SECTION 9

Site Conditions for Zone 3

9.1 General

As depicted on Plates 1 and 7, Zone 3 extends north-south from the northern terminus of I-710 through the cities of Los Angeles, Alhambra, South Pasadena, and Pasadena approximately to the intersection of I-210/ SR-134. Zone 3 is approximately 4.5 to 5.0 miles long and 2.4 miles wide at its northern limit (Plate 1). The delineation of Zone 3 anticipates a connection between the northern terminus of I-710 and SR-134, I-210, or SR-710 to the north. The general location of Zone 3 is shown in Figure 9-1.

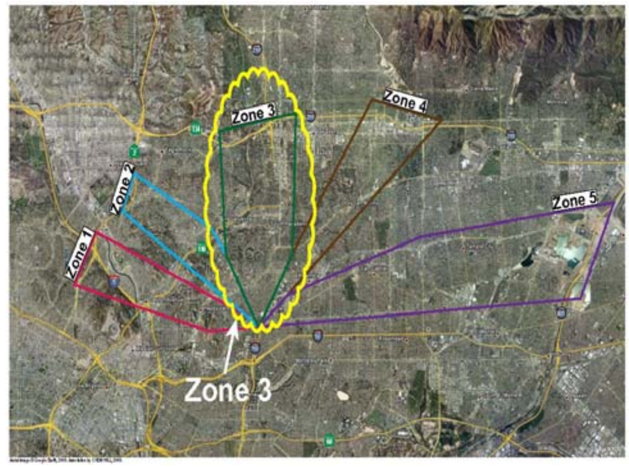

Figure 9-1. Zone 3 Location Map.

9.2 Existing Developments

Existing developments within Zone 3 consist primarily of single-family residential structures with some apartment and condominium buildings and local businesses along some of the major arterial streets. The northern part of the zone in the Pasadena area has a much greater number of commercial enterprises than the southern two-thirds, which is largely residential. The Huntington Hospital is in the northern part of the zone. Few of the buildings are multistory buildings over three or four stories high.

The SR-110 (Pasadena Freeway) passes through the northern part of the zone, entering from the west along the Pasadena/South Pasadena city boundary and extending northerly around Raymond Hill where shortly thereafter it changes into Arroyo Parkway, which continues northerly to downtown Pasadena. The Metro light rail (Gold Line) track crosses the northern part of the zone diagonally, somewhat parallel to SR-110 (Pasadena Freeway) and then north into Pasadena just west of Arroyo Parkway.

Other important surface roads that cross Zone 3 in a general east-west direction include, from south to north, Valley Boulevard, Alhambra Avenue, Mission Road, Main Street, Huntington Drive Road, Mission Street, California Boulevard and Colorado Boulevard. Fair Oaks Avenue and Orange Grove Boulevard run in a north-south direction in the northern portion of the zone. In addition, railroad tracks cross the southwestern part of the zone between Mission Road and Valley Boulevard.

Based on the densely urbanized nature of the area, it is anticipated that a large network of very shallow underground utilities are present directly underneath the surface streets.

However, during our investigation we did not become aware of any major underground utility or other infrastructure that could potentially impact the excavation of a tunnel at an anticipated depth of 200 feet.

9.3 Zone Geology

9.3.1 Physiography

The regional physiography of the area surrounding Zone 3 is described in Section 4.1 (Regional Geology). About half of Zone 3 is within the western part of the San Gabriel Valley, and half consists of the San Rafael Hills and the Repetto Hills (Figure 4-1).

The Repetto Hills and San Rafael Hills in the western part of the zone are characterized by small- and medium-sized rounded hills and intervening valleys. The maximum relief in the Repetto Hills of Zone 3 is generally in the 200- to 300-foot range. Although not of great relief, many of these hills have steep slopes.

A major geomorphic feature in Zone 3 is Arroyo Seco, which extends through Pasadena down the west-central part of Zone 3 and veers southwesterly near the Pasadena/South Pasadena city boundary. The arroyo continues southwesterly and exits Zone 3 to the west near the central part of the zone. Arroyo Seco is a steep-walled, flat-floored ravine about 500 to 1,000 feet wide and 50 feet deep. The arroyo widens into a relatively flat plain in South Pasadena. This change in relief is related to the Raymond fault scarp, which crosses through the central part of Zone 3. This scarp is a result of vertical fault displacement on the Raymond fault. Relief across the scarp is about 40 or 50 feet but has been highly modified by urban development.

The San Gabriel Valley, which encompasses the eastern part of Zone 3, is essentially a flat, gently south-sloping surface consisting of ancient (Pleistocene age) alluvial fans, flood plain, and basin fill alluvium. Elevations in the northern part of the Valley are in the 800- to 900-foot range, whereas in the south, elevations are in the 400- to 500-foot range. The flatness of the San Gabriel Valley surface is interrupted by several small hills and knolls, which are outliers of the Repetto Hills and San Rafael Hills. The largest of these hills is Raymond Hill, which is about 90 feet high. A smaller knoll just northwest of Raymond Hill is called Grace Hill. The other knolls are not named and are relatively subtle features that go largely unnoticed by the general public. Although subtle, these small knolls are important for understanding the geology of the region because they are bedrock exposures that reveal information regarding the surrounding subsurface geology.

9.3.2 Stratigraphy

The majority of Zone 3 rocks consist of Tertiary age (2 to 16 million years old) marine sedimentary rocks (Table 4-1). From oldest to youngest, these rocks are the Topanga Formation, Puente Formation, and Fernando Formation. Plate 1 shows the distribution of these units throughout Zone 3. Plate 7 illustrates the subsurface relationships of these various rock types along a north-south transect in the central part of Zone 3. However, it is important to recognize that the geologic profile is idealized and simplified to represent the entire zone. Zone 3 has the most diverse geology of all the five zones, illustrating the structure and stratigraphy of Zone 3 in a single geologic profile is complicated by the fact that the geological character changes considerably from the west to the east side of Zone 3. The west side consists primarily of rock formations, whereas the east side has thick alluvial deposits over the rock formations at depth.

Quaternary-age alluvium occurs as narrow valley fill in the valleys of the Repetto Hills and over the entire San Gabriel Valley. Alluvium is encountered at the north portal zone, where it is approximately 500-600 feet thick, and at the south portal zone where it is much thinner and on the order of 0 to 50 feet. Alluvium at the north portal is expected to consist of clay, silt, and sand with a major component of gravels and cobbles and some boulders, all composed of igneous and metamorphic rocks. The alluvium in the small valleys of the Repetto Hills is more silty and clayey with a smaller proportion of sand and gravel.

The principal formation in the southernmost portion of Zone 3 is the Fernando Formation which consists of soft and weak, massive claystone and siltstone. The Fernando Formation overlies the Puente Formation in the southern part of Zone 3. The contact is sharp and possibly unconformable (Dibblee, 1992).

The central part of Zone 3 is composed of the Puente and Topanga Formations separated by a fault on the north flank of the South Pasadena Anticline. The Puente Formation ranges from soft to moderately hard, well-bedded, siltstone, mudstone and sandstone. Minor local zones of carbonate-cemented beds form hard rocks. Such hard cemented beds comprise no more than about 5 to 10 percent of the formation. The Puente Formation in the southern portion of Zone 3, includes white to very pale-brown, soft, siliceous shale and thin-bedded mudstone. These rocks have a high percentage (sometimes nearly 100 percent) of diatoms or volcanic ash particles. The Topanga Formation occurs in the northern half of Zone 3. The Topanga Formation includes a wide variety of rock types ranging from coarse-grained rocks such as breccia, conglomerate, and sandstone to fine-grained sandstone and siltstone with minor claystone (mudstone). The part of the Topanga Formation south of the Raymond fault is predominantly thin- to thick-bedded siltstone with thin interbeds of sandstone and shale. These rocks are commonly very similar to those of the Puente Formation and various authors have in fact mapped them as Puente Formation. The Topanga Formation north of the Raymond fault is predominantly sandstone, conglomerate, and breccia. The Topanga Formation also has intrusive volcanic rocks. For example, a 10-foot-thick zone of hard volcanic rock was encountered in previous Metro study within boring EMI-2, immediately south of the Raymond fault (Plate 7).

The northern part of Zone 3, north of the San Rafael fault, consists of the Cretaceous age (approximately 120 to 160 million years ago) basement complex that is generally mapped in exposures of the San Rafael Hills as Wilson Diorite or Quartz Diorite (Dibblee, 1989c; Lamar, 1970).

The geologic conditions discussed in the 2006 Metro study for the three (then-proposed) tunnel alignments in this zone (PBI, 2006) are similar to those determined in this study. The Metro study indicated that the tunnel would be excavated through geologic terrain typified by folded and faulted bedrock composed of a variety of Tertiary-age sedimentary rocks and Mesozoic-age crystalline igneous and metamorphic rocks (basement complex rocks), both overlain locally by unconsolidated Quaternary-age alluvium.

9.3.3 Structural Geology

As shown in Plate 7, the geologic strata are deformed into a series of folds and faults. Most of the folds and faults are continuations of geologic structures in the Santa Monica Mountains and the Elysian Hills to the west. These structures trend southeasterly through the Repetto Hills and continue below the flat-lying Quaternary alluvium of the San Gabriel Valley. The major folds are the Elysian Park Anticline and the South Pasadena Anticline.

The folding shown in Plate 7 is generalized and simplified. In reality, there are numerous small-scale folds within the larger fold trends. Frequent changes in bedding orientation due both to folding and faulting should be expected at tunnel depths. Such changes in bedding orientation are portrayed in the stereonets derived from the ATV logs obtained at 10 of the borings drilled in this zone.

Many of the faults are intraformational features, meaning that the faults offset rocks of the same type. However, some of the faults could comprise highly fractured or clayey gouge zones.

9.4 Faulting

The faults of most interest to the proposed tunneling are the active faults that might result in ground rupture and displacement during an earthquake, and faults that might generate strong shaking of project facilities. The faults of most interest for Zone 3 are the Raymond fault, the San Rafael fault, and the Eagle Rock fault. As described in Section 4.2, the Eagle Rock fault and San Rafael fault are considered in this study to be separate and discrete features following the mapping of Lamar (1970). Depending upon final route selection, the Eagle Rock fault might not be crossed within Zone 3, but the Raymond and San Rafael faults will be intersected by tunnel alignments within this zone.

The Raymond fault is capable of generating earthquakes in the magnitude range of 6 to 6.7. Fault rupture displacement at the tunnel level can be expected to be in the 2- to 4-foot range. This displacement should be in a left-lateral oblique sense with the ground on the north side of the fault shifting to the left and upward relative to the south side. The Raymond fault in Zone 3 appears to be much narrower than to the east in Zone 4. In Zone 3, the fault may be a few tens of feet to a few hundred feet wide. However, the Raymond fault might be associated with another fault or several faults to the south near Monterey Road (Plate 7), the existence of these unnamed faults is uncertain. If these southern faults exist, the tunnel could go through a zone of faulting about 2,000 to 3,000 feet wide.

The San Rafael fault occurs on the north side of Raymond Hill and separates basement complex rock from the Topanga Formation (Plates 1 and 7). Published geologic maps (Lamar, 1970) show two surface traces. The aerial photograph lineament analysis and drilling performed for this project suggest that the more likely location is the northern branch. Borehole R-09-Z3B3 encountered a light-gray clay fault gouge about 85 feet thick. This material is primarily sheared and pulverized basement diorite rock. The large thickness of the gouge encountered in the boring is believed to represent the down-dip thickness (that is, the boring was drilled down a steeply dipping fault zone). If so, the width of the fault zone during tunneling would be expected to be approximately 20 to 40 feet wide. The San Rafael fault is considered potentially active and according to empirical relationships, could produce an earthquake with a maximum magnitude of about 6.0 (see Section 4.2).

The Eagle Rock fault is about 2,000 feet south of the San Rafael fault (Plates 1 and 7). The fault extends southeasterly into the Topanga Formation rocks in the knolls west and south of Raymond fault. Seismic-reflection line Z3-G2 (Appendix C.2) extends across this trace and indicates folding and faulting. Although the relationships are not clear, the seismic-reflection data are compatible with a steeply north-dipping fault. In addition, surface wave soundings Z3-S6 and Z3-S7 were conducted at the northern and southern ends of seismic line Z3-G2, respectively. S-wave velocity models for these soundings indicate that there is significant lateral velocity variation along the seismic line, possibly resulting from a fault bisecting seismic line Z3-G2. The Eagle Rock fault is considered potentially active. According to the Caltrans Seismic Design Criteria (2009) fault database, the Eagle Rock fault could produce an earthquake with a maximum magnitude of about 6.8.

9.5 Groundwater and Surface Water Conditions

The rocks in the Repetto Hills within Zone 3 are generally considered to contain little groundwater (Eckis, 1934) and this has been verified by permeability testing as part of this project. However, important groundwater aquifers do occur in the sand and gravel deposits of the San Gabriel and Raymond Basins, where they are the principal sources of water. The deep aquifers are overlain by perched groundwater bodies.

The historically highest groundwater in the sand and gravel deposits is shallowest on the north side of the Raymond fault where historically it has seeped to the ground surface and formed small ponds and springs. According to (CDMG, 1998d) the water level has been as shallow as 10 feet. The depth to water gradually increases both northerly and southerly to about 200 feet in the south part of Zone 3 and to about 100 feet below the ground surface in the northern part.

Plate 7 illustrates the variation of the groundwater conditions along Zone 3. Plate 7 also shows the groundwater contours in Zone 3. Groundwater depth varied from 13 to 158 feet bgs in the 11 piezometers installed as part of the current study in Zone 3.

Groundwater depths for 16 of the 24 surface wave soundings (Z3-S1, Z3-S6, Z3-S7, Z3-S9 to Z3-S11, Z3-S13, Z3-S14, Z3-S16 to Z3-S18 and Z3-S20 to Z3-S24) were estimated from simple seismic refraction analysis of MASW or seismic reflection shot records with groundwater modeled in the 10- to 56-foot depth range. Groundwater depths for four soundings (Z3-S2 to Z3-S5) were interpreted from nearby borehole velocity logs and interpolated as necessary. Groundwater in the vicinity of these surface wave soundings was estimated to occur in the 98- to 148-foot depth range. The MASW profiles were not long enough to image depth to groundwater at four of the sounding locations (Z3-S8, Z3-S12, Z3-S15, and Z3-S19).

No major springs are known to occur in the upland bedrock areas within Zone 3. Although there are no large surface water recharge areas within the zone, normal inflow of water from the ground surface will occur during periods of rainfall.

9.6 Hazardous Materials

The ISAs and the limited ESA identified 11 open cases located within Zone 3. The locations of these sites are shown in Figure 6-1. No regional groundwater contamination sites (NPL site) were identified in Zone 3.

Twelve sites with localized groundwater or soil contamination are located within Zone 3. Two of these sites, summarized below, are located in proximity (that is, less than 0.5 mile) to a portal zone for Zone 3:

- Kaiser Permanente, 393 Walnut Street, Pasadena, California (Map ID: 393 Walnut). This site is located within 0.5 mile of the northern portal area for Zone 3. The site has soil impacted with gasoline. This site is considered to have a potential to impact the project because it is located within the northern portal zone for Zone 3.
- Demolition Contractors, 5600 Alhambra, Avenue, Los Angeles, California (Map ID: 556/22). This site is located within 0.5 mile of the south portal zone for Zone 3. The site is suspected of having soil contamination. This site is considered to have a potential to impact the project because it is located within the southern portal zone for Zone 3.

Ten other sites with localized soil or groundwater contamination were identified in the central portion of Zone 3. They are considered to have a low potential impact to the project because they are greater than 0.5 mile from a portal zone and are at a depth of less than 150 feet bgs. Additional details for each of these sites, including the corresponding soil and/or groundwater contaminants, their corresponding concentrations, and depth of maximum concentration is included in the ESA in Appendix F.

9.7 Potential for Naturally Occurring Gas

Monitoring during drilling revealed potential gassy conditions in only one boring (R-09-Z3B11). However, the Puente Formation is a major petroleum-bearing unit in the Los Angeles region, so there is risk of encountering petroleum in this formation. The risk is considered lower than in Zones 1 and 2 as the reach of the Puente Formation is shorter in Zone 3.

9.8 Geotechnical Considerations for Tunnel Design and Construction

9.8.1 Key Ground Characteristics

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, groundwater 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; it is capable of generating earthquakes in the range of Mw 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 the Puente Formation (Plate 7).

9.8.2 Preliminary Assessment of Tunneling Considerations

Information presented above and in previous sections of this report was used to perform a preliminary assessment of tunnel design and construction requirements, as summarized below.

Tunnel excavation in this zone would be through several different rock types. As discussed above, the tunnel excavation methods would need to address a range of conditions including alluvium (soil), weak sedimentary rocks, and stronger granitic rocks. This would require the use of tunneling equipment adaptable to this range of conditions or a flexible approach that allowed methods to be changed to suit the geology.

Regardless of the excavation methods, provisions should be made for the inherent variability in the Puente and Topanga Formations, such as the cemented layers and concretions and variability between sandstone, siltstone, claystone, mudstone, and shale. These layers should be considered in the design of tunnel excavation equipment. Additionally, the design of the tunnel excavation equipment should consider the size and strength of the cobbles and boulders.

As discussed above for Zone 1, in the alluvium (or soil) that will be encountered close to the northern portal area as the tunnel rises to the ground surface, loss of ground and surface settlement will be an important factor in the selection of tunneling methods and equipment. As discussed in previous sections, groundwater control measures will be required for the saturated alluvium present in the vicinity of the portals. The need for special ground improvement measures or specialized tunneling machines for tunneling though saturated alluvium is the same as discussed for Zone 1. The support requirements and lining necessary for the formations in Zone 3 will be similar to those for Zone 1 in Section 7.8.2.

This zone has active and inactive steeply dipping faults. As indicated on the geologic cross section (Plate 7), these faults contribute to the variability of geologic conditions. Tunneling through these faults will require control of groundwater; excavation of fractured, poor-quality rock; and potential clayey fault gouge. It is known that the Raymond fault is a groundwater barrier. Other fault zones also have the potential to act either as groundwater barriers or as conduits.

In addition, ground displacements may be generated by active faults. This will require special design features in order to allow the tunnel lining to accommodate the ground displacement without rupturing. Typically, this is accomplished by overexcavating the portion of the tunnel in the fault zone and constructing the tunnel within this vault. This approach was used to construct the Metro Red Line tunnel crossing of the Hollywood fault (see Section 12.1.3).

Ground support, to control ground loss, and in turn surface settlement, similar to those discussed for the other zones would be needed for the tunnel through rock. In the saturated alluvium, a watertight initial support system as well as final lining would be required such as a bolted and gasketed precast concrete segmental lining system. At the fault crossings, where clay gouge may be present, ground squeezing may lead to much higher ground loads than in other portions of the tunnel. Squeezing ground refers to the time-dependent convergence that occurs around a tunnel excavation when the ground is overstressed. In addition, naturally occurring gas may be present in the southern portion of the zone and provisions for worker safety similar to those mentioned in Zones 1 and 2 should be considered during design.

Based on the information collected and reviewed in Zone 3, tunneling is feasible in this zone from the geotechnical standpoint. Subsurface conditions and other tunneling considerations discussed for this zone should be further evaluated in more detailed tunnel design studies.