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November 6, 2017

Linda H.J. Liang, P.E., G.E.
Rockridge Geotechnical
270 Grand Avenue | Oakland, CA 94610

Subject: Geophysical Investigation Results
Kensington Firehouse
217 Arlington Avenue
Kensington, California

Dear Ms. Liang:

1.0 INTRODUCTION

This letter presents the results of Advanced Geological Services, Inc. (AGS) geophysical investigation to look for indications of a geologic fault in the vicinity of the proposed footprint of a planned new, larger firehouse building at the site of the current firehouse building, 217 Arlington Avenue in Kensington, California (Figure 1).

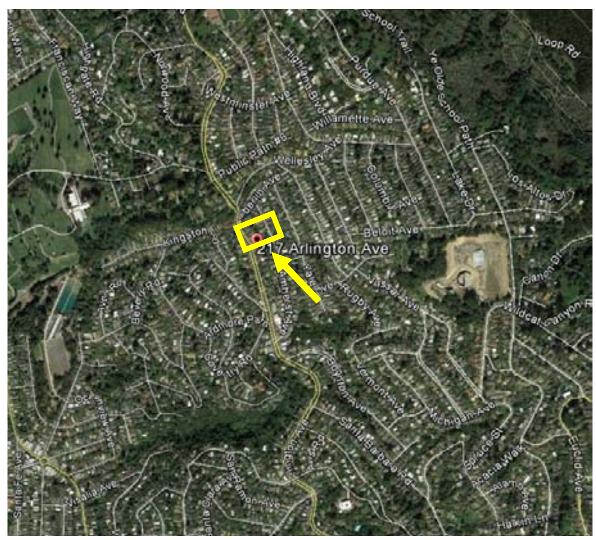


Figure 1 - Site Location in Kensington, CA

The investigation was performed on October 18 and 22, 2017 by AGS senior geophysicist Roark W. Smith. The investigation comprised seismic refraction and ground penetrating radar (GPR) surveys to look for discontinuities in the subsurface that could indicate the presence of a geologic fault.

The surveys were performed along three lines—one that extended across Arlington Avenue and up the driveway alongside the existing firehouse building (SL-2), a second running diagonally across the parking lot behind the building (SL-3), and a third through the neighbor's backyard east of the firehouse building (SL-1).

2.0 SUMMARY OF FINDINGS

- No definitive fault indications were observed in the seismic or GPR survey results. It is worth noting, however, that SL-1 exhibits different subsurface conditions than SL-2 and SL-3, which suggests there may be a geologic discontinuity at the gap between SL-1 and the other the two seismic lines (i.e., along the retaining wall between the back of the firehouse parking lot and the neighbor's yard).

- Specifically, SL-1 (in the neighbor's backyard) shows higher-velocity material ("bedrock") in the shallow subsurface, compared to SL-2 and SL-3. This result could simply mean that, as a result of erosion, bedrock is closer to the surface in the topographically higher portion of the site, or it may indicate a change in bedrock attitude (e.g., dip in bedding) that causes bedrock to be deeper towards the west. Or, the absence of the higher-velocity "bedrock" material in the SL-2 and SL-3 models could indicate that earth movement along a fault or slide plane dropped the bedrock layer below the investigation depth limits of the refraction survey.

- GPR profiles show shallow layering associated with pavement and fill material and reflections from buried utilities, but no layer offsets or disruptions indicative of a possible fault. The GPR survey achieved an investigation depth of approximately four feet.

3.0 SITE DESCRIPTION

The investigation was performed along a sloping, roughly east-west oriented, 400-foot long "Z"- shaped alignment that spanned Arlington Avenue and extended up the side driveway next to the fire station building, angled across the rear parking lot, and extended through the backyard and narrow side-yard of the neighbor's property at 220 Amherst Avenue (Figure 2). The sloping alignment exhibited approximately 40 feet of topographic relief from Amherst Avenue down to Arlington Avenue, with an approximately 8.50-foot drop at the retaining wall between the Amherst Avenue backyard and the firehouse parking lot, which also marks the gap between SL-1 and SL-3. The ground surface ranged from asphalt and concrete pavement on the streets and sidewalks to soil in the backyard at 220 Amherst Avenue. It is worth noting that numerous underground utility mark-outs were observed along SL-2.

4.0 SEISMIC REFRACTION (SR) METHOD OVERVIEW

The seismic refraction method uses compressional (P-) wave energy to delineate seismic velocity layers within the subsurface. Interpretation entails correlating the velocity layers to geologic features such as soil and various types of bedrock. To perform a refraction survey, an elastic wave (compressional, or P-wave) is generated at certain locations (shotpoints) along a survey line. The P-wave energy is usually produced with a small explosion or by striking the ground with a sledgehammer. As the P-wave propagates through the ground it is refracted along boundaries between geologic layers with different seismic velocities.

Part of the refracted P-wave energy returns to the ground surface where it is detected by vibration-sensitive devices called geophones, which are placed in a linear array along the seismic survey line. Using linear, "straight-line" geophone arrays is necessary for accurate assessments of the depth, thickness, and velocity of the detected geologic layers. The geophone data are fed to a seismograph, where they are recorded, and then to a computer, where they are analyzed to determine the depth and velocities of subsurface seismic layers. Key data for refraction analysis are the positions of the geophones and shotpoints along a seismic line, and the amount of time it takes for the refracted wave to travel from the shotpoint to each geophone location. Because the P-wave is the fastest traveling of all types of seismic waves, it can be readily identified as the first deflection ("first break") on a seismic trace.

Additional discussion of the refraction method, its limitations, and the relationship between seismic velocity and geologic materials is presented in Appendix A.

5.0 GROUND PENETRATING RADAR (GPR) METHOD

GPR uses radar technology to produce a graphical profile of the subsurface that shows soil layering and images of buried objects. GPR systems typically use a single transceiving antenna (one that both transmits and receives) that is dragged along the ground surface. The antenna emits a radar pulse into the ground; some of the radar energy reflects off of interfaces between materials with different electrical properties (e.g., soil and metal) and returns to the surface where it is detected by the antenna and sent via a cable to a separate control unit where it is amplified and displayed on a computer screen as a "wiggle trace," which is a vertical plot of changes in reflection amplitudes over time (although the vertical scale of a GPR profile is usually considered as depth, it actually measures the travel-time of the radar pulse from the surface to a reflecting interface and back to the surface). A subsurface profile is built as the antenna is pulled along the survey line and successive wiggle traces are recorded. GPR data are usually displayed as an array of closely-spaced traces, a technique that produces an image of the subsurface as the reflections (wiggles) on adjacent traces merge into coherent patterns.

Soil layer boundaries appear as laterally continuous horizontal bands across a GPR profile. Depending on their composition, buried objects appear as localized, high-amplitude (darker) reflection patterns, with the reflection amplitude ("darkness") being a function of burial depth and the degree of contrast between the object and the surrounding soil. Metallic objects usually produce strong reflections, while concrete can produce weak reflections because its electrical properties are so similar to those of sandy soil. Buried pipes and USTs often exhibit a characteristic "upside down U" hyperbolic pattern, which allows them to be readily identified on a GPR record. Geologic faults can appear as offsets or discontinuities and/or zones of chaotic reflection patters that disrupt the horizontal layering on a GPR profile. However, GPR is subject to investigation depth limitations; in electrically conductive soil (e.g., moist, fine-grained soil), the GPR signal may only penetrate 2 feet. Additionally, sites with heterogeneous fill material often produce "cluttered" GPR records that can mask utility images. And finally, a subsurface target requires a certain minimum diameter to be imaged by GPR; a good rule-of-thumb is that a target requires a least 1 inch of diameter for each foot of burial to be imaged with GPR. In other words, a 2-inch pipe buried 4 feet deep probably will not be imaged.

6.0 FIELD PROCEDURES

Seismic Survey

AGS obtained seismic data along three lines, designated SL-1, SL-2 and SL-3. The work at SL-1, located in the 220 Amherst Avenue backyard, was performed on October 18, 2017. The work at SL-2, which spanned Arlington Avenue, was performed starting at first light early Sunday morning October 22 so as not to obstruct vehicle traffic and also to avoid the associated seismic noise. SL-3, through the firehouse parking lot, was surveyed immediately after SL-2.

For each line, AGS first laid out a fiberglass tape measure and then placed 24 geophones on the ground at nominal 5- to 10-foot intervals depending on the available straight-line distance. SL-1 used 5-foot geophone spacings for a total length of approximately 125 feet. SL-2 used a mixture of 5- and 10-foot geophone spacings, although 15-foot spacings were used on Arlington Avenue so that vehicles could pass, for a total length of 175 feet. SL-3 used 5-foot geophone spacings, but only 17 geophones were used due to space limitations, so the total line length was 90 feet.

On pavement (most of SL-2 and SL-3), the geophones were coupled to the ground using metal plates attached to each geophone base. On soil (most of SL-1), the geophones were coupled to the ground with 4-inch metal spikes. From three to five shotpoints were used at each array, depending on the length. In general, shotpoints were located in the center and 5 feet beyond the ends of geophone array. Two additional shotpoints at the "quarter points" were used for SL-2 for a total of five shotpoints. AGS produced seismic waves through multiple impacts with a 16-lb sledge hammer on a metal plate placed on the ground surface at shotpoint locations on soil. The plate was not used for locations on pavement; the pavement was struck directly with the hammer. Five to ten hammer blows were used ("stacked") at each shotpoint. The seismic waves produced by the hammer impacts were detected using GeoSpace Corp. 4.5-Hz geophones.

The detected seismic signals were recorded using a DAQLink II seismic system connected to a laptop computer. The seismic signals were recorded for 2 seconds using a 0.125 millisecond (ms) sample rate. After the seismic data were obtained along each spread, AGS performed a hand-level survey to measure the relative elevation changes along the line so that the ground surface topography could be incorporated into the data analysis.

GPR Survey
AGS performed the GPR survey by wheeling the cart-mounted GPR system along the same lines as the seismic survey (Figure 2). Using the system's viewing screen to monitor the data as the survey progressed, the GPR profiles were inspected in the field for lateral discontinuities in layering that could indicate recent movement along a fault.

7.0 DATA PROCESSING AND ANALYSIS

Seismic Data
The seismic refraction data quality for this project was generally good to fair. Most "first break" picks were made easily and with high confidence; however, some data at the far (from the shotpoint) ends of the geophone spreads were poor due to noise and weak signal transmission through concrete pavement. Underground utilities crossing the seismic lines may have also contributed to the poor signal quality in places. Data quality was enhanced by "stacking," which entailed using multiple hammer blows at each shotpoint location to improve the signal-to-noise ratio. The additive affect of stacking of multiple hammer blows at the same location enhances or increases the amplitude of the signal (i.e., the refracted wave arrival) while amplitude of the background noise, which, being random in nature, tends to cancel itself on successive hammer blows and remains largely unchanged.

Seismic data were transferred from the seismograph to a desktop computer where they were processed using the *SeisImager* software package by Geometrics, Inc. Briefly, *SeisImager* is a computer inversion program that generates an initial velocity layer model, produces synthetic data from the model, and then adjusts the model so that the synthetic data better matches the observed field data. The agreement between the synthetic and observed data provides an indication of how well the model represents the true subsurface conditions.

First, AGS used the *SeisImager* module *PickWin* to interpret ("pick") the P-wave arrivals ("first breaks") for each of the shotpoint data sets ("shot gathers") per line. *PickWin* was also used to check (against the geophysicist's field log) that the proper locations were assigned to the geophones and shotpoints. Next, the first break files were fed to the SeisImager module *PlotRefra*, which was used review time-distance (TD) plots for the seismic lines and assign a seismic layer to each arrival time. For the refraction analysis, each P-wave arrival is considered to have refracted from a distinct seismic layer. The number of layers resolved by the seismic survey, and their thickness and average velocity, is indicated by straight line segments on the TD plot; because these straight-line segments represent a constant velocity condition within the subsurface, they often represent a distinct geologic layer. It is worth noting that estimates of velocity, thickness and depth of seismic layers can be made from the TD plots. Topographic elevation files, which were prepared from the hand-level data, were incorporated into the analysis at this point. Next, a time-term inversion was performed to produce layered velocity models. Time-term inversion is a linear least-squares technique that uses the layer assignments and the distances and travel times between the shotpoints and the geophones to develop a velocity layer model that best fits the observed data.

The layered velocity models were then used as starting models for the tomographic inversion process, which was used to assess lateral velocity variations along each seismic line to better show any discontinuities in the subsurface indicative of a fault. Briefly, tomographic inversion is a grid-based modeling process wherein the subsurface is divided into rectangular cells based on the geophone spacing. The tomography software assigns a velocity to each cell, produces a synthetic arrival-time data set based on seismic raypaths projected through the velocity grid, and then compares the synthetic data to the real data recorded in the field. The cell velocities are then adjusted and re-adjusted until the synthetic data achieve a "best fit" with the observed field data. Tomographic modeling is often used to complement layered modeling at sites where gradual velocity transitions, such as those often seen between weathered and unweathered bedrock, are expected. Tomographic modeling can also depict lateral velocity variations within the subsurface more accurately than a layered modeling approach.

GPR Data

Using the system's viewing screen to monitor the data as the survey progressed, the GPR profiles were inspected in the field for lateral discontinuities in layering that could indicate recent movement along a fault. The profiles were re-examined upon returning to the office.

8.0 RESULTS

The geophysical investigation results are presented on Figures 2, 3, and 4. Figure 2 shows the seismic and GPR line locations. Figure 3 shows the tomographic models generated from the seismic refraction data. Figure 4 shows the Ground Penetrating Radar profiles.

In general, the seismic results indicate three velocity layers— an upper, low-velocity layer (red-orange colors on the tomographic models) corresponding to soil and/or fill material, an intermediate velocity layer (yellow-green colors) representing weathered bedrock, and a higher-velocity basement layer (blue colors) that is interpreted to represent little-weathered bedrock. No definitive fault indications were observed in the individual tomographic models or GPR survey profiles.

It is worth noting, however, that SL-1 exhibits different subsurface conditions than SL-2 and SL-3, which suggests there may be a geologic discontinuity at the gap between SL-1 and the other two seismic lines (i.e., along the retaining wall between the back of the firehouse parking lot and the neighbor's yard). Specifically, SL-1 (in the neighbor's backyard) shows higher-velocity bedrock in the shallow subsurface, compared to SL-2 and SL-3. This result could simply mean that, as a result of erosion, bedrock is closer to the surface in the topographically higher portion of the site, or it may indicate a change in bedrock attitude (e.g., dip in bedding) that causes bedrock to be deeper towards the west.

Or, the absence of the higher-velocity "bedrock" material in the SL-2 and SL-3 models could mean that earth movement along a fault or slide plane dropped the bedrock layer just below the investigation depth limits of the refraction survey. Although not shown on the models, examination of the raw data (the TD plots) suggests that the higher-velocity material seen along SL-1 may be present at a depth of about 30 feet along SL-2.

GPR profiles show shallow layering associated with pavement and fill material and reflections from buried utilities, but no layer offsets or disruptions indicative of a possible fault. The GPR survey achieved an investigation depth of approximately four feet.

9.0 CLOSING

All geophysical data and field notes collected as a part of this investigation will be archived at the AGS office. The data collection and interpretation methods used in this investigation are consistent with standard practices applied to similar geophysical investigations. The correlation of geophysical responses with probable subsurface features is based on the past results of similar surveys although it is possible that some variation could exist at this site. Due to the nature of geophysical data, no guarantees can be made or implied regarding the targets identified or the presence or absence of additional objects or targets.

AGS appreciates working for you. We enjoyed this project and we look forward to working with you again.

Sincerely,

Roark W. Smith
Senior Geophysicist
Advanced Geological Services, Inc.

Figures:	Figure 1	Site Location Map (imbedded in Report text)
	Figure 2	Seismic and GPR Line Locations
	Figure 3	Seismic Refraction Survey Results
	Figure 4	Ground Penetrating Radar (GPR) Survey Results
Attachments:	Appendix A:	Seismic Velocity and Limitations of the Refraction Method

APPENDIX A

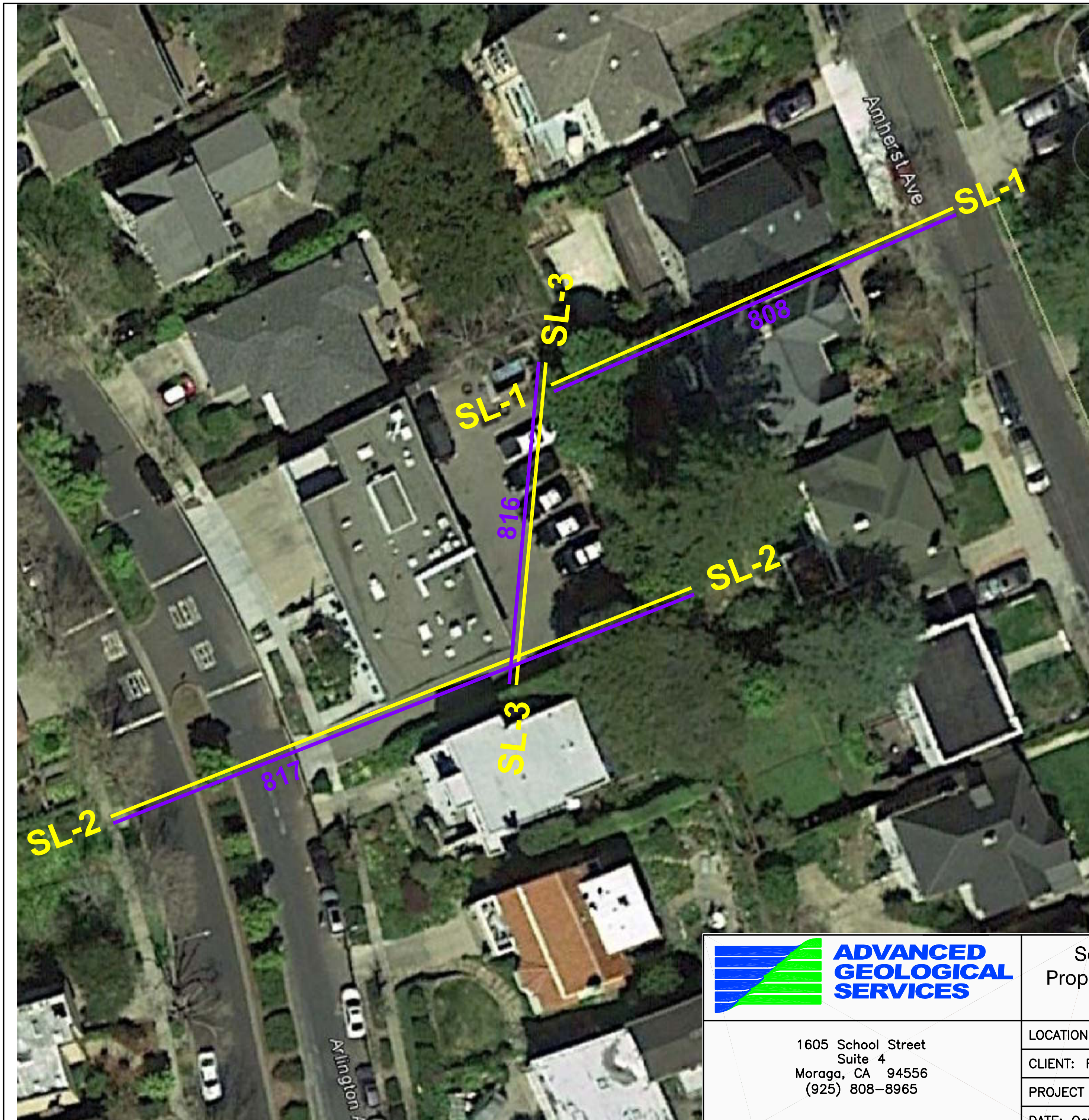
SEISMIC VELOCITY AND LIMITATIONS OF THE REFRACTION METHOD

The physical properties of earth materials (fill, sediment, rock) such as compaction, density, hardness, and induration dictate the corresponding seismic velocity of the material. Additionally, other factors such as bedding, fracturing, weathering, and saturation can also affect seismic velocity. In general, low velocities indicate loose soil, poorly compacted fill material, poorly to semi-consolidated sediments, deeply weathered, and highly fractured rock. Conversely, high velocities are indicative of competent rock or dense and highly compacted sediments and fill. The highest velocities are measured in unweathered and little fractured rock.

There are certain limitations associated with the seismic refraction method as applied for this investigation. These limitations are primarily based on assumptions that are made by the data analysis routine. The data analysis routine assumes that the velocities along the length of each spread are uniform. If there are localized zones within each layer where the velocities are higher or lower than indicated, the analysis routine will interpret these zones as changes in the surface topography of the underlying layer. A zone of higher velocity material would be interpreted as a low in the surface of the underlying layer. Zones of lower velocity material would be interpreted as a high in the underlying layer. The data analysis routine also assumes that the velocity of subsurface materials increase with depth. Therefore, if a layer exhibits velocities that are slower than those of the material above it, the slower layer will not be resolved. Also, a velocity layer may simply be too thin to be detected.

The quality of the field data is critical to the construction of an accurate depth and velocity profile. Strong, clear “first-break” information from refracted interfaces will make the data processing, analysis, and interpretation much more accurate and meaningful. Vibrational noise or poor subsurface conditions can decrease the ability to accurately locate and pick seismic waves from the interfaces.

Due to these and other limitations inherent to the seismic refraction method, resultant velocity cross-sections should be considered only as approximations of the subsurface conditions. The actual conditions may vary locally.



EXPLANATION

SEISMIC LINE

GPR LINE

0 40 ft 80

ADVANCED GEOLOGICAL SERVICES

1605 School Street
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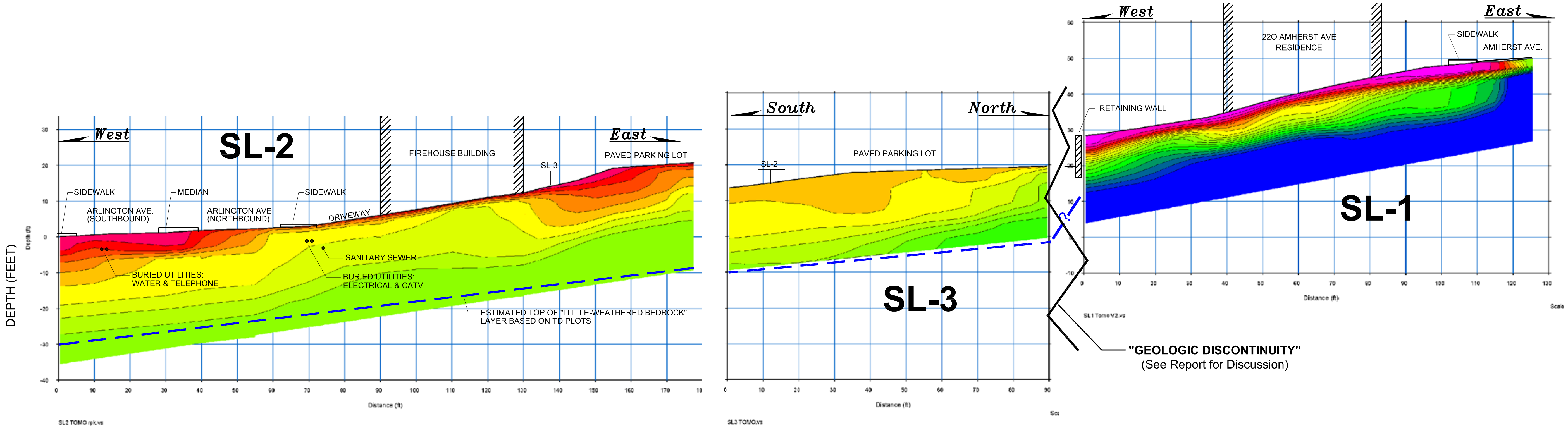
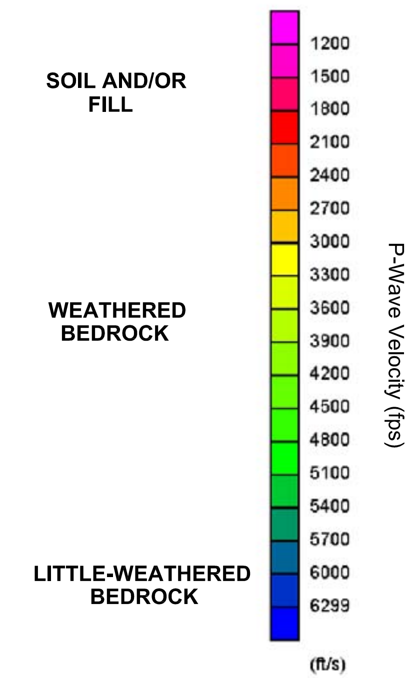
Seismic and GPR Line Locations
Proposed FirehouseBuilding Expansion
217 Arlington Avenue

LOCATION: Kensington, California	
CLIENT: Rockridge Geotechnical	FIGURE
PROJECT #: 17-139-1CA	2
DATE: October 29, 2017 DRAWN BY: R. SMITH	





LINE LOCATION MAP

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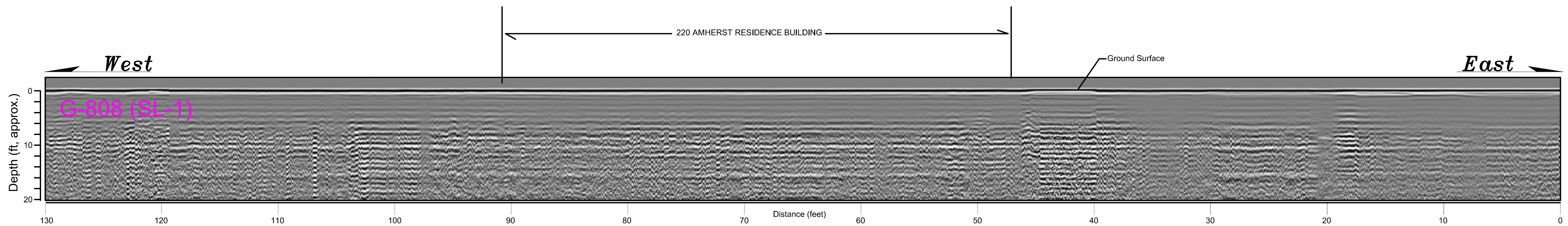
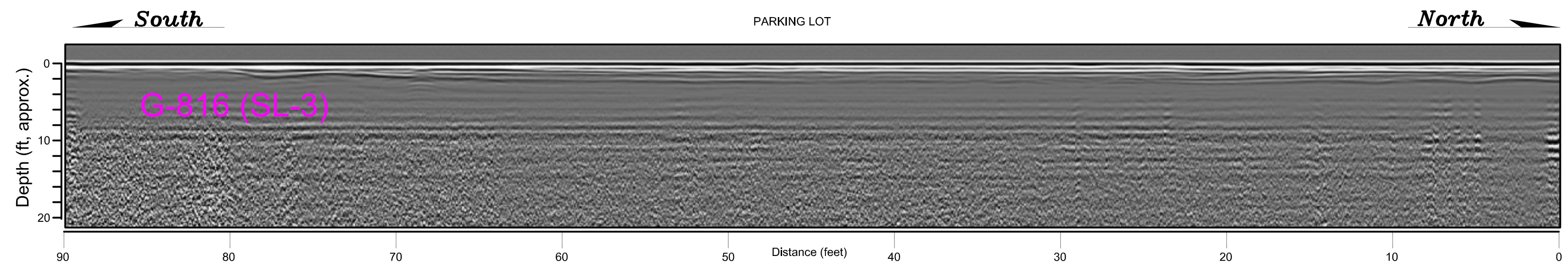
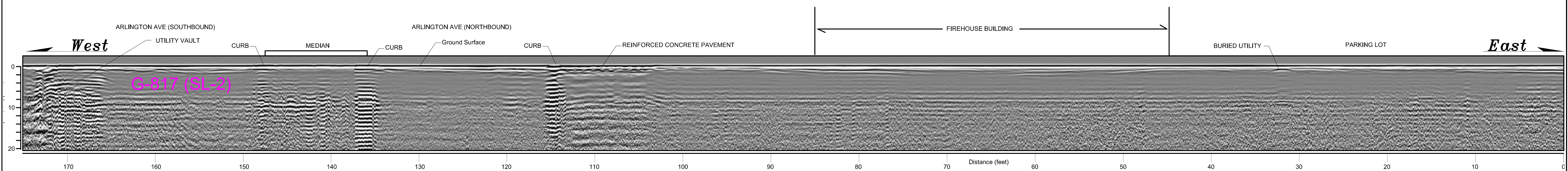
Seismic Refraction Survey Results
Proposed Firehouse Building Expansion
217 Arlington Avenue

LOCATION: Kensington, California	
CLIENT: Rockridge Geotechnical	FIGURE
PROJECT #: 17-139-1CA	3
DATE: October 29, 2017 DRAWN BY: R. SMITH	







LINE LOCATION MAP

ADVANCED GEOLOGICAL SERVICES

1605 School Street
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GPR Survey Results
Proposed Firehouse Building Expansion
217 Arlington Avenue

LOCATION: Kensington, California

CLIENT: Rockridge Geotechnical

PROJECT #: 17-139-1CA

DATE: Oct 29, 2017

DRAWN BY: R. SMITH

FIGURE
4

APPENDIX A

SEISMIC VELOCITY AND LIMITATIONS OF THE REFRACTION METHOD

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