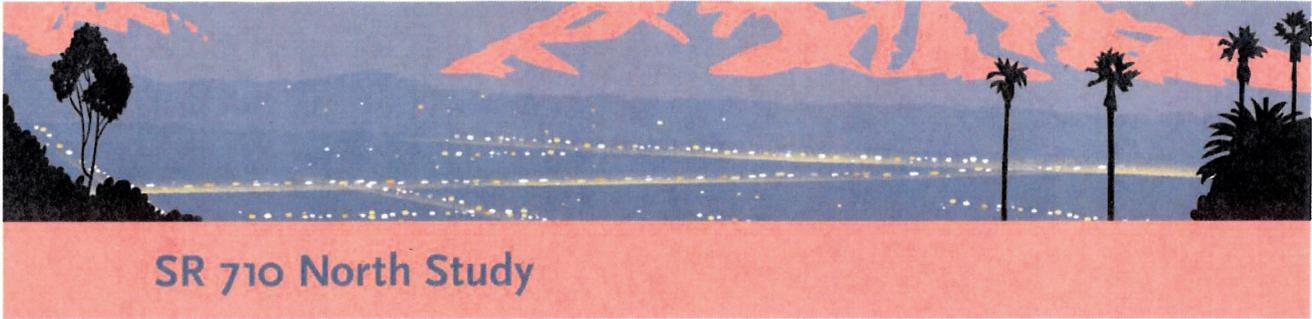


Appendix F
Preliminary Earthquake Acceleration Response
Spectra Technical Memorandum



SR 710 North Study

TECHNICAL MEMORANDUM

Preliminary Earthquake Acceleration Response Spectra, SR 710 North Study, Los Angeles County, California

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 PROJECT NUMBER: 428908



Introduction

This technical memorandum presents the results of preliminary seismic ground motion evaluations completed as part of environmental documentation for the State Route (SR) 710 North Study. Five Alternatives are being evaluated during the ongoing environmental documentation process. The five Alternatives are No-Build, Transportation System Management/ Transportation Demand Management [TSM/TDM], Bus Rapid Transit [BRT], Light Rail Transit [LRT], and Freeway Tunnel. Figure 1 shows the general vicinity of the SR 710 North Study area.

Seismic ground motions are an important consideration during the environmental assessment for two of the SR 710 North Study Alternatives: the Freeway Tunnel and the LRT. Both Alternatives, briefly described below, will be located in tunnels over much of their lengths:

- **Freeway Tunnel (Dual Bore Option):** The proposed Freeway Tunnel Alternative includes approximately 60-foot-diameter, 4.2-mile-long twin bored tunnels and cut-and-cover tunnels at both ends of the bored tunnels. The freeway tunnels will extend from the existing southern stub of SR 710 in Alhambra, north of Interstate (I)-10, and connect to the existing northern stub of SR 710, south of the I-210/SR 134 interchange in Pasadena. The invert of each tunnel will be roughly parallel to the ground surface at an average depth of about 200 feet below ground surface (bgs), except at the portals where the tunnels daylight.
- **LRT:** The LRT Alternative will consist of twin bored tunnels approximately 4.5 miles long, and will be located between Valley Boulevard on the south and the existing Fillmore Station on the Metro Gold Line on the north. The LRT Alternative will also consist of approximately 3.0 miles of overhead structure from the Metro Civic Center Station on the south to Valley Boulevard on the north. The LRT tunnel invert depth is approximately 80 feet bgs; the diameter is approximately 20 feet.

The two proposed tunnel alignments are located in a seismically active region of southern California and will cross through active fault zones, necessitating the development of earthquake ground motions along these alignments for design of the tunnels and aboveground structures. The discussion and development of fault rupture



displacements at the tunnel crossing locations are presented in a separate technical memorandum titled, *Fault Rupture Evaluation for the SR 710 North Study, Los Angeles County, California* (CH2M HILL and Earth Consultants International [ECI], 2013).

This technical memorandum presents preliminary peak ground accelerations (PGAs) and peak ground velocities (PGVs) for the conceptual design of the proposed tunnels and other project features within the Freeway Tunnel and LRT Alternatives, as required for the environmental assessment. In addition, 5 percent damped acceleration response spectra (ARS) were also developed for the elevated LRT sections. These ground motion parameters were developed using the probabilistic and deterministic ground motions obtained from the United States Geological Survey (USGS) and California Department of Transportation (Caltrans) Web sites. The ground motions were developed based on the subsurface conditions interpreted from the limited geotechnical field investigations conducted by CH2M HILL during the current study and the SR 710 Tunnel Technical Study (CH2M HILL, 2010), and therefore are preliminary.

These preliminary ground motion parameters will be updated in the future once a decision is made on the final Alternative for development. Additional field investigations will be conducted in future phases of the project to provide more specific geotechnical information for the selected Alternative. The results of these future field investigations will be used to update and verify these parameters after the preferred Alternative is selected.

Previous CH2M HILL Field Investigation

The SR 710 Tunnel Technical Study field investigation was conducted from January to May 2009 (CH2M HILL, 2010). The program included nine core borings, geophysical surveys along three seismic reflection lines, and 14 multichannel analysis of surface wave (MASW) tests in the vicinity of the proposed LRT and Freeway Tunnel Alternatives. The typical depth of the core borings was about 400 feet; the lengths of the seismic line ranged from approximately 1,600 feet to 1,900 feet; and the depth of measurement for the MASW was up to 200 feet. The information obtained from these explorations and previous studies was used to develop a preliminary interpretation of geologic and groundwater conditions along the proposed Alternatives.

SR 710 North Study Field Investigation

The current field investigation program involved explorations along the tunnel alignments for the LRT and Freeway Tunnel Alternatives, and in proximity to faults that have been identified near these tunnel alignments. The purpose of these additional explorations was to supplement previous geotechnical information by collecting additional geologic and groundwater information specific to the Freeway Tunnel and LRT alignments.

The following types and depths of investigations were carried out:

- **LRT Alignment:** Six hollow-stem auger (HSA)/rotary wash (RW) borings were drilled to a depth of approximately 100 feet bgs for the LRT alignment. These explorations were located along the LRT alignment to characterize the subsurface conditions and were placed between the previously drilled boring locations.
- **Freeway Tunnel Alignment:** Five HSA/rotary core borings associated with the Freeway Tunnel alignment were drilled to depths up to 280 feet bgs to evaluate the subsurface materials in the vicinity of the proposed tunnel. The explorations were widely spaced and located between the previously drilled boring locations.
- **Fault Characterization Studies:** Ten HSA borings at depths ranging from 75 to 125 feet within the alluvial soils, and two sonic borings at depths ranging from 270 to 280 feet were drilled for characterization of the Raymond, Eagle Rock, and San Rafael faults. The explorations were closely spaced and located on both sides of the faults.

Sampling intervals within the HSA/RW borings varied from every 5 feet in soils to continuous sampling within the bedrock. Continuous sampling was conducted to the total depth of the boring within the sonic borings and the HSA borings performed for the fault characterization. The previous and current CH2M HILL boring locations are shown in Figure 2.

Subsurface Conditions

Based on the current and previous field exploration data, the site conditions that could affect the project design and construction can be summarized as follows:

- The subsurface conditions along the proposed LRT and Freeway Tunnel alignments consist of various soil and rock deposits including alluvium, weak sedimentary rock (Fernando, Puente, and Topanga Formations), and igneous and metamorphic basement complex rocks (Wilson Quartz Diorite).
- The rock formations within the proposed area for the tunnel sections of each alignment exhibit a wide range of strength (from very weak to weak sedimentary rocks, to weak to higher-strength igneous and metamorphic rocks).
- The alluvium at the tunnel portals and along the elevated portion of the LRT alignment comprises primarily medium-dense to very dense sand and silty sand with localized beds or lenses of gravel, cobbles, and clay.
- The groundwater varies considerably along the proposed tunnel alignments, and generally occurs in the alluvial deposits. The estimated depth ranges from about 20 feet near the south end of the Freeway Tunnel to more than 100 feet near the northern terminus of the proposed Freeway Tunnel and LRT alignments. Rock formations in the project area are not considered water-bearing layers.

Liquefaction potential in the alluvial soils at the tunnel portals and along the elevated and tunnel portions of the LRT alignment will be evaluated in future design phases after field explorations are completed within the potential liquefiable areas.

Earthquake Sources

The proposed Alternatives are located within a seismically active region of southern California, dominated by active northwest-trending strike-slip and reverse faults. Fault data and information from several sources were reviewed for this study, including the California Geological Survey (CGS), USGS, Caltrans, and Southern California Earthquake Center (SCEC).

Significant active and potentially active faults are mapped within the general vicinity of the project area. The seismic sources that may generate strong earthquake ground shaking along the proposed alignments, as well as their seismic source parameters, are listed in Table 1. The locations of the proposed Alternatives relative to these faults and the more distant faults are shown in Figure 3.

TABLE 1
Summary of Nearby Active and Potentially Active Faults
SR 710 North Study, Los Angeles County, California

| Fault Name | Faulting Style ¹ | Probability of Activity | Maximum/Characteristic Magnitude | Dip (degrees/direction) |
|---|-----------------------------|-------------------------|----------------------------------|-------------------------|
| Raymond | ss | 1.0 | 6.7 | 79 (N) |
| Hollywood | ss | 1.0 | 6.6 | 70 (N) |
| Raymond + Hollywood | ss | 1.0 | 6.9 | 70-79 (N) |
| Verdugo – Eagle Rock/San Rafael | r | 1.0 | 6.8 | 55 (NE) |
| Alhambra Wash (East Montebello) | rl-r-o | 1.0 | 6.25 | NA |
| Elsinore Fault Zone (Whittier) | ss | 1.0 | 6.9 | 75 (NE) |
| Sierra Madre Fault Zone (Clamshell – Sawpit) | r | 1.0 | 6.6 | 50 (N) |
| Sierra Madre Fault Zone (Sierra Madre) | r | 1.0 | 7.2 | 53 (N) |
| Newport – Inglewood – (North Los Angeles Basin) | ss | 1.0 | 7.2 | 88 (NE) |
| Puente Hills Blind Thrust (LA) | r | 0.5 | 6.9 | 27 (NE) |
| Upper Elysian Park | r | 0.5 | 6.6 | 50 (N) |

Source: CGS (2002), USGS (2008a), Caltrans Fault Data Base (2012), SCEC (2012), ECI (2013), and CH2M HILL (2010)

¹ ll – left-lateral; rl – right-lateral; r – reverse; o – oblique; ss – strike-slip

N = north; NE = northeast; NA = not available

The active seismic sources that cross the proposed alignments are the Raymond fault and the Verdugo-Eagle Rock-San Rafael fault system. There are hypotheses that the Raymond fault may rupture together with the adjacent Hollywood, Santa Monica, and Malibu faults, or with the Eagle Rock and Verdugo faults. However, these cascading fault rupture events are judged to be unlikely or improbable (CH2M HILL and ECI, 2013), and are not considered in the ARS development.

Shear Wave Velocity Data

Seismic velocity measurements were made in the nine core borings (CH2M HILL, 2010) using downhole geophysical methods. These tests were conducted to obtain the shear and compressional wave velocities of the various soil and rock strata underlying the proposed alignments. Depths of the velocity measurements extend from the ground surface to approximately 200 to 300 feet bgs, depending on location.

Velocity data obtained from these measurements are grouped as follows:

1. **Alluvial Deposits:** Consisting of clay, silt, and sand, with gravels, cobbles, and some boulders. Shear wave velocity data from borings R-09-Z1B8, R-09-Z2B5, R-09-Z3B2, R-09-Z3B3, R-09-Z3B4, R-09-Z3B8, R-09-Z3B12, and R-09-Z4B4 were used to estimate the shear wave velocity profile in the alluvial deposits.
2. **Sedimentary Rock:** Including Tertiary-age Fernando, Puente, and Topanga Formations. Because of the large scatter in the velocity data measured in these formations, the sedimentary rock group was further divided into very weak and weak rocks. Velocity data for the very weak rocks were obtained from borings R-09-Z1B8, R-09-Z3B8, R-09-Z3B12, and R-09-Z4B4; data for weak rock were obtained from boring R-09-Z3B6.
3. **Metamorphic and Igneous Rock:** Including the basement complex rocks that consist of Mesozoic-age crystalline igneous and metamorphic rocks. Velocity data for this group were obtained from borings R-09-Z3B2, R-09-Z3B3, and R-09-Z3B4.

Plots of the measured shear wave velocities and the calculated means and means plus-and-minus one standard deviation versus depth for these three geologic groups are depicted in Figure 4. Compressional wave velocities obtained during the downhole geophysical testing are summarized in CH2M HILL (2010).

Preliminary Geologic Profiles

Review of the generalized geologic cross-sections developed along the Freeway Tunnel and LRT alignments identified soil and rock conditions with variable thicknesses and properties. These variable subsurface conditions will result in earthquake ground motions of different characteristics along the proposed alignments.

For this preliminary seismic evaluation, geologic profiles at nine locations (FT-1 through FT-5 on the Freeway Tunnel alignment, and LRT-1 through LRT-4 on the LRT alignment) were selected to represent the variation in the subsurface conditions and their proximity to the nearby seismic sources. Geologic profiles FT-1 through FT-5 and LRT-3 and LRT-4 represent site conditions along the tunnel alignments, while those at LRT-1 and LRT-2 represent site conditions along the elevated LRT structure (surface structure). The locations of these selected geologic profiles for the Freeway Tunnel and LRT alignments are shown in Figure 5.

For the development of ARS, including PGA and PGV, the average shear wave velocity in the upper 100 feet of the underlying foundation soils/rocks was used to account for the effects of local soils. For underground tunnels, the shear wave velocity that will affect the ground motions was assumed to be the average value within the 100-foot soil/rock column directly underlying the invert of the tunnel. Shear wave velocities at the tunnel depth ranged from 1,800 feet per second (fps) to 2,500 fps, and therefore generally represented firm-ground/soft-rock conditions.

For this preliminary evaluation, average shear wave velocities were used to predict the spectral acceleration values at the ground surface for the elevated LRT alignment and PGA and PGV at the tunnel inverts using published ground motion attenuation relationships. This approach is believed to be conservative for the tunnel sections since the ground motions below the tunnel do not capture near-surface ground motion increases, which are included in the ground motion attenuation relationships, and therefore, will likely result in an overestimating of ground motions, particularly for the deeper Freeway Tunnel Alternative. Spectral acceleration values estimated

using the attenuation relationships are for the free-field outcropping motions, and could be adjusted for the effects of reflected waves and dynamic responses of the overlying soil deposits and tunnel structure. Dynamic site-specific response analysis will be performed in subsequent design phases to quantify these effects.

Table 2 summarizes the average shear wave velocities of the 100-foot zones below the tunnel invert and elevated LRT section at the selected geologic profile locations.

TABLE 2
Selected Geologic Profiles and Average Shear Wave Velocities
SR 710 North Study, Los Angeles County, California

| Geologic Profile | Approximate Station ¹ (feet) | Latitude/Longitude (degrees) | Geology Types | Approximate Tunnel Invert Depth (feet) | Average Shear Wave Velocity ² (fps) |
|------------------------------|---|------------------------------|--|--|--|
| Tunnel Profiles | | | | | |
| FT-1 | 1480+30 (A-line) | 34.072/-118.161 | Alluvium/Sedimentary Rock | 40 | 1,800 |
| FT-2 | 1520+00 (A-line) | 34.082/-118.161 | Alluvium/Sedimentary Rock | 180 | 2,500 |
| FT-3 | 1656+00 (A-line) | 34.119/-118.156 | Alluvium/Sedimentary Rock | 220 | 2,500 |
| FT-4 | 1692+00 (A-line) | 34.129/-118.155 | Alluvium/Sedimentary Rock/ Metamorphic and Igneous Rock | 205 | 2,500 |
| FT-5 | 1734+90 (A-line) | 34.141/-118.155 | Alluvium/Metamorphic and Igneous Rock | 70 | 1,800 |
| LRT-3 | 263+00 (LRT-line) | 34.095/-118.152 | Alluvium/Sedimentary Rock | 75 | 2,000 |
| LRT-4 | 351+40 (LRT-line) | 34.119/-118.150 | Alluvium/Sedimentary Rock | 95 | 1,900 |
| Elevated LRT Profiles | | | | | |
| LRT-1 | 11+00 (LRT-line) | 34.035/-118.162 | Alluvium/Sedimentary Rock | NA | 1,300 ³ |
| LRT-2 | 65+90 (LRT-line) | 34.047/-118.166 | Sedimentary Rock | NA | 1,300 ³ |

¹ A-line refers to stations along the Freeway Tunnel alignment; LRT-line refers to stations along the LRT alignment.

² Average shear wave velocity of the 100-foot zones below the tunnel invert.

³ Average shear wave velocity of the 100-foot zone below the ground surface.

fps = feet per second

NA = not applicable

Estimated Earthquake Ground Motions

Preliminary ARS curves were developed in this study at the two geologic profile locations along the elevated LRT alignment (LRT-1 and LRT-2). For the geologic profiles that represent the site conditions along the tunnels (FT-1 through FT-5, LTR-3 and LTR-4), only PGA and PGV were estimated. The response spectra represent 5 percent damped responses for horizontal motions.

Both probabilistic and deterministic methods were utilized to estimate the 5 percent damped ARS values. In the probabilistic analysis, response spectral values for various ground motion return periods were calculated by considering the site and regional seismic sources and their seismic parameters and activities. In the deterministic analysis, ground motions were estimated from the occurrences of maximum earthquakes on nearby seismic sources at their closest distances to the geologic profile locations.

Probabilistic Response Spectra for Horizontal Motion

The probabilistic ARS values at the selected geologic profile locations were estimated using the 2008 USGS ground motion model, as provided in the USGS interactive Web application (<https://geohazards.usgs.gov/deaggint/2008>; Petersen et al., 2008). For each of the selected profiles, the USGS ground motion model was used to provide spectral accelerations for 10 periods at hazard levels of 1 percent, 2 percent, 5 percent, 10 percent, 20 percent, and 50 percent probabilities of exceedance in 50 years. These probabilities of exceedance correspond to average return periods (ARPs) of 4,975 years, 2,475 years, 975 years, 475 years, 224 years, and 72 years, respectively.

The calculated spectral values were subsequently used to develop hazard curves for the 10 periods and 9 profile locations. The 5 percent damped response spectra for ARPs of 100, 150, 1,000, 1,500, and 2,500 years were then estimated from these hazard curves by interpolating between calculated values. These interpolations were made to provide ground motions at return periods consistent with Caltrans and Metro criteria (see Seismic Design Criteria section below for discussion of Caltrans and Metro criteria). The average shear wave velocities in the 100-foot zone below the tunnel inverts or ground surface for the elevated LRT section used in the hazard calculations for the selected geologic profiles are listed in Table 2. The near-fault and basin effects were applied to the calculated probabilistic spectra following Caltrans procedures (Caltrans, 2013). This procedure accounted for near-fault effects by increasing the spectral values by 20 percent for periods greater than 1.0 second, and linearly up to 20 percent for periods between 0.5 and 1.0 second.

Figures 6 and 7 show the calculated probabilistic ARS curves for the various ARPs at the two elevated LRT geologic profile locations (LRT-1 and LRT-2). In addition, the Caltrans online probabilistic ARS curves are also included in these figures. Note that the Caltrans online ARS curves are for ground motions with a return period of 975 years; hence they are slightly lower than the ARS curves calculated for a 1,000-year return period. The PGA and PGV values at the nine selected profile locations along the LRT and Freeway Tunnel alignments were estimated for a number of ground motion return periods. The PGV values were estimated from the 1.0-second spectral acceleration using the formula given by the Federal Highway Administration (FHWA) in *Technical Manual for Design and Construction of Road Tunnels – Civil Elements* (FHWA, 2009). The estimated PGA and PGV values are summarized in Table 3.

TABLE 3
Summary of Estimated PGA and PGV Values
SR 710 North Study, Los Angeles County, California

| Profile Location | Peak Ground Acceleration (PGA) (g) | | | | Peak Ground Velocity (PGV) (inch/sec) | | | |
|------------------------------|---------------------------------------|-------------|---------------|---------------|--|-------------|---------------|---------------|
| | (100 years) | (150 years) | (1,000 years) | (2,500 years) | (100 years) | (150 years) | (1,000 years) | (2,500 years) |
| Tunnel Profiles | | | | | | | | |
| FT-1 | 0.23 | 0.30 | 0.78 | 1.07 | 13 | 16 | 44 | 64 |
| FT-2 | 0.21 | 0.28 | 0.75 | 1.05 | 10 | 13 | 35 | 50 |
| FT-3 | 0.23 | 0.30 | 0.84 | 1.15 | 11 | 14 | 40 | 57 |
| FT-4 | 0.23 | 0.30 | 0.84 | 1.13 | 11 | 14 | 40 | 57 |
| FT-5 | 0.25 | 0.33 | 0.84 | 1.14 | 13 | 17 | 46 | 65 |
| LRT-3 | 0.24 | 0.31 | 0.80 | 1.09 | 13 | 17 | 45 | 64 |
| LRT-4 | 0.24 | 0.32 | 0.87 | 1.18 | 14 | 18 | 51 | 73 |
| Elevated LRT Profiles | | | | | | | | |
| LRT-1 | 0.24 | 0.30 | 0.67 | 0.90 | 17 | 21 | 51 | 72 |
| LRT-2 | 0.24 | 0.30 | 0.71 | 0.97 | 15 | 19 | 49 | 71 |

g = acceleration due to gravity

inch/sec = inches per second

The calculated PGA values along the proposed Freeway Tunnel alignment at a depth of approximately 200 feet bgs vary from 0.75g to 0.84g for the ground motions with a return period of 1,000 years. Along the LRT alignment, the calculated PGAs for a return period of 1,000 years range from 0.67g to 0.87g.

Table 4 summarizes the magnitude-distance combinations and largest contributors that control the PGA for the 975-year return period ground motion at the selected profile locations. As shown in Table 4, the PGAs along the two proposed alignments are dominated by the Raymond fault and the Upper Elysian Park blind thrust fault system.

TABLE 4
Controlling Magnitude-Distant Pairs at Selected Geologic Profiles
 (PGA for 975-year return period ground motion)
SR 710 North Study, Los Angeles County, California

| Profile Location | Controlling Seismic Event | | |
|------------------------------|---------------------------|----------------|---------------------|
| | Mean Distance (km) | Mean Magnitude | Largest Contributor |
| Tunnel Profiles | | | |
| FT-1 | 6.3 | 6.6 | Upper Elysian Park |
| FT-2 | 6.0 | 6.6 | Upper Elysian Park |
| FT-3 | 4.7 | 6.6 | Raymond fault |
| FT-4 | 5.2 | 6.6 | Raymond fault |
| FT-5 | 6.0 | 6.6 | Raymond fault |
| LRT-3 | 6.2 | 6.6 | Upper Elysian Park |
| LRT-4 | 4.8 | 6.6 | Raymond fault |
| Elevated LRT Profiles | | | |
| LRT-1 | 8.5 | 6.6 | Upper Elysian Park |
| LRT-2 | 7.4 | 6.6 | Upper Elysian Park |

km = kilometer(s)

Deterministic Response Spectra for Horizontal Motion

Five percent damped deterministic median ARS values were calculated by CH2M HILL using the Caltrans ARS online tool (version 2.2.06; http://dap3.dot.ca.gov/ARS_Online). For each of the selected profiles, ground motions were estimated from the controlling fault(s) as the average of the median spectral values predicted from the attenuation relationships developed by Chiou and Young (2008) and Campbell and Bozorgnia (2008). The maximum magnitudes, faulting styles, and distances to the various seismic sources are based on the Caltrans fault database (2012). Similar to the probabilistic analysis, the near-fault and basin effects were applied to the deterministic spectra following Caltrans procedures. Figures 6 and 7 depict the calculated deterministic ARS, in comparison to the probabilistic ARS for the two elevated LRT geologic profile locations.

The deterministic ground motions are dominated by the Upper Elysian Park and Puente Hills blind thrust fault systems along the southern portion of the alignments, while the Raymond fault controls the hazards along the northern portion of the proposed Alternatives.

The calculated median PGA along the proposed Freeway Tunnel alignment varies from 0.62g to 0.74g, while the same value along the LRT alignment ranges from 0.62g to 0.69g. These deterministic PGA values at the selected profile locations are lower than the probabilistic PGA values estimated for the 975-year return period (or nominal 1,000-year return period).

Seismic Design Criteria

The appropriate seismic design criteria will depend on whether the LRT or the Freeway Tunnel Alternative is selected for implementation. The following subsections summarize the Caltrans and Metro seismic design criteria for each of these options.

LRT

Metro Supplemental Seismic Design Criteria (Revision 5, 2013) will be used for the LRT. It uses “Important Transit Facility” for LRT classification. Two levels of seismic event, consisting of Maximum Design Earthquake (MDE) and Operating Design Earthquake (ODE), must be considered for LRT tunnel design, in accordance with this Metro Supplemental Seismic Design Criteria.

- The MDE is defined as ground motion with a 2,500-year return period; the performance under the MDE event is as follows:
 - No collapse.
 - Structures are allowed to behave in an inelastic manner.
- The ODE is defined as ground motion with a 150-year return period; the performance under the ODE event is as follows:
 - Tunnel remains serviceable; no interruption in rail service during or after ODE.
 - Structures behave essentially elastic.

Freeway Tunnel

No Caltrans seismic design criteria for tunnels are currently available. For this preliminary design phase to support the environmental documentation, it was agreed that the Caltrans seismic design criteria for an Ordinary Nonstandard facility will be used as the basis for seismic design of the Freeway Tunnel. Project site-specific seismic design criteria will be developed in future design phases and used for final design of the Freeway Tunnel.

This facility classification is equivalent to Recovery Route classification. Two levels of seismic event, consisting of Safety Evaluation Earthquake (SEE) and Functional Evaluation Earthquake (FEE), must be considered for the Freeway Tunnel design.

- The SEE spectral acceleration at any period is defined as the largest of the following (Caltrans, 2013):
 - A probabilistic spectral value for a 5 percent chance of being exceeded in 50 years, which is equivalent to an ARP of 975 years.
 - A deterministic median spectral value estimated using the maximum magnitude, as defined by CGS, for any faults near the site.
 - A minimum spectral value defined as the median spectral value generated by a magnitude 6.5 earthquake on a strike-slip fault at a distance of 12 km from the site.

The design spectrum is further modified to account for the near-fault and basin effects by increasing the spectral values by 20 percent for periods greater than 1.0 second, and linearly up to 20 percent for periods between 0.5 and 1.0 second. As mentioned above, the deterministic PGA values at the selected profile locations are lower than the 975-year probabilistic PGA values; therefore, the 975-year (or nominal 1,000-year) probabilistic values should be used for SEE.

The performance criteria under SEE are as follows:

- Minimal to moderate damage may occur, as long as moderate damage is confined to local areas.
- The ductility of the tunnel should be between 2.5 and 3.0, similar to the ductility used in bridge capacity design.
- The FEE is defined as ground motion with a 100-year return period; the performance under FEE is to ensure that the tunnel is fully functional with minimal damage.

Based on the seismic design discussion with Caltrans for the Freeway Tunnel Alternative, the same seismic design criteria used for bored tunnel also should be used for the cut-and-cover tunnel section, portal structures, retaining walls, and slopes.

Vertical Ground Motions

A preliminary assessment of vertical ground motions was made, as these ground motions may be critical for the seismic design of tunnels and elevated structure, particularly if the site is located within 10 km of an active fault

(Applied Technology Council/Multidisciplinary Center for Earthquake Engineering Research [ATC/MCEER], 2003). Both the Freeway Tunnel and LRT Alternatives cross active faults, and therefore, vertical ground motions warrant consideration.

The PGA and 1.0-second spectral acceleration for vertical motion were developed using vertical-to-horizontal (V/H) ratios proposed by Bozorgnia and Campbell (2004) and by Gulerce and Abrahamson (2011). These ratios are a function of period, site distance, earthquake magnitude, anticipated site conditions, and ground motion intensity.

Based on the results of probabilistic and deterministic analyses, the ground motions along the Freeway Tunnel and LRT alignments are dominated by earthquakes with magnitudes between 6.6 and 6.9, occurring at distances less than 10 km. Using the average of the above two models and considering the ranges of magnitude, distance, expected site conditions, and design earthquakes, preliminary V/H ratios of 0.85 and 0.52 were determined for the PGA and 1.0-second spectral acceleration values, respectively, for vertical motion along the tunnel sections. For the elevated LRT sections, V/H ratios of 0.95 and 0.45 were estimated for the PGA and 1.0-second spectral values, respectively. These V/H ratios will be updated during future phases of the project using the results of additional investigations and after the preferred Alternative is selected.

Conclusions

Preliminary design earthquake ground motion parameters (5 percent damped response spectra and PGA and PGV values) have been developed for the proposed Freeway Tunnel and LRT Alternatives at nine locations along the alignments. Both probabilistic and deterministic response spectra were developed and used. The probabilistic ground motions were estimated for ARPs of 100, 150, 1,000, 1,500, and 2,500 years using the USGS hazard model. For the deterministic ground motions, the median spectral values of the controlling fault(s) were calculated using ground motion attenuation relationships recommended by Chiou and Young (2008) and Campbell and Bozorgnia (2008).

Results of these analyses show that PGAs could range from 0.75g to 0.84g for the Freeway Tunnel alignment and from 0.67g to 0.87g for the LRT alignment, based on a 7 percent probability of exceedance in 75 years (nominal 1,000-year return period). Based on median deterministic methods, median PGAs range from 0.62g to 0.74g for the Freeway Tunnel alignment and from 0.62g to 0.69g for the LRT alignment. Vertical motions at the zero-second (that is, PGA) and 1.0-second periods are estimated to be roughly 85 and 52 percent of the corresponding horizontal ground motion values, respectively, along the tunnel sections. For the elevated LRT sections, vertical motions at PGA and 1.0-second periods are estimated to be roughly 95 and 45 percent of the corresponding horizontal ground motion values, respectively.

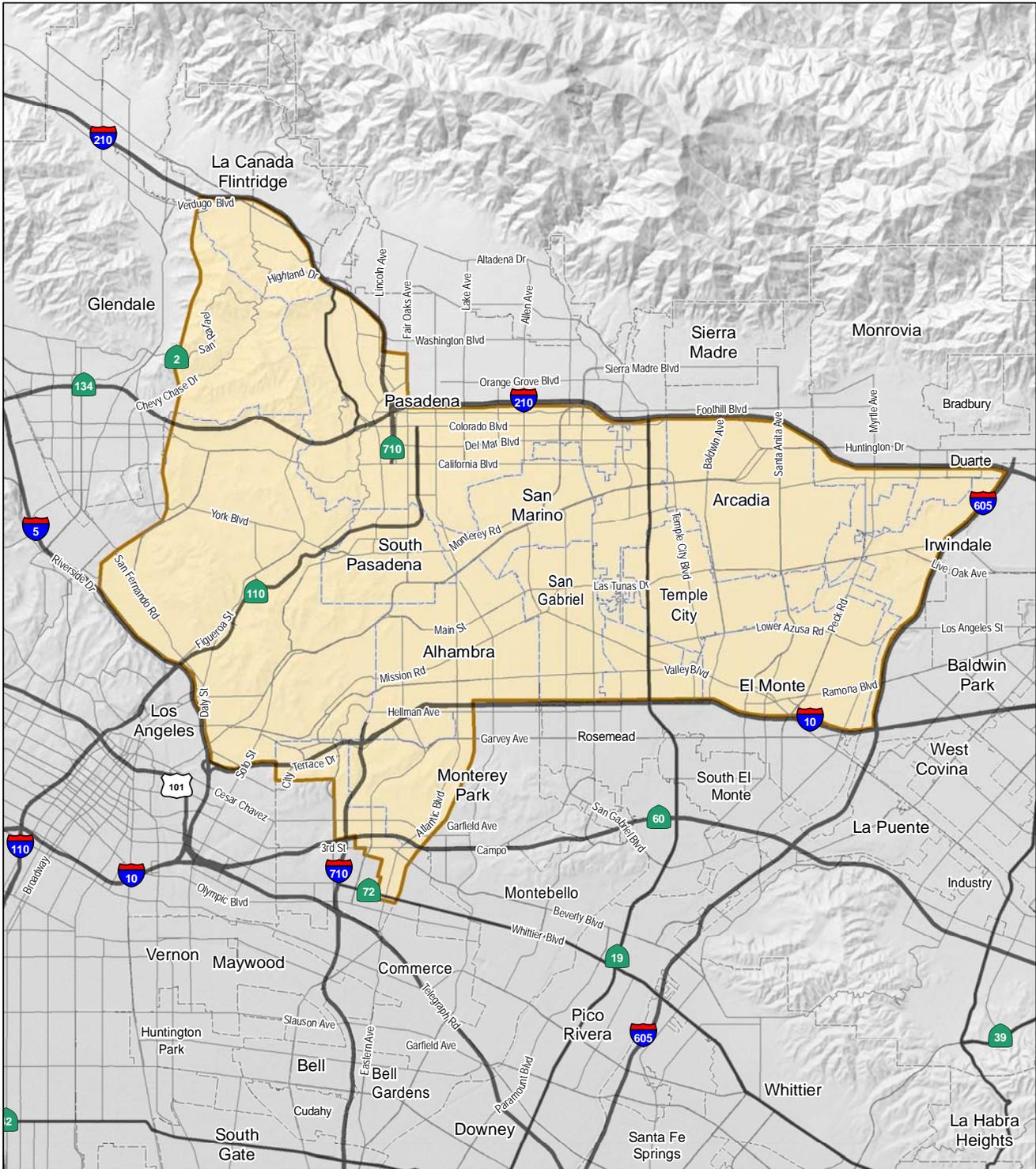
The effects of the overlying soil/rock deposits and tunnel structure to the design ground motions were not considered in this preliminary evaluation; however, they will be evaluated in the future design phases. Liquefaction potential of the alluvial deposits and the effects to ground motions and the 5-percent-damped response spectra for horizontal and vertical motions also will be evaluated.

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Figures



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SR 710 North Study Area

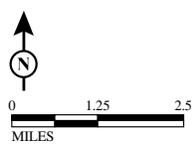
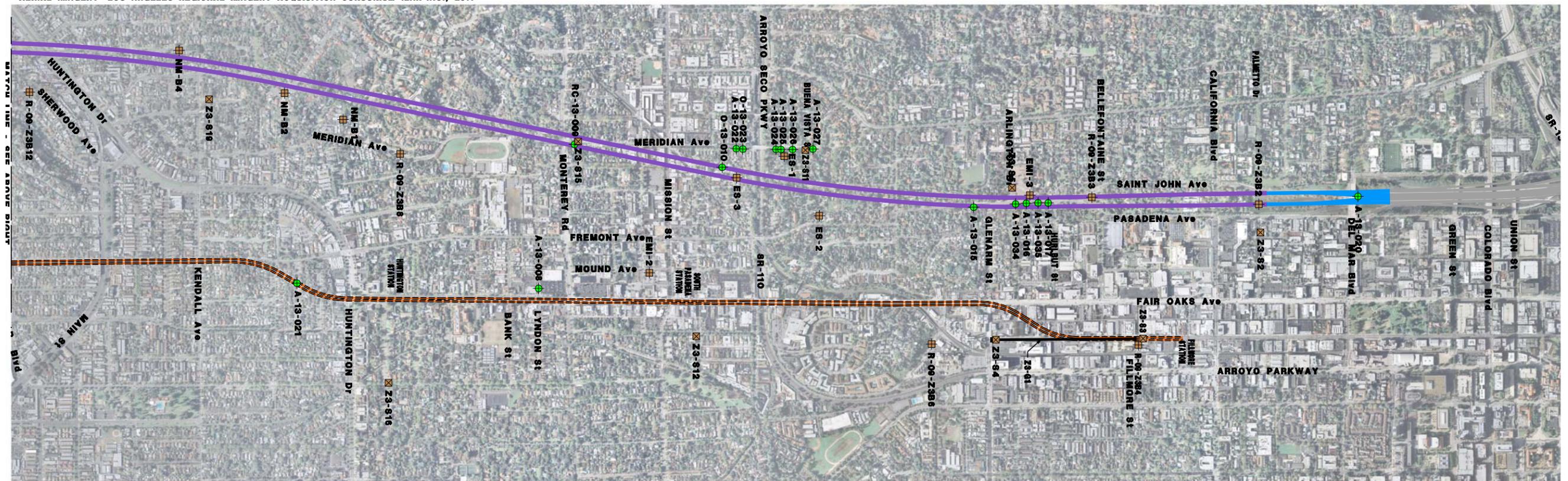


FIGURE 1
STUDY AREA MAP
 SR 710 North Study,
 Los Angeles County, California



AERIAL IMAGERY: LOS ANGELES REGIONAL IMAGERY ACQUISITION CONSORTIUM (LAR-IAC), 2011



- LEGEND:**
- █ FREEWAY TUNNEL ALTERNATIVE, CUT & COVER TUNNEL
 - █ FREEWAY TUNNEL ALTERNATIVE, BORED TUNNEL
 - █ FREEWAY TUNNEL ALTERNATIVE, SURFACE
 - █ LRT ALTERNATIVE, ELEVATED
 - █ LRT ALTERNATIVE, TUNNEL
 - A, R, RC, or O-13-001 CURRENT BORINGS (CH2M HILL and ECI, 2013)
 - Z3-G6 SEISMIC REFLECTION LINE (CH2M HILL, 2010)
 - Z3-S22 MULTI-CHANNEL ANALYSIS OF SURFACE WAVES (MASW), (CH2M HILL, 2010)
 - NM-B4; EMI-3; ES-2 PREVIOUS BORINGS (Ninyo and Moore, 1999; Earth Mechanics Inc., 2006; Caltrans, 1974)

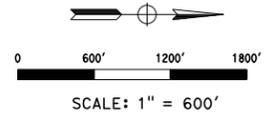
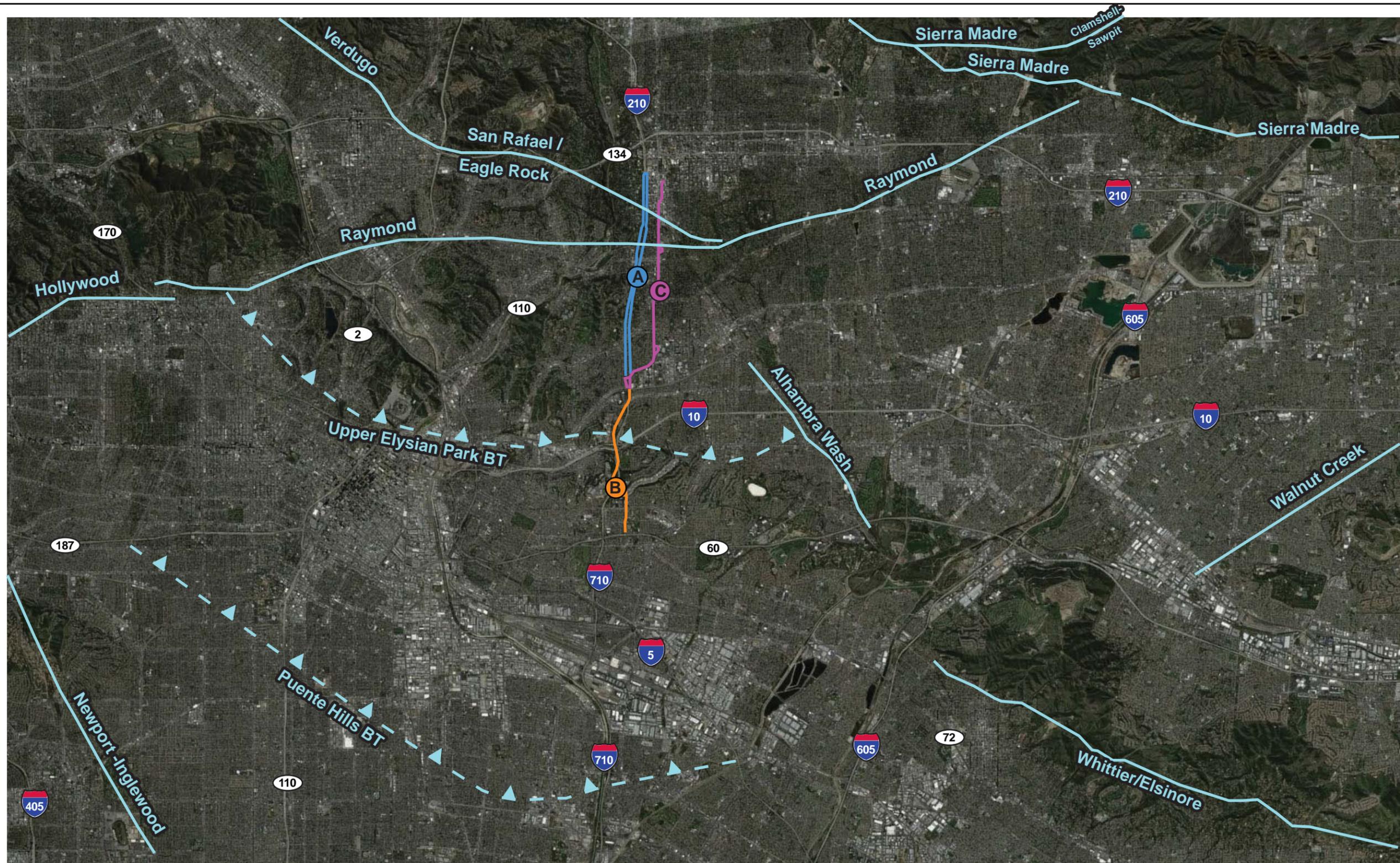


FIGURE 2
Boring Location Map
SR 710 North Study,
Los Angeles County, California



Aerial image © Google Earth, 2013. Annotation by CH2M HILL, 2013.

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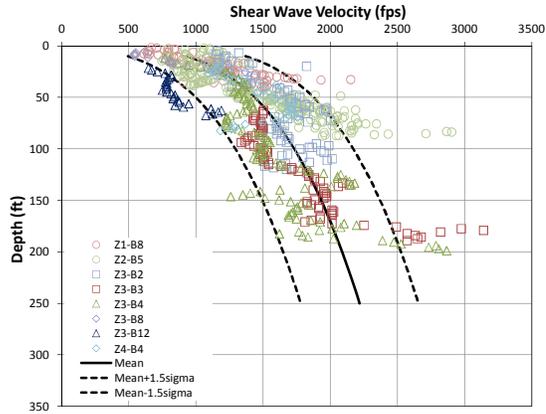
- Approximate Fault Location with Name (BT = Blind Thrust, Subsurface Fault, Barbs on Upper Block)
- A Freeway Alternative

- B LRT Alternative Overhead
- C LRT Alternative Tunnel

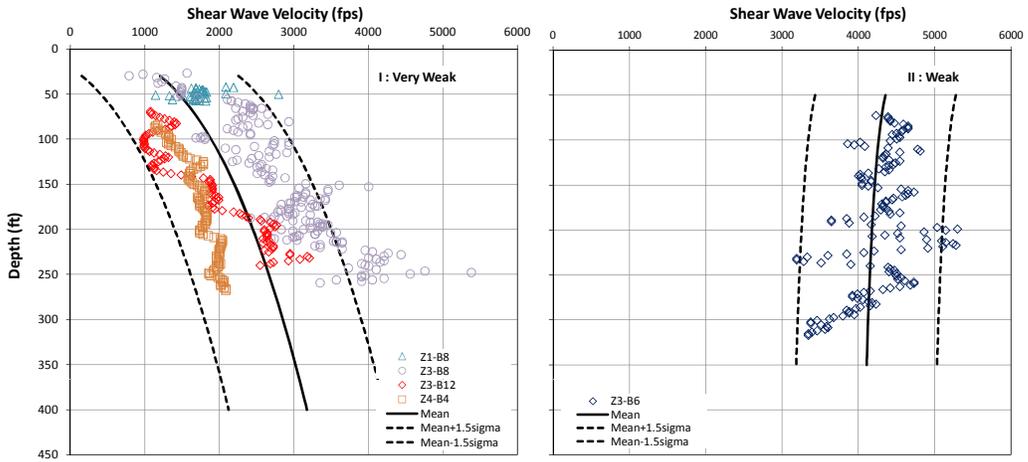


FIGURE 3
FAULT LOCATION MAP
 SR 710 North Study,
 Los Angeles County, California

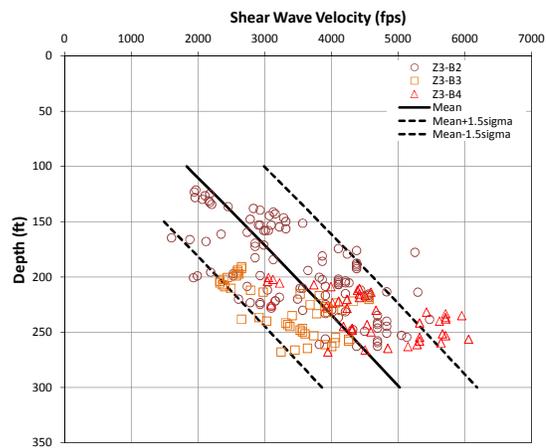
Fault Data from: Plesch et al., 2007 and USGS, 2010; with modifications based on this study.



(a) Alluvial Deposits

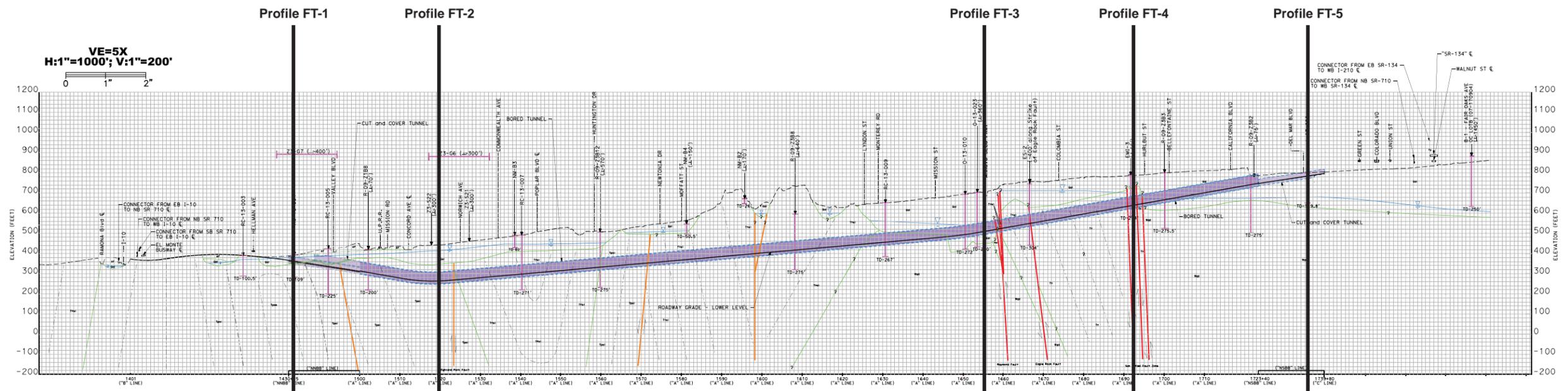


(b) Sedimentary Rocks

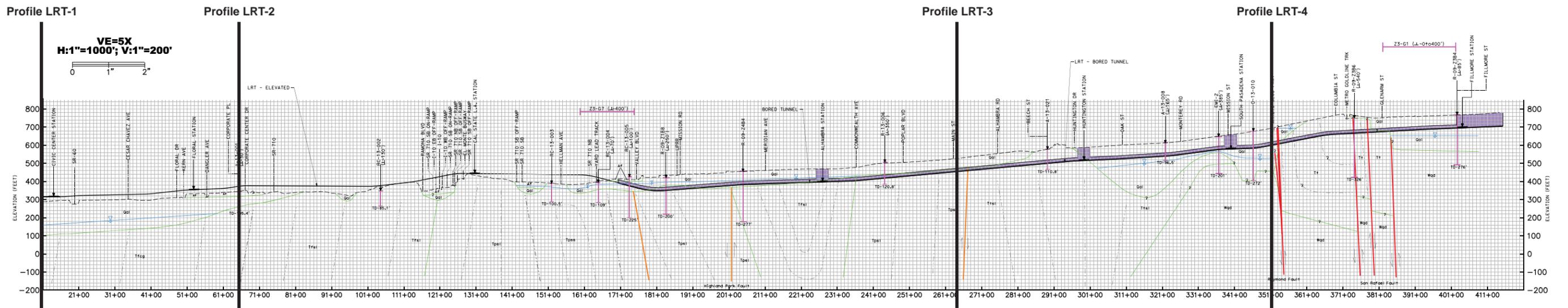


(c) Metamorphic and Igneous Rocks

FIGURE 4
Shear Wave Velocity Profiles
 SR 710 North Study,
 Los Angeles County, California



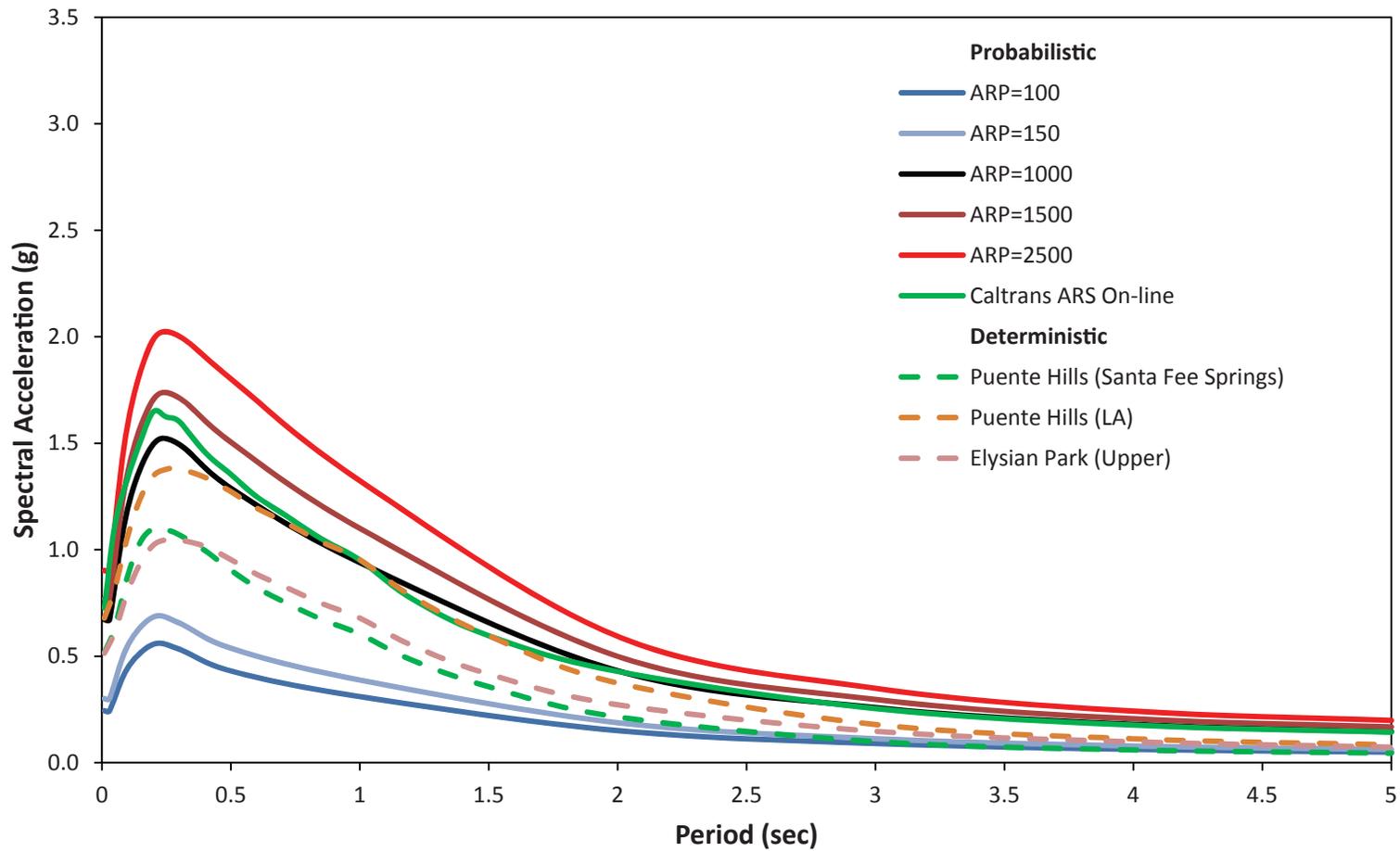
(a) Freeway Tunnel Alignment



(b) LRT Alignment

FIGURE 5
Geologic Cross Sections
SR 710 North Study,
Los Angeles County, California

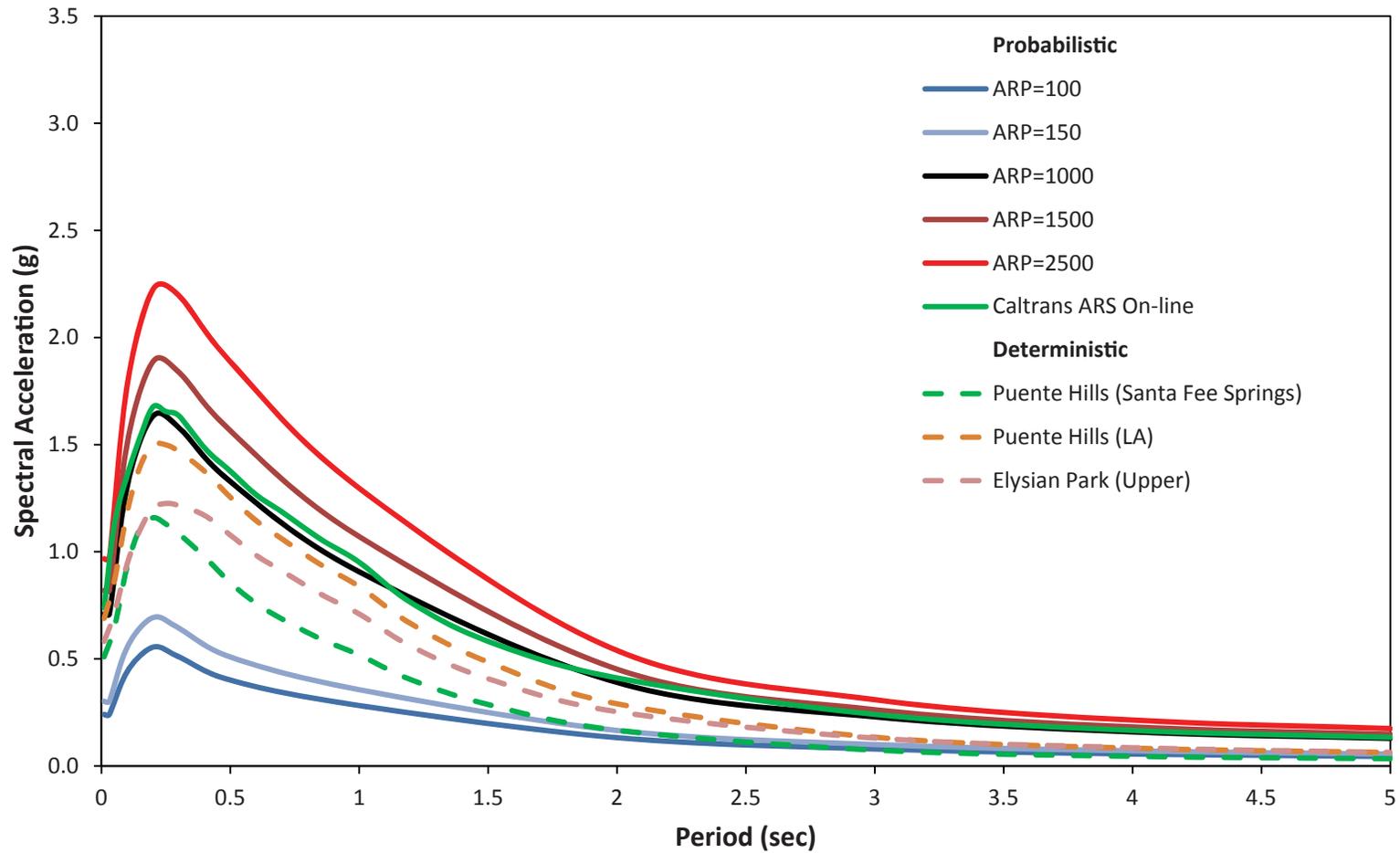
LRT Station 11+00



Five percent damping acceleration response spectra for geologic profile LRT-1

FIGURE 6
ARS Curve, Profile LRT-1
SR 710 North Study,
Los Angeles County, California

LRT Station 65+90



Five percent damping acceleration response spectra for geologic profile LRT-2

FIGURE 7
ARS Curve, Profile LRT-2
SR 710 North Study,
Los Angeles County, California