SECTION 13

Comparison of Zones

13.1 Geologic Conditions

This section compares key ground characteristics for tunneling, such as subsurface conditions, groundwater, faulting and seismicity, hazardous materials, and potential for gassy conditions, for each zone. These characteristics are also summarized in Table 13-1. Representative geologic profiles of the five zones are presented in Plate 10. This comparison of geologic conditions is used in later discussions as a basis for summarizing a number of tunnel design and construction issues, including tunnel excavation methods, seismic response, groundwater control, tunnel support and lining, settlement potential, and special hazardous materials considerations.

13.1.1 Stratigraphy

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.

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 as strong to very strong diorite. Strong cemented layers or concretions may be present in the sedimentary rock formations, and cobbles and boulders may be encountered in the alluvium and conglomerate of the Topanga Formation at the northern portion of the zone.

Zones 4 and 5 both consist mainly of Old Alluvium with some weak sedimentary rocks of the Fernando Formation and Puente Formation near the southern portals. Majority of the tunnel in these two zones will be excavated through unconsolidated Old 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.

The differences in stratigraphy will be an important consideration for the final selection of tunnel construction methods within specific alignments; however, as discussed later in this section, the stratigraphy does not preclude successful tunnel construction.

13.1.2 Groundwater

Groundwater is approximately 20 to 50 feet bgs within the alluvium in Zones 1 and 2. Shallow groundwater depth could affect portal construction on the western end of the tunnel within Zones 1 and 2. The potential for water inflows within the bedrock formations is expected to be low, except where the tunnel encounters porous strata, fractured or

fault rock. The potential for water inflow could be moderate to high at fault crossings due to the presence of fracture zones.

Variable groundwater depths should be anticipated in Zones 3 and 4 because of the presence of the Raymond fault in these zones. The Raymond fault acts as a groundwater barrier in Zones 3 and 4. A bedrock discontinuity was identified in Zones 4 and 5; this feature acts as a potential groundwater barrier, resulting in variable groundwater depths. The depth to groundwater varies in the alluvium of Zones 4 and 5; however, it is anticipated that the majority of the tunnel excavation would be in saturated ground.

Based on these observations, groundwater will represent an important consideration for the design, construction, and operation of the tunnel along each alignment. Groundwater is encountered during most tunnel projects, and therefore is not considered a unique issue. Alternatives for groundwater control are discussed later in this section.

13.1.3 Faulting and Seismicity

There are steeply dipping, inactive faults in all five zones. The active Raymond fault crosses near the northwest end of Zone 2. The Raymond fault, as mapped in Zone 3, is a groundwater barrier. The Raymond fault crosses Zone 4 as well where it is also a groundwater barrier. A potential fault displacement of 2 to 4 feet is expected during a major seismic event for the Raymond fault.

The potentially active San Rafael and Eagle Rock faults are also mapped across Zone 3, as are several inactive faults. The fault displacement for these potentially active faults is expected to be less than 4 feet. The Alhambra Wash fault is considered active and is currently mapped south of Zone 5; however, for the purpose of this study, this fault is projected from Zone 4 into Zone 5.

The occurrence of both active and inactive faults represents important tunnel design and construction considerations. Alignments crossing active faults with the potential of several feet of seismic-related fault displacement will require special design and construction methods to accommodate movement. As discussed previously in this report, these design and construction methods have been used elsewhere within the Los Angeles area.

13.1.4 Hazardous Materials

The major contamination issues are the existence of the two National Priorities List (NPL) sites 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 Site (Zones 4 and 5). In addition to the NPL sites, there are several localized soil and groundwater contamination sites within all of the zones (shown in Figure 6-1) that have the potential to impact the project, depending on the final tunnel alignment.

Tunnel alignment below areas with NPL listings will pose a particularly difficult situation in terms of being able to demonstrate that contaminated soil and groundwater will not pose a risk during construction and operations. While it may be technically possible to construct tunnels within this area, the risk could be beyond what can be accepted.

13.1.5 Naturally Occurring Gas

Based on conditions encountered in other projects in the area, it appears that naturally occurring gas may be encountered in the Puente Formation. The potential for gassy conditions in the other formations is considered low at this time. Because the Puente Formation extends for significant distances in Zones 1 and 2, the potential for encountering gas in these two zones is higher than the other zones. There is a moderate potential for naturally occurring gas in Zone 3 due to the extent of the Puente Formation. Likewise, there is a low potential for naturally occurring gas in Zones 4 and 5.

The gassy conditions encountered during the sewer and subway tunnel construction in the Los Angeles area are described in Section 12.0 of this report. Such conditions are not unusual, especially in Los Angeles, and special tunneling equipment, air monitoring, and safety procedures have been developed to deal with these conditions in a safe manner.

13.2 Tunnel Excavation Methods

In view of the stratigraphy and groundwater conditions noted above, tunneling methods will likely vary from zone to zone, and could vary within a zone. Factors that will affect the selection of the tunneling method are identified below:

Tunnel excavations in the Puente Formation, Topanga Formation, and Fernando Formation that are anticipated in Zones 1 and 2 are considered to be routine with modern tunneling equipment, such as the TBMs used for the 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 impact of the cemented layers and concretions would have to be addressed in the selection/design of tunnel excavation equipment, which might reduce tunnel advance rates; however, construction of a tunnel in these formations has been done previously.

An excavation through Zone 3 will encounter varied geologic conditions. Zone 3 includes soil, low-strength rock, and high-strength rock. The low-strength Puente Formation and Topanga Formation are similar to those described above for Zones 1 and 2. Cobbles and boulders present in the alluvium and Topanga Formation conglomerate may reduce the excavation rate. The diorite in the northern part of the alignment is a harder rock that would excavate differently 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 different types of geology or a combination of excavation methods.

Tunneling through alluvium involves a greater potential for surface settlement than tunneling through rock. Alluvium is the main material in Zones 4 and 5, and it may be present in short reaches near portals in Zones 1, 2, and 3. It is expected that the majority of the soil will be saturated at tunnel depth, which increases complexity of the excavation. Specialized TBMs with face control, including gated cutterheads and muck handling using earth-pressure balance or the slurry method, can manage ground loss and control 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 have

to be designed for the saturated alluvium, which contains cobbles and boulders, as well as the sedimentary rock at the southern end of the tunnel.

Open excavations in alluvial soils will likely be necessary in the tunnel portals in all of the zones. This construction will require groundwater and ground control by dewatering, permeation grouting, jet grouting, and installation of ground supports. Without these controls, there is the potential of high groundwater inflows, loss of ground, and surface settlement.

13.3 Seismic Considerations

There are steeply dipping, inactive faults in all five zones. Tunneling through these faults is expected to include fractured rock, clay gouge, and varied groundwater conditions. The groundwater head and the potential for groundwater inflow commonly change during a fault zone crossing. A TBM can normally excavate these fault crossings without major difficulty, although the rate of excavation is normally less than the rate in unfaulted rock. A precast concrete segmental initial (outside) tunnel lining (installed as a TBM advances) is expected to provide the ground support in the alluvium, Puente Formation, Topanga Formation, Fernando Formation, diorite, and the inactive fault zones. Ground support in the crossing of active faults may be require a special lining similar to the Metro Red Line Project crossing of the Hollywood fault described in Section 12.1.3. Ground support in the open excavations is expected to be provided by cast-in-place concrete box structures.

The Raymond fault is expected to cross near the portal area in Zone 2 and to cross the tunnel in Zones 3 and 4. Special considerations will be required for excavating through a fault and lining the tunnel in an active fault zone. For example, the Metro Red Line in Los Angeles was excavated through the Hollywood fault. An oversized vault was excavated in the fault zone to accommodate fault offset (see Section 12.1.3). This oversize excavation is something that is typically used in an excavation through a fault zone to accommodate a certain amount of displacement due to fault rupture.

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

13.4 Groundwater Control

Groundwater control measures will be important in saturated alluvium where moderate to heavy inflows could be expected. The potential for high groundwater inflows is expected for tunneling within saturated alluvium; such conditions are expected in all zones. However, saturated alluvium is the predominant material at tunnel depth in Zones 4 and 5. Additional heavy to moderate inflows could be expected in the fault zones (active and inactive), which could provide conduits for groundwater. In addition to the alluvium, there could be localized groundwater inflows when excavating in the other formations which are not considered to be aquifers. Porous Strata, fracture zones or fault zones may locally yield small to large inflows.

Specialized techniques would need to be implemented locally in Zones 1 through 3 where saturated alluvium or fault zones are expected, and over the majority of Zones 4 and 5 to mitigate unwanted groundwater inflows. These specialized methods are expected to include use of earth pressure balance machines or slurry systems to counter the water pressure. In addition to specialized excavation methods, the lining of the tunnel is dependent on the groundwater conditions.

Groundwater inflow will be an important consideration for most potential portal locations. Groundwater pumping systems; ground improvement by dewatering, permeation grouting, or jet grouting; or combinations of these can be used to control water.

In addition to consequences inside the excavation, groundwater inflows could impact the groundwater regime of the project area if inflows are not properly controlled. These inflows also must be controlled to prevent the lowering of groundwater in the areas surrounding the excavation.

13.5 Tunnel Support and Lining

The stability of the sedimentary rock formations and hard rock formations generally results in the need for modest tunnel support requirements in most areas; however, additional requirements may be needed for some areas, as summarized below.

Especially in this urban area, a full perimeter support system should be provided to control any loss of ground. Examples include steel ribs with timber lagging or a precast concrete segmental lining. Locally, where there is fault gouge or indications that there is ground squeezing potential, the ground support may need to be more robust.

In the saturated alluvium, which occurs mostly in Zones 4 and 5, a watertight initial support system as well as final lining would be required such as a bolted and gasketed precast concrete segmental lining system.

13.6 Settlement Potential

Face instability during excavation could lead to a loss of ground and the potential for measurable surface settlement. Control of such conditions is possible by using systematic ground improvement in the portal areas by dewatering, permeation grouting, or jet grouting. In the tunnel, specialized tunneling machines (such as earth-pressure balance or slurry machines) could be used to control these conditions. The magnitude of surface settlement depends on the depth of the tunnel (relative to its diameter), as well as the physical characteristics of the ground and the amount of ground lost at the tunnel face. These concerns are limited to the portions of the tunnel in alluvium, because ground movements associated with tunnel construction in the bedrock can be controlled without the need for ground improvement measures. Zones 4 and 5 would be excavated primarily through saturated alluvium; therefore, tunnel construction in these zones has the greatest risk for surface settlement.

13.7 Special Hazardous Materials Considerations

The Superfund sites in Zones 1, 4, and 5 have the potential to impact the tunnel excavation and muck disposal operations. Although these sites are located well above the tunnel, plumes of contaminated groundwater and soil contaminated by the groundwater might be encountered in the tunnel excavation. Although the severity of the hazardous condition might be less in the 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. This would likely reduce the advance rate of the excavation in the contaminated areas, as well as increase the cost for disposal of the contaminated muck.

If hazardous materials or gases are expected, continuous air monitoring would be necessary in the working area of the tunnel. In addition, workers could be required to wear respirators and other personal protective equipment (PPE) to safeguard against exposure to these contaminants depending on the level of exposure. To control against contaminated conditions, specialized tunneling methods such as a slurry TBM might be used. Slurry TBMs use closed pipes. The contaminated material would be transported to the portal within the slurry pipes. The workers would not be exposed to the VOCs because the excavated material would be contained inside the pipes.

The VOC-impacted muck would need to be stockpiled separately from the “clean” muck, tested, and disposed of at a landfill designated to receive hazardous materials. In addition, the presence of contaminated groundwater minimized the ability to dewater at the portals. Ground improvement such as jet grouting and/or ground freezing may be necessary to control and prevent the movement of contaminated groundwater during portal and approach excavation operations.

TABLE 13-1
Comparison of Zones

Zone	Approximate Length of Zone (miles)	Number of Geologic Formations	Predominant Geologic Formation(s)	Percentage of Zone in each Formation	Number of Reported/ Mapped Faults	Number of Active Faults	Potential for Gassy Condition [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