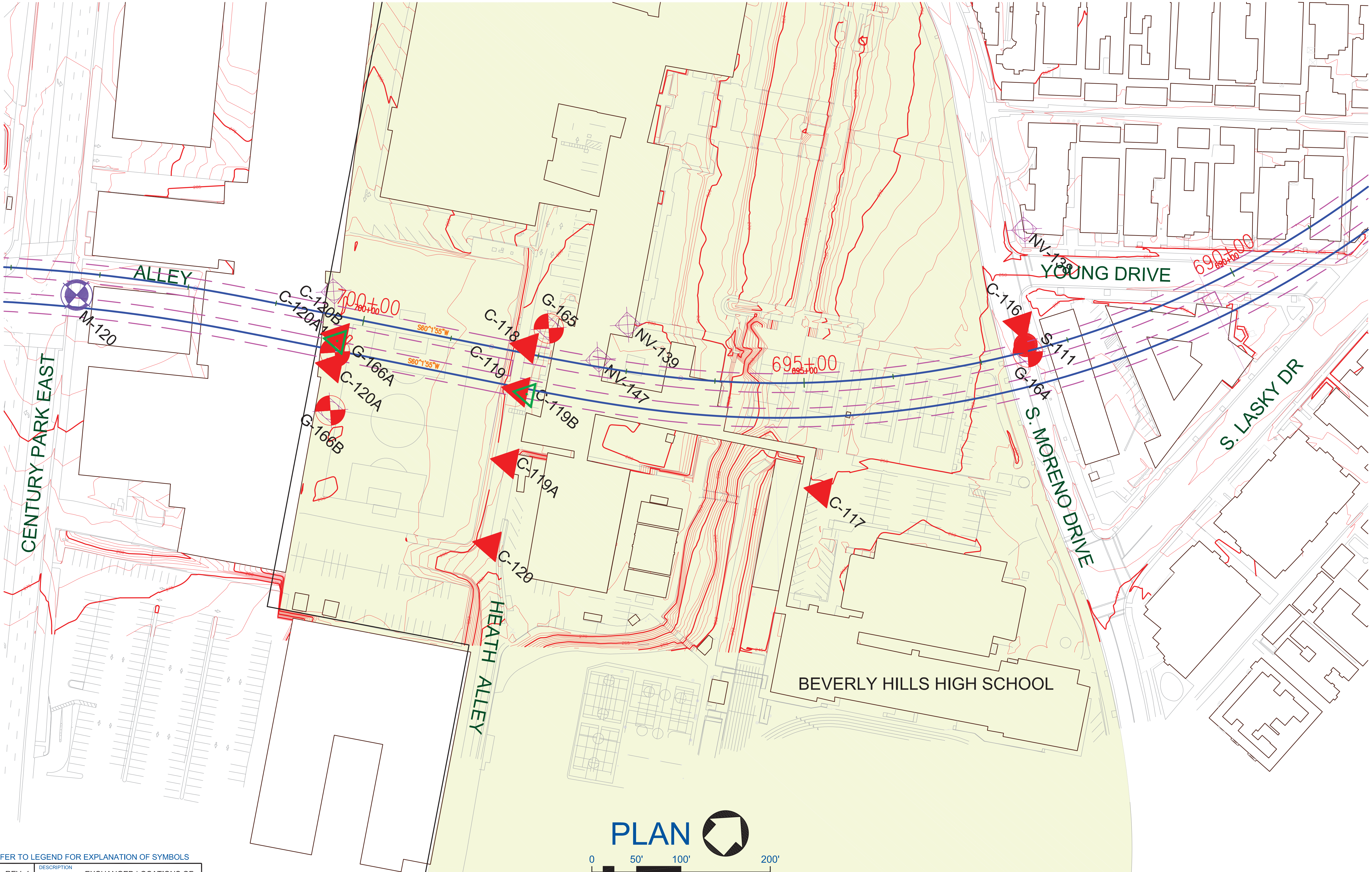
Well M-119 was monitored in June 2011, and results indicated trace to no methane from the shallower probes and 2.7 percent methane at the 45- to 50-foot screened standpipe and 12 percent methane from the 70- to 75-foot screened standpipe. A sample submitted to a fixed laboratory (Advanced Technology Laboratory) from the deepest well at M-119 resulted in 49,000 ppm by volume methane (4.9 percent). Hydrogen sulfide was not detected in any of the wells for either field measurements or from the sample submitted to the fixed laboratory. The geologic profile also presents the gas data from well M-119.

The team examined other methane data available in the area that was obtained for adjacent construction projects. In August and September 2004, wells were installed by others and sampled monitoring probes for the site located at 10131 Constellation Boulevard, at the intersection of Avenue of the Stars and Constellation Boulevard in the northeast quadrant. The consultant for the property owner performed this study as part of a preliminary design study of a proposed development site (in support of Final EIR, 10131 Constellation Boulevard, Technical Appendices, April 2006). Eleven probes were installed as part of this investigation (informally called Drill Site #2). Samples were taken at three different dates and times, and results were similar to those found at M-119 (probes were located to the north and east of M-119 approximately 100 to 150 feet). The highest methane concentrations were from the 60- to 70-foot depths at probe B-3 with 5.3 to 6.0 percent methane. Another probe, B-8, also was advanced to 70 feet, but methane concentrations from B-8 at 70 feet were non-detected (located at the north end of the study area). Probe B-3 is at the south end of the study area closest to the Project well M-119. The geologic profile, in this Appendix also presents the gas data from probes installed by others for Drill Site #2.

As part of the PE phase investigation, Metro completed two rotary-wash soil borings (G-165 and G-166B) within the BHHS campus. During drilling, an Organic Vapor Analyzer (OVA) such as a Photo Ionization Detector (PID) was used to measure the readings of gas in soil samples collected between the depths of

5 to 150 feet as a part of field monitoring. Maximum recorded methane readings were on the order of 4.6 ppm and 9.6 ppm in soil borings G-165 and G-166, respectively.

BAT® CPT sampling was performed by AMEC at the BHHS at a CPT location C-119B at depths of about 30, 40, 55, 75 feet below grade to quantify the magnitude of dissolved methane in water. Tests indicated non-detect values of methane, ethane, and propane at all three depths and 0.012 percent of methane at a depth of 75 feet bgs.



NOTE: REFER TO LEGEND FOR EXPLANATION OF SYMBOLS

REVISION REV. 1	DESCRIPTION EXCHANGED LOCATIONS OF C-119A WITH C-119B	
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DRAWN BY L. MORLEY	IN CHARGE MBH / PM	
CHECKED BY P.E. / R.M. / JAG	DATE SEPTEMBER, 2011	

Metro

LOS ANGELES COUNTY
METROPOLITAN TRANSPORTATION AUTHORITY

PB 125 YEARS

PROJECT MANAGER

WESTSIDE SUBWAY EXTENSION
PRELIMINARY ENGINEERING

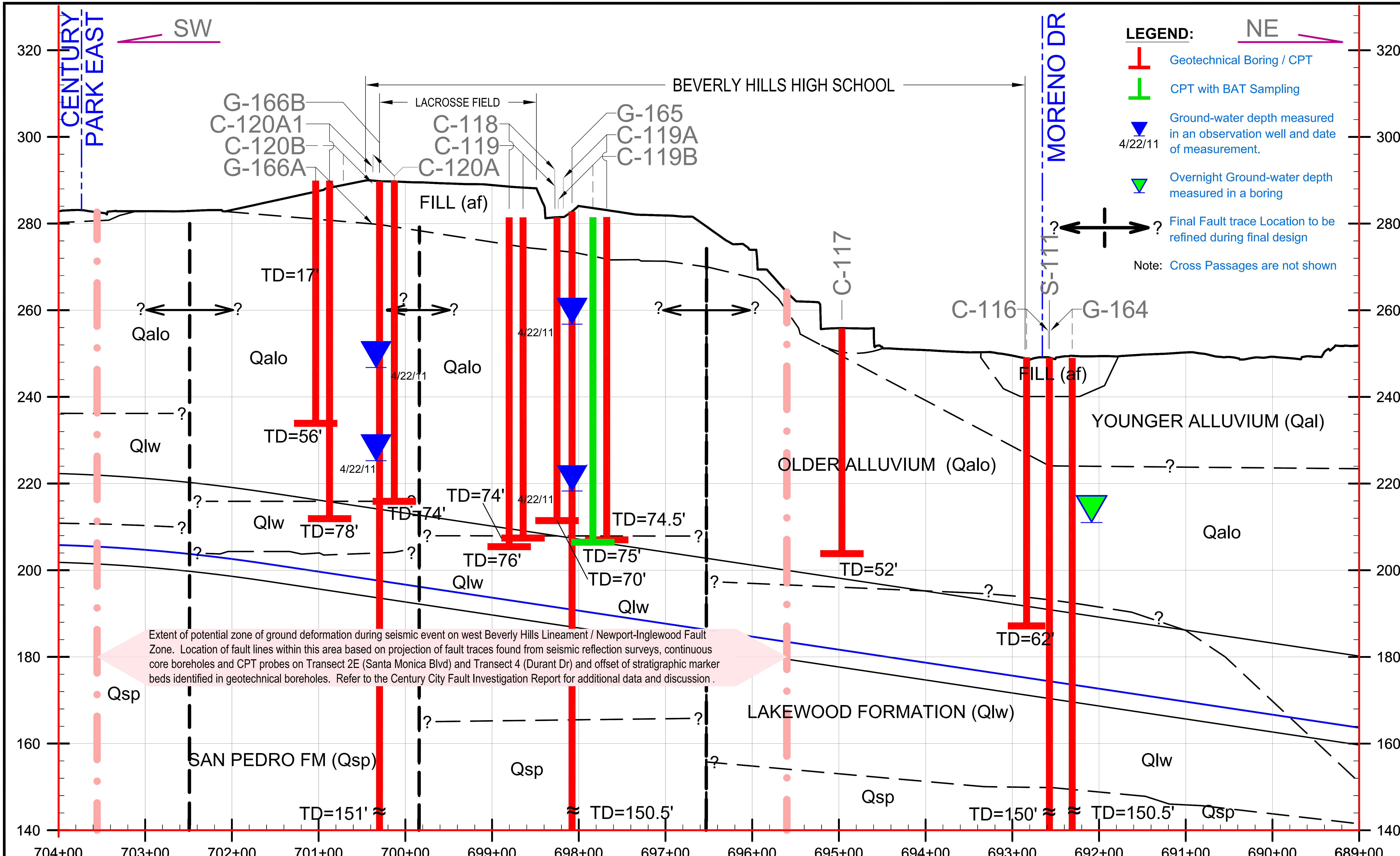
FIGURE 1

BORING PLAN
MORENO DRIVE TO CENTURY PARK EAST

SEE FIGURE 3 FOR LEGEND

PLAN

SCALE 1" = 100'



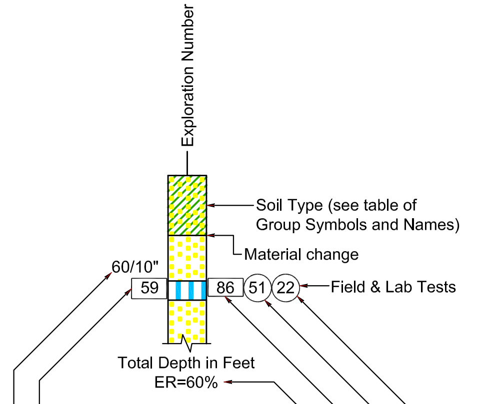
NOTE: REFER TO LEGEND FOR EXPLANATION OF SYMBOLS

PROFILE: H=100', V=20' VERTICAL EXAGGERATION = 5:1

FIGURE 2

DRAWN BY L. MORLEY	IN CHARGE MBH / PM	Metro LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY	PB	PROJECT MANAGER	WESTSIDE SUBWAY EXTENSION PRELIMINARY ENGINEERING	SOIL PROFILE MORENO DRIVE TO CENTURY PARK EAST	SOIL PROFILE
CHECKED BY P.E. / R.M. / JAG	DATE SEPTEMBER, 2011						SCALE AS NOTED

GROUP SYMBOLS AND NAMES	
Graphic/Symbol	Group Names
FILL	CLAYEY Artificial FILL
	SILTY SAND Artificial FILL
	SANDY Artificial FILL
CL	Lean CLAY
	SANDY lean CLAY
	Lean CLAY with GRAVEL
CL-ML	SILTY CLAY
	SILTY CLAY with GRAVEL
CL-CH	Lean to fat CLAY
	Lean to fat CLAY with GRAVEL
CH	Fat CLAY
	Fat CLAY with SAND
	Fat CLAY with GRAVEL
ML	SILT
	SILT with SAND
	SANDY SILT
MH	Elastic SILT
	Elastic SILT with GRAVEL
SM	SILTY SAND
	SILTY SAND with GRAVEL
SP-SM	Poorly graded SAND with SILT
	Poorly graded SAND with SILT and GRAVEL
SC-SM	SILTY, CLAYEY SAND
	SILTY, CLAYEY SAND with GRAVEL
SC	CLAYEY SAND
	CLAYEY SAND with GRAVEL
SP	Poorly graded SAND
	Poorly graded SAND with GRAVEL
SW	Well-graded SAND
	Well-graded SAND with GRAVEL



NOTES:

A. "N" Value Standard Penetration Test: Number of blows required to drive the SPT sampler 12 inches using a 140 pound automatic hammer falling 30 inches. Inches of penetration (if less than 12 inches) indicated after N-Values.

B. Number of blows required to drive the Crandall Sampler 12 inches using an automatic hammer falling 18 inches (hammer weight varies). Inches of penetration (if less than 12 inches) indicated after blow count.

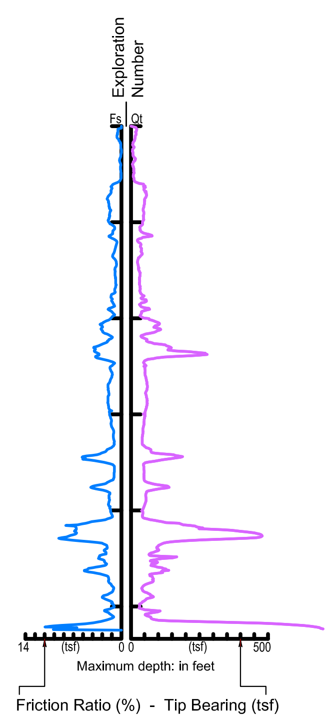
C. Hammer Energy Ratio

D. Percent passing No. 200 Sieve

E. Liquid Limit

F. Plasticity Index

ROTARY BORING



CONE PENETRATION TEST (CPT) SOUNDING

Geotechnical / Soil-Gas Investigation:

G-166 Geotechnical Rotary-Wash Boring

C-119B CPT [Geotechnical + Gas - BAT]

C-118 CPT [Geotechnical]

M-120 Gas Monitoring Well

Symbols Legend:

Site view of tracks (blue), tunnel outlines (magenta dash) with perpendicular lines representing cross passages.

4/22/11 Ground-water depth measured during 2009 to 2011 in an observation well, drilled by MACTEC and date of measurement.

Overnight Ground-water depth measured in a 2011 boring, drilled by MACTEC.

Ground-water depth measured during drilling of a boring in 2011, by MACTEC.

— — — —?— — Geologic contact line (? where queried).

Approximate location of Fault.

Geologic Units:

af — ARTIFICIAL FILL (undocumented)

Qal — YOUNGER ALLUVIUM (Holocene) - predominantly sand, silt and clay

Qalo — OLDER ALLUVIUM - varying layers of Silty Sand, Clayey/Silty Clay, and Silt with occasional gravel

Qlw — LAKEWOOD FORMATION (late Pleistocene) - interbedded Silty sands, Silts, and Clays with clayey Sand Layers

Qsp — SAN PEDRO FORMATION (mid Pleistocene) - predominately greenish gray and bluish gray fine-grained Sands, medium to coarse Sands and some Silt Layers.

Tf — FERNANDO FORMATION (Pliocene) - predominately massive Siltstone with some Claystone interbeds

Alignment based on data provided by PB (7/15/2011)

REV	DATE	BY	APP	REG NO	EXPIRES	SEAL HOLDER	DESCRIPTION

DESIGNED BY N. HARROLD
DRAWN BY L. MORLEY
CHECKED BY JAG / HP
IN CHARGE MBH / PM
DATE SEPTEMBER, 2011

Metro
LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY
PROJECT MANAGER

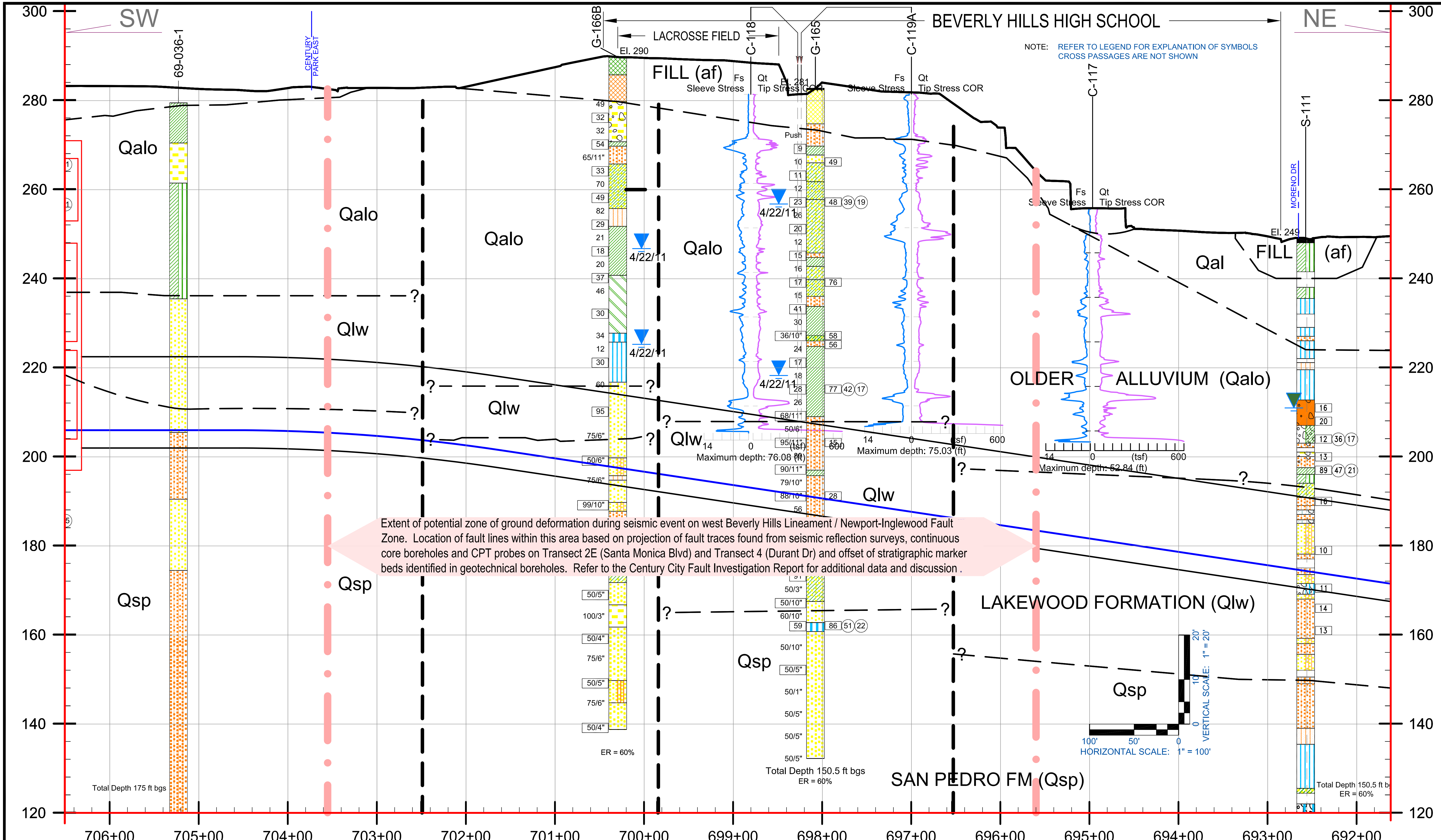
FIGURE 3

WESTSIDE SUBWAY EXTENSION
PRELIMINARY ENGINEERING

LEGEND SHEET
GEOTECHNICAL INVESTIGATION

CONTRACT NO
DRAWING NO
REV
SCALE
SHEET NO

FILE NAME: C:\Users\LAMorley\Documents\CAD\4953-11-1421_WSE\BHHS-XHBT(11.11).dwg [Fig3 Legn] DATE: November 29, 2011 TIME: 11:51 AM



REV	DATE	BY	APP	REG NO	EXPIRES	SEAL HOLDER	DESCRIPTION
1	11/28/11	JAG					RENAME C-119B TO C-119A

DESIGNED BY

DRAWN BY L. MORLEY

CHECKED BY JAG / HP

IN CHARGE MBH / PM

DATE SEPTEMBER, 2011

Metro

LOS ANGELES COUNTY
METROPOLITAN TRANSPORTATION AUTHORITY

PROJECT MANAGER

FIGURE 4

WESTSIDE SUBWAY EXTENSION
PRELIMINARY ENGINEERING

SOIL PROFILE WITH
DETAILED BORING DATA

CONTRACT NO

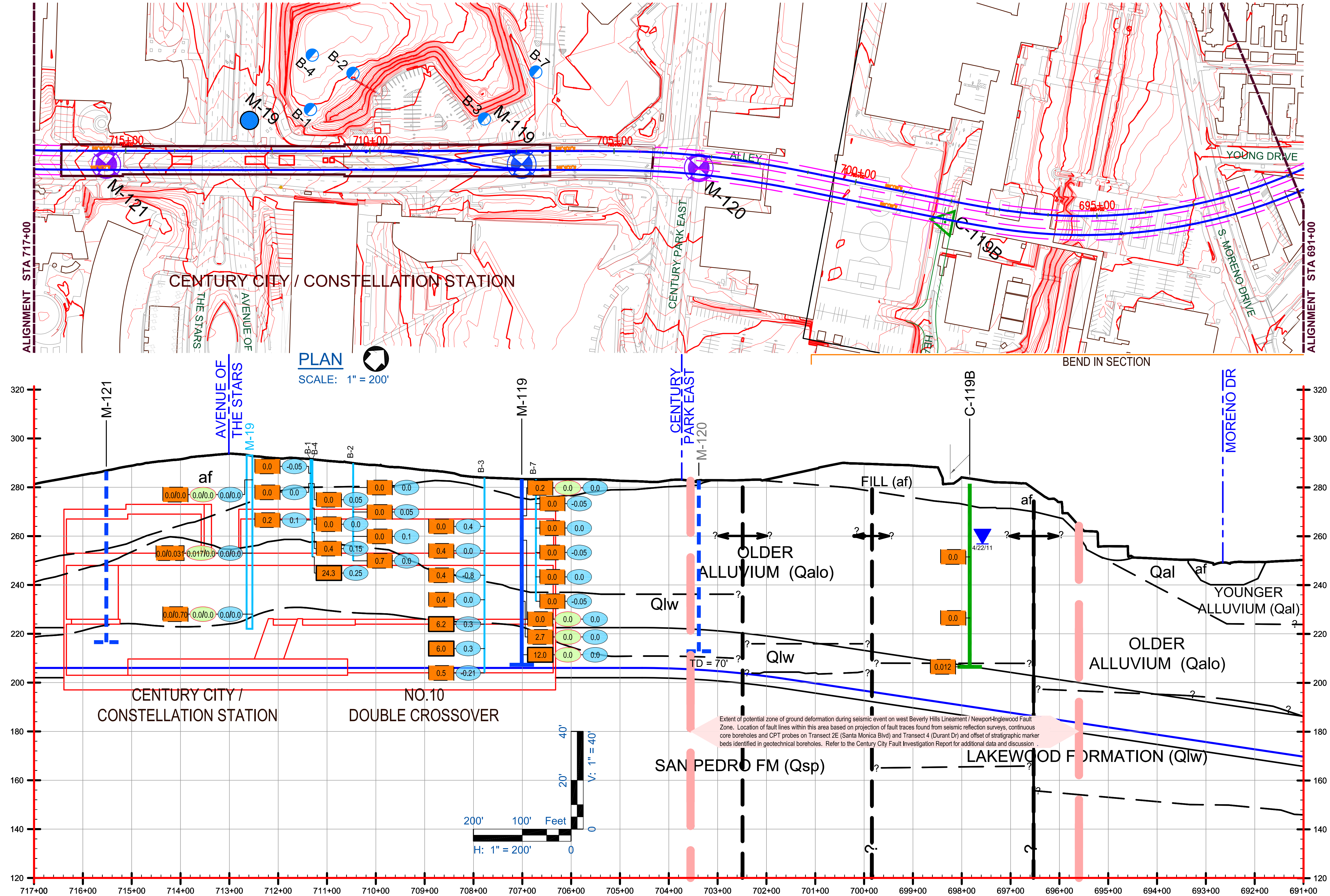
DRAWING NO

REV

SCALE AS NOTED

SHEET NO

TIME: 11:51 AM DATE: November 29, 2011



GAS SYMBOLS

Methane Encountered:

- 4 < 5% by Volume
- 25 5 - 25% by Volume
- 100 26 - 100% by Volume

H_2S Encountered:

- 0.7 0.7 ppm (Parts Per Million by Volume)

Pressure Encountered:

- 0.7 0.7 inches of Water

NOTES:

1. Slash "/" indicates year taken (2011/2009) otherwise all data is 2011.
2. W = Water encountered negating Data
3. H = High (off scale)
4. NA = No Measured Data (not available)
5. ▼ 5/26/11 Ground-Water Level and Date Measured
6. M-19 is prior ACE MACTEC gas well.
7. M-119 is current PE Phase MACTEC gas well.
8. C-119B is PE Phase MACTEC CPT BAT exploration.
9. B-1 to B-7 are 2004 gas data of drill site 2 (10131 Constellation Blvd) by others.
10. For clarity purposes Geotechnical Borings are not shown on the Plan and Profile. Only Geologic Units and Contacts are shown on the Profile.
11. Cross Passages are not shown.

REV	DATE	BY	APP	REG NO	EXPIRES	SEAL HOLDER	DESCRIPTION
1	11/28/11	JAG					UPDATED GAS DATA FOR M-19
1	11/28/11	JAG					RELOCATED C-119B IN PLAN VIEW

DESIGNED BY
DRAWN BY L. MORLEY
CHECKED BY JAG / HP
IN CHARGE MBH / PM
DATE SEPTEMBER, 2011

Metro
LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY
PB
PROJECT MANAGER

WESTSIDE SUBWAY EXTENSION
PRELIMINARY ENGINEERING
SOIL PROFILE WITH GAS DATA

FIGURE 5

CONTRACT NO
DRAWING NO
REV
SCALE AS NOTED
SHEET NO

FILE NAME: C:\Users\LAMorley\Documents\CAD4953-11-1421_WSE\BHS-XHBT(11.11).dwg [Fig5 Gas] DATE: November 29, 2011 TIME: 11:50 AM

Appendix C
BHUSD Buildings Near Tunnel Alignment

APPENDIX C BHUSD BUILDINGS NEAR TUNNEL ALIGNMENT

Existing Buildings Under the Beverly Hills High School (BHHS) Campus

The following buildings owned by the BHUSD are near the proposed tunnel alignment alternative for the Project. They include the BHUSD Administration Building and an Adult Instructional Center and buildings on the Beverly Hills High School campus.

BHUSD Administration Building

The BHUSD Administration Building (Figure C-1) is located at 255 S. Lasky Drive. It is a two-story steel-framed structure with a partial basement that was built in the 1960s.

Figure C-1: Administration Building—Steel Framed Structure—Built in 1960s

Adult Instructional Center

The Adult Instructional Center Building (Figures C-2, C-3 and C-4) is located on the east side of S. Moreno Drive, directly opposite the school campus. It serves as the center for adult instruction for the school district. It is a three-story steel-framed structure without a basement and was built in the 1960s. The proposed tunnel alignment will cross beneath the northwest corner of this building.

Figure C-2: Instructional Center Building

Figure. C-3: Frontage of Instructional Center

Figure C-4: View from Instructional Center Looking Southwest

Building F—Swim Gym

Building F (refer to Figures C-5 and C-6) is an arch-shaped structure built in the 1930s. (A plaque indicates it was opened in 1939.) It is the indoor sports facility for the school (and is known as the "swim gym"). It houses a basketball court overlying a swimming pool beneath. The basketball court rolls aside when the pool is in use. As a result, the bottom of the basement structure housing the pool is at least 28 feet below grade. The school is proposing to build a new indoor sport facility but Building F would remain, serving the local community. Building F is not within the zone of influence of the proposed tunnel alignment.

Based on the draft Master Plan (2008), the main roof of the structure is constructed with wood sheathing supported by wood joists that span between wood beams. The beams are supported by wood arched-truss members that form the arched roof. The wood arches are supported by pile caps with deep caissons. The depth of these caissons is unknown. The draft master plan also identifies a subterranean passage running from Building F to Building B.

The area to the north and east of Building F is used for car parking.

Figure C-5: Building F—Interior

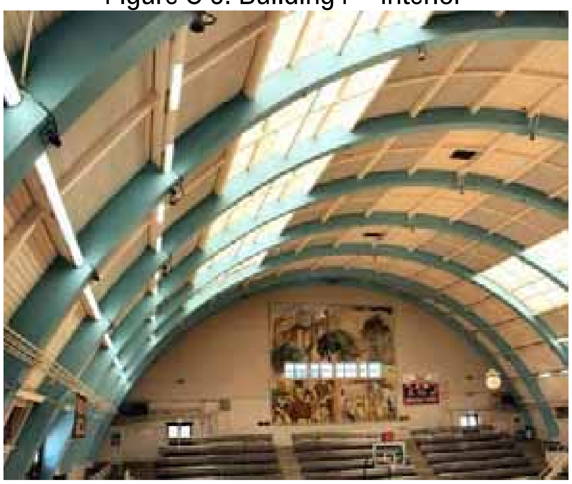


Figure C-6: Building F—Arch Roof

Building B

Figure C-7 showing pathway between the tennis courts and the main lawn area illustrates the height change across the campus as one proceeds westward. The pathway leads to Building B.

Figure C-7: Pathway leading to Building B

Figure C-8: Courtyard Columns in Building B

Figure C-9: Building B—Interior Corridor

Figure C-10: Building B Interior

Figure C-11: Building B—Exterior Looking West

Building B (Figures C-8, C-9, C-10 and C-11) is a steel-framed building with unreinforced masonry brick walls. It was built in the late 1920s and has eight different floor elevations within its structure. The building has a courtyard surrounded on three sides by a walkway with arches (see Figure C-8). The columns between arches appear to have a concrete core. It is not known whether these cores are reinforced. The building had renovations carried out in the 1970s but their extent is unknown. This designation also incorporates structures previously known as Building C and Building D.

Based on the Draft Master Plan (2008), interior clay tile interior walls have been strengthened with reinforced gunite (shotcrete). The building is founded on conventional shallow concrete wall footings with spread footings beneath interior concrete columns.

Based on observations of Building C, the structures forming Building B, which appear to have been built at the same time, have wall footings with a ground-floor slab reinforced with expanded metal with a crawl space beneath. The suspended floor slabs have concrete T-beams and columns in the interior and unreinforced masonry exterior walls.

The proposed tunnel alignment crosses the southern end of Buildings B, C, and D complex.

Building A

Heath Avenue (Figure C-12) is a public street passing through the campus on an approximately northwest-southeast orientation. It provides access to the parking in Building A. Utilities located within the street include water, sewer, signals and other unidentified vaults. To the west of Heath Avenue are the Lacrosse Field and Building A.

Figure C-12: Heath Avenue Looking South

Building A (Figures C-13 and C-14) contains a below-grade parking structure with classrooms and other facilities above. Based on the Draft Master Plan (2008), it is a steel-framed structure, built from 1967 to 1970 and enclosing about 325,000 square feet. The building is supported on a shallow reinforced-concrete foundation system with isolated spread footings below interior columns and continuous foundations below interior and perimeter concrete shear walls.

Figure C-13: Building A—Exterior

Figure C-14: Walkway from Building A over Heath Avenue