Geotechnical Baseline Report
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1.0 INTRODUCTION

1.1 Purpose of the Geotechnical Baseline Report

This Geotechnical Baseline Report (GBR) is issued by the Los Angeles County Metropolitan Transportation Authority (Metro) as part of the Design-Build Contract Documents for construction of the underground facilities of the Regional Connector Transit Corridor (RCTC) project. The GBR was prepared based on an evaluation and interpretation of the boring logs and other geotechnical data in the GDR, inspection of borehole samples, review of regional and local geology, and on experience in drilling, excavating, and tunneling in Los Angeles.

The primary objectives of the GBR are to:

1. Provide a summary of the ground conditions, ground behavior, groundwater, and in-ground obstructions, contamination, and gas conditions in order to facilitate the Design–Builder’s and owner’s project management team’s understanding of the geotechnical features and ground behavior to be addressed during proposal preparation and during design and construction of the underground facilities.

2. Establish baselines for the anticipated geotechnical conditions, to be relied upon in the preparation of proposals, in bid submittals, and in the design and the construction of the underground facilities.

3. Assist in administering the differing site conditions clause contained in the Contract Documents by providing a basis for their evaluation.

The GBR describes and baselines ground conditions and basic tunnel ground behavior. Ground behavior described in the GBR is based on assumptions regarding construction means and methods. If different methods are employed, ground behavior may differ from that described. The Design-Builder must complete its own independent review and evaluation of the Contract Documents, GBR, GDR, and other geotechnical information and consider how its selected means and methods and designs will affect ground behavior and the construction of the underground facilities. As provided in the Contract Documents, the Design-Build team requires a qualified geotechnical engineer/engineering geologist throughout the proposal, design and construction phases of the project to review and evaluate the GBR and its baselines, the GDR and other geotechnical information, to inspect boring samples, and to consider the application of the geotechnical information to the Design-Builder's design and construction plans.

Proper geotechnical and civil design requires that material parameters be selected based on representative exploration data and test results and geologic information and that the inherent variability of geologic materials be taken into account in selecting probable ranges of soil parameters to be incorporated into the design process.

The GBR is contractually binding and must be read in conjunction with the Geotechnical Data Report (GDR) and other Contract Documents. While the GBR is not the exclusive source of geotechnical information, the General Conditions of the Contract provide that the GBR takes precedence over the GDR, as well as and any other geotechnical information, references or interpretations.
1.2 Scope of the Geotechnical Baseline Report

This GBR pertains to the underground portions of the RCTC project. As described in more detail in the following sections, the underground portions of the project include the bored tunnels, cut-and-cover tunnels, portal and station excavations, crossover structures, transition structures as well as cross-passages and sump structures. Section 2 provides a summary of these project elements. The Plans and Specifications are to be consulted for specific details.

1.3 Sources of Geologic and Geotechnical Data

Geotechnical data along the RCTC project alignment are available from several sources. A significant amount of data is available from geotechnical and environmental investigations carried out for other projects, such as the numerous buildings along the alignment. More recent data were collected specifically for the RCTC project. The data sources are summarized below and in the GDR, which was prepared by AMEC (2012).

1.3.1 Previous Investigations

The proposed project alignment extends through a portion of downtown Los Angeles where there are numerous existing buildings and other engineered structures. As a result, the RCTC design team utilized geotechnical information from these previous investigations. However, many of these prior investigations did not address the specific data needs for underground construction and the RCTC project. Nonetheless, those investigations provide a useful source of information regarding the subsurface distribution of geologic units and some of their basic engineering properties. As such, the results from the previous investigations are incorporated in the GDR and were considered in preparing this GBR.

In all, the GDR includes geologic and geotechnical data from approximately 110 “historic” borings that were drilled in the vicinity of the RCTC alignment, post 1950. These borings were drilled by AMEC and its predecessor firms, namely MACTEC, LeRoy Crandall and Associates and Law/Crandall. For the purposes of including information from these borings in the Regional Connector project without duplicating boring numbers, these historic borings were renumbered as borings P-1 through P-110 (as indicated on the boring logs that are reproduced in the GDR).

More recently, site investigation was performed in support of a Draft Environmental Impact Statement (DEIS) / Draft Environmental Impact Report (DEIR) for the Regional Connector project. The final report of that investigation was completed in November 2010 by MACTEC (now AMEC), for Camp Dresser & McKee (CDM) and Metro. That investigation included: the compilation of previous data (the approximate 110 historic borings noted above); drilling of 11 additional borings (geotechnical and environmental); installation of piezometers and monitoring of groundwater elevations; and laboratory testing of selected samples. These borings were numbered 1 through 11 and the results are included in the GDR.

1.3.2 Preliminary Engineering Investigations

In support of the Advanced Conceptual Engineering/Preliminary Engineering (ACE/PE) phase studies by the Corridor Partnership, AMEC performed a supplemental geotechnical investigation. The investigation was directed toward providing information to address recent modifications to the project, including alignment, grade, station locations, and presumed construction methods.
The investigation included 28 borings, additional soil testing, groundwater testing and water elevation monitoring, and preparation of a GDR (AMEC, 2012). These borings are numbered G2-1 through G2-16 and E-1 through E-6.
2.0 PROJECT DESCRIPTION

2.1 Project Description

As shown on Figure 1, the RCTC project provides a 1.86 mile-long connection between the Gold Line LRT lines from Pasadena and East Los Angeles, to the Blue Line to Long Beach and new Expo Line to Culver City, with the provision of new tracks through downtown Los Angeles mainly within twin tunnels. In the direction of increasing stationing (i.e. from west to east) the underground components of the project include the following:

<table>
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<th>Underground Component</th>
<th>Start Station</th>
<th>End Station</th>
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<td>R80+20</td>
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<td>Mangrove Site (Possible TBM Launch Area)</td>
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Notes: R indicates right track stationing and includes 1st St. branch of Wye; R1 indicates right track stationing for Alameda St. branch of Wye.

Although the project components are listed above from west to east, and the project stationing increases from west to east, it is anticipated that tunnel drives would begin at the east end and proceed west. For convenience, the project components are summarized in Sections 2.1.1 through 2.1.6. For details regarding the project components, the reader should consult the project plans and specifications.

2.1.1 Mangrove Site – Potential TBM Launch Area

As shown on Figure 1, the Mangrove site is located between the 1st Street and Alameda Street branches of the alignment. It is anticipated that this area will be provided for the Design-Build Contractor's use and would provide space for a TBM launch pit. Currently the Mangrove site is occupied by a parking lot. Historical aerial photographs indicate that from 1948 to at least 1980
the site was occupied by one- to five- story buildings, some of which are believed to have had basements. Although foundation details are lacking, it is believed that all of the buildings had shallow foundations. The decision to construct a TBM launch pit at the Mangrove site, and the position of the pit will be the responsibility of the Design Builder. As such, a length of tunnel from the start of the launch pit to the 1st/Central Station is not listed in the table above.

2.1.2 East End “Wye”

East of Station R:80+20 (where the 1st/Central cut-and-cover station ends beneath the intersection of 1st Street and Alameda Street), the alignment splits into two directions. This “Wye” will be constructed by cut-and-cover excavation methods, with branches extending to the east and north. The eastern branch (adjacent to 1st Street) extends approximately 280 feet within a cut-and-cover excavation, to the beginning of an open trench structure. The open trench structure extends approximately 524 feet farther east, toward the end of the alignment along 1st Street. The northern branch (adjacent to Alameda Street) extends approximately 811 feet within a cut-and-cover excavation, to the beginning of an open trench structure. The open trench structure extends approximately 449 feet farther to the north, to the beginning of an above grade section. When completed, the depth of cover over these cut-and-cover sections ranges from a few feet to approximately 15 feet. It is noted that the Design Builder may choose to construct a portion of this section using tunneling methods, from a TBM launch pit at the Mangrove site.

2.1.3 Flower Street Cut–and–Cover

The southwest end of the project is at the intersection of the Regional Connector with the existing 7th/Flower Station, at approximately Station R:1+65. From this intersection to Station R:19+02 (at the southwest end of the bored tunnels), construction of the twin tunnels would be performed by cut-and-cover methods. This method of construction was selected because of anticipated conflicts with hundreds of existing foundation tie-back anchors along this part of the alignment and considering the relatively shallow excavation depth. Along this 1,737 foot long section of cut-and-cover tunnels, the depth from ground surface to top of rail ranges from approximately 32 to 50 feet.

2.1.4 Stations

The project includes three underground stations, anticipated to be constructed using conventional cut-and-cover construction methods. The limits of these stations are listed above in Section 2.1. They are summarized below, from east to west.

1st/Central Station

This station is located on the south side of 1st Street, diagonally between Central Avenue and Alameda Street and will be constructed using conventional cut-and-cover construction methods. The station alignment and box location were established to meet the requirements of the tunnel portal locations on 1st Street and Alameda Street, as well as providing connection to the existing north bound and east bound Gold Line tracks. The provision of a “Wye” intersection to the north and east bound tracks also influenced the location of the station box. The depth of excavation will be approximately 45 to 50 feet below the existing ground surface.
2nd/Broadway Station

The 2nd/Broadway Station will be constructed beneath 2nd Street and between Broadway and Main streets, within a relatively narrow right-of-way. The station would be constructed using conventional cut-and-cover construction methods, and the depth of excavation will be approximately 90 to 95 feet below the existing ground surface.

2nd/Hope Station

The 2nd/Hope Street Station is an underground LRT center platform station and is diagonally oriented between 3rd Street and 2nd Street, Flower Street and Hope Street. The depth of the excavation is approximately 120 feet below the sidewalk elevation adjacent to Hope Street and General Thaddeus Kosciuszko Way (GTK Way). The existing surface street of West GTK Way and the 2nd Place Bridge will be demolished and the area above the station/ancillary box will be re-graded.

2.1.5 Crossover Cavern

The project includes one crossover structure, which is located immediately east of the 2nd/Broadway station. It is 354 feet in length and the finished internal dimensions of the cavern would be approximately 56 feet wide and 30 feet high. Ground cover over the cavern is approximately 60 feet. It is anticipated that this structure will be constructed using Sequential Excavation Methods (SEM) to enlarge the previously bored tunnels.

2.1.6 Bored Tunnels

The limits of the stations, crossover cavern, the two end sections, and the cut-and-cover tunnel section (described above) result in three reaches of twin-bored tunnels. These tunnels will have a finished diameter of approximately 22 feet, and a widely variable depth of cover. Because it is envisioned that the tunnels would be driven starting at the east end of the project, these reaches are numbered herein starting with Reach 1 at the east.

Reach 1 extends from Station R:57+30 to Station R:76+45, a distance of 1,915 feet. These tunnels will be beneath 2nd Street, with a depth of cover (above tunnel crown) ranging from approximately 25 to 60 feet. From approximately Station R:44+00 to R:71+00, the Regional Connector tunnels will be constructed beneath an existing storm drain, with a distance from tunnel crown to storm drain invert of approximately 9 to 44 feet. This reach includes two cross passages, located at Stations R:62+50 and R:69+00.

Reach 2 extends east/southeast from the 2nd/Hope Station, beginning at Station R:32+81 and ending at Station R:49+11, a distance of 1,630 feet. The depth of cover (tunnel crown to ground surface) ranges from approximately 70 feet to 130 feet along this reach. This reach includes one cross passage, located at Station R:40+50. From Station R:34+60 to R:43+40, a distance of 880 feet, the tunnels will be beneath the existing 2nd Street tunnel, where the distance between the 2nd Street tunnel invert and the crown of the Regional Connector tunnels will range from approximately 45 to 75 feet. Where the Regional Connector tunnels cross beneath Hill Street, they cross under the existing Red Line tunnels. The distance between the crown of the Regional Connector tunnels and the invert of the Red Line tunnels ranges from approximately 5 to 6 feet.
Reach 3 extends from Station R:19+02 to R:29+37, a distance of 1035 feet. The majority of this tunnel reach will be beneath Flower Street, with a depth of cover (above tunnel crown) ranging from approximately 33 to 60 feet. These tunnels pass between the existing pile foundations for the 4th Street overpass, where the distance between the existing pile foundations (at tunnel springline) is approximately 55 feet. This leaves little clearance between the edge of the tunnel excavations and the existing pile foundations, and results in a reduced pillar width between the tunnels. In addition to providing clearance for locating the tunnels between the bridge foundations, the reduced pillar width between 3rd and 4th Streets, provides clearance between the tunnel excavation and a number of existing tie-back anchors that remain from the construction of adjacent buildings. Based on ACE/PE studies, the clearance between the Left and right tunnel alignment and the nearest tie-back anchors is at least 5 feet. This tunnel reach includes one cross passage, located at Station R:24+00.
3.0 SITE CONDITIONS

The following information is summarized from the Geotechnical Data Report (GDR), and formed the basis for establishing the baselines in Section 4.

3.1 Geologic Setting

3.1.1 Regional Tectonic and Seismic Setting

As shown on Figure 2, the alignment traverses the southeastern end of the Elysian Park Hills and a portion of the ancient Los Angeles River floodplain. The Elysian Hills comprise the low-lying hills west of the Los Angeles River and southeast of the eastern end of the Santa Monica Mountains. The alignment along Flower, 2nd, 1st, and Alameda Streets will encounter artificial fill and geologic units that range in age from Miocene to Holocene. From oldest to youngest in geologic age are the Pliocene-age sedimentary strata of the Fernando Formation, Pleistocene-age alluvium (referred to in this report as Qa12 alluvium), and Holocene-age alluvium (Qa11).

Miocene-age bedrock of the Puente Formation has been mapped at the surface on Bunker Hill to the north of the alignment. The upper contact of the Puente Formation forms a slight angular unconformity with the overlying Fernando Formation and the contact appears to extend beneath the planned excavations for this project. Borehole data support this and indicate that the Puente Formation will not be encountered along the project alignment.

The bedrock formations are unconformably overlain by Pleistocene- and Holocene-age alluvial sediments. The Pleistocene sediments are present as remnant depositional terraces in the Bunker Hill area, whereas, the more recent Holocene alluvial sediments are present along the floodplain east of Bunker Hill and filling in the paleo-drainage along portions of Flower Street.

Artificial fill has been placed at various locations along the alignment including areas overlying both existing and abandoned tunnels.

3.1.2 Bedding Orientation, Local Faulting and Folding

As discussed in the GDR, geologic maps prepared by Soper and Grant (1932) and Lamar (1970) show that the dip of bedding in the local bedrock formations ranges from 32 to 83 degrees to the southeast and south. Bedding dips ranging from 22 to 42 degrees to the southwest and southeast in former cut slopes adjacent to 4th Street, between Flower and Hope Streets were reported by Glen A. Brown and Associates (1969). Borehole surveys performed as part of the ACE/PE investigation indicate a strong trend of nearly due south dip, at approximately 65 to 80 degrees.

Borehole surveys indicate two general trends for orientations of joints:

- Northwest to southwest dip ranging from approximately 55 to 80 degrees
- Northeast to east dip ranging from approximately 50 to 80 degrees
- Bedding-parallel joints

The bedrock is locally cut by small shears that have minor displacement. Thin clay gouge seams have been reported along some shears (Hood and Schmidt, Inc., 1966).
Fault Rupture and Warping

Faults that have surface evidence of past rupture include those classified by the California Geological Survey (Hart, 1999) as active, potentially active, and inactive. Based the available data, no active or potentially active surface faults are known to cross the proposed project alignment (AMEC, 2012). In addition to these surface faults, two buried thrust faults commonly referred to as blind thrusts, are interpreted to underlie the project area at depth. These are the Puente Hills Blind Thrust fault (PHBT) and the Upper Elysian Park fault. Rupture surfaces for these faults are not exposed at the ground surface and thus these faults do not present a potential surface fault-rupture hazard for this project. However, they are considered active and potential sources for future earthquakes.

Uplift along the Elysian Park Anticline is believed to have been produced by movement along the Elysian Park blind thrust. The south flank of this anticline has been called the Coyote Pass Escarpment and is identified by a south-facing slope that trends approximately east-west to northeasterly. In the vicinity of the project, the escarpment is believed to pass south of the 1st/Central Station, with the Station being situated near the crest of the escarpment. Previous studies for Metro projects (Earth Consultants International, 2001) modeled the distribution of coseismic strain (warping) across the escarpment, and estimated a maximum coseismic strain of 0.1 to 0.3 percent within a 75 to 25 foot wide zone, respectively, along the base of the escarpment. Based on that model, strain at the top of the escarpment (i.e. at the 1st/Central station location) would be significantly less than at the base. Because the station is approximately parallel to the escarpment, the potential effects of small magnitude ground warping may be negligible for the design and operation of the station, but this needs to be confirmed during final design studies. Such studies will likely require definition of the actual location of the escarpment relative to the 1st/Central Station.

Seismic Ground Shaking

As described in the GDR, a probabilistic Seismic Hazard Analysis (PSHA) was performed based on information obtained from the USGS 2009 PSHA Interactive Deaggregation Web Site (USGS, 2009). This was done to develop site-specific response spectra for seismic design for each of the proposed stations in accordance with the Metro Rail Design Criteria.

In accordance with Metro Rail Design Criteria, the probabilistic Maximum Design Earthquake (MDE) response spectrum should be taken as the response spectrum with a 4% probability of being exceeded in 100 years which is nearly identical to the response spectrum with a 2% probability of being exceeded in 50 years. The probabilistic Operating Design Earthquake (ODE) response spectrum was taken as the response spectrum with a 50% probability of being exceed in 100 years. The site-specific MDE and ODE response spectra are provided in the GDR (Amec, 2012).

Liquefaction

The potential for liquefaction is characterized as “high” within saturated upper (Qal1/younger) alluvium that is within 40 feet of the ground surface. The potential for liquefaction in the upper alluvium is considered “low” where it is not saturated. Because the lower (Qal2/older) alluvium is relatively dense, its liquefaction potential is characterized as “low”, irrespective of the degree of saturation. Areas where a high potential for liquefaction is considered to exist within the planned excavations include:
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3.0 – Site Conditions

- Portions of the upper alluvium within the cut-and-cover reach along Flower Street, between the 7th/Flower Station and the start of the bored tunnels
- Limited portions of upper alluvium above of the 2nd/Broadway Station

3.2 Geologic Units

The planned excavations will encounter one or more of the following units: artificial fill; alluvium; and the Fernando Formation. The characteristics of these units are described below. Baselines for the various characteristics are provided in Section 4 according to tunnel reach, Station, etc.

3.2.1 Artificial Fill

Artificial fill of variable thickness underlies the ground surface along much of the alignment. The fill consists of mixtures of gravel, sand, silt, and clay, with variable amounts of construction debris. At some locations, artificial fill contains up to 60 percent construction debris, which includes various sized pieces of brick, asphalt, plaster, metal, wire, timber, and concrete. Typically, the construction debris ranges in size from gravel to cobbles. However, fragments that are several feet in maximum dimension (i.e. boulder size) are present.

Deep areas of fill, to depths of approximately 25 to 35 feet below ground surface, are located along and adjacent to Flower Street, from 2nd Street to 4th Street, above abandoned tunnels, above storm drain excavations, and above other structure excavations that have been backfilled.

3.2.2 Alluvium

Holocene to probable late Pleistocene age alluvial deposits are present along the alignment beneath variably thick artificial fill. The alluvium overlies an erosional contact with the Fernando Formation and thins out laterally against an irregularly sloping contact with the Fernando Formation at variable depths in the subsurface.

The alluvial deposits thicken southward along Flower Street between 2nd Street and 6th Street. The elevation of the alluvium/bedrock contact along Flower Street is near the proposed tunnel crown elevation. Data from prior geotechnical/foundation investigations and current boring data indicate an eastward increase in alluvial deposit thickness and increased depth to the Fernando Formation beneath 2nd Street between Main Street and Alameda Street.

Geologic maps prepared by Soper and Grant (1932) and Lamar (1970) show the alluvial deposits in depositional contact (i.e., the alluvium laterally thins or pinches out) against bedrock near the intersection of Hill Street and 2nd Street. Geologic maps prepared by the CGS (2010) and the U.S. Geological Survey (2005) have delineated the alluvial deposits beneath Flower Street and 2nd Street as separate alluvial units. The alluvial deposits along Flower Street were deposited within a relatively small drainage area, whereas, the alluvial deposits along 2nd Street were deposited in a higher energy environment, primarily as floodplain, channel, and sheet flow deposits derived from the Los Angeles River.
Flower Street

Alluvial deposits along Flower Street consist primarily of interlayered silty clays, sandy silts, clayey sands, and silty sands with some sand layers containing variable gravel and few cobbles. South of 6th Street, coarser-grained alluvium was encountered beneath the upper finer-grained alluvium at depths of approximately 20 feet below ground surface (bgs). This coarser-grained alluvium consists of poorly- to well-graded sand with variable gravel and cobble content.

2nd Street

Alluvial deposits beneath 2nd Street are overlain by a variable thickness of fill. The depth of the alluvial/bedrock contact beneath 2nd Street ranges from 15 feet to 47 feet bgs. From Central Avenue to Alameda Street, the depth of the alluvial/bedrock contact ranges between approximately 45 and 50 feet bgs. From Hill Street to Alameda Street, the alluvial deposits consist of variably thick layers of silty sand, poorly- to well-graded sand, sand with gravel and poorly- to well-graded gravel.

The upper portion of the alluvial deposits from about San Pedro Street eastward to Alameda Street consist primarily of silty sand, poorly graded fine- to medium-grained sand, and well-graded sand with generally less than 20 percent gravel content. A coarser-grained alluvial unit was encountered beneath artificial fill between Broadway and San Pedro Street and beneath the upper alluvial unit from about San Pedro Street eastward to Alameda Street. The base of this lower alluvial unit forms an erosional contact with the underlying Fernando Formation at variable depth. The coarser-grained alluvial unit consists primarily of poorly- to well-graded sand, sand with gravels, and poorly- to well-graded gravel with cobbles. East of Main Street, gravel content ranges to 50 percent and cobble content ranges to 20 percent. Boulders up to 20 inches in diameter have been reported in the historical borings. Boulders up to 4 feet in maximum dimension were reported on other local projects. Cobble and boulders are dominantly igneous and metamorphic rocks that are fresh to slightly weathered and strong to very strong.

Qal1, Qal2, and Younger vs. Older Alluvium

Based on the characteristics described above, on Plates 1 through 3, the alluvial deposits are subdivided into two units: Qal1, which is typically finer grained; and Qal2, which is typically coarser grained. In addition to this general difference in soil type, the subdivision of the alluvium is based on penetration blow count data and geologic observations of drive samples and sonic cores that indicate the coarser grained alluvial deposits beneath 2nd Street and Alameda Street (Qal2) are notably denser than the upper alluvial deposits (Qal1). In addition to this density contrast, locally the Qal2 unit has slight cementation. Together, these characteristics suggest that the lower coarser-grained alluvial unit (Qal2) is notably older, probably early Holocene to late Pleistocene age. A similar condition exists locally along Flower Street. As a result, these units are also be referred to as “younger alluvium” and “older alluvium” similar to how they are described by various local and regional geologic maps and geotechnical reports.
Qal1 (Younger Alluvium)

A review of available boring logs along the project alignment was made to estimate the distribution of USCS soil types and maximum layer thickness within Qal1. The results are shown on Figure 3, which shows that Qal1 is dominantly comprised of sandy soils, with the following being the dominant types and percentages, with maximum layer thickness:

- 22 percent layers of well graded sand (27 feet maximum thickness)
- 20 percent layers silty sand (11 feet maximum thickness)
- 15 percent layers of poorly graded sand (20 feet maximum thickness).

For reference, Figure 3 also shows the number of gradation tests performed on each soil type.

The dry density of Qal1 has a broad range, varying from approximately 80 to 140 pounds per cubic foot (pcf), and based on a total of approximately 300 tests, the average dry density is approximately 108 pcf. The moisture content ranges from a few percent to approximately 40 percent, and based on approximately 300 tests averages approximately 14 percent. The wet density ranges from approximately 100 to 150 pcf and has an average of approximately 123 pcf. Figures 4, 5 and 6 show the distribution of dry density, moisture content, and wet density within the Qal1 unit.

The relative density (from sampler penetration blow counts) of the Qal1 varies widely, depending on soil type, with blow counts ranging from approximately 13 blows per foot (bpf) to 50+ bpf for a few inches of sampler penetration. The instances of high blow counts (i.e. approximately 50 blows for a few inches of penetration) are generally limited to within the gravelly and cobbly soils.

Figure 7 shows the results of all gradation tests performed in Qal1. It is noted that the results of the gradation tests reflect the particle size of the soil samples actually obtained, and for coarse grained samples, these results do not accurately represent the in situ material. This is because coarse-grained materials commonly contain particles larger than the sampler opening and thus are not sampled.

Hydraulic conductivity within the Qal1 alluvium varies widely based on soil type. No hydraulic conductivity testing was performed in the Qal1 alluvium during the recent EIR or ACE/PE studies. However three results are available from investigations performed by CEG Consultants (1981, 1983) where results ranged from $2.9 \times 10^{-5}$ cm/s to $4.4 \times 10^{-4}$ cm/s. Layers of relatively clean sand and gravel are expected to have higher hydraulic conductivity, ranging up to $10^{-2}$ cm/s. Based on the compilation of data from boring logs shown on Figure 3, such higher conductivity layers comprise 15 to 20 percent of the Qal1 alluvium unit.

Qal2 (Older Alluvium)

A review of available boring logs along the project alignment was made to illustrate the distribution of USCS soil types and maximum layer thickness within the Qal2 unit. The results are shown on Figure 8, which shows that the Qal2 is dominantly comprised of sandy soils, with the following being the dominant types and percentages, and maximum layer thicknesses:

- 49 percent layers of well graded sand (40 feet maximum thickness)
25 percent layers of poorly graded sand (32 feet maximum thickness).

In comparing Figures 3 and 8, it is apparent that the Qal2 contains more poorly graded and well graded sand, more gravely soils, and much less silty and clayey soils, as compared to the Qal1. For reference, Figure 8 also shows the number of gradation tests performed on each soil type.

The dry density of the Qal2 has a broad range, varying from approximately 80 to 140pcf, and based on a total of approximately 200 tests, the average density is approximately 115pcf. The moisture content ranges from a few percent to approximately 40 percent, and based on approximately 200 tests, averages approximately 10 percent. The wet density ranges from approximately 100 to 160pcf and has an average of approximately 126pcf. Figures 4, 5 and 6 show the distribution of dry density, moisture content, and wet density within the Qal2.

The relative density of the Qal2 varies with soil type, and overall, this unit is denser than the Qal1. Where it is gravelly/cobbly, penetration resistance within Qal2 is commonly over 50 bpf or 50+ bpf for a few inches of sampler penetration.

Figure 9 shows the results of all gradation tests performed in Qal2. As with the Qal1, the results of the gradation tests for the Qal2 reflect the particle size of the soil samples actually obtained, and for coarse grained samples, these results do not accurately represent the in situ material.

One hydraulic conductivity test (a slug test using the standpipe piezometer installed in boring G2-15) was performed in the Qal2 during the ACE/PE studies. The test zone primarily included poorly to well graded sands with silt and some gravel, with approximately 3% to 9% fines (passing the #200 sieve). The test result indicates an average conductivity of approximately \(4 \times 10^{-4}\) cm/s. One test result is available from investigations performed by CEG Consultants (1983) with a result of \(2.3 \times 10^{-6}\) cm/s. Local layers of clean sand and gravel are present and are expected to have hydraulic conductivity ranging up to \(10^{-3}\) cm/s. However, overall, the Qal2 has a higher fines content (i.e. silt and clay) than the Qal1 alluvium and therefore is expected to have a lower hydraulic conductivity, averaging \(10^{-5}\) cm/s.

As part of the ACE/PE geotechnical investigation, the relative abrasiveness of the Qal2 was tested by performing Soil Abrasion Tests (SAT) and Miller abrasion tests. The results of these tests are summarized on Figures 10 and 11. As shown on Figure 10, the three samples of Qal2 showed “medium” abrasiveness based on a comparison to the AVS rock abrasivity scale. As shown on Figure 11, the three samples that were subjected to Miller Abrasion testing to evaluate the abrasiveness of the material in a slurry, ranked as high to very high.

Colluvium

Deposits inferred to be of colluvial origin were encountered beneath thick artificial fill on the western flank of Bunker Hill between 3rd Street and Hope Street. These deposits were about five feet thick and primarily consist of medium dense clayey sand and stiff to very stiff, sandy to clayey silt.
3.2.3 Fernando Formation

The Fernando Formation (bedrock) consists of a poorly bedded to massive clayey siltstone to silty claystone that is poorly cemented and extremely weak to very weak (per ISRM, 1978). Although its appearance in excavations is massive, on close inspection the formation does contain bedding, which is commonly apparent as bedding plane partings. Locally, the formation is diatomaceous, and locally the formation includes sandy layers, concretions, and nodules that range from moderately to strongly cemented and range in strength from weak to strong (per ISRM, 1978).

Weathering

The Fernando Formation commonly exhibits a weathered profile, which as described on some boring logs ranges from “moderately weathered” to “highly weathered”, this being in comparison to the underlying “slightly weathered” to “fresh” bedrock (refer to the GDR for an explanation of weathering grades). The thickness of the more weathered, weaker bedrock ranges from 0 to approximately 60 feet along the project alignment. As shown on Plates 1 and 2, the thickest weathering underlies the high terrain in the vicinity of 2nd and Hope Streets (i.e. from approximately Station R:29+00 to R:45+00), where the depth to slightly weathered/fresh bedrock ranges from approximately 30 to 60 feet below the top of bedrock. The thickness of the more highly weathered bedrock decreases toward the flanks of the hill.

Sampler Penetration Resistance

Within the moderately to highly weathered zones, the consistency of the Fernando Formation, as evidenced by sampler penetration resistance, is as low as approximately 10 bpf and as high as approximately 50 bpf. Where slightly weathered to fresh, the penetration resistance is markedly higher, typically 50 bpf or higher.

Cemented Materials

Borehole Data

Some intervals in the Fernando Formation are notably stronger than is typical for the formation. These materials have been described in boring logs in a variety of ways, including:

- Carbonate cemented siltstone; carbonate cemented weak rock; carbonate cemented zone; cemented layer; cemented layer of limestone; cemented lens; cemented lumps; cemented nodules; cemented siltstone and sandstone; cemented zone; concretion; hard; hard cemented layer; hard layer; hard lens; highly cemented layer; layer of cemented lumps; layer of limestone; layer of limestone gravel; limestone nodule; siltstone concretion; trace cemented shell fragments; very hard cemented lens; and well cemented siltstone.

Field observations of excavations in downtown Los Angeles indicate that with few exceptions (i.e. the cemented layer in boring G2-4) these cemented materials are concretions. Field observations indicate that these concretions extend laterally for a distance of 3 to 5 times their thickness and are typically elongate in shape.

To evaluate the size of the cemented materials, borehole data were evaluated and as shown on Figure 12, approximately 80% of the cemented intervals encountered in borings were 1 foot or
less in thickness. Field observations indicate that the maximum size of concretions is approximately 10 feet.

Plates 1 through 3 illustrate the locations where these stronger materials were encountered in borings, and as shown, their frequency is greater in the area between approximately Stations R:1+65 to R:28+00, and Stations R:49+00 to R:54+00, as compared to other locations along the alignment.

The cemented layer in boring G2-4 is a notable exception to the observation that cemented materials in the Fernando Formation are limited to concretions. That cemented layer was studied to evaluate its potential to be intersected in excavations for the Regional Connector project. It was determined that, based on nearby borings and dip of the formation, the layer encountered in boring G2-4 will not intersected in the planned excavations.

Red Line Tunnels

Information regarding the distribution of concretions within the Fernando Formation is available from construction records for the Red Line tunnels. A review was made of those records, for the area between Civic Center Station and Wilshire/Alvarado Station, where the Fernando Formation was encountered.

For the tunnels between Civic Center Station and 5th/Hill Station (Metro Construction Contract A-141), information on ground conditions encountered was recorded by the construction management team and the construction contractor. For the tunnels between 7th/Flower Station and Wilshire/Alvarado Station (Metro Construction Contract A-171), information on ground conditions is only available from the construction management team.

Based on the available information, the strong cemented materials were described by the Construction Management team using the following terms:

Some concretions; 18” concretion; small concretions; several concretions; scattered concretions; 6”-8” concretions; concretion nodules; some concretion nodules; concretions of 2”-3” diameter; seam(s) of concretions; scattered concretions < 2’ across; concretions to 6” diameter and nodules; concretions 3’ x 1” and 4’ x 18”; 10” seam of hardened siltstone; bands of concretions; concretion layer.

Similar to field observations, with few exceptions the tunnel logs refer to the strong cemented materials as concretions. The records suggest that the concretions were encountered at individual locations and also scattered along tunnel intervals that were a few hundred feet long. With few exceptions, the records indicate that the concretions ranged to approximately 1 foot in thickness and approximately 4 feet in lateral extent. The construction management records do not indicate that there was difficulty in excavating the concretions with the digger shields that were used.

Using the construction records, an estimate was developed for the lengths of the AR and AL tunnels where concretions were observed. The results are summarized below:
Summary of Cemented Materials (Concretions) In Red Line Tunnels*

<table>
<thead>
<tr>
<th>Tunnel Segment</th>
<th>Tunnel Segment Length (ft)</th>
<th>Estimated Total Length of Tunnel Where Concretions were Reported in Construction Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AR Tunnel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feet</td>
</tr>
<tr>
<td>Contract A-141: Civic Center Station to 5th/Hill Street Station (aka Pershing Square)</td>
<td>1762 to 1772</td>
<td>457</td>
</tr>
<tr>
<td>Contract A-171: 7th/Flower Station to Wilshire Alvarado Station</td>
<td>4937</td>
<td>1066</td>
</tr>
</tbody>
</table>

* Estimates based on Construction Management team descriptions

For the tunnels from Civic Center Station to 5th/Hill Station, the construction records also contain observations from the construction contractor. Those reports do not describe the stronger materials as concretions, as did the construction management team, but rather as “rock”, “rocky”, “hard rock”, or “hard ground”; this description being in contrast to the description of “good” or “good ground”.

In evaluating this information, it was noticed that the locations of cemented materials identified by the construction contractor do not align well with the locations where the construction management team identified concretions. As a result, it is interpreted that the construction contractor was referring to stronger layers within the Fernando Formation, and not isolated concretions. Based on where the stronger material (i.e. rock, hard rock) was reported by the construction contractor, the following summary was developed:

Summary of “Hard Rock” In Red Line Tunnels*

<table>
<thead>
<tr>
<th>Tunnel Segment</th>
<th>Tunnel Segment Length (ft)</th>
<th>Estimated Total Length of Tunnel Where Hard Rock was Reported in Construction Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AR Tunnel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Feet</td>
</tr>
<tr>
<td>Contract A-141: Civic Center Station to 5th/Hill Street Station (aka Pershing Square)</td>
<td>1762 to 1772</td>
<td>180</td>
</tr>
<tr>
<td>Contract A-171: 7th/Flower Station to Wilshire Alvarado Station</td>
<td>Data not available</td>
<td></td>
</tr>
</tbody>
</table>

* Estimates based on Construction Contractor descriptions
The tunnel reaches where rock/hard rock was encountered range in length from approximately 5 to 50 feet. Within these reaches, the largest recorded size of hard rock was 8 feet by 12 feet (presumed to be length and width of the layer). The largest dimension overall was 14 feet long. These dimensions are considered more representative than can be estimated using boring data, however the maximum observable dimension is still limited to the width of the tunnel and the dip of the formation. The thickness of the seams/layers of “hard rock” is not well documented, but appears to be limited to approximately 2 feet. In one instance, in the AR tunnel between 2nd Street and the 5th/Hill station, it was reported that the tunnel encountered “hard rock” in the invert and that the shield was possibly damaged.

Density and Moisture Content

The dry density of the Fernando Formation ranges from approximately 70 to 100 pcf, and based on a total of over 1,100 tests, the average dry density is approximately 93 pcf. The moisture content ranges from approximately 16 to 55 percent, and based on over 1,100 tests, averages approximately 29 percent. The wet density ranges from approximately 110 to 140 pcf and averages approximately 120 pcf. Figures 4, 5 and 6 show the distribution of dry density, moisture content, and wet density within the Fernando Formation.

In reviewing the moisture-density data, it is recognized that there are some locations where light weight (<90 pcf dry density) and/or high water content (>40%) materials are present. The locations where laboratory tests are available to identify these materials are shown on Plates 1 through 3 and as shown, the light weight/high water content materials appear to be more common in the vicinity of Bunker Hill. These light weight materials need to be evaluated relative to soil conditioning requirements for EPB tunneling.

Gradation

Figure 13 shows the results of all gradation tests performed on samples of Fernando Formation. To perform these tests, the bedrock samples had to be disaggregated in the laboratory to form a soil. All of the available gradation data were used to create Figure 14, which summarizes the minimum, maximum, and average gradation, together with one standard deviation above and below the average gradation.

Plasticity

Figure 15 shows the distribution of soil plasticity testing results for samples of the Fernando Formation. These results are for samples that were processed to disaggregate the otherwise firm bedrock material to a soil material that could be subjected to Atterberg Limits testing. As shown on Figure 15, the results indicate that the material is near the silt/clay borderline, and ranges in plasticity from low to high.

Stickiness

The available plasticity and moisture content data were used to determine soil consistency indices. The consistency index values are plotted together with the plasticity indices on Figure 16, which illustrates the relative potential for the formation to exhibit clogging behavior during Tunnel Boring Machine (TBM) excavation. The “low”, “medium”, and “high” categories for potential for clogging that, shown on Figure 16, are based on Thewes and Burger (2005) for tunneling in clay. Based on the results shown on Figure 16, the Fernando Formation will exhibit
a “medium” to “high” potential for clogging. However, this assumes that the formation will be disaggregated to a high degree by the TBM, during excavation at the face, muck mixing in the plenum, and throughout the muck transport process. The actual tendency for clogging may be less than suggested by Figure 16, if the TBM can be configured to reduce material breakdown.

Strength

The unconfined compressive strength of the typical weakly to uncemented siltstone/claystone of the Fernando Formation ranges from approximately 25 psi to 300 psi. As discussed above, the formation contains cemented materials that are notably stronger than the typical siltstone/claystone material. Carbonate cemented materials range in unconfined compressive strength from 5,000 to 13,000 psi. Silica cemented materials are significantly stronger and range in unconfined compressive strength from 20,000 to 30,000 psi.

The strength testing results from the ACE/PE investigation, excluding the strongly cemented materials, are shown in Figure 17, which indicates a trend of increasing strength with depth below the bedrock surface. This increase in strength with depth below top of bedrock may be due, in part, to the effects of weathering.

Figure 18 shows the distribution of strength results for all tested samples of Fernando Formation, including the test results for cemented materials. Figure 18 illustrates the significant strength difference between the typical Fernando Formation and those materials that are moderately to highly cemented. Based on the strength classifications of ISRM (1978), the typical Fernando Formation would be considered “extremely weak” to “very weak” rock and the cemented materials would be considered weak to very strong rock.

Figure 19 provides an expanded distribution chart for the lower end of the strength range, to illustrate the distribution of strength within the typical “extremely weak” to “very weak” Fernando Formation.

Slake Durability

Being a weak rock that is composed of silt/clay, the Fernando Formation is subject to slaking due to changes in moisture content. Testing of 14 bedrock samples shows that the second cycle slake durability index ranges from 0.3 to 69 with an average of 34. Figure 20 graphically shows the distribution of these test results. As shown on Figure 19, over 90% of the Formation has a low to very low durability.

Abrasion

The relative abrasiveness of the bedrock was tested by performing Soil Abrasion Tests (SAT) and Miller abrasion tests. The results of these tests are summarized on Figures 10 and 11 (together with results for samples of alluvium). As shown on Figure 10, the six tested samples showed “very low” to “low” abrasiveness. As shown on Figure 11, seven samples that were subjected to Miller Abrasion testing ranked as “low” to “moderate”.

Hydraulic Conductivity

Due to its fine grained texture, typical massive condition (i.e. lack of well developed bedding planes), and lack of open fractures, the Fernando Formation has a relatively low hydraulic...
conductivity. Information from previous investigations (i.e. for the Red Line tunnels) indicates that the hydraulic conductivity in the bedrock ranges from approximately $10^{-6}$ cm/s to $10^{-8}$ cm/s.

The following summarizes the results obtained during the ACE/PE investigation:

**Summary of Hydraulic Conductivity Test Results**

<table>
<thead>
<tr>
<th>Boring</th>
<th>Packer Test Results (cm/s)</th>
<th>Slug Test Results (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rising Head</td>
</tr>
<tr>
<td>G2-1b</td>
<td>-</td>
<td>$1.9 \times 10^{-4}$</td>
</tr>
<tr>
<td>G2-4</td>
<td>-</td>
<td>$1.8 \times 10^{-7}$</td>
</tr>
<tr>
<td>G2-9b</td>
<td>-</td>
<td>$2.1 \times 10^{-7}$</td>
</tr>
<tr>
<td>G2-10</td>
<td>$9.4 \times 10^{-5}$</td>
<td>-</td>
</tr>
</tbody>
</table>

Based on the available information, it should be assumed that the overall average hydraulic conductivity of the rock mass is $10^{-8}$ cm/s, except where specific values are given in Section 4 for inflow baselines.

**Discontinuities**

The bedrock contains discontinuities that include bedding planes (bedding plane partings/bedding plane joints), joints and shears. The results from recent acoustic televiwer (ATV) surveys are summarized on Figure 21, which indicates the following trends:

- Bedding dip ranges from approximately 65 to 80 degrees, across an azimuth range of approximately 165 to 195 degrees.

- Two sets of joints are apparent, both with a broad range of orientation. Within one set, the dip ranges from approximately 55 to 80 degrees, across an azimuth range of approximately 235 to 295 degrees. Within the other set, the dip ranges from approximately 50 to 80 degrees, across an azimuth range of approximately 55 to 105 degrees.

- Other joint orientations occur, but at a relatively low frequency.

**Field Observations**

As part of the ACE/PE investigation, in late August 2011, a review was made of the foundation excavation for the future Broad Museum, which is bounded by Hope Street, Grand Avenue, 2nd Street, and GTK Way. This site is of interest because it provides an example of the characteristics of the bedrock in an excavation similar to that envisioned for the proposed cut-and-cover subway stations, and also because the RCTC alignment passes beneath a portion of that site. The foundation excavation primarily exposed Fernando Formation bedrock, part of which was exposed across the bottom of the excavation at the time of the field visit.
The exposed bedrock was predominantly a massive, gray, slightly weathered to fresh, clayey siltstone, as shown in Figure 22, which shows a footing excavation in the bottom of the building excavation. Although the footing excavation depicted in Figure 22 is relatively shallow, the vertical walls are stable, with the exception of local overbreak (small wedge failures and spalling) that formed along joint surfaces. Figure 23 shows a closer view of the same excavation, pointing out the exposed joint surfaces. These joints are narrow to tight in aperture, approximately planar, and are variably coated with iron oxides.

Figure 24 shows the typical appearance of the moderately to highly weathered bedrock. As shown, where moderately to highly weathered, the bedrock is typically yellow brown to brown in color and the joints tend to be wider in aperture with more iron oxide accumulation. Because the more deeply weathered material is weaker in strength, with more pronounced joints, excavations tend to experience a greater degree of small wedge failures (i.e. raveling and spalling).

As noted above, the bedrock is subject to slaking behavior due to changes in moisture content. Figure 25 shows a bedrock exposure (within the Broad Museum foundation excavation) that has begun to breakdown due to desiccation.

During observation of the Broad Museum foundation excavation, at least three joint sets were apparent:

- One set dipped approximately 75 to 80 degrees to the southwest.
- A second set dipped approximately 70 to 80 degrees to the south (this would be approximately parallel to bedding).
- A third set appeared to strike northward and dip to the west and east at 80 degrees to vertical.

In addition to the above, several joints were observed to dip to the northeast at approximately 55 to 70 degrees.

The joint surfaces were commonly coated with iron-oxides, appeared wavy and slightly rough, and had lateral persistence on the order of at least five to ten feet along strike.

### 3.3 Groundwater Conditions

Perched groundwater generally exists within the lower portion of the alluvial deposits, due to the relatively low permeability of underlying Fernando formation. In addition, a regional water level is present within the Fernando Formation.

Perched and regional water levels, measured during drilling or in piezometers, are shown on Plate 1. Using those data points, the elevation of the perched and regional water levels were interpreted and are shown on Plate 1. These groundwater elevations should be expected to vary due to seasonal rainfall, with elevations varying 3 feet above and below the levels shown on Plate 1.
3.4 Hazardous Gas

As discussed in the GDR, the Regional Connector alignment crosses a portion of the Union Station Oil Field, which has been delineated as a Methane Zone by the City of Los Angeles Department of Public Works, Bureau of Engineering. As a result, there is a significant potential for encountering methane and hydrogen sulfide gas.

Field evidence for naturally occurring gas (i.e. methane and/or hydrogen sulfide) along the project alignment includes:

- Of a total of 11 soil gas samples tested during the ACE/PE investigation, four samples (MB2-10', MB2-35', MB9-50' and MG2-16-35) were detected with a methane concentration of 0.1 % by volume or 1,000 ppmv, which was the detection limit of the measuring instrument.

- Of a total of 9 soil gas samples measured for hydrogen sulfide, three samples from boring G2-16 at 15, 35 and 55 feet depth were detected with H$_2$S concentrations of 0.004, 0.004 and 0.003 ppmv, respectively.

- A total of 9 soil gas samples were measured for VOCs, methane and fixed gases, and methane was detected above the minimum detection limit (MDL) of 10 ppmv in 5 samples. The maximum concentration was 640 ppmv detected from sample MB9-50'.

- Boring E2-2: Strong sulfur odor in Fernando Formation at a depth of 38 feet and readings of 1 to 5 ppm H$_2$S in bedrock, down to 55 feet. The maximum field H$_2$S reading of 5 ppm was detected at 45 feet bgs.

Information regarding gas encountered during construction of the Red Line tunnels (in Fernando Formation), is available from the Construction History records as follows:

**Construction Contract A-141** (Civic Center Station to 5th/Hill Street Station (aka Pershing Square Station) included 1,762 feet for the AL tunnel and 1,772 feet for the AR tunnel, all of which was reportedly in the Fernando Formation. In the AL tunnel, gas (presumably methane) at a concentration of 2% Lower Explosive Limit (LEL) was reported at one location, approximately 200 feet south of the Civic Center Station. This occurrence apparently resulted in 5 hours of construction down time. No hydrogen sulfide gas was reported in the AL tunnel.

For the AR tunnel, records indicate four locations where gas was encountered; one location was methane, one location did not indicate the type of gas, and two locations were hydrogen sulfide. The location where methane was reported was located approximately 300 feet south of the Civic Center Station, and thus was near the location where methane was encountered in the AL tunnel. At this location, the methane concentration was reported at 0.5% and the tunnel was cleared of personnel until readings no longer detected methane. The location where the type of gas was not noted occurred approximately 600 feet south of the Civic Center Station. This encounter apparently required a shut down. For the two locations where hydrogen sulfide was encountered, one location occurred approximately 1,000 feet south of the Civic Center Station; the other occurred between approximately 1,250 and 1,350 feet south of the Civic Center Station. Within these two locations of hydrogen sulfide gas, records indicate strong odors.
and/or concentrations ranging from 5 to 27 ppm. Tunnel excavation was either slowed or temporarily shut down within these two locations.

**Construction Contract A-171** (7th/Flower Station to Wilshire Alvarado Station) included a total of 4,937 feet of twin bore tunnel, nearly all of which encountered the Fernando Formation. For the AR tunnel, neither the Construction Management team nor the Construction team noted encountering methane or hydrogen sulfide gas. However, for the AL tunnel, the Construction Management team recorded hydrogen sulfide gas at four locations, located between approximately 400 and 700 feet west of the 7th/Flower Station. Three of these locations reported a hydrogen sulfide concentration of 6 ppm, whereas the fourth location reported a hydrogen sulfide odor.

### 3.5 Contaminated Soil and Groundwater

Contamination of soil and groundwater is locally evident, based on historic and recent boring information. Field evidence for contamination along the project alignment includes:

- **Strong hydrocarbon odor** that was detected in the alluvial soils at a depth of approximately 45 feet below the ground surface at the northwest corner of 1st and Alameda Streets (LeRoy Crandall and Associates, 1989).

- **Petroliferous odors** reported by LeRoy Crandall and Associates (1964) in several borings drilled north of 3rd Street between Flower Street and Grand Avenue.

- **Boring E2-1**: Petroleum odor was reported within fill at a depth of approximately 7 to 15 feet bgs. The maximum field VOCs reading was 2.2 parts per million (ppm) detected at 30 feet bgs (7 feet below the top of the Fernando Formation).

- **Boring E2-2**: The maximum field VOCs reading was 1.5 ppm detected at 90 feet bgs (in Fernando Formation). A sample of Fernando Formation from a depth of 65 feet bgs was tested for semi volatile organic compounds (SVOC) and Benzo(a)pyrene was detected with a concentration of 480 micrograms per kilogram (µg/kg). This concentration is above the Environmental Protection Agency (US EPA) Region IX Regional Screening Levels (RSLs) of 210 µg/kg. A soil sample from a depth of 50 feet bgs was found to contain petroleum hydrocarbons.

- **Boring E2-3**: The maximum field VOCs measurement was 2.8 ppm detected at 10 feet bgs, in fill material. A soil sample from a depth of 35 feet bgs was found to contain petroleum hydrocarbons.

- **Boring E2-4**: The maximum field VOCs measurement was 2.2 ppm, detected at 15 feet bgs, in alluvium. Soil samples from depths of 35, 40, and 50 feet bgs were found to contain petroleum hydrocarbons.

- **Boring E2-5**: The maximum field VOC measurement was 1.0 ppm, detected at 25 feet bgs, in Fernando Formation.

- **Boring E2-6**: Petroleum odor was reported in an approximate 10 foot interval between 30 and 40 feet bgs. The maximum field VOC measurement was 24.2 ppm, detected at 30
feet bgs, in fill. Soil samples from depths of 30, 35, and 45 feet bgs were found to contain petroleum hydrocarbons. A groundwater sample from boring E2-6 was analyzed for Title 22 Metals and all metals with concentrations above the laboratory PQL were below their respective PHGs for drinking water, except for mercury, which was detected with a concentration of 5.3 µg/L [or 5.3 parts per billion (ppb)], exceeding the PHG of 1.2 ppb.

These findings indicate that contaminated soil and groundwater is locally present and will be encountered sporadically. As a result, appropriate handling and disposal will be required, and will be dependent on the contaminant concentrations encountered. Volumes of soil that are to be expected to require special treatment/disposal are discussed in Section 4.
4.0 ANTICIPATED GROUND CONDITIONS

This section provides baseline conditions for the project elements identified in Section 2. Baselines are provided for ground, groundwater and gas/contamination conditions. For convenience, ground and groundwater conditions are depicted on Plates 1 through 3. The depth of the geologic contacts will vary plus or minus 5 feet from that shown on Plates 1, 2 and 3. Ground behaviors described in the Sections below are according to the descriptions provided in Table 1.

4.1 Mangrove Site – Potential TBM Launch Area

As noted above, currently the site is a parking lot however, it was previously the site of a number of one- to five-story buildings. Sometime between 1980 and 1994, the above ground structures were demolished. The extent of demolition of the underground elements (basements and foundations) is unknown. As a result, it is to be assumed that shallow foundations and basement slabs/walls exist in the site area, and that these building remnants will be encountered during excavation of a TBM launch pit and also in a TBM drive within the limits of the site.

According to a report by LeRoy Crandall Associates (1990), some of the building basements were used to collect “sludge”, the characteristics of which are not well known at this time. Several holding tanks were present in a building on the site. These tanks reportedly contained wastewater generated during industrial processes on site. The basement of the building, below the tanks, contained an undetermined thickness of sludge, which is presumably residue from the wastewater operations. The LeRoy Crandall Associates report also indicates there were five underground storage tanks within the limits of the Mangrove site and that these tanks were removed. One of those underground tanks contained diesel oil, which is reported to have leaked into surrounding soils. The location of identified underground tanks and known extent of contamination is described in that report. The extent of site clean-up is not known.

4.2 East End “Wye”

Depending on the preference of the Design Builder, a portion of the Wye section may be constructed using tunneling methods, from a TBM launch pit at the Mangrove site. As shown on Plate 2 and 3, this section of the project (east/north of Station R83+72) will be excavated in artificial fill and alluvium.

The artificial fill ranges from 5 to 10 feet thick. Soil types in the fill and alluvium are variable but primarily include silty to gravelly, poorly graded sand and well graded sand. The upper 20% of the soils within the planned excavation have a loose consistency. The underlying 80% is medium dense to very dense. The soils typically become more gravelly with depth.

Cobbles and boulders that are strong to very strong (based on the categories defined by ISRM, 1978) are common in the alluvium, and similar size fragments of construction debris are contained within the fill. On a volume basis, 5% cobbles and 2% boulders will make up both the fill and alluvium. The fill and alluvium soils will be moderately to highly abrasive.

The fill and alluvium will exhibit slow to fast raveling in unsupported vertical walls and poorly graded sands will run. As a result, these soils will require immediate support in excavation
walls. Groundwater control or ground reinforcement will be required to mitigate fast raveling, running and/or flowing conditions.

The regional groundwater elevation is below the base of the excavation throughout this section. However, local perched groundwater will be present. As a result, minor (less than 5 gpm) inflows are expected to occur locally. These inflows will diminish to slow seeps with time. Sustained inflow from the entire section will not exceed 20 gpm.

Methane and hydrogen sulfide will be encountered locally. Petroleum contamination may be present in the area, but will be below the bottom of the proposed excavation. Therefore, special treatment/disposal of soil (due to contamination) will not be required.

4.3 Flower Street Cut–and–Cover

As shown on Plate 1, this cut-and-cover excavation will encounter artificial fill, alluvium, and the Fernando Formation. The base of this excavation will encounter Fernando Formation, except along the southwestern 200 feet where the bedrock is below the excavation bottom. Subsurface excavations for some of the adjacent buildings along this section are known to have been supported by tie back anchors. This is a primary reason for excavation by cut-and-cover construction methods for this section of the project. Based on review of existing as-built drawings several hundred tie-back anchors are to be expected to be encountered in this cut-and-cover excavation.

The fill soils are dominantly (75% to 80%) low plasticity clays and silts, with 20% to 25% silty sands that range from poorly to well graded. The upper alluvium (Qal1) is comprised of 60% to 65% low plasticity clays and silts, 20% to 25% silty and clayey sands, and 10% to 15% poorly to well graded sand. The lower alluvium (Qal2) is comprised of 15% to 20% low plasticity clays and silts, 20% to 25% silty sand, 10% to 15% poorly graded sand, and 50% to 55% well graded sand. The soils are medium dense to dense with local intervals that are loose or very dense.

Cobbles and boulders that are strong to very strong (ISRM, 1978) are common in the alluvium. The fill contains a variety of construction debris, which ranges in size from gravel to boulders up to 4 feet across. It is to be expected that on a volume basis, the fill and alluvium will contain cobbles (3%) and boulders (1%). The alluvium and fill soils will be moderately to highly abrasive.

Where above the groundwater level, the artificial fill and alluvium will exhibit slow raveling behavior in unsupported vertical cuts. Where below groundwater, these materials will exhibit fast raveling to flowing behavior in unsupported vertical cuts. As a result, these materials will require immediate support in excavation walls. Groundwater control measures or ground stabilization will be required to prevent loss of ground due to fast raveling to flowing conditions below the groundwater level.

The characteristics of the bedrock are as described in Section 3.2.3. As discussed, concretions are common and they are significantly stronger than the typical bedrock. It is to be expected that 95 percent of the concretions are cemented with calcium carbonate and will range in unconfined compressive strength from 3,000 to 12,000 psi. Five percent are dolomitic and will range in unconfined compressive strength from 20,000 to 30,000 psi. The distribution in thickness of these concretions is depicted on Figure 12. The lateral dimensions vary from 3 to 5 times the thickness. As shown on Plates 1 and 2, there is a higher frequency of cemented
materials in the bedrock along this section, as compared to elsewhere along the alignment. These cemented materials will comprise 5% of the bedrock (by volume). In addition to concretions, it is to be expected that one 3 foot thick layer of calcium carbonate cemented sandstone will be encountered. The layer will be parallel to bedding and will cross the entire excavation.

Where the Fernando Formation bedrock is encountered in excavation walls, it will exhibit firm to slow raveling conditions. Raveling will occur at joint intersections, as shown in the photographs of the foundation excavation for the Broad Museum in Figures 22 and 23. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected. The bedrock will part parallel to bedding.

Groundwater is present in the alluvium in a perched condition above the top of the Fernando Formation. A regional groundwater level is also present. The perched and regional groundwater elevations are shown on Plate 1, and will vary by 5 feet from the elevation shown. Where the excavation is below these groundwater elevations, inflows will occur as seeps and discrete flows from the fill and alluvium. Inflows will also occur from joints/shears in the bedrock and these will be limited to slow seeps. Total sustained inflows from within this cut-and-cover section will be 20 gpm per 100 feet of excavation.

Petroleum odors were reported in borings at the northeast end of this section, and there is evidence of Volatile Organic Compounds (VOC’s) in the same area. As a result, it is to be expected that the groundwater will contain VOC’s, SVOC’s and/or petroleum hydrocarbons, and as such will require special treatment/disposal. A portion of the excavated soils, assumed to total 13,000 bank cubic yards (bcy), will require special handling, treatment and disposal.

Hydrogen sulfide and methane gas are to be expected within the bedrock. These gasses will be generated from off-gassing of groundwater that flows into the excavation and from joints and fractures in the rock mass. The concentration, pressure, and volume of these gasses are to be expected to be sufficiently low that the inflow of these gasses can be mitigated through adequate ventilation.

4.4 Stations

4.4.1 1st/Central Station

The excavation will encounter artificial fill and alluvium. Fernando Formation bedrock is beneath the bottom of the excavation. At this location, the fill is comprised of 0% to 5% low plasticity clayey and silty soils, 40% to 45% silty sand, 5% to 10% poorly graded sand, and 40% to 45% well graded sand. The upper alluvium (Qa1) is comprised of 5% to 10% low plasticity silt and clay, 20% to 25% silty sand, 40% to 45% poorly graded sand, and 20% to 25% well graded sand. The lower alluvium (Qa12) is comprised of 10% to 15% silty sand, 25% to 35% poorly graded sand, 10% to 15% well graded sand, 5% to 10% poorly graded gravel, and 30% to 35% well graded gravel.

Cobbles and boulders that are strong to very strong (ISRM, 1978) are contained in the alluvium, and cobble and boulder size obstructions are contained in the fill. The cobbles and boulders will comprise 3% and 1%, respectively, of the excavated volume both the fill and alluvium. The alluvium and fill soils will be moderately to highly abrasive.
As shown on Plate 2, the majority of this station will be above the groundwater level. Where above the groundwater elevation, the alluvium will exhibit slow raveling behavior in vertical cuts. Within the limited area (at the west end of the station) where the alluvium will be encountered below the groundwater elevation, these materials will exhibit fast raveling to flowing behavior in vertical cuts.

The groundwater level will range from below the base of the excavation to approximately 10 feet above the base at the western end of the station. Sustained inflows are expected to range from drips to slow seeps.

Methane and hydrogen sulfide have been detected east of this station, and as a result, are to be expected to be present in the alluvium. Petroleum contamination may be present in the area, but will be below the bottom of the proposed excavation, except for the western portion where groundwater is above the bottom of the excavation. Therefore it is to be expected that special handling and treatment/disposal of groundwater (due to contamination) will be required, and that a total of 1,250 bcy of contaminated soil will require special handling and treatment/disposal.

### 4.4.2 2nd/Broadway Station

The excavation will encounter approximately 15 to 25 feet of artificial fill and alluvium, with the Fernando Formation bedrock below. The depth of moderately to highly weathered bedrock is shown on Plate 2.

At this location, the fill is comprised of 40% to 45% low plasticity clayey and silty soils, 30% to 35% silty sand, 5% to 10% poorly graded sand, and 10% to 15% well graded sand. The alluvium is comprised of 80% to 85% silty sand and 15% to 20% well graded sand. Cobbles and boulders that are strong to very strong (ISRM, 1978) are contained in the alluvium and cobble- and boulder-size obstructions are to be expected in the fill. The fill and alluvium will contain cobble- and boulder-size materials at 5% and 2%, respectively, of the excavated volume of the fill and alluvium. The alluvium and fill soils will be moderately to highly abrasive.

The characteristics of the bedrock are as described in Section 3.2.3. As discussed, concretions are common and they are significantly stronger than the typical bedrock. It is to be expected that 95 percent of the concretions are cemented with calcium carbonate and will range in unconfined compressive strength from 3,000 to 12,000 psi. Five percent are dolomitic and will range in unconfined compressive strength from 20,000 to 30,000 psi. The distribution in thickness of these concretions is depicted on Figure 12. The lateral dimensions vary from 3 to 5 times the thickness. As shown on Plates 1 and 2, there is a higher frequency of cemented materials in the bedrock along this section, as compared to elsewhere along the alignment. These cemented materials will comprise 3% of the bedrock (by volume). In addition to concretions, it is to be expected that one 3 foot thick layer of carbonate cemented sandstone will be encountered. The layer will be parallel to bedding and will cross the entire excavation.

Where above the groundwater level, the artificial fill and alluvium will exhibit slow raveling behavior in vertical cuts. Where below groundwater elevation these materials will exhibit fast raveling to flowing behavior in vertical cuts. As a result, these materials will require immediate support in the excavation walls. Groundwater control or ground stabilization will be required to prevent ground loss due to fast raveling to flowing conditions below the groundwater level.

Where the Fernando Formation bedrock is encountered in the excavation walls, it will exhibit firm to slow raveling conditions. Raveling will occur at joint intersections, as shown in the
photographs of the foundation excavation for the Broad Museum in Figures 22 and 23. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected.

Perched and regional groundwater levels will be encountered at the elevations shown on Plate 2, plus or minus 5 feet. Local groundwater inflows from the fill and alluvium will be limited to slow to fast seeps. Inflows from the bedrock will occur from joints/shears and will be limited to slow seeps. Total sustained inflows are expected to be up to 20 gpm per hundred lineal feet of excavation.

Hydrogen sulfide and methane are to be expected within the bedrock. These gasses will be generated from off-gassing of groundwater that flows into the excavation and from joints and fractures in the rock mass. The concentration, pressure, and volume of these gasses are expected to be sufficiently low that the inflow of these gasses can be mitigated through ventilation.

Evidence for contaminated soils in this area includes a strong petroleum odor within the alluvium at a depth of 15 feet in historic boring No. 80. As a result, it is expected that groundwater inflows into the excavation will require special treatment/disposal, and a total of 8,800 bcy of soil will require special handling and treatment/disposal.

### 4.4.3 2nd/Hope Station

As shown on Plate 1, the excavation will encounter 10 to 30 feet of artificial fill and colluvium, and the Fernando Formation below. The upper moderately to highly weathered portion of the Fernando Formation extends deeper at this location than elsewhere along the alignment. As shown on Plate 1, slightly weathered to fresh bedrock will be exposed at the bottom 5 to 30 feet of the excavation.

At this location, the fill is comprised largely (85% to 90%) of low plasticity clayey and silty soils. The remainder of the fill is comprised of silty to clayey sand (5% to 10%) and well graded sand (<5%). The colluvium is comprised of low plasticity silt. Cobble and boulder size obstructions that are strong to very strong (ISRM, 1978) are to be expected in the fill and these will comprise 3% and 1% of the volume of the unit, respectively. The alluvium and fill soils will be moderately to highly abrasive to digging equipment.

Where above the groundwater level, the artificial fill and colluvium will exhibit slow raveling behavior in vertical cuts. Where seeps occur, these materials will exhibit fast raveling to flowing behavior in vertical cuts. As a result, this material will require immediate support in excavation walls. Groundwater control or ground stabilization will be required to mitigate ground loss due to fast raveling to flowing conditions below the groundwater level.

The characteristics of the bedrock are as described in Section 3.2.3. As discussed, concretions are common and they are significantly stronger than the typical bedrock. It is to be expected that 95 percent of the concretions are cemented with calcium carbonate and will range in unconfined compressive strength from 3,000 to 12,000 psi. Five percent are dolomitic and will range in unconfined compressive strength from 20,000 to 30,000 psi. The distribution in thickness of these concretions is depicted on Figure 12. The lateral dimensions vary from 3 to 5 times the thickness. As shown on Plates 1 and 2, there is a higher frequency of cemented
materials in the bedrock along this section, as compared to elsewhere along the alignment. These cemented materials will comprise 5% of the bedrock (by volume). In addition to concretions, it is to be expected that one 3 foot thick layer of carbonate cemented sandstone will be encountered. The layer will be parallel to bedding and will cross the entire excavation.

Where the Fernando Formation bedrock is encountered in the excavation walls, it will exhibit firm to slow raveling conditions. Raveling will occur at joint intersections, as shown in the photographs of the foundation excavation for the Broad Museum in Figures 22 and 23. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected.

Perched and regional groundwater elevations are as shown on Plate 1, plus or minus 5 feet. Local groundwater inflows from the fill and colluvium will be limited to drips and slow seeps. Inflows from the bedrock will occur from joints/shears and will be limited to slow seeps. Total sustained inflows will be 20 gpm per hundred lineal feet of excavation.

Hydrogen sulfide and methane are to be expected to be encountered within the bedrock. These gasses will be generated from off-gassing of groundwater that flows into the excavation and from joints and fractures in the rock mass. The concentration, pressure, and volume of these gasses are to be expected to be sufficiently low that the inflow of these gasses can be mitigated through adequate ventilation.

Evidence for contaminated soils was observed as petroleum odors in the fill encountered in historic boring No. 48, and as low concentrations of VOC’s in the upper portion of recent boring G2-3. As a result, it is to be expected that groundwater inflows into the excavation will require special treatment/disposal, and that a total of 3,500 bcy of soil will require special handling and treatment/disposal.

4.5 Crossover Cavern

The excavation for the crossover cavern will encounter Fernando Formation bedrock, with the same characteristics as described below for Reach 1b, except that the rock will range from slightly weathered to fresh and the strength of this rock will vary in unconfined compressive strength from 100 to 300 psi.

The bedrock will exhibit firm to slow raveling conditions, and based on the material strength and ground cover, will exhibit a tendency toward stress slabbing. Raveling will occur at joint intersections and bedding planes. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected.

The perched and regional groundwater level at this location will be as shown on Plate 2, plus or minus 5 feet. This will lead to minor inflows (drips and slow seeps) along joints and/or shears in the bedrock. Total unrestricted sustained inflows are to be expected to be 30 gpm per 100 lineal feet.

Methane and hydrogen sulfide are to be expected, occurring from joints/shears in the bedrock and off-gassing from groundwater inflows. Ground and groundwater contamination is to be expected to be limited to within alluvium sediments above the tunnel, and not in the Fernando Formation. Groundwater within the bedrock is to be expected to be impacted by contamination.
in the overlying alluvium, and as such, if inflows are allowed to occur from the bedrock, they are to be expected to require special handling and treatment/disposal.

4.6 Bored Tunnels

**Reach 1 (Station R:53+76 to R:76+45)**

Based on subsurface conditions, this reach is divided into two sub-reaches: Reach 1a and 1b. The boundary between these reaches is approximate and is to be anticipated to vary plus or minus 50 feet from the indicated station.

**Reach 1a**

From Station R:68+00 to R:76+45 the tunnels will encounter a mixed face condition of alluvium over Fernando Formation bedrock. The alluvium includes a wide variety of sandy and gravelly soils, ranging from poorly graded to well graded sands and gravels. As described in Sections 3.2.2, overall, the upper Qal1 alluvium contains a greater percentage of fine grained soils and is less dense than the lower Qal2 alluvium. Both alluvium units contain cobbles and boulders. Within the tunnel excavation the Qal1 and Qal2 alluvium in this reach are to be expected to include a total of 30% to 35% poorly graded sand, which occurs in layers that range in thickness from 3 feet to 25 feet. The remainder of the alluvium includes well graded sand, silty sand, and clayey sand. A total of 100 cobbles and 10 boulders up to 4 feet in maximum dimension are to be expected within this reach of alluvium. The cobbles and boulders are expected to be strong to very strong (ISRM, 1978).

Within Reach 1a, the Fernando Formation bedrock is to be expected to range from highly weathered to fresh. The characteristics of the bedrock are as described in Section 3.2.3. In this reach the bedrock will range in unconfined compressive strength from 25 psi to 300 psi. As discussed in Section 3.2.3, concretions are common and they are significantly stronger than the typical bedrock. It is to be expected that 95 percent of the concretions are cemented with calcium carbonate and will range in unconfined compressive strength from 3,000 to 12,000 psi. Five percent are dolomitic and will range in unconfined compressive strength from 20,000 to 30,000 psi. The distribution in thickness of these concretions is depicted on Figure 12. The lateral dimensions vary from 3 to 5 times the thickness. These cemented materials will comprise 2% of the bedrock (by volume). In addition to concretions, it is to be expected that one 3 foot thick layer of carbonate cemented sandstone will be encountered in both tunnels. The layer will be parallel to bedding and will cross the entire excavation.

Where the Fernando Formation bedrock is encountered it will exhibit firm to slow raveling conditions. Raveling will occur at joint intersections, as shown in the photographs of the foundation excavation for the Broad Museum in Figures 22 and 23. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected.

Conditions in this reach will be influenced by perched and regional groundwater elevations, which occur as shown on Plate 2, plus or minus 5 feet. In an unpressurized excavation, groundwater inflows would be limited to drips and slow seeps from local joints and/or shears in the bedrock, and slow seeps to local inflows of tens of gallons per minute in the alluvium. Total inflows from the alluvium and bedrock within this Reach are to be expected to be 30 gpm per 100 lineal feet of tunnel.
Indications of methane and hydrogen sulfide have been detected along this reach and these gasses are to be expected. Contamination in the form of VOC’s, SVOC’s, and/or petroleum hydrocarbons has also been detected and therefore it is to be expected that groundwater inflows will require special handling and treatment/disposal. In addition, for the two tunnel bores, a total of 2,000 bcy of the excavated material is to be expected to require special handling and treatment/disposal.

**Reach 1b**

From Station R:53+76 to R:68+00 the tunnels will encounter a full face of Fernando Formation bedrock, which will vary from highly weathered to fresh. The characteristics of the bedrock in Reach 1b are the same as described above for Reach 1a. The bedrock will exhibit firm to slow raveling conditions, and based on the material strength and ground cover, will exhibit a tendency toward stress slabbing. Raveling will occur at joint intersections and bedding planes. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected.

The perched and regional groundwater level along this reach will be as shown on Plate 2, plus or minus 5 feet. This will lead to minor inflows (drips and slow seeps) along local joints and/or shears in the bedrock, if unrestricted. Total unrestricted sustained inflows are to be expected to be 15 gpm per 100 lineal feet of tunnel in the bedrock.

If unsupported, the bedrock will exhibit firm to slow raveling behavior in the slightly weathered to fresh bedrock and slow to fast raveling behavior in moderately to highly weathered bedrock. The bedrock will also exhibit a tendency for stress slabbing where blocks and wedges of unstable rock fall out of the crown or sidewalls. Local wedge failures are expected along joints, bedding planes, and/or shears. If allowed to desiccate, the bedrock will slake, and if the invert is not protected, construction equipment traffic and water will cause the bedrock to breakdown and become soft and muddy.

Methane and hydrogen sulfide are to be expected, occurring from joints/shears in the bedrock and off-gassing from groundwater inflows. Ground and groundwater contamination is to be expected to be limited to within alluvium sediments above the tunnel, and not in the Fernando Formation. Groundwater within the bedrock is to be expected to be impacted by contamination in the overlying alluvium, and as such, if inflows are allowed to occur from the bedrock, they are to be expected to require special handling and treatment/disposal.

**Reach 2 (Station R:32+81 to R:49+11)**

The entire length of the tunnels in Reach 2 will encounter slightly weathered to fresh bedrock of the Fernando Formation. The characteristics of the bedrock are as described in Section 3.2.3. However, bedrock in the Reach will range in unconfined compressive strength from 100 psi to 300 psi. As discussed in Section 3.2.3, concretions are common and they are significantly stronger than the typical bedrock. It is to be expected that 95 percent of the concretions are cemented with calcium carbonate and will range in unconfined compressive strength from 3,000 to 12,000 psi. Five percent are dolomitic and will range in unconfined compressive strength from 20,000 to 30,000 psi. The distribution in thickness of these concretions is depicted on Figure 12. The lateral dimensions vary from 3 to 5 times the thickness. These cemented materials will comprise 3% of the bedrock (by volume). In addition to concretions, it is to be expected that...
one 3 foot thick layer of carbonate cemented sandstone will be encountered in both tunnels. The layer will be parallel to bedding and will cross the entire excavation.

The perched and regional groundwater elevations are as shown on Plate 2, plus or minus 5 feet. If unrestricted, groundwater inflows should be expected to be limited to drips and slow seeps from local joints and/or shears in the bedrock. Total unrestricted inflows are expected to be 15 gpm per 100 lineal feet of tunnel in the bedrock.

In an unsupported excavation, the bedrock will exhibit firm to slow raveling behavior, with local wedge failures along joints, bedding planes, and/or shears. Raveling will occur at joint intersections, as shown in the photographs of the foundation excavation for the Broad Museum in Figures 22 and 23. Two joint sets are present, and these will trend according to the ranges discussed above and shown on the orientation diagram in Figure 21. Additional joints, at random orientations, are to be expected.

Methane and hydrogen sulfide are to be expected, occurring from joints/shears in the bedrock and off-gassing from groundwater inflows. Indications of petroleum contamination are present near the top of the Fernando Formation, and such contamination is considered to be restricted to within the overlying alluvium. Therefore, it is not expected that petroleum contamination will be encountered in the tunnels within this reach. However, if groundwater inflows are allowed, it is to be expected that the water will be impacted by contamination within the alluvium, and thus special handling and treatment/disposal will be required.

Reach 3 (Station R:19+00 to R:29+37)

Based on subsurface conditions, this reach is divided into three sub-reaches: Reach 3a, 3b, and 3c. The boundaries of these reaches are approximate and are to be anticipated to vary plus or minus 50 feet from the indicated stations.

Reach 3a

The tunnels will encounter a full face of Fernando Formation bedrock from Station R:26+80 to R:29+37. Within Reach 3a the bedrock will vary from highly weathered to fresh. The characteristics of the bedrock are as described for Reach 2, except that the concretions will be more frequent, and will comprise 5% of the excavated material, by volume.

The perched and regional groundwater elevation are as shown on Plate 1, plus or minus 5 feet. It is to be expected that unrestricted groundwater inflows will range from drips to slow seeps from joints/shears and bedding planes, and total unrestricted sustained inflows will average 15 gpm per 100 lineal feet of tunnel.

In an unsupported condition, the bedrock will exhibit firm to fast raveling behavior, with local wedge failures along joints, bedding planes, and/or shears. The ground will also exhibit a tendency for stress slabling.

Methane and hydrogen sulfide are to be expected, occurring from joints/shears in the bedrock and off-gassing from groundwater inflows. Indications of petroleum contamination have been identified within the bedrock and above the tunnel crown. The source of this contamination is from the overlying fill/alluvium. It is to be expected that groundwater that inflows into this reach
will require special handling and treatment/disposal, and a total of 1,000 bcy of tunnel spoil will require special handling and treatment/disposal from the two tunnel bores.

**Reach 3b**

From Station R:22+50 to R:26+80 the tunnels will encounter a mixed face condition of alluvium and/or artificial fill over Fernando Formation bedrock. The fill/alluvium will be present in the upper portion of the tunnel face and consist of a wide range of soil types, including: silt, clay, and silty sand (70% to 80%); poorly graded sand (10% to 15%); and well graded sand (10% to 15%). Where fill is present, it will contain cobble and boulder size fragments of construction debris. These fragments are expected to be strong to very strong (ISRM, 1978). A total of 20 cobble size objects and 5 boulder size objects are to be expected in this reach. The bedrock will vary from highly to moderately weathered. The characteristics of the bedrock are as described for Reach 3a.

Perched and regional groundwater elevations are as shown on Plate 1, plus or minus 5 feet. Unrestricted inflows from the bedrock are to be expected to occur as drips and slow seeps. However, where fill/alluvium may be encountered in the crown, unrestricted initial inflows are to be expected to be 100 gpm per 100 lineal feet of tunnel, and reducing with time so that sustained inflows will be 25 gpm per 100 lineal feet of tunnel.

In an unsupported condition, the bedrock will present firm to slow raveling behavior in the slightly weathered to fresh bedrock and slow to fast raveling behavior in the moderately to highly weathered bedrock. Local wedge failures along joints, bedding planes, and/or shears are to be expected, as well as a tendency for stress slabbing. The fill/alluvium will exhibit fast raveling to flowing behavior.

Methane and hydrogen sulfide are to be expected, occurring from joints/shears in the bedrock and off-gassing from groundwater inflows. Petroleum contamination is to be expected within the fill/alluvium and to a lesser degree within fractures in the bedrock. Therefore, groundwater that inflows into this sub-reach will require special handling and treatment/disposal, and a total of 5,300 bcy of spoil (from the two tunnels) will require special handling and treatment/disposal.

From Station R:25+40 to R:26+20 the tunnel excavation will intersect a total of 30 tie-backs, which are expected to be removed prior to tunneling using cut-and-cover construction methods.

**Reach 3c**

The tunnels will encounter a full face of Fernando Formation from Station R:19+00 to R:22+50. Within this sub-reach, the upper portion of the face will expose moderately to highly weathered bedrock, and slightly weathered to fresh bedrock below. The characteristics of the bedrock are as described for Reach 3a.

Perched and regional groundwater elevations are as shown on Plate 1, plus or minus 5 feet. Unrestricted groundwater inflows will be limited to drips and slow seeps from joints/shears.

In an unsupported condition, the bedrock will present firm to slow raveling behavior in the slightly weathered to fresh bedrock and slow to fast raveling behavior in the moderately to highly weathered bedrock. Local wedge failures will occur along joints, bedding planes, and/or shears.
Methane and hydrogen sulfide are to be expected, occurring from joints/shears in the bedrock and off-gassing from groundwater inflows. Indications of petroleum contamination have been identified within the alluvium and at shallow depth into the bedrock. It is expected that the source of this contamination is from the overlying fill/alluvium. As a result, groundwater that inflows into this reach will require special handling and treatment/disposal, and a total of 1,500 bcy of tunnel spoil will require special handling and treatment/disposal from the two bores.

4.7 Cross Passages

A total of four cross passages will be constructed. Ground and groundwater conditions for each of these cross passages are to be expected as follows:

Cross Passage at Station R:69+00

This cross passage will be mostly in the Fernando Formation bedrock, but will also encounter Qal2 alluvium in the crown. The Qal2 alluvium will contain 5 cobbles that are strong to very strong (ISRM, 1978). Above springline the cross passage is expected to encounter bedrock that is moderately to highly weathered and weaker than the slightly weathered to fresh bedrock below. The characteristics of the bedrock are described above for Reach 1b. Concretions are to be expected in the cross passage excavation, with the same characteristics as described for Reach 1b.

Perched and regional groundwater levels are shown on Plate 1, plus or minus 5 feet. Unrestricted inflows from the bedrock will be limited to drips and slow seeps that will occur along joints and/or shears, and/or along bedding planes and cemented layers. Unrestricted inflows from the alluvium will be expected to be 50 gpm initially as a flush flow and then subside to a sustained flow of 20 gpm.

Slightly weathered to fresh bedrock will exhibit firm to slow raveling and a tendency for stress slabbing behavior with local unstable wedges along joints, bedding planes, and/or shears. Moderately to highly weathered bedrock will exhibit slow raveling and/or slabbing behavior. It should be expected that alluvium will exhibit fast raveling to flowing behavior.

Cross Passage at Station R:62+50

This cross passage will be completely in unweathered bedrock of the Fernando Formation. The characteristics of the Fernando Formation bedrock are described above for Reach 1b. Concretions are to be expected in the cross passage excavation, with the same characteristics as described for Reach 1b.

Perched and regional groundwater elevations are as shown on Plate 2. Unrestricted inflows from the bedrock will occur as drips to slow seeps that will occur along joints and/or shears, and/or along bedding planes and cemented layers.

The slightly weathered to fresh bedrock will exhibit firm to slow raveling behavior with stress slabbing in the crown. Local unstable wedges will form along random joints, bedding planes, and/or shears in the walls and crown.
Cross Passage at Station R:40+50

This cross passage will be completely in unweathered bedrock of the Fernando Formation. The characteristics of the Fernando Formation bedrock are described above for Reach 2. Concretions are to be expected in the cross passage excavation, with the same characteristics as described for Reach 2.

Perched and regional groundwater elevations will be as shown on Plate 2, plus or minus 5 feet. Inflows from the bedrock will occur as drips to fast seeps that will occur along joints and/or shears, and/or along bedding planes and cemented layers.

The slightly weathered to fresh bedrock will exhibit firm to slow raveling behavior with a tendency for stress slabbing. Local unstable wedges will form along random joints, bedding planes, and/or shears in the walls and crown.

Cross Passage at Station R:24+00

This cross passage will be mostly in the Fernando Formation, but will encounter artificial fill and/or alluvium in the crown. The bedrock will range from highly weathered to fresh and its characteristics are as described above in Reach 3b. Concretions are to be expected in the cross passage excavation, with the same characteristics as described for Reach 3b.

Perched and regional groundwater elevations are as shown on Plate 1, plus or minus 5 feet. Inflows from the bedrock will be limited to drips and slow seeps that will occur along joints and/or shears, and/or along bedding planes and cemented layers. Inflows from artificial fill/alluvium will occur as 50 gpm flush flows that will subside to sustained flows of 25 gpm.

Slightly weathered to fresh bedrock will exhibit firm to slow raveling behavior with tendency for stress slabbing, and local unstable wedges will form along random joints, bedding planes and/or shears. Moderately to highly weathered bedrock will exhibit slow to fast raveling and/or a tendency for slabbing behavior. Where artificial fill/alluvium is encountered, it will contain variable amounts of construction debris and cobbles, and because it will contain groundwater it will exhibit fast raveling to flowing behavior.
5.0 REFERENCES


### Table 1  
#### Ground Behavior Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Firm rock or soil</strong></td>
<td>is a material which will stand unsupported in a tunnel for several days or longer. The term includes a great variety of materials: sands and sand-gravels with clay binder, stiff unfissured clays at moderate depths, and massive rock.</td>
</tr>
<tr>
<td><strong>Massive, moderately jointed rock</strong></td>
<td>contains joints and cracks, but the blocks between joints are locally grown together or are so intimately interlocked that vertical surfaces do not require lateral support.</td>
</tr>
<tr>
<td><strong>Blocky and seamy rock</strong></td>
<td>consists of chemically intact or nearly intact rock fragments, separated from each other by joints or other discontinuities that are imperfectly interlocked. In such rock, vertical surfaces may require support. When individual blocks are larger than one foot, the rock is called moderately blocky; when blocks are smaller than one foot, the rock is called very blocky and seamy.</td>
</tr>
<tr>
<td><strong>Crushed rock</strong></td>
<td>consists of chemically intact rock fragments that have the character of crusher run. Individual particles are of gravel size or smaller. This material behaves like gravel or sand.</td>
</tr>
<tr>
<td><strong>Squeezing ground</strong></td>
<td>slowly advances into the tunnel without perceptible volume increases. Squeezing conditions are associated with a high percentage of microscopic and sub-microscopic particles of micaceous minerals or of clay minerals with a low swelling capacity. A prerequisite for squeeze is an overstress of the material close to the tunnel opening, hence, for a given material the overburden stress is an important parameter.</td>
</tr>
<tr>
<td><strong>Swelling ground</strong></td>
<td>advances into the tunnel chiefly on account of expansion. The capacity to swell seems to be limited to those rocks which contain clay minerals such as montmorillonite, with a high swelling capacity.</td>
</tr>
<tr>
<td><strong>Raveling ground</strong></td>
<td>is used to describe a material which gradually breaks up into chunks, flakes, or angular fragments after the ground has been exposed in the tunnel. The process is time dependent and materials may be classified by the rate of disintegration as fast or slow raveling. If the raveling process starts within a few minutes, the ground is fast raveling. Otherwise, it is referred to as slow raveling. Examples are fine moist sand, and gravels with some clay binder, stiff fissured clays, jointed rocks, and weak rocks.</td>
</tr>
<tr>
<td><strong>Running ground</strong></td>
<td>indicates a material which will invade the tunnel until a stable slope is formed at the face. Stand-Up time is zero or nearly zero. Examples are clean medium to coarse sands and gravels above the groundwater level. If running ground has a trace of cohesion, then the run is preceded by a brief period of progressive raveling. Materials intermediate between running and raveling are described as cohesive-running.</td>
</tr>
<tr>
<td><strong>Flowing ground</strong></td>
<td>acts as a thick liquid and differs from running ground in that it invades the tunnel not only from above and from the slides, but also through the bottom. If the flow is not arrested, it continues until the tunnel is completely filled.</td>
</tr>
</tbody>
</table>

Modified from Terzaghi in Proctor and White (1946), Heuer (1974), and Deere et al. (1969).
FOUNDATION EXCAVATION IN FERNANDO FORMATION – MODERATELY TO HIGHLY WEATHERED

GEOTECHNICAL BASELINE REPORT – REGIONAL CONNECTOR PROJECT

Figure 24
Slake Durability - Fernando Formation

**Slake Durability Classification Ranges (Gamble, 1971):**

- 0 to 30 (Very Low)
- 31 to 60 (Low)
- 61 to 85 (Medium)
- 86 to 95 (Medium High)
- 96 to 98 (High)
- >98 (Very High)

**Frequency Distribution:**

- 0 to 30 (Very Low): 40%
- 31 to 60 (Low): 55%
- 61 to 85 (Medium): 10%
- 86 to 95 (Medium High), 96 to 98 (High), >98 (Very High): 0%
Includes 45 tests performed on typical samples of Fernando Formation. Tests for cemented layers are not included.
SUMMARY OF UCS DISTRIBUTION – FERNANDO FORMATION; ALL SAMPLES

Includes 45 tests performed on “typical” samples of Fernando Formation and 8 tests performed on cemented layers.
Results for cemented materials are not included.

4.3.2 UNCONFINED COMPRESSION STRENGTH vs DEPTH – FERNANDO FORMATION

**Figure 17**

UNCONFINED COMPRESSION STRENGTH vs DEPTH; FERNANDO FORMATION

GEOTECHNICAL BASELINE REPORT – REGIONAL CONNECTOR PROJECT
Clogging potential categories are based on Thewes and Burger (2005)
Figure 15: SOIL PLASTICITY – FERNANDO FORMATION
GEOTECHNICAL BASELINE REPORT
REGIONAL CONNECTOR PROJECT

The graph shows a correlation between Plasticity Index (PI) % and Liquid Limit (LL) %. The data is categorized into different soil types: CL, CL/ML, ML, OL, CH, MH, and OH. The CEG Data is represented by triangles, and the Amec Data is represented by squares.
UNIFIED SOIL CLASSIFICATION

<table>
<thead>
<tr>
<th>GRAVEL</th>
<th>SAND</th>
<th>SILT AND CLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>COARSE</td>
<td>FINE</td>
<td>COARSE</td>
</tr>
<tr>
<td>U. S. STANDARD SIEVE SIZES</td>
<td>HYDROMETER</td>
<td></td>
</tr>
</tbody>
</table>

Gradation Charts.xlsx
Regional Connector GBR
Some intervals in the Fernando Formation are notably stronger than is typical for the formation. These materials have been described in boring logs in a variety of ways, including:

- Carbonate cemented siltstone
- Carbonate cemented weak rock
- Carbonate cemented zone
- Cemented layer
- Cemented layer of limestone
- Cemented lens
- Cemented lumps
- Cemented nodules
- Cemented siltstone and sandstone
- Cemented zone
- Concretion
- Hard cemented layer
- Hard layer
- Hard lens
- Highly cemented layer
- Layer of cemented lumps
- Layer of limestone
- Layer of limestone gravel
- Limestone nodule
- Siltstone concretion
- Trace cemented shell fragments
- Very hard cemented lens
- Well cemented siltstone

Field observations of outcrops and excavations indicate the above materials, with rare exceptions, are concretions.
### SUMMARY OF MILLER ABRASION TEST RESULTS

**GEOTECHNICAL BASELINE REPORT - REGIONAL CONNECTOR PROJECT**

**Figure 11**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Boring</th>
<th>Depth (ft)</th>
<th>Formation</th>
<th>Soil Type</th>
<th>-1000 micron Solid Mass</th>
<th>pH Low</th>
<th>pH High</th>
<th>Abrasivity Departure</th>
<th>Ca(OH)2 mg</th>
<th>pH Low</th>
<th>pH High</th>
<th>Abrasivity</th>
<th>Departure</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1671</td>
<td>9/26/11</td>
<td>G2-2</td>
<td>49.0-49.8</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 46% 8.0 8.0</td>
<td>56</td>
<td>-8%</td>
<td>11.7 12.4</td>
<td>17</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1672</td>
<td>9/27/11</td>
<td>G2-4</td>
<td>115.6-116.5</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 46% 4.6 5.0</td>
<td>65</td>
<td>-4%</td>
<td>10.3 11.5</td>
<td>17</td>
<td>18%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1673</td>
<td>9/27/11</td>
<td>G2-5</td>
<td>113.3-114.0</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 50% 7.4 7.7</td>
<td>56</td>
<td>-9%</td>
<td>11.5 12.7</td>
<td>17</td>
<td>7%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>M1674</td>
<td>9/27/11</td>
<td>G2-6</td>
<td>142.2-143.0</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 50% 7.5 7.7</td>
<td>63</td>
<td>-4%</td>
<td>10.6 11.9</td>
<td>13</td>
<td>-23%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>M1675</td>
<td>9/28/11</td>
<td>G2-7D</td>
<td>95.6-96.3</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 50% 7.3 7.8</td>
<td>57</td>
<td>-5%</td>
<td>10.9 12.0</td>
<td>17</td>
<td>-2%</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>M1676</td>
<td>9/28/11</td>
<td>G2-9B</td>
<td>97.2-98.0</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 50% 7.8 8.0</td>
<td>61</td>
<td>-3%</td>
<td>10.5 12.0</td>
<td>21</td>
<td>24%</td>
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</tr>
<tr>
<td>M1677</td>
<td>9/28/11</td>
<td>G2-10</td>
<td>47.5-49.0</td>
<td>Tf</td>
<td>Siltstone</td>
<td>100% 50% 7.4 7.9</td>
<td>69</td>
<td>-3%</td>
<td>11.0 11.8</td>
<td>23</td>
<td>8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1690</td>
<td>9/29/11</td>
<td>G2-11</td>
<td>30.8-31.4</td>
<td>Qal2</td>
<td>GP</td>
<td>57% 50% 7.4 7.8</td>
<td>193</td>
<td>-9%</td>
<td>11.2 12.1</td>
<td>110</td>
<td>-7%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>M1691</td>
<td>9/29/11</td>
<td>G2-14</td>
<td>30-31</td>
<td>Qal2</td>
<td>SM/ML &amp; SP</td>
<td>50% 45% 8.1 8.4</td>
<td>201</td>
<td>-7%</td>
<td>11.7 12.4</td>
<td>159</td>
<td>-5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1692</td>
<td>9/29/11</td>
<td>G2-14</td>
<td>32-33</td>
<td>Qal2</td>
<td>SP-SM &amp; SW</td>
<td>48% 50% 8.2 8.3</td>
<td>240</td>
<td>-12%</td>
<td>11.6 12.4</td>
<td>173</td>
<td>-14%</td>
<td></td>
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</tr>
</tbody>
</table>
### Soil Abrasion Test (SAT) Results

#### Regional Connector Project

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Location (Depth)</th>
<th>Formation</th>
<th>Soil Type</th>
<th>SAT Result (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>G2-10 (66.7 to 67.4 ft)</td>
<td>Tf</td>
<td>Siltstone</td>
<td>8.3</td>
</tr>
<tr>
<td>2</td>
<td>G2-2 (63.3 to 64.0 ft)</td>
<td>Tf</td>
<td>Siltstone</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>G2-5 (95.1 to 95.8 ft)</td>
<td>Tf</td>
<td>Siltstone</td>
<td>1.6</td>
</tr>
<tr>
<td>4</td>
<td>G2-6 (108.1 to 108.8 ft)</td>
<td>Tf</td>
<td>Siltstone</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>G2-7D (101.3 to 102.0 ft)</td>
<td>Tf</td>
<td>Siltstone</td>
<td>2.1</td>
</tr>
<tr>
<td>6</td>
<td>G2-9B (65.8 to 66.6 ft)</td>
<td>Tf</td>
<td>Siltstone</td>
<td>1.4</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Weight loss in mg

(2) EL = extremely low; VL = very low; L = low; M = medium; H = high; VH = very high; EH = extremely high

### SUMMARY OF SOIL ABRASION TEST (SAT) RESULTS

**Geotechnical Baseline Report**

**Regional Connector Project**

Figure 10
Soil Types in Qal2 Alluvium

Value indicates the number of available gradation tests per soil type

Layer Thickness in Qal2 Alluvium

Maximum Layer Thickness in Borings (ft)
PARTICLE-SIZE DISTRIBUTION CURVES
FOR Qa1 ALLUVIUM
GEOTECHNICAL BASELINE REPORT

Figure: 7
SUMMARY OF WET DENSITY

GEOTECHNICAL BASELINE REPORT
REGIONAL CONNECTOR PROJECT

Figure 6
SUMMARY OF MOISTURE CONTENT

GEOTECHNICAL BASELINE REPORT
REGIONAL CONNECTOR PROJECT
Summary of Dry Density

Qal1 (Avg = 107.6; N = 305)
Qal2 (Avg = 114.9; N = 207)
Tf (Avg = 93.3; N = 1178)

SUMMARY OF DRY DENSITY

GEOTECHNICAL BASELINE REPORT
REGIONAL CONNECTOR PROJECT

Figure 4
Soil Types in Qal1 Alluvium

Value indicates the number of available gradation tests

Layer Thickness in Qal1 Alluvium

DISTRIBUTION OF SOIL TYPES IN YOUNGER ALLUVIUM

GEOTECHNICAL BASELINE REPORT
REGIONAL CONNECTOR PROJECT

Figure 3
2nd/Hope Station

2nd/Broadway Station

Crossover Cavern

Wye Section

Regional Connector LRT

1st/Central Station

Mangrove Site

7th/Flower Station (existing)

Red Line Tunnel (existing)
Plates