SECTION 3

Field Investigation

3.1 General

The field investigation program included rotary-wash core borings, geological reconnaissance, and geophysical surveys. The field investigation program was jointly conducted by the Caltrans Geotechnical Services and CH2M HILL team. The purpose of the investigation is to characterize the subsurface material and determine the engineering properties of the soil and rock within each zone. The locations of the borings and geophysical surveys were selected based on the site reconnaissance and review of available geotechnical and geological information. The locations of the borings and the geophysical survey are shown on the Geotechnical Maps (Plates 1 and 2) and Surface Wave Testing Location Maps (Plates 3 and 4). The investigation also incorporated borings previously drilled within the study area by others. The details of the site reconnaissance/geologic mapping, field investigation, field testing, in situ testing, seismic geophysical testing, and the laboratory testing are presented below.

In developing the exploration program, the following factors that influence tunneling were considered:

- Type of material at tunnel level
- Variability of the subsurface conditions within the zone, including whether mixed face conditions are expected
- Groundwater conditions
- Presence of major geologic structures in each zone, such as faults and folds
- Potential for naturally occurring gas
- Potential for contaminated soil, rock, and/or groundwater

In addition to the 25 borings, the exploration program also included in situ testing and groundwater monitoring within the borings, and two types of geophysical testing. The in situ testing and groundwater monitoring are described in Section 3.4 of this report. The seismic geophysical testing, which is described in Section 3.5, involved the following two types of seismic geophysical tests:

- Seismic reflection testing to identify the location and orientation of selected active and inactive faults, the contact between alluvium and bedrock, and depth to groundwater.
- The surface-wave seismic method to obtain information on depth of alluvium and the dynamic characteristics of the underlying material.

3.2 Geologic Reconnaissance

Project team members conducted a site reconnaissance within the study area to identify suitable boring and geophysical survey locations. The selected locations were photographed to document existing surficial conditions. Limited geologic reconnaissance within the project study area was also conducted to verify and refine existing geological data. Due to the urbanized nature of the study area, geologic field reconnaissance was limited to areas with rock outcrops. The geologic field reconnaissance consisted of spot-checking regional geologic maps available for the study area. Geological maps utilized during this study included those published by Lamar (1970), Dibblee (1989a, 1989b, 1989c, 1998, and 1999), Tan (2000), and Yerkes and Campbell (2005). Geotechnical maps covering Zones 1 through 3 are presented on Plate 1; Zones 4 and 5 are covered on Plate 2.

3.3 Field Exploration

3.3.1 Review of Previous Exploration

Subsurface information utilized in the current study is based on the review of previous investigations performed by others within the project study area, including the LOTB sheets in the as-built plans of the highway bridge structures within the project study area. Review of existing borings provided subsurface information in all five zones and helped to identify data gaps and additional borings needed in this study.

The number of available existing borings in each zone is shown in Table 3-1. Because there were numerous existing borings and subsurface information, only one new boring was drilled in Zone 4 for this investigation. No borings were drilled in Zone 5 because the existing boring coverage is considered to be adequate for characterization at this time. Appendix A.2 presents the previous boring logs and as-built LOTB sheets for the borings referenced in Table A-2, which summarizes the previous borings and as-built LOTB information.

TABLE 3-1
Exploration Summary

Zone	Number of Available Previous Borings	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	25	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

3.3.2 Current Exploration

Twenty-five borings were drilled between January 6 and May 1, 2009 using the rotary wash method for the current exploration program. All borings were drilled vertically, except Boring R-09-Z1B2, which was drilled at an inclination of approximately 60 degrees. The purpose of the inclined boring was to intercept the Elysian Park fault. During the planning phase of the work, several other borings were considered for inclined drilling, but these could not be performed because the inclination would have advanced the borings beneath private properties.

Figure 3-1. Drilling Operation at Boring Location R-09-Z3B12.

The geotechnical drilling program was divided between Caltrans Geotechnical Services and the CH2M HILL team. The Caltrans drilling services from Sacramento, California, drilled 13 borings. Cascade Drilling, Inc. of La Habra, California, drilled 12 borings under subcontract to CH2M HILL. The borings were designated as R-09-ZaBb, where "Za" represents the zone and "Bb" represents the boring number within each zone.

- Seven borings were drilled in Zone 1.
- Five borings were drilled in Zone 2.
- Twelve borings were drilled in Zone 3.
- One boring was drilled in Zone 4.
- No borings were drilled in Zone 5 for this current study.

Because of obstruction to drilling, Boring R-09-Z2B2 was terminated at 282 feet, which is shorter than the planned depth of 400 feet. Inclined Boring R-09-Z1B2 was terminated at 291 feet due to drilling difficulties; the planned depth this boring was 525 feet. The boring locations are shown in Plates 1 and 2. Figure 3-1 shows the drilling operation at boring location R-09-Z3B12. Table 3-1 summarizes the exploration program by zone. Also included in this table is the available relevant previous boring information for each zone.

After completion of the drilling, all but three of the borings (R-09-Z2B2, R-09-Z3B4, and R-09-Z1B2) were converted to piezometers to enable determination of groundwater depth. Boring R-09-Z2B2 was not converted to a piezometer because of obstruction to drilling. Inclined Boring R-09-Z1B2 also was not converted to a piezometer. Because of future proposed improvements at this location, Boring R-09-Z3B4 was not converted to a piezometer. These three borings were backfilled with bentonite grout and finished to match the existing surface conditions. Each piezometer was fitted with a locking cap and traffic-rated well box, except boring locations R-09-Z1B8 and R-09-Z3B2, where standpipes were used. The piezometer construction details are provided in Appendix B. The boring locations were surveyed after the completion of the drilling operations.

Rock quality designation (RQD) values provided in the boring logs are based on the sum of intact core pieces that were 4 inches or greater in length between two natural discontinuities. The majority of core samples obtained in this study are soft and weak and commonly do not meet the "sound core" definition for the American Society for Testing and Materials (ASTM) standard RQD method (ASTM D 6032). These RQD values should not be used to evaluate the rock mass quality for soft and weak rock. The RQD values reported for hard rock in Zone 3 are valid for such analysis. However, the density of fracturing (reflected by different RQD percentages) in weak and hard rock may play a significant role in the secondary permeability of those materials and may directly influence the occurrence of groundwater and its flow.

Boring information, including exploration number, ground-surface elevation, exploration depth, and groundwater table elevation are summarized in Table A-1. Drilling and sampling details are provided in Appendix A.1 along with detailed boring logs. Photographs of rock core samples are presented in Appendix A.3.

3.4 Field Testing

The exploration work included downhole (in situ) testing and groundwater monitoring. In situ testing and logging were conducted to investigate the characteristics of the rock mass. Laboratory testing of core specimens characterizes the rock material but not the discontinuities of the rock mass. Field and laboratory test information are necessary to develop a complete picture of subsurface conditions. The geophysical survey was performed by Geovision Geophysical Services of Corona, California, and Caltrans Geophysics and Geology Branch. The pressuremeter testing was conducted by In Situ Testing of Snohomish, Washington, and the packer testing was conducted by Cascade Drilling, Inc. of La Habra, California, all under subcontract to CH2M HILL. Groundwater depths were initially measured upon completion of drilling, prior to installation of piezometers.

3.4.1 In Situ Testing and Logging

In situ testing was performed on vertical borings. The in situ tests included downhole geophysical measurements, caliper logging, ATV recordings, pressuremeter testing, and packer testing. The following subsections provide brief descriptions of the tests conducted in the borings. Additional information from these tests, including the results, is provided in Appendices B, C, and D of Volumes 2, 3, and 4.

3.4.1.1 Downhole Geophysical Testing and Logging

Downhole geophysical testing and logging included caliper logging, seismic velocity measurements, natural-gamma logging, and ATV recordings. The results of this testing and logging was used in combination with core logs to identify rock type, geologic structures, and the engineering properties of the rock mass. Caltrans Geophysics and Geology Branch preformed resistivity logging on borings drilled by Caltrans drilling services. The downhole geophysical tests were performed in accordance with ASTM D 5753, Standard Guide for Planning and Conducting Borehole Geophysical Logging. Downhole geophysical testing was not performed in inclined Boring R-09-Z1B2 and in Boring R-09-Z2B2. Results of the downhole geophysical tests are provided in Appendix C.1.

3.4.1.2 Pressuremeter Testing

A prebored mono-cell pressuremeter was used to record the response of the loading and unloading of the material being tested. Pressuremeter test results are used to estimate the in situ modulus of the rock mass including a sampling of the discontinuities. Figure 3-2 shows the pressuremeter set up at boring location R-09-Z1B5.

Figure 3-2. Pressuremeter set up at Boring Location R-09-Z1B5.

To characterize each formational material, two to three pressuremeter tests were performed on each formational material. Forty-six pressuremeter tests were performed for the current study to obtain representative in situ measurements for each formation. A summary of pressuremeter tests is provided in Table D-1. Recovery and RQD information is presented in this table to indicate the type of material in which the pressuremeter results were obtained. Results of pressuremeter tests are presented in Appendix D.1.

3.4.1.3 Packer Testing

Permeability of the rocks was measured by packer testing, which involves injecting water under pressure into the rock through the walls of the borehole. A double packer assembly consisting of two packers was lowered into the borehole to the desired testing interval to determine the permeability of the material. The testing interval (packer spacing) was kept generally at 10 feet. Observations of the elapsed time and the volume of water pumped at different pressures were recorded.

Generally, four tests were performed in each boring. Two tests were performed above the anticipated tunnel crown, one test below the tunnel invert, and one test within the anticipated tunnel zone. Packer inflation pressure was adjusted for the depth and the rock type and corresponding geologic structure. A summary of the packer tests is presented in Table D-2 and the results are included in Appendix D.2.

3.4.2 Groundwater Monitoring

At the completion of in situ testing, all but three borings were converted to a piezometer. Inclined boring R-09-Z1B2 was not converted to a piezometer. Vertical Boring R-09-Z2B2 was not converted to a piezometer because of obstruction to drilling. Boring R-09-Z3B4 also was not converted to a piezometer because of planned future proposed improvement at this location. The piezometers were constructed to record the depth of the groundwater table over a period of time. Groundwater measurement was taken in the piezometers approximately 2 to 4 months after installation of the piezometers. Because some of the piezometers were not developed, groundwater may not have been stabilized at the time of reading. These piezometers should be developed in future phases of the project for groundwater level measurements. A summary of piezometer installations and groundwater elevations is presented in Table B-1.

3.5 Seismic Geophysical Testing

Two types of seismic geophysical tests were performed as part of the SR-710 exploration program: (1) seismic reflection testing and (2) MASW and ReMi testing. The objective of the geophysical studies was to characterize subsurface geology, structure, and geotechnical conditions up to a target depth of approximately 300 to 400 feet bgs at various locations within each of the five study zones.

3.5.1 Seismic Reflection Testing

Seismic reflection testing was conducted to collect compressional wave velocity (P-wave) information at locations identified by the CH2M HILL team. P-wave reflection data were acquired along each profile using an IVI™ MiniBuggy vibratory source. Seventeen seismic-reflection tests were performed as part of this study. Typical length of the seismic line was approximately 1,600 to 1,900 feet. One seismic line (Z4-G1) was extended to 3,500 feet to evaluate the Raymond fault zone. Figure 3-3 shows the seismic-reflection testing set up for the SR-710 Tunnel Technical Study. Locations of these lines are shown in Plates 1 and 2. A summary of seismic-reflection testing is presented in Table C-1 in Appendix C.2.

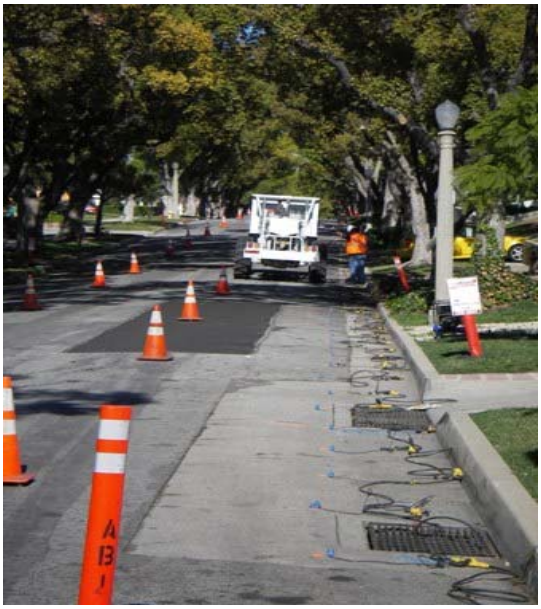

Figure 3-3. Seismic Reflection Testing.

3.5.2 MASW and ReMi Testing

This testing method involved collection of shear-wave velocity data using the MASW and ReMi testing methods. The MASW uses an active source to obtain shear wave velocity (S-wave) data, while the ReMi procedure uses ambient vibration data to collect S-wave velocities. This technique is ideally suited to two-dimensional shear wave imaging, with data collected in a roll-along manner similar to that of the seismic reflection technique. Typical depths of measurement range up to 200 feet.

S-wave data have many potential applications related to site characterization including correlation of seismic properties between boreholes; estimating depth to bedrock (providing there is sufficient contrast in velocity between bedrock and overlying sediments), estimating N-value using empirical correlations between S-wave velocity and N-value, estimation of excavatability or rippability of rock.

Seventy-eight MASW tests were performed for this study. Test locations are provided in Plates 3 and 4. Summary of test locations are presented in Table C-2; the results of the MASW testing are presented in Appendix C.3.

3.6 Laboratory Testing

The properties of the soil and rock within the five zones were estimated on the basis of laboratory testing performed on similar soil and rock as part of other projects, and by conducting laboratory tests collected as part of the SR-710 Tunnel Technical Study. Results of the laboratory tests were used to measure the properties of the soil and intact rock. These properties, in combination with the rock mass properties from in situ testing and logging, are used to estimate the requirements for tunnel design and construction.

3.6.1 Previous Laboratory Test Data

Limited applicable laboratory test results were obtained from previous borings and as-built LOTB sheets. The available laboratory test data were generally performed to confirm the visual classification of the soil and rock at shallow to only moderate depths below the ground surface, and therefore originates from much shallower depths than is of interest for this project. In most cases, the depths of exploration for buildings and bridges are terminated once the formational materials are encountered, and therefore would provide information useful to only the tunnel portal component.

The geotechnical reports prepared for the two tunnel projects (NEIS and Avenue 45 Sewer) within the project study area provide laboratory test information on formational material that is relevant to the current study. EMI (2006) summarizes laboratory information for the Metro SR-710 tunnel feasibility assessment study specifically relevant to tunnel design. Information from these previous laboratory test results are presented in Appendix E.2.

3.6.2 Current Laboratory Test Results

A laboratory test program was developed to provide data on relevant engineering properties of the soil and rock that exist within the project area. The intent of the testing program was to supplement the limited data that were obtained from previous exploration programs. The focus of the testing was on characterization of soil and rock properties from the likely depth of the tunnel within each zone.

Selected soil and rock samples were tested for classification, moisture content and density, compressibility, strength, rock characteristic, corrosion potential, and petrographic analysis. The CH2M HILL team selected samples for testing based on formational type, rock weathering and hardness, sample depth related to tunnel, and portal location.

The laboratory tests were performed by the following companies:

- AP Engineering and Testing, Inc., Pomona, California
- Colorado School of Mines, Golden, Colorado
- Earth Mechanics, Inc., Fountain Valley, California
- Geoscience Consultants, Las Vegas, Nevada
- Geo Test Unlimited, Nevada City, California
- Leighton Consulting, Inc., Irvine, California
- Sierra Testing Laboratories, Inc., El Dorado Hills, California
- Spectrum Petrographics, Inc., Vancouver, Washington

All testing was performed in general accordance with the applicable ASTM standards (ASTM, 2008) or California Test Methods (CTMs) (Caltrans, 1990a). Figure 3-4 shows a typical triaxial laboratory testing setup. The type of tests performed on the soil and rock samples collected from the borings are summarized in Table 3-2.

The results of the laboratory testing are presented in Appendix E.1. A table at the beginning of Appendix E.1 presents a summary of the index, physical, strength, and corrosion parameters.

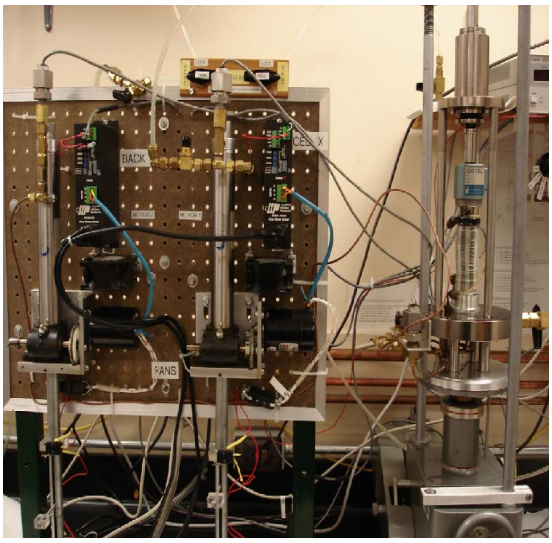

Figure 3-4. Triaxial Laboratory Testing.

TABLE 3-2
Summary of Laboratory Test Methods

Laboratory Test	Test Method
Moisture and Dry Density	ASTM D2937
Moisture Content	ASTM D 2216
Grain Size Distribution	ASTM D422
Atterberg Limits	ASTM D4318
Expansion Index	ASTM D 4829
Consolidation	ASTM D 2435
Direct Shear (Consolidated Drained)	ASTM D3080
Unconsolidated Undrained Triaxial Compressive Strength	ASTM D 2850
Cerchar Abrasivity Index	N/A
Petrographic Thin Section Analysis	N/A
Slake Durability	ASTM D 4645
Point Load Index	ASTM 5731
Elastic Moduli with Compressive Strength	ASTM D7012
Unconsolidated Undrained Triaxial Shear	ASTM D2850
Corrosion Suite (Sulfate, Chloride, pH, Resistivity)	CTM 417, 422 and 532/643