ROCKRIDGE
GEOTECHNICAL

January 31, 2018
Project No. 17-1381

Kensington Fire Protection
217 Arlington Avenue
Kensington, California 94707
c/o: Ms. Brenda Navellier

Subject: Preliminary Fault Investigation
Proposed Kensington Essential Services Building
217 Arlington Avenue
Kensington, California

Dear Ms. Navellier:

This letter presents the results of our preliminary fault investigation for the proposed new essential services building to be constructed at 217 Arlington Avenue in Kensington, California. Our preliminary fault investigation was performed in general accordance with our proposal dated July 31, 2017 and our discussions with you and the Kensington Fire Protection District.

The subject property is located on the northeastern side of Arlington Avenue, south of its intersection with Oberlin Avenue, as shown on the Vicinity Map, Figure 1. The site is approximately square-shaped with plan dimensions of about 100 by 100 feet. The site is situated on a hillside that has been cut and filled to construct Arlington Avenue and building pads on the northeastern and southwestern sides of Arlington Avenue. Currently, the site is occupied by an existing building at the western portion of the site and a parking lot at the eastern portion (rear) of the site, as shown on the Site Plan, Figure 2. The existing building is occupied by the Kensington fire and police departments. A driveway that provides access to the rear parking lot is located at the southern portion of the site. There is also a 12 feet high retaining wall along the eastern property line. Available as-built plans show the existing retaining wall was constructed with a T-shaped footing that extends a minimum of 4 feet downslope and 9 feet upslope of the retaining wall.

Current conceptual plans being considered are to demolish the existing building and construct a new two-story building for essential services (i.e. fire protection and public safety) that will occupy the entire site. The new building will be at-grade fronting Arlington Avenue and about 1-1/2 levels below grade along the eastern property line. Construction of the proposed new building will require increasing the height of the existing retaining wall to about 25 feet high along the eastern property line. Similar walls would be needed along the northern and southern property lines.

1.0 ALQUIST-PRIOLO EARTHQUAKE FAULT ZONE

The Hayward Fault is a roughly 74-mile long, right-lateral strike slip fault zone that traverses the base of the hills along the east side of the San Francisco Bay. The Hayward Fault is generally characterized by a broad zone of deformation that often includes multiple subparallel fault splays. The Hayward Fault is considered an active fault by the State of California. Therefore, in accordance with the Seismic Hazards Mapping Act, the State of California has designated a zone of required investigation (formerly termed *Earthquake Fault Zones*, and previously *Special Studies Zones*) for the Hayward Fault. The site is located entirely within the State of California designated zone as shown on the Official Earthquake Fault Zones Map, Figure 3.

Projects located within the designated earthquake fault zone boundaries are subject to special studies to determine the site-specific potential for surface fault rupture. Projects that will create buildings for human occupancy with greater than 2,000 man-hours per year are required to be adequately setback from the active fault trace to minimize the potential adverse impacts of surface fault rupture beneath the foundation.

2.0 SCOPE OF SERVICES

The purpose of this project was to conduct a preliminary fault investigation to determine appropriate setbacks for the proposed new building from active fault traces. Our scope of services included the following tasks:

- reviewing readily available geologic maps and literature pertinent to the site
- reviewing previous geotechnical reports prepared for the site
- performing a site reconnaissance of the neighborhood to check for indications of fault-related features
- performing a seismic refraction survey
- evaluating the geologic information obtained
- preparing this letter report.

3.0 FIELD INVESTIGATION AND DATA REVIEW

3.1 Previous Site Studies

A geotechnical investigation for the original fire station building was performed by the consulting firm, Woodward-Clyde & Associates, in 1969. The investigation included excavation of three exploratory trenches and drilling five borings. The investigation concluded the site was feasible for the planned construction (the existing building) and provided geotechnical recommendations for site development. However, the investigation trenches (T-1 and T-3) did not reveal continuous in-place bedrock upslope of the existing building that will be within the footprint of the proposed new building. The approximate locations of the Woodward-Clyde trenches and borings are shown on Figure 2.

In 1990, Seidelman Associates, Inc. performed a geotechnical study to evaluate reported ground settlement at the site. The study included drilling two borings and installing slope inclinometers to monitor for subsurface landslide movement. The study did not address fault locations. The approximate locations of the Seidelman Associates borings are shown on Figure 2.

In 1997, Geomatrix Consultants, performed a geologic and geotechnical study assess earthquake-related hazards (i.e. surface fault rupture, landsliding, and slope instability) for the site. The Geomatrix study did not perform additional site exploration.

In 2009, Kleinfelder Inc. performed a geotechnical study to evaluate foundation settlement and to provide recommendations to improve conditions. The Kleinfelder study did not perform additional site exploration.

3.2 Geophysics Survey

To evaluate the possible presence of fault traces at the site, we initially proposed to excavate and log one exploratory trench to shadow the proposed building footprint. The exploratory trench would be located along the driveway and the rear parking lot. However, trenching could only be performed within the site boundaries and therefore was not sufficient to evaluate expansion of the building footprint back to the eastern property line. Therefore, prior to excavating trenches, we retained Advanced Geological Services (AGS) from Moraga, California to perform a geophysical survey of the site. The geophysical survey using the seismic refraction method was able to cover a much broader area than trenching alone. The seismic refraction method was used to look for discontinuities in the subsurface that could indicate the presence of a geologic fault.

The seismic refraction method uses compressional (P-) wave energy to delineate subsurface seismic velocity layers. 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 co-linear array along the seismic survey line. 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. Interpretation entails correlating the velocity layers to geologic features such as soil and various types of bedrock.

As part of this study, AGS performed three seismic refraction lines at the approximate locations shown on Figure 2. The seismic lines were extended off site to the east and west to gain additional coverage for the fault investigation. Detail descriptions and results of the geophysical survey are presented in Appendix A.

Based on the results of the geophysical survey and our review of available geologic information of the site and vicinity (see Section 3.3), we developed conclusions and recommendations regarding appropriate setbacks for the proposed new building from active fault traces as presented in Section 4.0.

3.3 Geologic Mapping

Regional Geology

The site is located in the Coast Ranges Geomorphic Province of California. The Coast Ranges are characterized by a series of northwest-trending, folded and faulted mountain chains and intervening valleys. Folding and faulting has caused deformation over the past few million years resulting in the pronounced northwest–tending structural grain of the region created by the right-lateral strike-slip relative motions between the Pacific and North American tectonic plates. The majority of active deformation in the San Francisco Bay Area is believed to have occurred over the past few million years.

Regional geologic maps (listed in the references) show the site to be underlain by northwest trending bands of sea floor sediments belonging to the Franciscan Complex geologic unit. The Franciscan Complex represents a series of sea-floor sediments and basement rocks that that formed during the Jurassic and Cretaceous Periods of geologic time, roughly 65 to 150 million years before present. In this portion of the province, the Franciscan Complex is mapped as mélange. The Franciscan Complex melange represents a mixture of sea-floor and basement rocks that have been altered, sheared and mixed together during subduction of the Farallon Plate beneath North America.

Regional maps indicate that the bands of melange are fault-bound blocks oriented in a northwest trend. The map shows faults on both sides of the site. A portion of the geologic map by Dibblee and Minch (2005) is provided on Figure 4.

Hayward Fault Mapping

The Hayward Fault has been extensively studied in the region and several maps have been created that show potential locations of fault splays along the Hayward Fault zone. All maps we reviewed suggest at least two splays of the Hayward Fault are in close proximity to the site. The Official Earthquake Fault Zones Map by the State of California (Figure 3) shows a main somewhat continuous fault splay downslope of the site to the west along Arlington Avenue and a suspected fault splay upslope of the site near Amherst Way. The geologic map by Dibblee and Minch (Figure 4) also shows three faults near the site, with two (including the main trace) downslope and another suspected splay upslope of the site. The U.S. Geological Survey maintains a data server called the Quaternary Fault and Fold Database (QFFD) that shows the approximate locations of faults in the region. The QFFD (Figure 5) shows two faults, with one fault crossing the center of the site and a fault just upslope of the site above Amherst Way. Note that the QFFD is registered to Google Earth images and are approximate. Additionally, the Tri City Seismic Safety Element report (Figure 6) also shows three faults, with one fault along Arlington Avenue, one fault to the west below Arlington Avenue, and one fault upslope of the site near Yale Avenue.

The currently accepted locations of active traces of the Hayward Fault are shown on maps by the U. S. Geological Survey (Lienkaemper, 2006). The Lienkaemper maps were based on field mapping fault-related deformation such as offset curbs, pavement cracks, linear drainages and other fault-related geomorphic features. The Lienkaemper map shows the main trace of the Hayward fault about 225 feet downslope of the site to the west and a smaller suspected fault splay crossing through the eastern portion of the site as shown on Figure 7.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, we conclude that the main trace of the Hayward Fault is located west of the site and that there is a strong possibility of a fault splay near the eastern property boundary that requires geologic setbacks for the proposed new building intended for human occupancy. The location of the suspected fault and resulting setbacks are expected to significantly limit the potential of extending the footprint of the proposed building to the eastern property line. Previous exploration work at the site is not adequate to provide coverage to clear the proposed new building of active faulting because trenches T-1 and T-3 by Woodward-Clyde (1969) encountered landslide deposits and did not demonstrate continuous un-faulted bedrock.

The seismic refraction survey performed by AGS (Appendix A) covered a linear transect extending from Amherst Way upslope of the site to the west side of Arlington Avenue, west of the site. The results of the survey were interpreted by the geophysicist to reflect the three geologic materials described in Table 1.

TABLE 1
Geologic Layers Interpreted by Seismic Refraction Survey

Material	P-Wave Velocity (fps)
Soil and or/Fill	0 to 2,700
Weathered Bedrock	2,700 to 5,700
Little-Weathered bedrock	Greater than 5,700

Within the site boundaries, the geophysics interpreted soil/fill and weathered bedrock extending down to the limit of the survey at about 35 feet below the ground surface. Upslope of the site, on the adjacent parcel, the geophysics encountered "little-weathered bedrock" underlying 15 feet of soil/fill and weathered bedrock. The "little-weathered bedrock" was not encountered within the site boundaries. The geophysical survey suggests that the bedrock changes at the eastern property boundary; which is called out as a "discontinuity" by the geophysicist between lines SL-1 and SL-3. A discontinuity in geologic terms means there is a lack of continuous geologic structure. The data also suggests there is a sudden change in bedrock type at the eastern property boundary since SL-1 was located on the adjacent property and SL-3 was located within the site boundaries do not overlap and the subsurface conditions do not match.

A sudden change in bedrock and an apparent discontinuity in the subsurface conditions suggest the possible presence of a fault at that location. The possible presence of a fault at the eastern property boundary would coincide with previous mapping of a suspected fault upslope of the site as shown on the five geologic maps previously referenced (Figures 3 through 7). Therefore, based on available geologic information and the results of the geophysics survey, we judge the discontinuity at the eastern property line to be a fault that matches the regionally mapped conditions.

Determining setbacks for buildings intended for human occupancy from active faults requires an evaluation of the fault line and the area of associated ground deformation anticipated from any given earthquake event. This includes a visual evaluation of the fault feature by trenching. Visual examination of the discontinuity would require removing the retaining wall and trenching through and into the upslope properties. Prior to removing the retaining wall, the slope would need to be shored and properly supported to protect the upslope properties. We understand this level of effort to facilitate trench excavation through the eastern property line is not feasible at this time.

Since the suspected fault feature located beneath or behind the 12-foot high retaining wall cannot be effectively investigated with an open trench at this time, we recommend the discontinuity observed at the eastern property line be considered as an active fault or fault splay for planning purposes. This assumption is consistent with suggested fault and fault splays shown on regional geologic maps. Therefore, for planning purposes, we recommend a 50-foot setback from the suspected fault feature at the eastern property line; this setback distance can be modified (i.e. increased or decreased), as appropriate, based on geologic features exposed in a fault trench excavated through the eastern property line.

We trust this letter provides the information you need. If you have any questions, please call.

Sincerely yours,
ROCKRIDGE GEOTECHNICAL, INC.

REGISTERED PROFESSIONAL ENGINEER HUI JUN LIANG GE2663 Exp. 6/30/2018 GEOTECHNICAL STATE OF CALIFORNIA

PROFESSIONAL GEOLOGIST KEVIN JAMES RYAN NO. 2404 CERTIFIED ENGINEERING GEOLOGIST STATE OF CALIFORNIA

Linda H. J. Liang, P.E., G.E.
Associate Engineer

Kevin James Ryan, P.G., C.E.G
Principal Engineering Geologist

Attachments:

References

Figures:

- Figure 1 – Vicinity Map
- Figure 2 – Site Plan
- Figure 3 – Official Earthquake Fault Zones Map
- Figure 4 - Regional Geologic Map
- Figure 5 – Quaternary Fault Map
- Figure 6 – Active Faults and Tsunami Risk Map
- Figure 7 – Active Traces of the Hayward Fault

Appendix A – Geophysics Investigation Results

REFERENCES

Bishop, C.C., Knox, R.D., Chapman, R.H., Rodgers, D.A. and Chase G.B., 1973, Geological and geophysical investigation for Tri-Cities (El Cerrito, Richmond and San Pablo) Seismic safety and environmental resource study, Contra Costa County, California: California Division of Mines and Geology Preliminary Report 19.

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Woodward-Clyde & Associates (1969). Soil Investigation for the Proposed Kensington Fire Station, 215-217 Arlington Avenue, Kensington, California. May 28, 1969.

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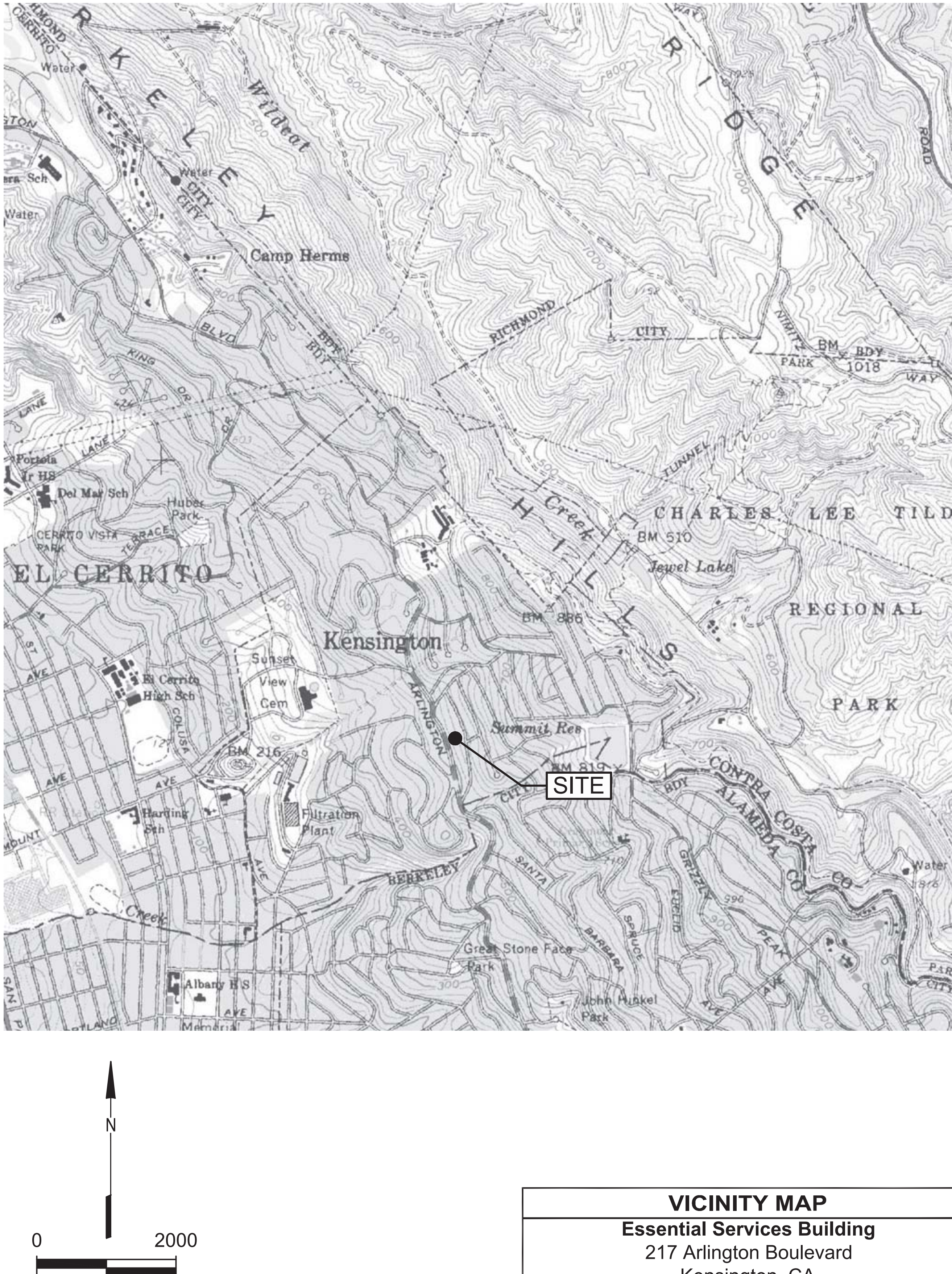
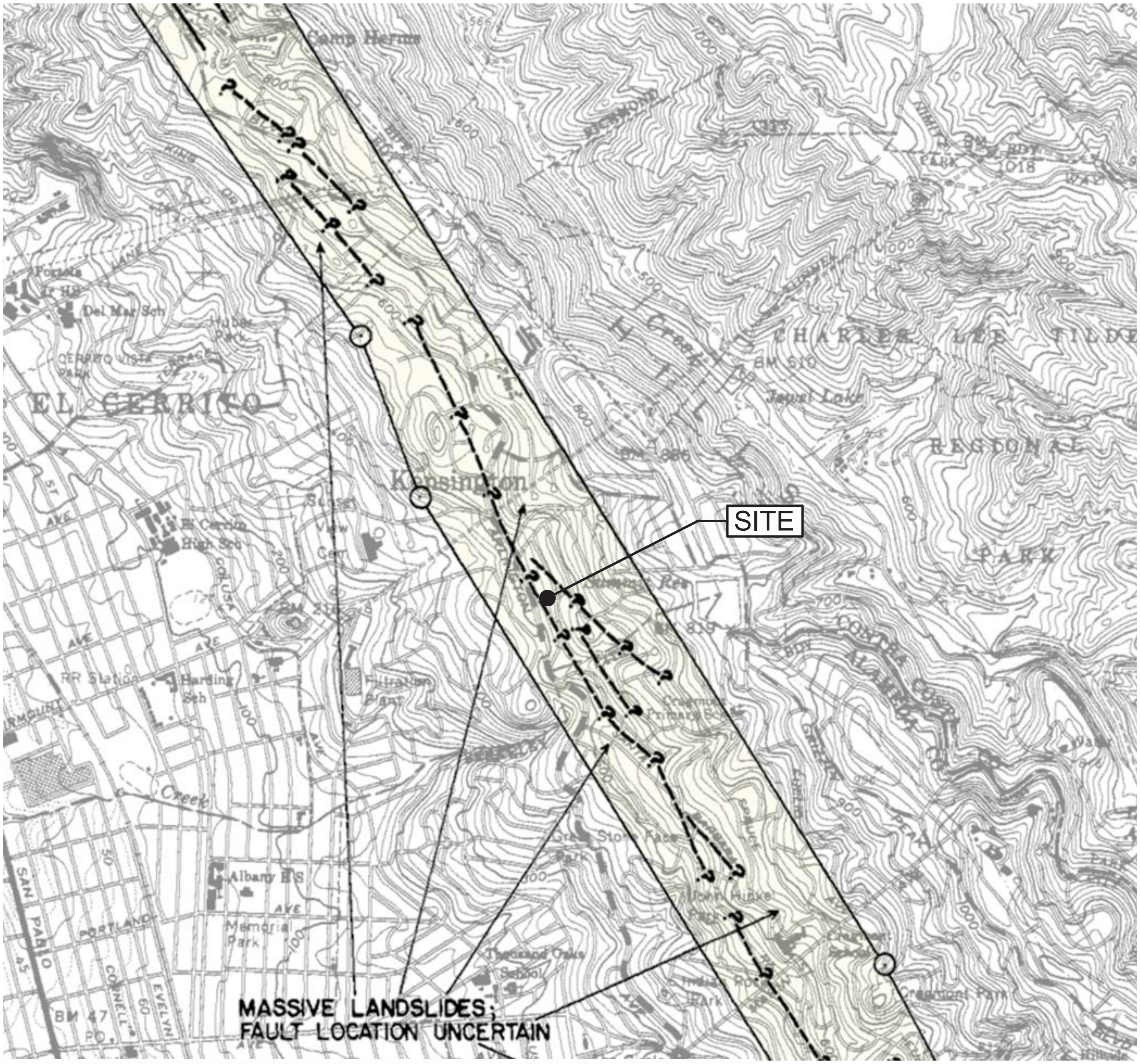
FIGURES



BASE: PORTIONS OF U.S.G.S. 7.5 MINUTE TOPOGRAPHIC QUADRANGLE, RICHMOND, CALIFORNIA AT A SCALE OF 1:24,000.

VICINITY MAP		
Essential Services Building 217 Arlington Boulevard Kensington, CA		
DATE: 1-23-18	Project No. 17-1381	Figure 1
ROCKRIDGE GEOTECHNICAL		


0
20
1"=20'
DISCONTINUITY IN
ROCK TYPE BETWEEN
SL-1 AND SL-3
AMHERST AVENUE
SL-1
RETAINING WALL ALONG
REAR PROPERTY LINE
ARLINGTON AVENUE
HOLE 4
TRENCH NO. 3
HOLE 1
BH#1
EXISTING BUILDING
PARKING
HOLE 3
SL-3
HOLE 5
TRENCH NO. 2
TRENCH NO. 1
HOLE 2
BH#2
SL-2
DRIVEWAY
EXPLANATION
PROJECT BOUNDARY
SL-3
APPROXIMATE LOCATION OF SEISMIC LINES (ADVANCED 2017)
BH#2
APPROXIMATE BORING LOCATIONS (SEIDELMAN ASSOCIATES, INC. 1990)
HOLE 5
APPROXIMATE BORING LOCATIONS (WOODWARD CLYDE 1969)
TRENCH NO. 3
APPROXIMATE TRENCH LOCATIONS (WOODWARD CLYDE 1969)
SITE PLAN
Essential Services Building
217 Arlington Boulevard
Kensington, CA
DATE: 1-23-18
Project No. 17-1381
Figure 2
ROCKRIDGE
GEOTECHNICAL



MAP EXPLANATION

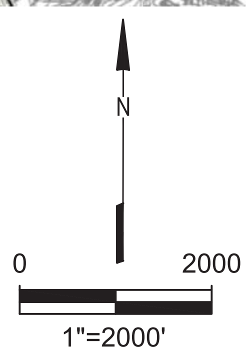
Potentially Active Faults

Faults considered to have been active during Holocene time and to have a relatively high potential for surface rupture; solid line where accurately located, long dash where approximately located, short dash where inferred, dotted where concealed; query (?) indicates additional uncertainty. Evidence of historic offset indicated by year of earthquake-associated event or C for displacement caused by creep or possible creep.

Special Studies Zone Boundaries

These are delineated as straight-line segments that connect encircled turning points so as to define special studies zone segments.

Seaward projection of zone boundary.



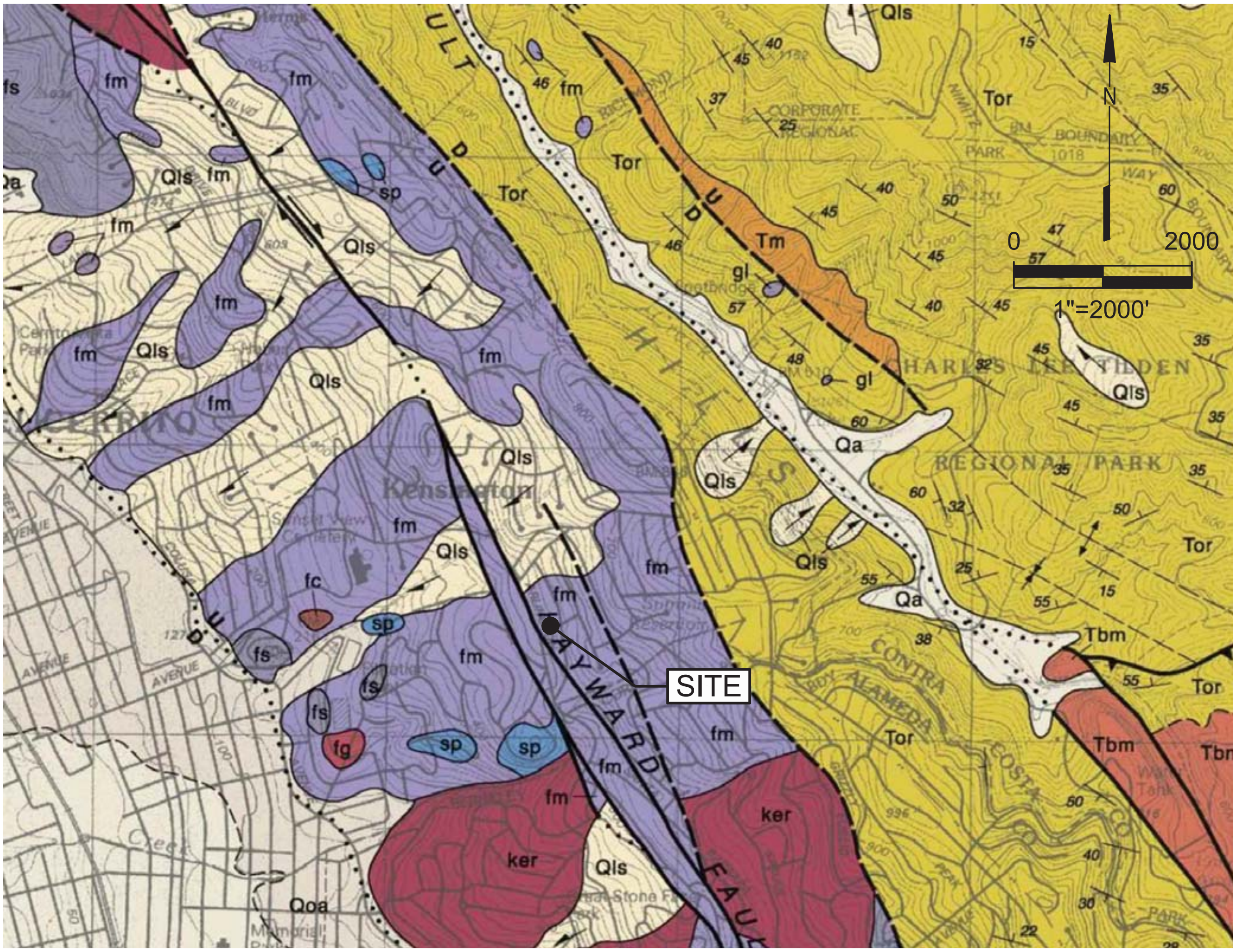
OFFICIAL EARTHQUAKE FAULT ZONES MAP

Essential Services Building
217 Arlington Boulevard
Kensington, CA

DATE: 1-23-18 | Project No. 17-1381 | Figure 3

ROCKRIDGE GEOTECHNICAL

BASE: PORTION OF STATE OF CALIFORNIA SPECIAL STUDIES ZONES ,RICHMOND QUADRANGLE, CALIFORNIA AT A SCALE OF 1:24,000.



EXPLANATION

(solid line)	CONTACT - DEPOSITIONAL OR INTRUSIVE CONTACT, DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED
(dashed line)	FAULT - DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED
(strike and dip symbol)	STRIKE AND DIP OF BEDDING
Qa	ALLUVIAL GRAVEL, SAND AND CLAY OF VALLEY AREAS
Qls	LANDSLIDE RUBBLE
Qoa	DISSECTED OLDER ALLUVIAL GRAVEL AND SAND, UNDERFORMED; AGE LATE PLEISTOCENE
Tor	TERRESTRIAL PEBBLE CONGLOMERATE, SANDSTONE AND CLAYSTONE, INTERBEDDED, GRAY TO GREENISH GRAY
sp	SERPENTINITE, HYDROTHERMALLY METAMORPHOSED FROM ULTRAMAFIC IGNEOUS ROCKS, SUCH AS DUNITE, HYDROUS MAGNESIUM SILICATE, MASSIVE, AMORPHOUS, BLUE-GREEN GRAY, MUCH FRACTURED, SHEARED, SLICKENSIDED
fm	MELANGE (MIXTURE) OF FRANCISCAN ROCK FRAGMENTS IN MATRIX OF PERVASLVELY SHEARED DARK CLAYSTONE AND GRAYWACKE
fg	GREENSTONE (METABASALT)
fc	CHERT OR METACHERT, VARICOLORED, THIN BEDDED, BRITTLE, CONTORTED
fs	GRAYWACKE SANDSTONE, GRAY, MASSIVE, FINE GRAINED HARD

BASE: PORTION OF GEOLOGIC MAP OF THE RICHMOND QUADRANGLE, CONTRA COSTA AND ALAMEDA COUNTY, CALIFORNIA BY DIBBLEE AND MINCH, 2005 #DF-147

REGIONAL GEOLOGIC MAP

Essential Services Building
217 Arlington Boulevard
Kensington, CA

DATE: 1-23-18	Project No. 17-1381	Figure 4

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EXPLANATION

HAYWARD FAULT ZONE, NORTHERN HAYWARD SECTION (HAYWARD FAULT)

QUATERNARY FAULT MAP

Essential Services Building
217 Arlington Boulevard
Kensington, CA

DATE: 1-23-17	Project No. 17-1381	Figure 5

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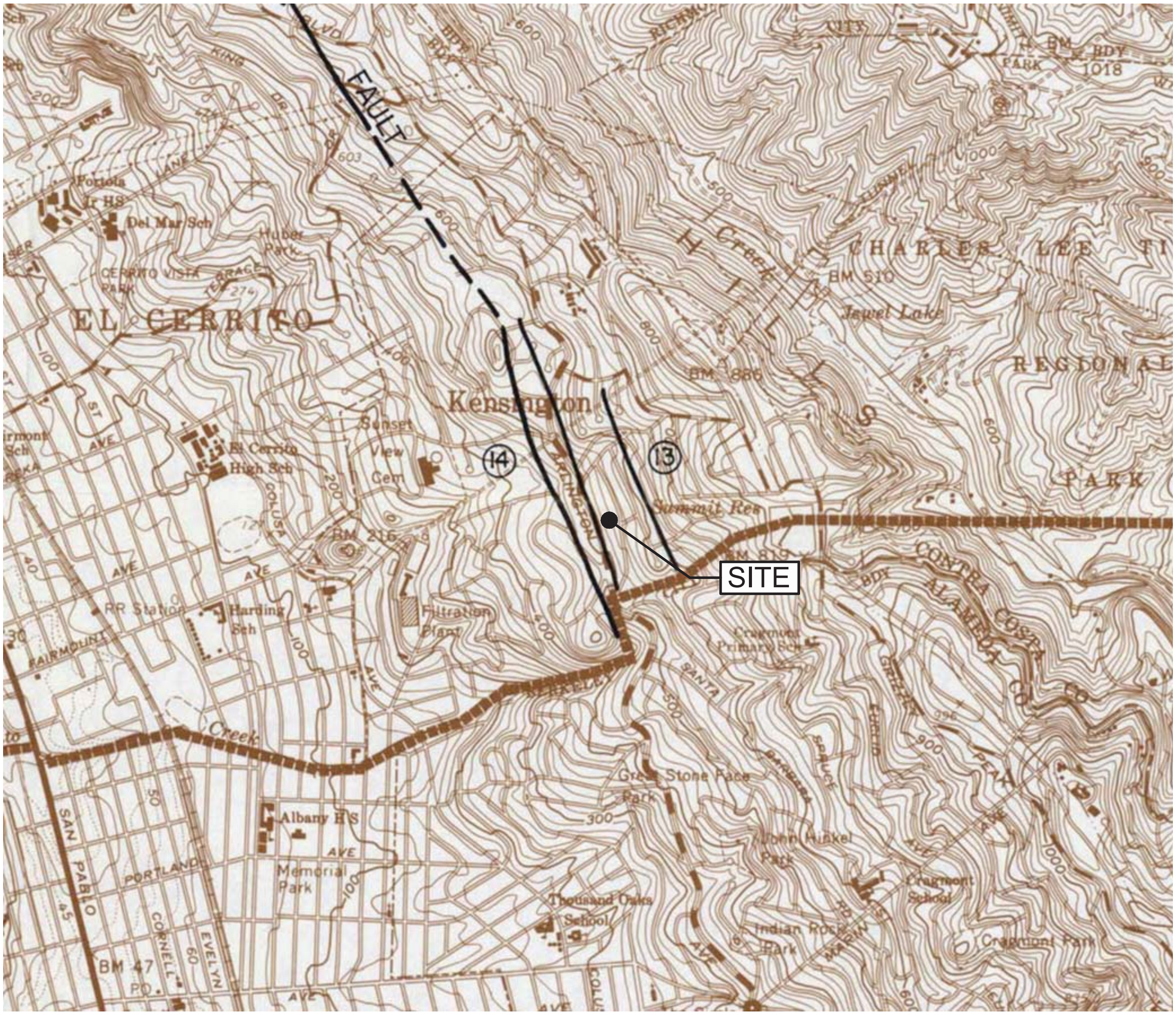
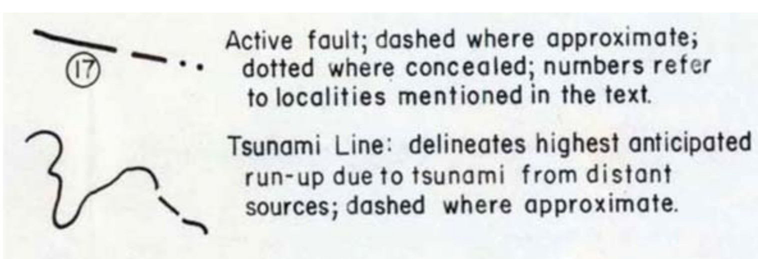
BASE: GOOGLE EARTH AERIAL IMAGE





BASE: TRI CITIES SEISMIC SAFETY ELEMENT, PRELIMINARY REPORT 19, PLATE 2, TITLED, "ACTIVE FAULTS AND TSUNAMI RISK MAP"

ACTIVE FAULTS AND TSUNAMI RISK MAP

Essential Services Building
217 Arlington Boulevard
Kensington, CA

DATE: 1-23-18	Project No. 17-1381	Figure 6

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C - CREEP EVIDENCE

2 - DISTINCT AND CERTAIN CREEP EVIDENCE
3 - INCONCLUSIVE EVIDENCE FOR CREEP
ec - EN ECHELON LEFT-STEPPING CRACKS IN PAVEMENT
hb - LINEAR HILLSIDE BENCH
lv - LINEAR VALLEY OR TROUGH
ra - RIGHT LATTERLY OFFSET AQUEDUCT PIPE OR TUNNEL
rb - DISTORTION OR RACKING OF ABOVE-GRADE STRUCTURE (INCLUDING SEPARATING ADDITIONS AND STAIRWAYS)
rc - RIGHT-LATERALLY OFFSET CURB OR FORM LINE
rf - RIGHT LATERALLY OFFSET FAINTED LINE
rs - RIGHT-LATERALLY OFFSET STREAM OR GULLY
so - SURVEYED OFFSET FEATURE

G - GEOMORPHIC FEATURES

G1 - STRONGLY PRONOUNCED FEATURE
G2 - DISTINCT FEATURE
G3 - WEAKLY PRONOUNCED FEATURE
GI - LINEAR BREAK (OR GRADUAL INFLECTION) IN SLOPE
LV - LINEAR VALLEY OR TROUGH
SL - LINEAR SCARP, UNDIFFERENTIATED
HV - LINEAR HILLSIDE VALLEY
SE - SUBSOIL EXPOSED

HAYWARD FAULT
CREEP EVIDENCE

N

0 1000

1"=1000'

BASE: PORTION OF USGS DIGITAL MAP OF RECENTLY ACTIVE TRACES OF THE HAYWARD FAULT, CALIFORNIA

ACTIVE TRACES OF THE HAYWARD FAULT

Essential Services Building
217 Arlington Boulevard
Kensington, CA

DATE: 1-23-18	Project No. 17-1381	Figure 7

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APPENDIX A
Geophysical Investigation Results

ADVANCED GEOLOGICAL SERVICES

1605 School Street, #4
Moraga CA 94556
925 (808-8965)

November 6, 2017

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

Subject: Geophysical Investigation Results
Kensington Public Safety Building
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 public safety building at the site of the current public safety building, 217 Arlington Avenue in Kensington, California (Figure 1).

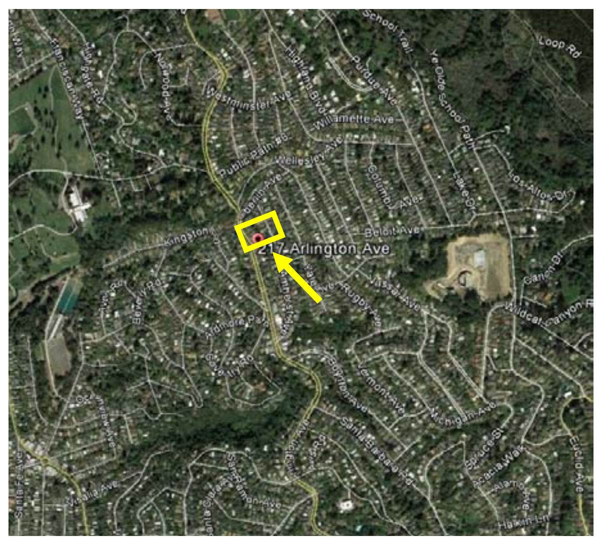


Figure 1 - Site Location in Kensington, CA

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 public safety 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 public safety 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 public safety building 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 public safety building 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 public safety building 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 public safety building 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

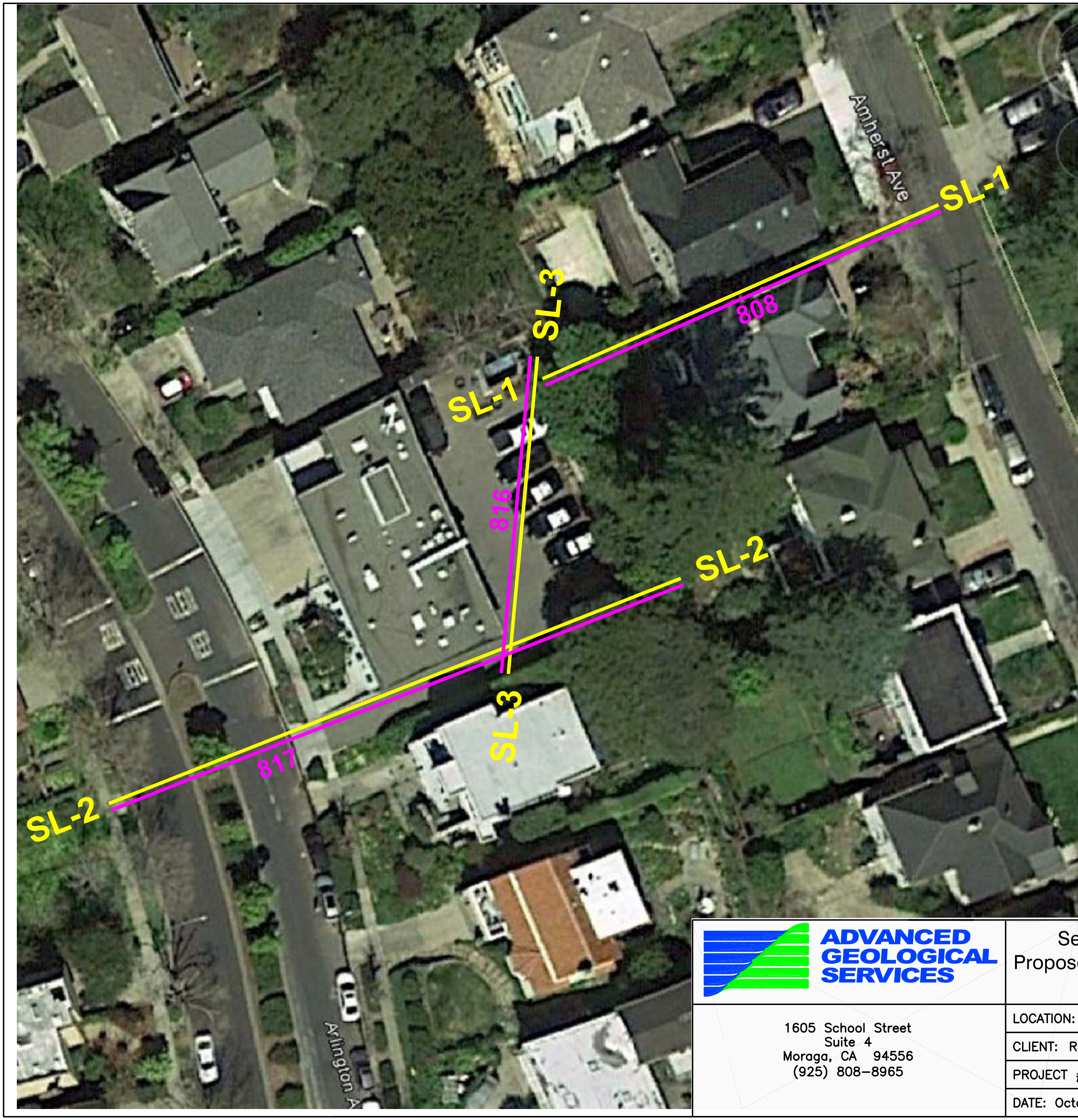
All geophysical data and field notes collected as a part of this investigation will be archived at the AGS office. The data collection and interpretation methods used in this investigation are consistent with standard practices applied to similar geophysical investigations. The correlation of geophysical 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



EXPLANATION

SEISMIC LINE

GPR LINE

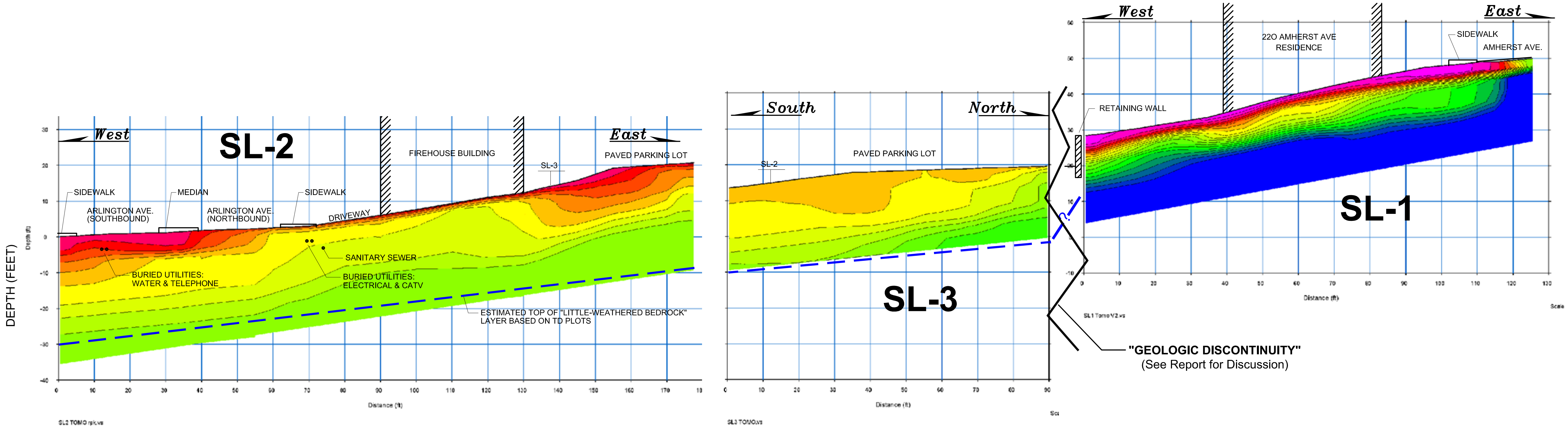
0 40 ft 80

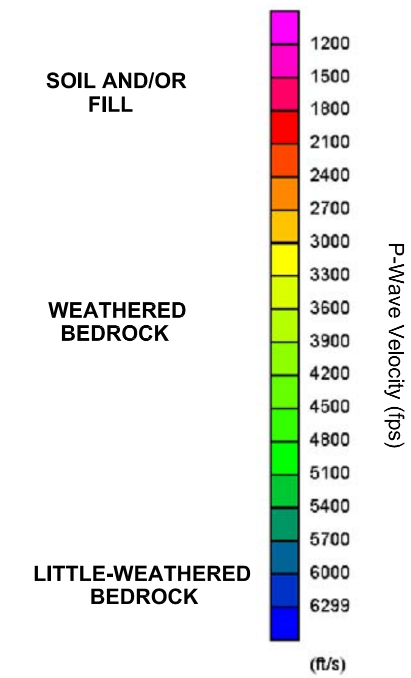
ADVANCED GEOLOGICAL SERVICES

1605 School Street
Suite 4
Moraga, CA 94556
(925) 808-8965

Seismic and GPR Line Locations
Proposed Public Safety Building 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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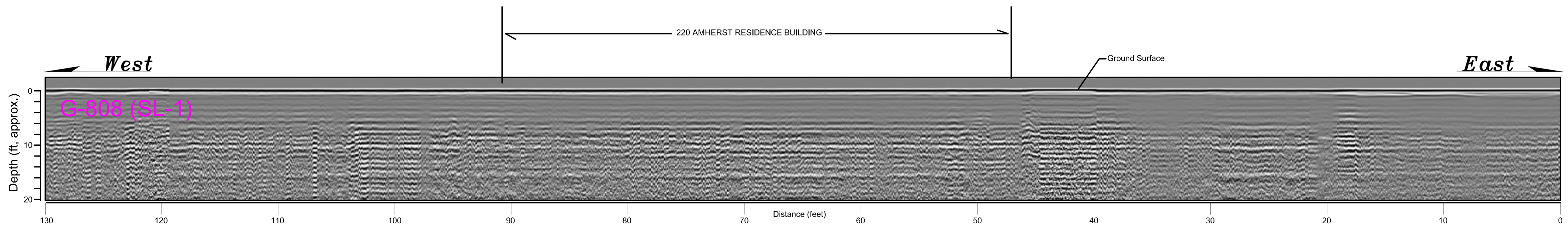
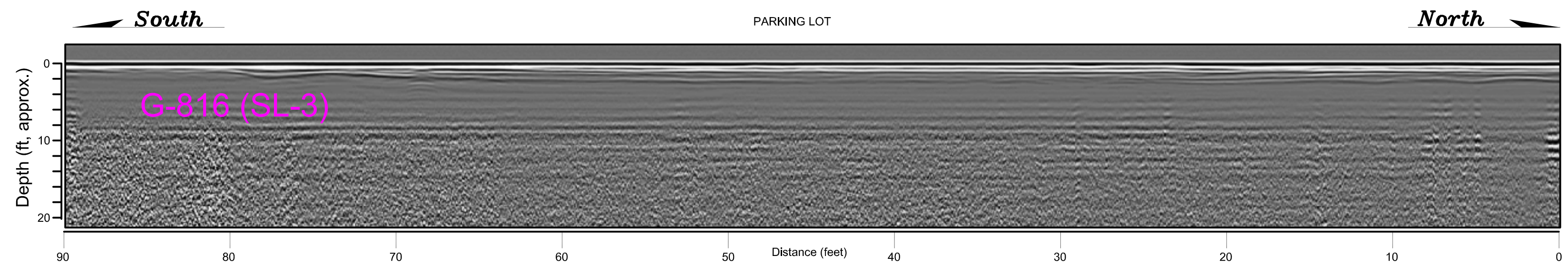
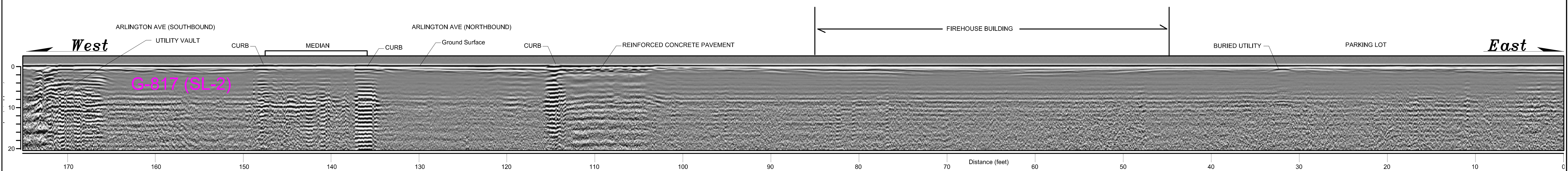
FIGURE 3







LINE LOCATION MAP

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FIGURE
4

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.