Executive Summary

Introduction

The California Department of Transportation (Caltrans) and the Los Angeles County Metropolitan Transportation Authority (Metro) have proposed a tunnel for extending Interstate (I-) 710 within the area shown in Figure 1-1. The intent of this extension is to alleviate traffic congestion within the area, with a secondary benefit of improving air quality. In 2006, Metro performed a feasibility assessment study of a tunnel to connect I-710 at Valley Boulevard to Interstate (I-) 210. In 2008, Caltrans retained a team led by CH2M HILL to evaluate the geologic conditions on all practical tunnel routes within the project area shown in Figure 1-1. Caltrans Geotechnical Services and the CH2M HILL team jointly conducted the study, including planning of the exploration program, conducting field exploration, and evaluation of geotechnical data. CH2M HILL, Earth Mechanics, Inc. (EMI), Jacobs Associates (JA), and ILF comprise the CH2M HILL team.

The project area has been defined as between I-10 to the south, State Route (SR-) 2 to the west, I-210 to the north, and I-605 to the east. Based on requests from local communities, the study was to be guided by "route-neutral" principles for the extension of I-710. Route-neutral means that all routes receive equal attention and no route for the tunnel is favored over another. It also requires that all practical routes for extending I-710 be considered. As part of the route-neutral concept, Caltrans along with the CH2M HILL team, identified five study zones as shown in Figure 1-2, representing the potential corridors for extending I-710.

The purpose of the geotechnical study is to determine the geologic, groundwater, and seismic conditions within the selected study zones to identify factors that affect the geotechnical feasibility of designing and constructing the proposed tunnel, and to provide a basis for a comparison of the geologic conditions with respect to tunneling design and construction.

For the purpose of this study, the invert (bottom) of the tunnel is assumed to be about 200 feet below ground surface (bgs) and the diameter of the tunnel to be about 50 feet. Our understanding is that a detailed evaluation of the tunnel profile and tunnel configuration will be made during the environmental documentation phase in the future.

The following subsections of this Executive Summary provide a synopsis of the work that was carried out for this project.

Data Collection and Review

This task involved a comprehensive compilation and review of reports and publications from public and private files regarding the surface and subsurface conditions in the five zones. This collection and review task was performed to establish background information for the zones and to guide development of the field exploration program conducted for this phase of the project.

Data were compiled from public agencies including Caltrans, the United States Geological Survey (USGS), the California Geological Survey (CGS), California Department of Transportation (Caltrans), the Southern California Earthquake Center (SCEC), the California Division of Oil and Geothermal Resources (CDOGR), the City of Los Angeles, the Los Angeles County Department of Public Works - Geotechnical and Materials Engineering Division (LACDPW), the California Department of Water Resources (CDWR), the Main San Gabriel Watermaster (MSGW), the Raymond Basin Management Board (RBMB), and the Dibblee Foundation. In addition, unpublished reports by other consultants were reviewed.

Historical and recent aerial photographs were examined to identify linear topographic and vegetation alignments that could be the surface expression of earthquake faults. Black and white photographs within the Fairchild Collection at Whittier College were the principal photographs utilized for the lineament analysis.

Field Exploration Program

Field explorations were conducted to provide additional data for characterizing geologic and groundwater conditions within the tunnel zones. Exploratory borings and geophysical surveys were completed to determine the characteristics of soil/rock units and to estimate the limits of the anticipated geologic formations within the study area.

The field investigation program included core borings, geological reconnaissance, and geophysical surveys. The locations of the borings and geophysical surveys were selected based on the site reconnaissance and review of available geotechnical and geological information. Twenty-five core borings, 17 seismic reflection lines, and 78 multi-channel analysis of surface wave (MASW) tests were performed to characterize subsurface conditions. Table ES-1 summarizes the exploration program, including the previous borings available in each zone.

TABLE ES-1
Exploration Summary

Zone	Number of Previous Borings Available	Number of Borings in Current Study	Number of Seismic Reflection Lines	Number of Surface Wave Lines	Approximate Length of Zone (miles)
1	74	7	4	20	5.0 to 5.5
2	61	5	3	12	5.0 to 5.5
3	40	12	6	24	4.5 to 5.0
4	34	1	2	10	6.0 to 7.5
5	77	0	2	12	9.5 to 11.0

Caltrans Geotechnical Services and CH2M HILL completed the core borings. Caltrans completed 13 borings, and the remaining borings were completed by the CH2M HILL team. Representative samples of soil and rock core were obtained from each of the borings. Selected samples of soil and rock were tested in a laboratory to determine the properties of the different geologic materials encountered during this study. After completion of the drilling, all but three of the borings were converted to piezometers for monitoring groundwater levels.

In situ testing and downhole logging were completed in selected borings to determine the physical characteristics and engineering properties of the in-place soil/rock units. These tests/surveys included pressuremeter tests, caliper tests, acoustic televiewer (ATV), downhole compression and shear-wave velocity measurements, natural gamma and resistivity logging, and packer tests.

Regional Geology, Faulting, and Seismicity

The SR-710 project area encompasses portions of the San Gabriel Valley, the southern San Rafael Hills, the Elysian Hills, and the Repetto Hills areas of the Los Angeles-Pasadena region (Figure 4-1). These areas are within a transition zone between the northwest-southeast-trending Peninsular Ranges physiographic province to the south and the east-west-trending Transverse Ranges province to the north. A detailed description of the regional geology is presented in Section 4 of this report.

The project area is underlain by Quaternary-age alluvium (less than approximately 2 million years old), Tertiary-age sedimentary rocks (approximately 2 to 16 million years old), and ancient crystalline basement complex rocks (igneous and metamorphic rocks older than 120 million years). Table ES-2 presents a generalized stratigraphic column of the geologic units within the project area.

TABLE ES-2
Project-Specific Stratigraphic Column

Geologic Unit/ Formation Name	Map Symbol	Geologic Epoch (Period)	Approximate Age (Years)	Generalized Description
Young Alluvium	Qa, Qg, Qal	Holocene (Quaternary)	0 to 10,000	Sand and gravel with scattered cobbles and boulders and layers/lenses of silt and clay; stream and fan deposits. Poorly defined, lenticular, discontinuous bedding.
Old Alluvium	Qae, Qalo, Qoa, Qof, Qt, Qvoa	Pleistocene (Quaternary)	10,000 to 2 million	Sand and gravel with scattered cobbles and boulders and layers/lenses of silt and clay stream and fan deposits. Poorly defined, lenticular, discontinuous bedding.
Fernando	Tfcg, Tfss, Tfsl, Tfs, Tfr	Pliocene (Tertiary)	2 to 5 million	Predominantly claystone, siltstone and mudstone, with some sandstone and conglomerate. Massive, marine deposits.

TABLE ES-2
Project-Specific Stratigraphic Column

Geologic Unit/ Formation Name	Map Symbol	Geologic Epoch (Period)	Approximate Age (Years)	Generalized Description
Puente (includes Monterey, Modelo, and Unnamed Shale)	Tpsl, Tpsh, Tpds, Tpss, Tpun, Tmy, Tmss, Tmsh, Tmlv	Late Miocene (Tertiary)	5 to 11 million	Claystone, siltstone, diatomaceous siltstone, mudstone, shale, and sandstone. Laminated to thinly bedded, locally thickly bedded. Marine deposits.
Topanga	Ttss, Ttcg, Ttsl, Ttqdc, Ttsc, Ttqdb	Middle Miocene (Tertiary)	11 to 16 million	Siltstone, mudstone, sandstone, and conglomerate, with local volcanic intrusions. Thinly to thickly bedded, marine deposits.
Basement Complex Rocks	Wqd, Wqg	Cretaceous and Pre Cretaceous	120 to 160+ million	Crystalline igneous rocks (diorite, quartz diorite, monzonite, foliated igneous rocks) and layered metamorphic rocks (gneiss).

Several active, potentially active, and inactive faults cross the project area. The active faults identified in the project area include the Raymond fault and the Alhambra Wash fault. The Raymond fault crosses Zones 2, 3, and 4 and is considered to be the most significant fault for the project. The Alhambra Wash fault is projected to cross Zones 4 and 5. The major potentially active faults in the study area are the Eagle Rock, San Rafael, and an unnamed fault zone along the south side of York Boulevard valley. A detailed description of these faults and other faults is provided in Section 4.2.

Groundwater Conditions

Results of the literature reviews performed for this project determined that Zones 1 through 5 straddle five separate groundwater basins of the South Coast Hydrologic Region (CDWR, 2003):

- The Los Angeles River portion of Zone 1, located north of SR-110 and the broad valley located along Eagle Rock Boulevard (westernmost portion of Zone 2) are part of the San Fernando Valley Groundwater Basin.
- The portion of the Los Angeles River located south of SR-110, the Arroyo Seco, and all other drainages located in the eastern portions of Zones 1 and 2 and the southwestern portion of Zone 3 are part of the Coastal Plain of the Los Angeles Groundwater Basin – Central Sub-basin. A portion of Eagle Rock Basin is located in the northwest region of Zone 2.
- Zone 3 straddles three separate groundwater basins: the Central Sub-basin in the southwest; the San Gabriel Valley Groundwater Basin in the southeast; and the Raymond Groundwater Basin in the north.

- Zone 4 is located within two groundwater basins: the San Gabriel Valley Groundwater Basin in the south and the Raymond Groundwater Basin in the north.
- Finally, Zone 5 is located exclusively in the San Gabriel Valley Groundwater Basin.

Groundwater levels vary considerably across the study area and occur as deep aquifers and as shallow perched zones. Several of the faults within the study area act as groundwater barriers with different levels on either side of the fault. The alluvium has the potential for inflow during tunneling excavations unless control measures are implemented. The underlying rock formations contain groundwater but are not aquifers. However, isolated bodies of groundwater might be encountered within faulted and/or fractured zones in the rock. Impact to groundwater should be kept minimal during tunnel construction and operation. Tunnel construction technology should be selected so that there will be minimal impact to groundwater resources. Further details regarding groundwater conditions are provided in Section 5 of this report.

Hazardous Materials

The potential for hazardous materials within the zones was evaluated using information from the 3 Initial Site Assessments (ISAs) for the 13 borings drilled by Caltrans and a limited Environmental Site Assessment (ESA) performed for the project study area.

The ISAs and the limited ESA identified several sites within the five study zones that have soil and groundwater contamination issues (see Figure 6-1).

The most significant contamination issues are the existence of the two National Priorities List (NPL) sites located within Zones 1, 4, and 5. These two NPL sites (also known as Superfund sites) are the San Fernando Valley Superfund Site (Zone 1) and the San Gabriel Valley Superfund Sites (Zones 4 and 5). The sites have known groundwater contamination.

Most of the groundwater contamination is due to chlorinated volatile organic compounds (VOCs) that are the result of past industrial activities in the area. Therefore, the potential of encountering the contaminated groundwater should be considered in tunnel design, and contamination containment should be part of the construction method.

In addition to the above NPL sites, a large number of small soil and groundwater contamination sites are identified in each zone. These sites are expected to be less important than the NPL sites for tunnel design and construction because of the small size of most sites and the depth of the tunnel. Further details about hazardous materials are provided in Section 6 of this report.

Description of Zone Geologic Conditions

A summary of the geologic conditions determined for each zone in this preliminary evaluation is discussed below.

Zone 1 Geologic Conditions

Based on the results of this evaluation, the key geologic factors for this zone in terms of tunnel design and construction considerations (along the generalized geologic profile shown in Plate 5) are:

- Subsurface conditions are fairly uniform in most of this zone, consisting mainly of weak sedimentary rocks of the Puente Formation. Typically, the formation in this zone consists mostly of sandstone, siltstone, and shale. Locally, there is a potential for encountering alluvium (or soil) near the portals and in shallow cover beneath the Los Angeles River.
- Rock mass is generally only slightly fractured. Although several inactive faults will likely be encountered, no active faults are mapped within this zone.
- Most of the rock is considered weak to moderately weak, though there is a potential for stronger cemented layers and concretions within the Puente Formation.
- The groundwater table within the alluvium is shallow (approximately 20 to 50 feet below grade) in parts of this zone. The rock mass is not expected to transmit large quantities of groundwater into the tunnel, except for possibly beneath the Los Angeles River. In this area, recharge from the river could lead to higher sustained groundwater inflows. High groundwater inflows are also expected in the saturated alluvium at the portal areas.
- The water-bearing alluvial materials along the Los Angeles River within the limits of Zone 1 are considered to be susceptible to liquefaction (CDMG, 1999d) in areas where groundwater is near the ground surface and loose cohesionless soils occur.
- One Superfund site is located in the northwest portion of the zone, which could be a source of contaminated soil and groundwater in the tunnel. This concern applies mainly to the portal zone and approach excavations for the tunnel.
- There is a relatively high potential of encountering naturally occurring gas (methane and/or hydrogen sulfide) in this zone.

Zone 2 Geologic Conditions

Based on the results of this evaluation, the key geologic factors for this zone in terms of tunnel design and construction considerations (along the generalized geologic profile shown in Plate 6) are:

- Subsurface conditions are fairly uniform in this zone, consisting mainly of weak sedimentary rocks of the Puente and Topanga Formations. The Puente Formation includes sandstone, siltstone, and shale and is found in the southern portion of the zone. Siltstone and sandstone of the Topanga Formation is expected in the northern portion (Plate 6). In addition, depending on the location of the tunnel, sandstones and conglomerates of the Fernando Formation may also be encountered. Locally, alluvium (or soil) is expected near the portals.

- Rock is generally slightly to moderately fractured. Several inactive faults will be encountered in this zone (Plate 1). The active Raymond fault crosses the zone at the northwestern end and could be encountered within the portal area and/or the approach excavation for the tunnel. The Raymond fault is capable of generating earthquakes in the range of M_W (earthquake moment magnitude) 6 to 6.7, and producing displacement at the tunnel level of about 2 to 4 feet.
- Most of the rock is considered weak to moderately weak, although there is a potential for stronger cemented layers and/or concretions in the Puente and Topanga formations.
- Groundwater is shallow in alluvial valleys (approximately 20 feet below grade), but it is believed to be ponded on top of bedrock. The rock mass generally has low permeability, and therefore is not expected to transmit large quantities of groundwater into the tunnel except for possibly in the saturated alluvium of the portal areas.
- Some minor soil and groundwater contamination, associated with two gas stations, could result in hazardous materials being encountered in the portal and tunnel approach excavations.
- CDMG (1999d) identifies the alluvial materials within the drainages that dissect Zone 2 as potentially susceptible to liquefaction in areas where the groundwater location is in loose cohesionless soils.
- There is a relatively high potential of encountering naturally occurring gas (methane and/or hydrogen sulfide) in this zone.

Zone 3 Geologic Conditions

Based on the results of this evaluation, the key geologic factors for this zone in terms of tunnel design and construction considerations (along the generalized geologic profile shown in Plate 7) are:

- Subsurface conditions vary in this zone at tunnel depth including unconsolidated soil deposits (alluvium), weak sedimentary rocks (Puente, Fernando and Topanga formations), and strong granitic basement rocks (diorite or quartz diorite).
- Rock strength varies widely in this zone from the sedimentary rocks (which are very weak to weak) to the higher strength granitic rocks. There is a potential for strong cemented layers and/or concretions in the Puente and Topanga Formations. Strong volcanic flows, dikes, or sills are also present in the unnamed fault zone south of the Raymond fault. Additionally, cobbles and boulders can be expected in the northern portion of this zone, within the Topanga Formation conglomerate and the alluvium.
- The Raymond fault and San Rafael fault are groundwater barriers. Depth to groundwater varies from as shallow as 50 feet bgs near the Raymond fault to more than 100 feet in both the northern and the southern parts of the zone. Groundwater elevations vary by more than 100 feet on opposite sides of the San Rafael fault. Rock formations are not expected to transmit large quantities of groundwater into the tunnel. However, ground inflows are expected when tunneling in the saturated alluvium.

- There is one active, two potentially active and several inactive faults in this zone. The Raymond fault is active and is capable of generating earthquakes in the range of M_W 6 to 6.7, and producing displacement at the tunnel level of about 2 to 4 feet. The activity of the San Rafael and Eagle Rock faults and the unnamed fault zone are unknown; potentially active and inactive faults may act as groundwater barriers.
- CDMG (1999d) identifies the alluvial materials within the drainages that dissect Zone 3 as potentially susceptible to liquefaction in areas where the groundwater location is in loose cohesionless soils.
- Two sites with minor soil contamination are located at the northern limits of this zone and could impact the project depending on the actual portal location.
- There is a moderate potential of encountering naturally occurring gas (methane and/or hydrogen sulfide) in this zone, as the southern portion of the zone is underlain by Puente Formation (Plate 7).

Zone 4 Geologic Conditions

Based on the results of this evaluation, the key geologic factors for this zone in terms of tunnel design and construction considerations (along the generalized geologic profile shown in Plate 8) are:

- Subsurface conditions are fairly uniform in this zone at tunnel depth and consist mainly of Old Alluvium with a limited amount of sedimentary rocks (Fernando and Puente Formations) near the southern end of the zone. The majority of the tunnel is expected to be in the Old Alluvium. The Old Alluvium is generally expected to be uncemented coarse sand and gravel interbedded with sand, silt, and clay. The Fernando Formation is expected to consist of siltstone and claystone. The Puente Formation is expected to be composed of clayey siltstone and silty claystone (commonly called mudstone), as well as some sandstone.
- The Old Alluvium exhibits the strength characteristics of a soil with low cohesion (i.e., low undrained shear strength). The Fernando and Puente Formations are expected to be moderately weak to weak rock. Cobbles and boulders can be expected in the Old Alluvium. Strong cemented layers and concretions may be encountered in the Puente Formation.
- The active Raymond fault and Alhambra Wash fault cross this zone, and could cause ground rupture during a large earthquake. Several inactive faults within the Tertiary-age rocks cross the southwestern portion of this zone.
- Most of the tunnel in this zone would be at or below the water table. Depth to groundwater varies; however, it could be as shallow as 100 feet below grade. The Raymond fault is a groundwater barrier; historically, groundwater is shallowest on the north side of this fault. Groundwater inflows could occur while tunneling below the groundwater table in the saturated alluvium.
- CDMG (1999d) identifies the alluvial materials within Zone 4 as potentially susceptible to liquefaction in areas where the groundwater location is in loose cohesionless soils.

- One Superfund site is located approximately at the southwestern end of this zone. The United States Environmental Protection Agency (USEPA) is currently evaluating the extent of the contamination and will subsequently complete a Record of Decision (ROD). Six other sites with various levels of soil contamination are also present in this zone close enough to impact the tunnel. Most of these sites are located in the vicinity of the northern portal.
- There is a low potential for encountering naturally occurring gas in this zone due to the limited portion of the tunnel in the Puente Formation.

Zone 5 Geologic Conditions

Based on the results of this evaluation, the key geologic factors for this zone in terms of tunnel design and construction considerations (along the generalized geologic profile shown in Plate 9) are:

- Subsurface conditions are fairly uniform in this zone at tunnel depth and consist mainly of Old Alluvium with a limited amount of sedimentary rocks (Fernando and Puente Formations) near the southern end of the zone. The majority of the tunnel is expected to be in the Old Alluvium. The Old Alluvium is generally expected to be uncemented coarse sand and gravel interbedded with sand, silt, and clay. The Fernando Formation is expected to consist of siltstone and claystone. The Puente Formation is expected to be composed of clayey siltstone and silty claystone (commonly called mudstone), as well as some sandstone.
- The Old Alluvium exhibits the strength characteristics of a soil with low cohesion (i.e., low undrained shear strength). The Fernando and Puente Formations are expected to be moderately weak to weak rock. Cobbles and boulders can be expected in the Old Alluvium. Strong cemented layers and concretions may be encountered in the Puente Formation.
- The Alhambra Wash fault is considered active and projects into this zone. The inactive Workman Hill fault projects toward the western portion of the zone.
- Most of the tunnel in this zone would be at or below the groundwater table. Depth to groundwater varies; however, the depth could be as shallow as zero feet below grade at some locations. Groundwater inflows could occur when tunneling below the groundwater table in alluvium. Additionally, many aquitards exist throughout this zone.
- The perennial Rio Hondo and San Gabriel Rivers, as well as recharge lakes, are located in the eastern portion of this zone.
- As a result of the shallow historical highest groundwater level, and based on the composition of the shallow alluvial materials that occur along the eastern portion of Zone 5, potentially liquefiable conditions have been identified for the general area. In addition, based on the potential presence of lakes in the easternmost portion of the zone and the perennial character of the Rio Hondo and San Gabriel Rivers, potentially liquefiable conditions are anticipated in the eastern portal area (CDMG, 1998a, 1998b, 1999a, and 1999b).

- One Superfund site is located in the south-central portion of the zone, which could be a source of soil and groundwater contamination in this zone. Seven other sites with various levels of soil and groundwater contamination are also present in this zone close enough to potentially impact the tunnel. Most of these sites are located near the eastern portal or central portion of this zone.
- There is a low potential for encountering naturally occurring gas in this zone due to the limited portion of the tunnel in the Puente Formation.

Geotechnical Considerations for Tunnel Design and Construction

Information collected during this project was interpreted relative to the design of construction of tunnels with each of the zones. Results of these reviews are summarized as follows:

Geologic Conditions in Zones 1 and 2

Tunnel excavations in Zones 1 and 2 will likely be in the Puente Formation, Topanga Formation, and Fernando Formation depending on the location of the tunnel through the study zones. These formations consist of sedimentary rocks that all have similar characteristics. There is some inherent variability within these formations, such as occasional cemented layers and concretions within the sandstone.

Tunnel excavations in Zones 1 and 2 are considered to be routine with modern tunneling equipment, such as the tunnel boring machines (TBMs) used for the Northeast Interceptor Sewer Line (NEIS) project. Several tunnels have been successfully constructed through these or similar formations in the Los Angeles area. The uniformity of geological conditions in Zones 1 and 2 will simplify construction planning. The potential impact of the cemented layers and concretions will need to be addressed in the selection/design of tunnel excavation equipment, which might reduce tunnel advance rates; however, tunnels have been successfully completed in the past in these formations.

Geologic Conditions in Zone 3

Variable geologic conditions are anticipated within Zone 3. Alluvium (soil), low-strength rock, and high-strength rock are all expected to be encountered in this zone. The bedrock material is expected to consist of the weak rocks of the Puente Formation, Fernando Formation, and Topanga Formation as well stronger basement complex rocks. Strong cemented layers or concretions may be present in the sedimentary rock formations; cobbles and boulders may be encountered in the alluvium and conglomerate of the Topanga Formation in the northern portion of the zone.

A tunnel through Zone 3 will encounter varied geologic conditions, including several geologic formations with a wide range of strength and other physical properties. The basement complex rocks in the northern part of the alignment are stronger rocks that would likely require greater effort to excavate than the sedimentary rocks previously discussed.

Although Zone 3 presents the most varied lithology of all the zones, excavation of a tunnel in this zone could be done with a specialized machine suited for variable geologic conditions or using a combination of excavation methods.

Geologic Conditions in Zones 4 and 5

Zones 4 and 5 consist mostly of alluvium with some weak sedimentary rocks of the Fernando Formation and Puente Formation near the southern and western portals, respectively. The majority of the proposed tunnels in each of the zones will be excavated through the alluvium. The alluvium is generally expected to be uncemented coarse sand and gravel interbedded with sand, silt, and clay with potential for cobbles and boulders.

Tunneling through alluvium involves a greater potential for surface settlement than tunneling through rock. Alluvium is the main formation in Zones 4 and 5, and in the eastern portion of Zone 3. Alluvium also may be present in short reaches near the portals in Zones 1, 2, and 3. It is expected that the majority of the soil at tunnel depth will be saturated, which increases the potential for instability and surface settlement. Specialized TBMs with face control, using earth-pressure balance (EPB) or slurry methods, can control ground loss and surface settlement. The design of specialized TBMs and tunnel operations become more complex as the groundwater head increases. A tunnel excavation method for Zones 4 and 5 would need to be designed for the saturated alluvium, which contains cobbles and boulders, as well as the sedimentary rock at the southern (Zone 4) and western (Zone 5) portals.

Surface excavations in alluvial soils will be required for the tunnel portals in Zones 1 through 5. Construction of these excavations will require groundwater control and ground stabilization by dewatering, permeation grouting, jet grouting, or a watertight excavation support system (such as slurry diaphragm wall, target piles, or deep soil mix walls). Without these controls, the potential for high groundwater inflows, loss of ground, and surface settlement exist. Although the geology of Zones 4 and 5 is not as variable as that of Zone 3, it is not as uniform as the geology of Zones 1 and 2.

Active and Inactive Faults

There are steeply dipping, inactive faults in all five zones. Tunneling across these faults is expected to include excavation in fractured rock, clay gouge, and variable groundwater conditions. The groundwater head can vary considerably across a fault if it is acting as a groundwater barrier. Therefore, the potential for groundwater inflows could be expected to vary dramatically across a fault zone. Fault zones are typically less than 50 feet wide; however, fault zones over 1,000 feet wide exist as well. Additionally, a tunnel crossing a fault could encounter a wider zone of faulting if the tunnel crosses the trend of the fault obliquely. A TBM equipped with proper capabilities can normally excavate these fault crossings without major difficulty, although the rate of excavation is normally less than the rate in rock.

The active Raymond fault is expected to cross the portal area in Zone 2 and to cross a potential tunnel in Zones 3 and 4. Special considerations will need to be made for excavating through a fault and lining a tunnel in an active fault zone. For example, the Metro Red Line in Los Angeles was excavated through the Hollywood fault. An oversized tunnel was excavated in the fault zone to accommodate fault offset (see Section 12.0). This oversize

excavation is something that is typically used in an excavation through a fault zone to accommodate a certain amount of offset during fault rupture.

Additionally, when mining a tunnel through a fault, there is a possibility of squeezing conditions in the clayey fault gouge. Special procedures might be required to advance the TBM shield through the clayey zone and provide permanent ground support. The final lining of a tunnel will need to be designed for the expected seismic conditions. Similar considerations should be provided for tunnel crossings of the Alhambra Wash fault, and perhaps the Eagle Rock and/or San Rafael faults and the unnamed fault zone.

Contaminated Soil and Groundwater

The Superfund sites in Zones 1, 4, and 5 have the potential to impact the tunnel excavation and muck-disposal operations. Plumes of contaminated groundwater and soil contaminated by the groundwater could be encountered during tunnel excavation. Although the severity of the hazardous conditions might be less in a tunnel than on the ground surface, handling hazardous materials in the confinement of a tunnel could be challenging. The contaminated soil, water, and vapors must be controlled to protect the workers and avoid contaminating adjacent areas. The contaminated soil and water must be conveyed to treatment facilities and transported to final disposal sites.

Naturally Occurring Gas

Naturally occurring gas could be encountered in the Puente Formation in Zones 1 through 5. Although this was not confirmed in borings, tunneling experience in the vicinity of Zone 2 in the Puente Formation suggests that gas could be present in the subsurface. Appropriate precautions should be considered for safety of personnel operating the TBMs.

Other Tunnel Considerations

The competent sedimentary formations typically result in the need for relatively modest tunnel support requirements. Nevertheless, typically a full perimeter support system (that is, steel ribs and timber lagging, or an expanded or fixed-diameter precast concrete segmental lining) is provided to control loss of ground, particularly in developed urban areas. Ground support in open excavations is expected to be provided by cast-in-place concrete box structures. There is the possibility of encountering squeezing conditions during excavation of a tunnel within clayey fault gouge. Special procedures might be required to advance the TBM shield through the clay gouge zone and provide permanent ground support. Groundwater inflows can be controlled in the alluvium with the use of a bolted gasketed precast concrete segmental lining.

Comparison of Zones

Key ground characteristics for tunneling, such as subsurface conditions, groundwater, contamination, faulting and seismicity, and potential for gassy conditions, were compared between each zone and are summarized in Table ES-3.

TABLE ES-3
Comparison of Zones

Zone	Approximate Length of Zone (miles)	Number of Geologic Formations	Predominant Geologic Formation(s)	Percent of Zone in each Formation	Number of Reported/ Mapped Faults	Number of Active Faults Crossing Zone	Potential for Gassy Conditions[a]	Percent of Zone under Superfund Sites
1	5.0 to 5.5	2	Puente	80 to 90	5	0	H	5 to 10
			Alluvium	10 to 20				
2	5.0 to 5.5	4	Puente	70 to 80	7	1	H	0
			Topanga	10 to 15		(NW Portal)		
			Fernando	5 to 10				
			Alluvium	5 to 10				
3	4.5 to 5.0	5	Topanga	30 to 40	7	3[b]	M	0
			Alluvium	10 to 20				
			Puente	20 to 30				
			Fernando	5 to 10				
			Diorite	10 to 20				
4	6.0 to 7.5	3	Alluvium	70 to 80	5	2	L	5 to 15
			Fernando	10 to 15				
			Puente	10 to 15				
5	9.5 to 11.0	3	Alluvium	75 to 85	3	1	L	5 to 30
			Fernando	10 to 15				
			Puente	5 to 10				

Notes:
[a] H-High, M-Moderate, L-Low
[b] Includes potentially active faults

Concluding Remarks

Information in this report provides a preliminary summary of geotechnical conditions within the five zones being considered for the SR-710 tunnel. Sections in this report contain detailed information about the geology, faults, seismicity, groundwater, contaminated materials, and potential for gassy conditions within each zone. This information provides a basis for evaluating the geotechnical feasibility of tunneling within each of the zones. Based on the information collected and reviewed as part of the current geotechnical study, tunneling is geotechnically feasible in all five zones. Geotechnical feasibility implies that it is feasible to construct a tunnel in the geologic formations expected, including the geotechnical conditions associated with these formations using currently available tunneling technologies. Section 12 discusses several tunnel projects and the construction technologies available for conditions similar to those present within the zones under consideration for this project.