GEOMATRIX

ASSESSMENT OF EARTHQUAKE-RELATED GEOLOGIC/GEOTECHNICAL HAZARDS AND EXISTING FOUNDATION DISTRESS

Kensington Fire Station
Kensington, Contra Costa County, California

Prepared for:

Kensington Fire Protection District
Kensington, California

October 1997
Project No. 4247

Geomatrix Consultants

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GEOMATRIX

October 30, 1997
Project No. 4247

Mr. Don Dommer
Kensington Fire Protection District
600 Wellesley Avenue
Kensington, California 94705

Dear Mr. Dommer:

Geomatrix Consultants is pleased to submit the attached report that documents the results of our geologic and geotechnical engineering study to assess earthquake-related hazards (i.e., surface fault rupture, lansliding/slope instability) to the site of the Kensington Fire Station, located at 215 Arlington Avenue in Kensington, California, as well as to assess existing ground distress affecting the Fire Station structure and paved area behind the structure. This study was conducted in support of an overall seismic safety and retrofit evaluation being undertaken by the Kensington Fire Protection District for the Fire Station.

Please do not hesitate to contact us if you have any questions regarding the attached report or if we may be of further assistance to the District. We appreciate the opportunity to work with you on this challenging and important project for the Kensington Fire Protection District.

Sincerely,
GEOMATRIX CONSULTANTS, INC.

John A. Egan

John A. Egan
Principal Engineer
RGE No. 291

JAE/ckk
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Attachment

Geomatrix Consultants, Inc.
Engineers, Geologists, and Environmental Scientists

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EXECUTIVE SUMMARY

A geologic and geotechnical engineering study has been conducted for the site of the Kensington Fire Station to assess the potential for experiencing earthquake-related geologic/geotechnical hazards (i.e., surface fault rupture, landsliding/slope instability) at the site during future earthquakes in the region. Existing ground deformation affecting the Fire Station structure and the paved area behind the structure was also examined and assessed during the study. The geologic/geotechnical hazards assessment was primarily based on readily available information including the design soils investigation report (circa 1969), published maps, historic aerial photographs, and historic ground shaking effects, as well as ground reconnaissance of the site and vicinity and geotechnical analyses. In addition, to help assess existing foundation distress, a test pit was excavated adjacent to the Fire Station structure. Key findings of the study may be summarized as follows:

- **Surface fault rupture hazard.** The Fire Station is situated within the Alquist-Priolo Special Studies Zone defined by the California Division of Mines and Geology for the Hayward fault. Our review of previous mapping, aerial photographs, and our field reconnaissance indicates that the main trace of the Hayward fault lies to the west of Arlington Boulevard, and that there is no evidence for the presence of additional fault traces to the east of Arlington Boulevard where the Fire Station is situated. Thus, it is our opinion that there is not a surface-fault rupture hazard to the Fire Station site.

- **Landsliding/slope instability hazard.** Stability analyses performed during the study indicate that the sloping ground at and in the vicinity of the Fire Station is generally stable under gravity (static) loading for the lower groundwater conditions prevalent during drier seasons of the year; however, as groundwater rises in wetter seasons, the slope becomes marginally stable and prone to downslope creeping of the surficial soil deposits. Observed distress of curbs and retaining walls in the Fire Station vicinity are interpreted to be a result of such slope creep movement. Slope creep is an on-going geologic process and its associated ground deformation will be manifest and affect the performance of the Fire Station site in a gradual/long-term sense.

Earthquake ground-shaking experienced at the site since construction of the Fire Station has probably not been strong enough to have contributed to the ground deformation effects that have been manifest at the Fire Station site. Significantly stronger ground-shaking, however, is expected to be experienced at the site from moderate to large earthquakes on the Hayward fault. We anticipate that such ground shaking will produce temporary instability of the Fire Station site that would be manifest by downslope movements; based on our analyses, we are of the opinion that downslope movements in the range of a few inches to approximately a foot could occur.

- **Foundation distress.** Directly beneath the driveway slab, a 1 to 2 inch void space was observed when we excavated the test pit, which was probably caused by settlement associated with long-term compaction of the apparently medium dense to loose crushed rock and sand fill materials. We are of the opinion, however, that the more pervasive distress being experienced by the Fire Station structure is a result of foundation/footing movements resulting from what we have interpreted to be an on-going slope creep process. We are further of the opinion that the minor subsidence observed in the parking area behind the structure is probably a sympathetic response of the soil/fill in that area to the downslope movements being experienced by the foundations and probably, therefore, to a lesser degree by the structure.

We are of the opinion that effects of ground deformation on the Fire Station structure may be mitigated by strengthening/stiffening the foundation system; there is little that can practically be implemented to mitigate the on-going slope creep process itself. We recommend that a grid of grade beams be installed beneath the ground-floor slabs to tie the existing continuous footings together, as well as to tie the footing system to the more massive retaining wall foundation at the rear of the structure. It may be prudent, also, to attach the floor slabs to the footings and grade beams; this would further increase the rigidity of the foundation system. We anticipate that if foundation strengthening/stiffening were to be undertaken, it would occur coincidently with retrofit of the overall structure.

1.0 INTRODUCTION

This report presents the results of a geologic and geotechnical engineering study conducted by Geomatrix Consultants (Geomatrix) to assess earthquake-related geologic/geotechnical hazards (i.e., surface fault rupture, landsliding/slope instability) that may be experienced at the site of the Kensington Fire Station, located at 215 Arlington Avenue in Kensington, California, as well as existing ground distress affecting the Fire Station structure and the paved area behind the structure. We understand that this geologic and geotechnical engineering study was conducted in support of an overall seismic evaluation of the Fire Station being undertaken by the Kensington Fire Protection District (District). We further understand that the District plans to utilize this building for emergency response operations and, as such, it is classified as an Essential Facility.

As stated previously, the primary objectives of this study were to examine and address existing ground distress conditions at the site and to assess the potential for experiencing earthquake-related geologic/geotechnical hazards (i.e., surface fault rupture, landsliding/slope instability) at the site that could affect the intended performance of the building. To accomplish these objectives, we performed the following scope of services:

- Assembling and reviewing readily available topographic maps, geologic maps, fault maps, aerial photographs, and other pertinent information to help identify the presence of active faulting and known landsliding or slope instability.
- Reviewing the available geotechnical reports prepared for the site to help characterize existing subsurface soil and groundwater conditions at the site.
- Reviewing available information regarding historic ground shaking and occurrences of earthquake-induced ground failure in the site vicinity.
- Performing ground reconnaissance of the site and vicinity.
- Excavating a test pit to expose and observe the Fire Station's foundation and soil below the foundation.

- Performing geotechnical analyses, as necessary, of the characterized subsurface soil and groundwater conditions to assess potential slope instability and earthquake-induced slope deformations.
- Preparing this written report documenting the results of the study.

Geomatrix Consultants personnel who contributed to this study included: Mr. John Egan, Principal Engineer and Project Manager, Mr. Donald Wells, Senior Geologist, Mr. Fernando Rivera, Project Engineer, Dr. Dario Rosidi, Project Engineer, and Mr. Richard Sun, Staff Engineer.

2.0 PREVIOUS INVESTIGATIONS

In 1969, Woodward-Clyde & Associates served as the soil engineers for the design and construction of the Kensington Fire Station. The soils investigation performed at the site was documented in the report entitled "Soils Investigation for the Proposed Kensington Fire Station, 215-217 Arlington Avenue, Kensington, California, dated May 28, 1969 (Woodward-Clyde Project S-11804).

The borings and trenches performed by Woodward-Clyde indicated surficial soils consisting of medium stiff silty clay to depths of about 6 to 7.5 feet [1¾ to 2¼ m] below grade, which are underlain by sheared and weathered shales having a thickness ranging from about 3 to 10 feet [1 to 3 m]. These shales become less weathered and sheared with depth and are underlain by a dense, relatively hard shale.

Based on the construction drawings, the two-story building is supported on continuous footings bearing on soils at a depth of approximately 2½ to 3 feet [¾ to 1 m] below the adjacent finished grade.

3.0 GEOLOGIC AND SEISMIC SETTING

3.1 Regional and Local Geology

Kensington is located along the eastern margin of San Francisco Bay, on the west-facing slopes of the hills that form the eastern boundary of the bay. San Francisco Bay occupies a broad, shallow depression that developed in response to minor crustal extension between the San Andreas fault on the west and Hayward fault on the east. The San Francisco Bay depression appears to be a pull-apart basin that has been slowly subsiding during late Quaternary time (the past 700,000 years) and perhaps longer. The basin is predominantly filled with late Quaternary alluvial, fluvial, and estuarine deposits, overlying older basement rocks. The oldest rocks in the San Francisco Bay area belong to the Franciscan Assemblage of Jurassic to Cretaceous age (195 to 63 million years before present). These rocks form the basement complex beneath the basin, and are exposed along the margins of basin west of the Hayward fault and east of the San Andreas fault. Franciscan Assemblage rocks are exposed along the slopes of the East Bay Hills between San Pablo and Oakland on both sides of the Hayward fault. Middle to Late Miocene Contra Costa Group rocks (formed about 13 to 9 million years ago) are exposed to the east of an older strand of the Hayward fault that lies approximately 2000 feet [600 m] east of the presently active strand of the Hayward fault.

The Franciscan Assemblage consists of a heterogeneous assemblage of deep-sea sediments and related oceanic crustal rocks, including graywacke sandstone and interbedded shale, with lesser amounts of submarine basalt (greenstone), chert, serpentinite, and rare high-pressure metamorphic rocks known collectively as blueschist (Bailey and others, 1964). These rocks bear the imprint of tectonic subduction, a process in which an oceanic plate collides with and slides beneath a continental plate such as is occurring today of the west coast of South America, and off the Northern California, Oregon, and Washington coasts. As a result of the subduction processes, the Franciscan Complex is now highly disrupted, and much of it has been reduced to a tectonic "paste" called melange.

Mapping by Dibblee (1980) indicates that the Kensington Fire Station site is underlain by melange or sheared rocks (greenstone, sandstone, and chert) in a sheared shale matrix. Soil borings completed by Woodward Clyde (1969) show that the project site is underlain by weathered light gray to unweathered gray shale and sandy shale. A detailed log of geologic conditions through the East Bay Hills from the East Bay Municipal Utility District (EBMUD) San Pablo Tunnel was included in Geomatrix Consultants (1993). This tunnel is located approximately 900 feet [275 m] north of the project site. Geologic units mapped near the Hayward fault in the tunnel include shale, serpentine, and schist of the Franciscan Assemblage, and shale and sandstone of the late Jurassic (160 to 144 millions of years ago) Knoxville Formation (reported in Geomatrix Consultants, 1993). The Knoxville Formation is comprised predominantly of dark colored marine shale, sandstone (graywache), and conglomerate.

The Contra Costa Group comprises non-marine sedimentary rocks deposited in alluvial fans, such as sandstone, siltstone, and conglomerate of the Orinda Formation, and volcanic rocks. The Moraga Volcanics, which comprise tuff breccia and basalt, overlie the sedimentary rocks, while the Bald Peak Basalt and Grizzly Peak Basalt are intruded into the sedimentary rocks along the East Bay Hills in the vicinity of Kensington, Berkeley and Oakland (Dibblee, 1980; Curtis, 1989; Wahrhaftig, 1989).

3.2 Active Faults And Historic Seismicity

Based on its record of historic earthquakes and its position astride the North American-Pacific plate boundary, the San Francisco Bay region is considered to be one of the more seismically active regions of the world. During the historical period (about 160 years), faults within this plate boundary zone have produced numerous small magnitude and, as summarized in Table 1, more than a dozen moderate to large magnitude earthquakes (i.e., $M \geq 6$) within the Bay region (Toppozada and others, 1979; Real and others, 1978; Working Group on California Earthquake Probabilities, 1988, 1990). The WGCEP (1990) has estimated that there is an approximately 67-percent probability of one or more large ($M \geq 7$)

earthquakes occurring within the Bay region during the 30-year time period between 1990 and 2020; however, Schwartz (1994) indicates that continually improving understanding of fault behavior and new information obtained since 1990 suggest that the probability of a large earthquake is substantially higher than the WGCEP (1990) estimate.

The Hayward fault has been the source of at least one, possibly two, major earthquakes during the historical period, an M6.8 event in October 1868 and possibly an M6.8 event in June 1836 and (Toppozada and others, 1981). The WGCEP (1990) has postulated that there is a 28 percent probability of a M7 earthquake occurring on the northern segment of the Hayward fault, which runs through Kensington, during the 30-year time period between 1990 and 2020; the southern segment of the fault, situated approximately 12½ mi [20 km] south of Kensington, has been assigned a 23 percent probability for the occurrence of a M7 earthquake during that 30-year time period. These probabilities indicate that for the Hayward fault zone as a whole entity, there is an aggregated probability of about 45 percent for the occurrence of a M7 earthquake within that 30-year time window. Based on existing data and interpretations, the expected maximum earthquake for Hayward fault is judged to be M_W 7 to 7¼.

Other potentially significant faults with respect to ground shaking hazard at the site include: the San Andreas fault, situated approximately 19 mi [30 km] west-southwest of Kensington, the Rodgers Creek-Healdsburg fault, situated approximately 12½ mi [20 km] north of Kensington and the Calaveras fault, situated approximately 18 mi [29 km] east-southeast of Kensington. The San Andreas fault, which extends over 750 mi [1200 km] from the Gulf of California to Cape Mendocino, is the major fault within the region and has generated three large earthquakes during the historical period, an M7 event in June 1838, the great M8 earthquake in April 1906, and the recent M7 Loma Prieta earthquake on October 17, 1989; the Southern Santa Cruz Mountains segment of the San Andreas fault, on which the Loma Prieta earthquake occurred, is situated approximately 53 mi [85 km] south of Kensington. The Rodgers Creek-Healdsburg fault is believed to have been the source of the

M6.2 Mare Island earthquake in March 1898 (Toppozada and others, 1981). The southern Calaveras fault has produced three moderate-magnitude earthquakes during the historical period, an M6.2 event in June 1897, an M6.6 event in July 1911, and the April 1984 M6.2 Morgan Hill event; during the past fifteen or so years, the Calaveras fault has also produced a number of other earthquakes, most notably the M5.8 Coyote Lake event in August 1979. Based on existing data and interpretations, the expected maximum earthquake for the San Andreas fault is judged to be in the range of M_W 7¾ to 8, for the Rodgers Creek-Healdsburg fault, it is judged to be in the range of M_W 7 to 7¼, and for the Calaveras fault, it is judged to be M_W 6¾ to 7.

3.3 Earthquake Ground Shaking

Due to its close proximity, the Hayward fault dominates ground-motion considerations for the Fire Station site. Deterministic estimates of peak ground accelerations were developed assuming the occurrence of a magnitude (M_W) 7 to 7¼ earthquake rupturing the Hayward fault through Kensington and a magnitude (M_W) 8 earthquake rupturing through the closest point on the San Andreas fault from Kensington. Four published ground motion attenuation relationships developed for competent soil/soft rock conditions (Sadigh and others, 1997; Abrahamson and Silva, 1997; Boore and others, 1997; Campbell and Bozorgnia, 1994) were used to develop these deterministic estimates, with each relationship given equal weight. Results of the analyses indicate that for an event of M_W 7 to 7¼ on the Hayward fault, peak horizontal ground accelerations of approximately 0.6g may be expected to be experienced at the site. For an M_W 8 event on the San Andreas fault, the site is expected to experience peak horizontal ground accelerations of approximately 0.25g. These ground motions represent the expected (median) level for the given event; ground motions at a median-plus-one-standard-deviation level (i.e., 84th percentile) would be about 1.55 times greater than the expected (median) ground motion level.

The duration of strong ground shaking is primarily a function of the magnitude of the earthquake responsible for generating the ground motion. Empirically-derived duration relationships presented by Dobry and others (1978) and Bullen and Bolt (1985) indicate that for an M_W 7 to 7¼ event on the Hayward fault, a significant duration of strong ground shaking of approximately 15 to 20 seconds may be expected; for a more distant M_W 8 event on the San Andreas fault, the expected significant duration of strong ground shaking may be approximately 35 to 45 seconds (Dobry and others, 1978). We expect, therefore, that the strong shaking durations associated with the earthquakes that dominate the ground motion hazard presented previously for the site will be approximately 15 to 20 seconds, although lower amplitude shaking may continue longer.

As mentioned previously, the Fire Station is situated in close proximity to the Hayward fault, which dominates the ground motion considerations. Near-field strong motion recordings obtained from earthquakes that have occurred during the past 20 years have exhibited vertical motions equal to or exceeding the horizontal motions, especially at sites underlain by competent soil/soft rock profiles (Egan and others, 1994). Examination by these authors of available ground motion data from recent moderate to large ($M_W \geq 6½$) California earthquakes indicates that within about 10 mi [15 km] of fault ruptures, peak ground accelerations and higher frequency ($T < 0.2$ sec) response spectral ordinates for the vertical component approximately equal or exceed those of the horizontal components that for longer period motions ($T > 0.3$ sec), average vertical to horizontal ratios for spectral ordinates are about one-half or less.

3.4 Historic Ground Shaking Observations

Kensington has experienced ground shaking from the numerous small magnitude and more than a dozen moderate to large magnitude (i.e., $M \geq 6$) earthquakes (Table 1) that have occurred in the greater San Francisco Bay region during the historic time period (approximately 160 years). Ground shaking experienced in Kensington from most of the historic earthquakes in the region has been of generally imperceptible or quite small amplitude and produced effects observed in the vicinity that may be categorized as I through V on the Modified Mercalli Intensity (MMI) scale (see Table 2 for intensity descriptions). There have been, however, nearly two dozen events in the region that have induced ground shaking strong enough in the site vicinity to produce reported MMI VI or greater effects (as described in Table 2, MMI VI corresponds to the lowest intensity level with which some level of damage (slight) is associated); characteristics of these events are summarized in Table 1.

The most recent of these events was the previously-mentioned the M_W 7 Loma Prieta earthquake in October 1989, which ruptured on or near the southern Santa Cruz Mountains segment of the San Andreas fault approximately 53 mi [85 km] south of Kensington and produced MMI VI effects in Kensington. Ground motion recordings of the Loma Prieta earthquake obtained on instruments operated by the California Division of Mines and Geology and United States Geological Survey in Oakland, Berkeley, and Richmond were characterized by peak horizontal ground accelerations in the range of 0.06 to 0.13g (Shakal and others, 1989; Maley and others, 1989); we anticipate that similar ground shaking levels were experienced in Kensington. It may be noted that the peak horizontal ground acceleration levels experienced in Kensington during the Loma Prieta earthquake were considerably lower in amplitude than those cited previously as expected to be associated with a major event rupturing the Hayward fault through Kensington. Another significant observation regarding the Loma Prieta earthquake and the ground motions it produced is the relatively short duration of ground shaking due to the bilateral nature of the fault rupture. Strong shaking of about 6 to 8 seconds, which typified recordings obtained throughout the felt area of the earthquake, is approximately one-half the duration that may be expected for a M7 earthquake having unilateral fault rupture (Dobry and others, 1978); according to Dobry and others (1978), strong ground shaking of a 6 to 8 second duration is more typical of earthquakes having magnitudes of approximately M6.

The other moderate magnitude earthquake experienced by the Fire Station was the M6.2 Morgan Hill earthquake in April 1984, which ruptured along the Calaveras fault approximately 65 mi [100 km] south of Kensington and produced MMI V effects in the

Kensington vicinity (U.S. Earthquakes, 1984); ground shaking from the earthquake recorded on instruments in Oakland and El Cerrito was characterized by peak horizontal ground of 0.01g to 0.02g (Shakal and others, 1986).

Based on the estimates of MMI reported for the Kensington vicinity, as summarized in Table 1, significantly stronger ground shaking than was experienced in 1989 was quite likely experienced in the Kensington vicinity during at least three of the historic Bay region events. Among these are: the M6.8 earthquake in June 1836 that may have ruptured the northern segment of the Hayward fault and produced effects in the Kensington vicinity estimated from reports by Louderback (1947) to be MMI VIII to IX; the M6.8 earthquake in October 1868 that ruptured the southern segment of the Hayward fault and produced MMI VIII effects in Kensington (Toppozada and others, 1981; 1982); and the great M8 San Francisco earthquake in April 1906 that ruptured the San Andreas fault and produced MMI VIII effects in Kensington (Toppozada and Parke, 1982).

4.0 SITE RECONNAISSANCE

Based on our conversations with Mr. Dommer, the Fire Station structure has been affected by ground deformation, particularly on the front of the structure where some distress has been observed. In addition, minor subsidence has also been observed in the upper paved area behind the structure.

To assess the possible reasons for ground distress, we visited the site on September 4, 1997 to perform a test pit excavation. We excavated a test pit in the garage driveway, located at the front of the structure as shown on Figure 1, to expose and observe the foundation and soils below the foundation. The driveway surface consists of a concrete slab that slopes mildly downward to Arlington Avenue.

The test pit was approximately 7 ft [2.1 m] long by 1½ ft [0.5 m] wide by 4¾ ft [1.45 m] deep and was excavated using a backhoe supplied by Cal-Neva Excavators from El Cerrito, California. At the test pit location, the concrete driveway slab was fractured due, apparently, to ground distress. The test pit excavation indicated that the concrete slab was approximately 6 in [150 mm] thick and was reinforced with steel bars (#4) spaced 18 in [450 mm] on centers. Directly underneath the slab there was 1 to 2 in [25 to 50 mm] void followed by a 15 in [380 mm] layer of crushed rock and sand fill materials, which were medium dense to loose and in wet conditions. Stiff silty clay soils were encountered below the fill materials to the 4¾ ft [1.45 m] depth explored, where groundwater was encountered.

Groundwater was also measured at three inclinometer locations (I1, I2, I3), shown on Figure 1. According to Seidelman Associates (1990), two of these inclinometers (I1 and I2) were installed in December 1989; the origin of inclinometer I3 is not known. Groundwater levels at the time of our field investigation were about 3½ ft [1.1 m] and 4 ft [1.2 m] below ground surface toward the front of the building (inclinometers I3 and I2, respectively) and 13½ ft [4.1 m] (inclinometer I1) in the upper area behind the building.

During our field investigation we observed, along the garage front, a relative lateral displacement of about 3 in [75 mm] between the driveway slab and the garage floor, as shown on Figure 1. Reportedly, this gap was filled with 2 in [50 mm] of new concrete about ten years ago. There was also some indication of lateral ground movement on the driveway located on south side of the building, where we observed a 3 in [75 mm] gap on both driveway curbs. However we did not observe any distress pattern in the paved driveway.

Of greater significance, were the distress patterns inside the building structure, such as gaps between floor slabs and walls, cracks on wall intersections and door frames out of plumb. The walls are directly supported by continuous footings, which are not tied to the concrete floors. We could not inspect the continuous footings, but there was no indication of significant differential settlement. We observed ¾ to 1 in [20 to 25 mm] horizontal gaps between the floor slab and the wall in the office area located at the front of the building.

In the paved area behind the building, we observed some localized ground subsidence of about 2 to 3 in [50 to 75 mm], as shown on Figure 1. Furthermore, there was some subsidence along the outer edge of the sidewalk of about 1 to 1½ in [25 to 40 mm].

5.0 EARTHQUAKE-RELATED GEOLOGIC HAZARDS ASSESSMENT

5.1 General

Geologic hazards are evaluated for their potential to cause damage to the Fire Station and site vicinity. Seismic-geologic hazards that were evaluated include surface-fault rupture and landsliding/slope instability. Conditions susceptible to other potential earthquake-related geologic hazards such as soil liquefaction, soil differential compaction, and flooding are not present at the project site. The hazard evaluations were conducted based on ground reconnaissance, subsurface investigations, existing information such as maps, reports, and aerial photographs.

The first step in the hazard evaluation is to check as to whether a hazard has previously occurred at the site (or near the site in similar geotechnical conditions) during historical earthquakes. Two historic earthquakes that occurred prior to construction of the Fire Station and nearby residential structures, the 21 October 1868 "Haywards" earthquake and the 18 April 1906 "San Francisco" earthquake, apparently resulted in (Modified Mercalli Intensity) MMI VIII to IX ground shaking in Kensington Hills area (Tables 1 and 2; Toppozada and Parke, 1982; Lawson, 1908). There are no reports of landslides occurring along the western slopes of the hills in Kensington, Berkeley or other nearby areas as a result of either of these earthquakes (Youd and Hoose, 1978).

The second step is check whether the site is in an area for which a regional earthquake hazard map (such as a regional landslide hazard map) has been prepared by a federal or state agency. Maps showing the location of known active and potentially active surface faults in the Kensington area have been prepared by the California Division of Mines and Geology (CDMG) (Alquist-Priolo Special Studies Zone Maps, Hart, 1994; Bortugno and others, 1991; Jennings 1994) and the U.S. Geological Survey (Radbruch, 1967; Radbruch-Hall, 1974; Lienkaemper, 1992). Maps showing the location of known landslides have been published by the U.S. Geological Survey (Nilsen, 1975; Dibblee, 1980) and others (Crane, 1995).

Detailed mapping by Radbruch-Hall (1974) and Lienkaemper (1992) indicates that the Hayward fault lies directly west of Arlington Boulevard near the Fire Station site, based on the presence of linear scarps and a right deflection of a stream channel. Radbruch-Hall also indicates that a weak linear alignment of disturbances of streets and sidewalks may result from fault displacement or landsliding; this linear alignment passes along Amherst Street, directly east of the project site. Lienkaemper also indicates that a weakly defined linear hillside bench along Arlington Boulevard may be related to faulting or to excavation for the road.

Mapping by Nilsen (1975) indicates that most of the west-facing slope of the hills in Kensington are underlain by landslide deposits, including the Fire Station site along Arlington Boulevard. Mapping by Crane (1995), however, indicates that the slopes along the drainage directly north of the site are part of a large landslide, but that the project site is not shown as located within a landslide zone. Additional evaluations of the potential for surface faulting and landsliding at the project site are described below.

5.2 Surface-Fault Rupture Hazard

We reviewed aerial photographs and conducted a brief field reconnaissance to evaluate the potential for surface faulting at the project site. As shown on Figure 2, the Hayward fault is mapped along the west side of Arlington Boulevard, and directly across the road from the project site. There are no other mapped faults located near to the Fire Station site such that the projection of any of these faults along trend would pass near to the Fire Station site.

We reviewed aerial photographs taken in 1939, 1946, and 1950 (Table 3); these photographs predate construction of the Fire Station, but postdate construction of roads and most residential structures near the site. Several distinct fault-related features were observed on these photographs, including a bedrock knob, a right-lateral displacement of a drainage channel, and a linear scarp. These features are consistent with the location of the fault trace shown by Lienkaemper (1992) on the west side of Arlington Boulevard between Sunset Drive and Coventry Road (Figure 2). Lienkaemper also identifies a linear scarp along Arlington Boulevard in this area; his mapping indicates that this feature may be artificial. Based on review of aerial photographs and our field reconnaissance of the area, we also conclude that the linear scarps along Arlington Boulevard likely result from excavation of the hill slope for construction of the road. The south-facing natural hill slope and the east-west trending drainage channel located in the area of Wellesley Avenue and Oberlin Avenue are not displaced laterally (in contrast to the distinct displacement of the drainage channel west of Arlington Boulevard); because these linear geomorphic features are not deformed, we conclude that no lateral fault slip has occurred along the eastern side of Arlington Boulevard.

Radbruch-Hall (1974) shows a linear feature along Amherst Avenue that is defined as a zone of disturbed sidewalks and streets. This feature is parallel to the main trace of the Hayward fault, which they shown along the west side of Arlington Boulevard. During our reconnaissance of Amherst Street and the area surrounding the Fire Station, we observed extensive cracking of sidewalks, curbs, driveways, and staircases throughout the area shown on Figure 2. No evidence for lateral displacement (consistent with right-lateral strike slip fault creep) was observed. Curb and retaining walls that trend east-west in the area between Amherst Street and Arlington Boulevard were not displaced laterally, indicating that there are no actively creeping faults immediately east of Arlington Boulevard. In addition, Lienkaemper (personal communication, 1997) notes that no evidence of fault creep has been observed along the hayward fault in Kensington. Thus, the observed deformation appears to result from westward (down-slope) movement of the near-surface soil and rock. We conclude that slope creep is occurring throughout this zone, and that the observed deformation along or east of Arlington Boulevard likely results from down-slope creep rather than creep on secondary faults. No reconnaissance was completed outside of the zone of slope creep shown on Figure 2.

The observations made in the EBMUD San Pablo Tunnel indicate that sandstone and shale of the Knoxville Formation occur east of active trace of the Hayward fault, while serpentine and schist of the Franciscan Assemblage occur west of the fault. The borings completed by Woodward Clyde (1969) indicate that the Fire Station site is underlain by dark shale that may correspond to the Knoxville Formation. In addition, we observed an outcrop of sandstone along the east of Arlington Boulevard, approximately 500 ft [150 m] south of the Fire Station site; this sandstone appears to be part of the Knoxville Formation. If the geologic relationships and contacts observed in the San Pablo tunnel to the north of the Fire Station site are consistent southward along the Hayward fault near the site, then the presence of Knoxville Formation rocks directly east of Arlington Boulevard indicates that the Hayward fault lies along or west of Arlington Boulevard, and does not pass through the Fire Station site.

Our review of previous mapping, aerial photographs, and our field reconnaissance studies indicate that the main trace of the Hayward fault lies to the west of Arlington Boulevard, and that there is no evidence for the presence of additional fault traces to the east of Arlington Boulevard. Thus, it is our opinion that there is not a surface-fault rupture hazard to the Kensington Fire Station site.

5.3 Landsliding/Slope Stability Hazard

The potential for landsliding or downslope movement is dependent on slope geometry, subsurface soil, rock and groundwater conditions, past slope performance, and, in the event of an earthquake, the level of ground shaking. Therefore, landsliding/slope stability hazard at the Fire Station site that may be associated with on-going geologic/slope processes and/or earthquake-related slope instability/deformation was be assessed primarily based on geologic/geotechnical ground reconnaissance of the site and immediate vicinity, the available information on subsurface geologic/geotechnical conditions (i.e., logs of trenches and soil borings, as well as associated laboratory test results) developed previously (Woodward-Clyde, 1969), available topographic, geologic and landslide maps, available aerial photographs, historic earthquake effects, and pertinent engineering analyses.

As we discussed previously, we interpret the observed deformation of curbs and retaining walls in the area between Amherst Street and Arlington Boulevard to be a result of westward (down-slope) slope creep movement of the near-surface soil and rock that appears to be occurring throughout this zone. Such slope creep is an on-going geologic/slope process that occurs in response to gravitational forces, seasonal groundwater elevation changes, weathering effects on soil properties, etc., with associated ground distress being manifest and affecting the performance of the Fire Station site in a gradual/longer-term sense. Earthquake ground-shaking experienced at the site since construction of the Fire Station has probably not been sufficiently strong to have significantly affected the stability of the site soils and therefore, is unlikely to have contributed to the ground deformation effects that have been manifest at the Fire Station site.

Future earthquake ground-shaking may, however, affect the stability of the Fire Station site by causing large transient seismic inertia forces to be added to gravitational forces within the slope, producing temporary instability that would be manifest by lateral "downslope" movement. For the duration of ground shaking associated with moderate to large earthquakes such as may occur on the Hayward fault, there could be many such occurrences of temporary instability, producing an accumulation of "downslope" movement.

Slope stability analyses were performed using computer program SLOPE/W (GEO-SLOPE, 1995). Subsurface soil stratigraphy at the Kensington Fire Station was developed for this study using the available boring and trenching information. The engineering properties of the slope materials were obtained from the laboratory test results and listed on the logs of borings. Where no specific information is readily available for a soil deposit, a range of values for the soil property was assumed for the analyses.

Figure 3 shows an idealized cross-section of the natural slope through the Kensington Fire Station site. The slope stability model suggests that the majority of ground deformation at the site occurs along an interface between the decomposed shale and shale deposits. Static factors of safety of two potential sliding surfaces (indicated on Figure 3 as slides A and B) were calculated assuming two ground water conditions. The two ground water elevations represent the conditions of the ground water during the dry (present) and wet seasons. For the dry ground water condition, factors of safety in the 1½ to 2 range were calcualted. Factors of safety for the wet ground condition, however, were calculated to be only slightly greater than unity (i.e., about 1.1 to 1.2). These results indicate that the sloping ground at and in the vicinity of the Fire Station is generally stable under gravity (static) loading for the lower groundwater conditions prevalent during drier seasons of the year; however, as groundwater rises in wetter seasons, the slope becomes marginally stable and prone to creeping of the surficial soil deposits.

Potential seismically-induced deformations of the slope were estimated using Newmark type analysis procedures. The methodology used for these analyses to account for the various aspects affecting slope performance under earthquake loading is described in Updike and others (1988) and incorporates simplified procedures, modified from Newmark (1965) and Makdisi and Seed (1978), to estimate potential slope movement. The procedures used to estimate the permanent deformations involve the following steps (Makdisi and Seed, 1978):

- The yield acceleration, K_y, is calculated using limit-equilibrium pseudostatic slope stability method,

- The peak (maximum) acceleration, K_{max}, within a potential sliding mass is estimated using the results of the deterministic analyses of ground motions.

- When the induced peak acceleration exceeds the yield acceleration, the magnitude of downslope permanent deformation of the sliding mass is calculated using relationship that relates the K_y/K_{max} ratio to the estimated deformation. This relationship is an update from the one that was developed by Makdisi and Seed (1978).

Results of analyses indicate a yield acceleration range of about 0.11g to 0.27g for potential slip surfaces analyzed (see Figure 3) and the range of soil properties considered for these analyses. As discussed previously, a maximum magnitude earthquake rupturing the Hayward fault through Kensington is expected to produce horizontal peak ground accelerations of about 0.6g. This induced ground motion level would exceed the calculated yield accelerations for the slip surfaces and downslope movements would, therefore, be expected to occur along the direction of the potential slip surface. Using the previously-cited ground motion and yield acceleration ranges, potential lateral downslope movements of the Kensington Fire Station site slope could be in the range of a few inches to approximately a foot [0.3 m].

6.0 FOUNDATION DISTRESS

Foundation Distress. To help assess possible reasons for the apparent distress to the front foundation of the structure, we excavated a test pit at the front of the structure to expose the foundation and soil/rock below the foundation for observation. Although directly beneath the driveway slab there was 1 to 2 in [25 to 50 mm] void, probably caused by settlement associated with long-term compaction of the apparently medium dense to loose crushed rock and sand fill materials, we are of the opinion that the distress being experienced by the Fire Station structure is a result of foundation/footing movements resulting from what we have interpreted to be an on-going slope creep process.

Upper Paved Area Subsidence. During our ground reconnaissance of the site, we observed the upper paved area behind the structure to help assess the occurrence of subsidence in that area. We are of the opinion that this minor subsidence is probably a sympathetic response of the soil/fill in that area to the downslope movements being experienced by the foundations and probably, therefore, to a lesser degree by the structure.

7.0 RECOMMENDATIONS

In a practical (and economic) sense, there is little that can be implemented to mitigate the on-going slope creep process that has been and will continue to deform the ground at and in the vicinity of the Fire Station site. We are of the opinion, however, that effects of ground deformation on the Fire Station structure may be mitigated by strengthening/stiffening the foundation system. To achieve such strengthening/stiffening, we recommend installing a grid of grade beams beneath the ground-floor slabs to tie the existing continuous footings together, as well as to tie the footing system to the more massive retaining wall foundation at the rear of the structure. It may be prudent, also, to attach the floor slabs to the footings and grade beams; this would further increase the rigidity of the structure foundation system. Such strengthening/stiffening (or increased rigidity) would enable the foundation system to act as a unit to resist and withstand ground deformations, rather than allowing differential footing to footing response, which likely is resulting in the structure distress currently observed that we believe is associated with slope creep. We anticipate that if foundation strengthening/stiffening were to be undertaken, it would occur coincidently with retrofit of the overall structure.

We are of the opinion that the available geologic and geotechnical information for the site is adequate for design of foundation modifications; therefore, we are not recommending that further field exploration work be performed. We anticipate that structural loads associated with retrofit the structure become more well-defined (we understand that a code-based approach will likely be utilized), limited additional design-related geotechnical consultation (e.g., to re-examine footing bearing capacities and/or lateral wall pressures recommended in the original design soils investigation) may be required. Similarly, we anticipate that plan review and/or construction observation services may be requested by the District.

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TABLE 1

HISTORICAL SAN FRANCISCO BAY REGION EARTHQUAKES PRODUCING MODIFIED MERCALI INTENSITY (MMI) ≥ VI IN THE KENSINGTON VICINITY

Date of Earthquake	Magnitude[1]	Fault/Locality[1]	MMI Kensington Vicinity[2]	PGA (g)[3]
1836 June 10	6.8	Hayward Fault	VIII-IX[4]	0.26 - 0.53
1838 June	7.0	San Andreas Fault	VI+[4]	0.07
1856 February 15	5.5	S.F. Peninsula	VI	0.06
1858 November 26	6.1	San Jose	VI	0.06
1861 July 4	5.6	San Ramon Valley	V-VI	0.03 - 0.06
1864 March 5	5.7	East of S.F. Bay	VI	0.06
1864 May 21	5.3	East of S.F. Bay	V-VI	0.03 - 0.06
1865 October 8	6.3	San Andreas Fault	VI	0.06
1868 October 21	6.8	Hayward Fault	VIII	0.26
1870 April 2	5.3	East of S.F. Bay	V-VI	0.03 - 0.06
1884 March 26	5.9	Santa Cruz Mtns.	V-VI	0.03 - 0.06
1889 July 31	5.2	East of S.F. Bay	V-VI	0.03 - 0.06
1892 April 19 and 21	6.4, 6.2	Vacaville	V-VI	0.03 - 0.06
1897 June 20	6.2	Calaveras Fault	V-VI	0.03 - 0.06
1898 March 31	6.2	Rodgers Creek Fault	V-VI	0.03 - 0.06
1903 June 11	5.8	San Jose	V-VI	0.03 - 0.06
1903 August 3	5.8	San Jose	VI	0.06
1906 April 18	8.0	San Andreas Fault	VIII	0.26
1911 July 1	6.6	Calaveras Fault	V-VI	0.03 - 0.06
1926 October 22	6.1	Monterey Bay	VI	0.06
1957 March 22	5.3[5]	San Andreas	VI[5]	0.06
1984 April 24	6.2	Calaveras Fault	V-VI[5]	0.03 - 0.06
1989 October 17	7.0	San Andreas Fault	VII[6]	0.12[7]

[1] Ellsworth (1990).

[2] Toppozada and others (1981); Toppozada and Parke (1982a, 1982b). See Table 3 for description of Modified Mercalli Intensity (MMI) scale.

[3] Based on Trifunac and Brady (1975) relationship between MMI and PGA.

[4] Estimated based on Louderback (1947).

[5] U.S. Earthquakes (1957, 1984).

[6] Plafker and Galloway (1989).

[7] Shakal and others (1989).

TABLE 2

MODIFIED MERCALLI INTENSITY SCALE

I. Not felt by people, except rarely under especially favorable circumstances.

II. Felt indoors only by persons at rest, especially on upper floors. Some hanging objects may swing.

III. Felt indoors by several. Hanging objects may swing slightly. Vibrations like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Felt indoors by many, outdoors by few. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.

V. Felt indoors and outdoors by nearly everyone; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset; some dishes and glassware broken. Doors swing; shutters, pictures move. Pendulum clocks stop, start, change rate. Swaying of tall trees and poles sometimes noticed.

VI. Felt by all. Damage slight. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks and books fall off shelves; pictures of walls. Furniture moved or overturned. Weak plaster and masonry cracked.

VII. Difficult to stand. Damage negligible to buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in badly designed or poorly built buildings. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken. Damage to masonry; fall of plaster, loose bricks, stones, tiles, and unbraced parapets. Small slides and caving in along sand or gravel banks. Large bells ring.

VIII. People frightened. Damage slight in specially designed structure; considerable in ordinary substantial buildings, partial collapse; great in poorly built structures. Steering of automobiles affected. Damage or partial collapse to some masonry and stucco. Failure of some chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed pilings broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Damage considerable in specially designed structures; great in substantial buildings, with some collapse. General damage to foundations; frame structures, if not bolted, shifted off foundations and thrown out of plumb. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Landslides on river banks and steep slopes considerable. Water splashed onto banks of canals, rivers, lakes. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

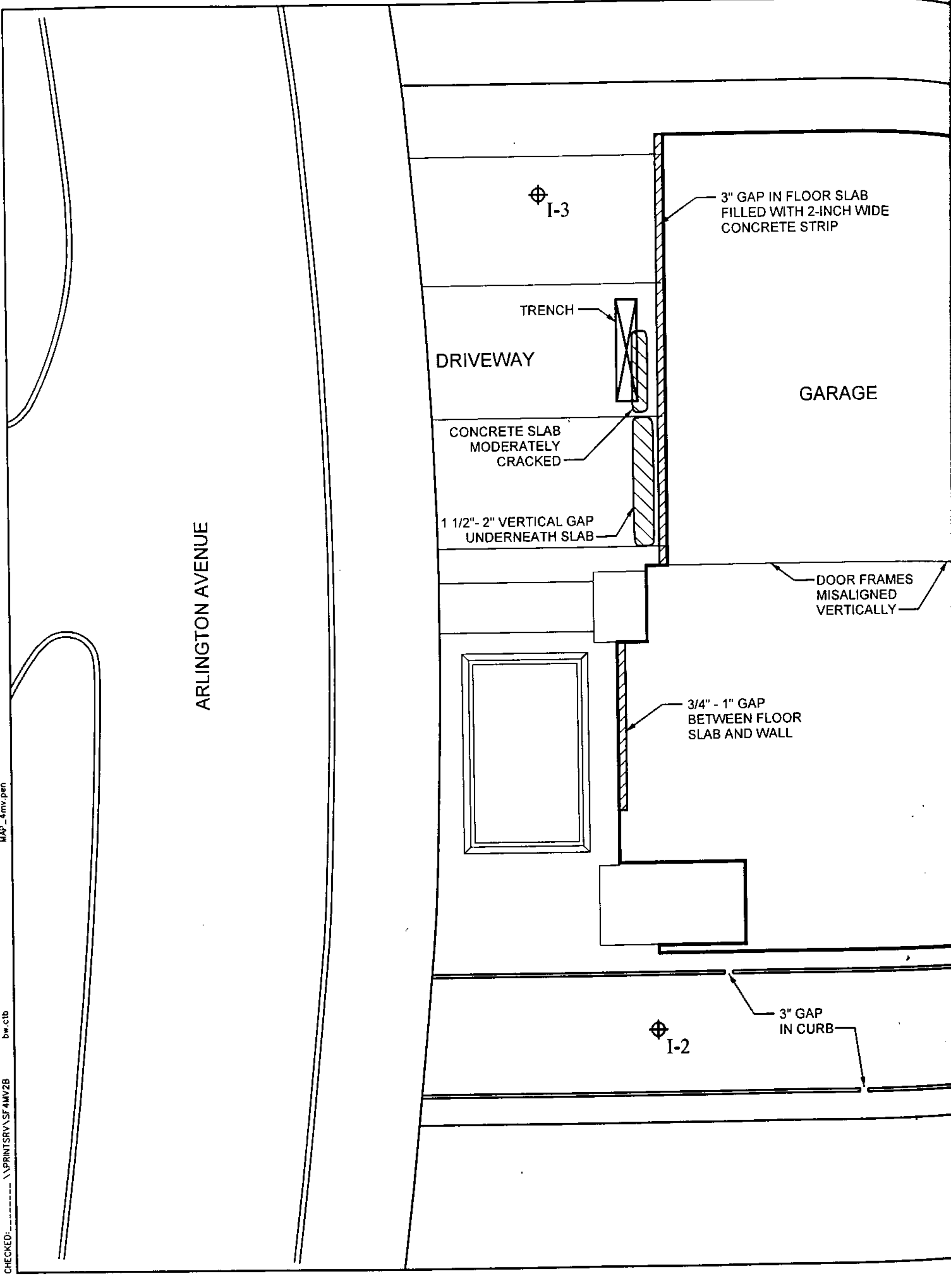
XI. Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground; earth slumps and landslides widespread. Underground pipelines completely out of service. Rails bent greatly.

XIII. Damage nearly total. Waves on ground surfaces. Large rock masses displaced. Lines of sight and level distorted. Objects thrown upward into the air.

TABLE 3

LIST OF AERIAL PHOTOGRAPHS REVIEWED

Source	Date	Photography
U.S. Department of Agriculture	1939	BUU-BUT Series 283, scale ~1:24,000
U.S. Geological Survey, Eros Data Center, Salt Lake City	09-06-1946	GS-CP FL5 #'s 12-14, scale 1:24,000
Pacific Aerial Surveys, Oakland	04-14-1950	AV28, FL13, #'s 24-26, scale 1:7,200



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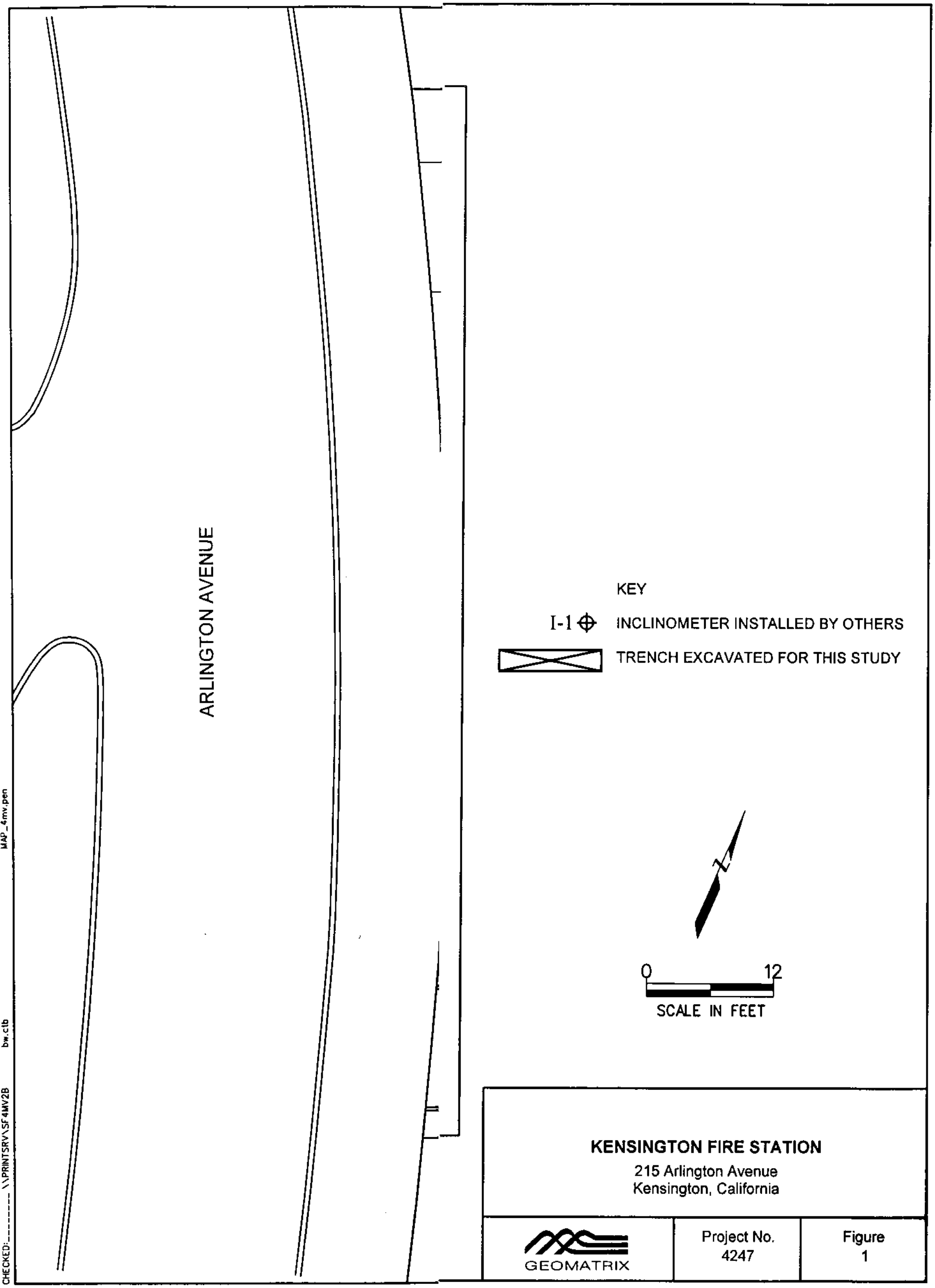

KEY

I-1 ⊕	INCLINOMETER INSTALLED BY OTHERS
☒	TRENCH EXCAVATED FOR THIS STUDY

KENSINGTON FIRE STATION

215 Arlington Avenue
Kensington, California

GEOMATRIX	Project No. 4247	Figure 1

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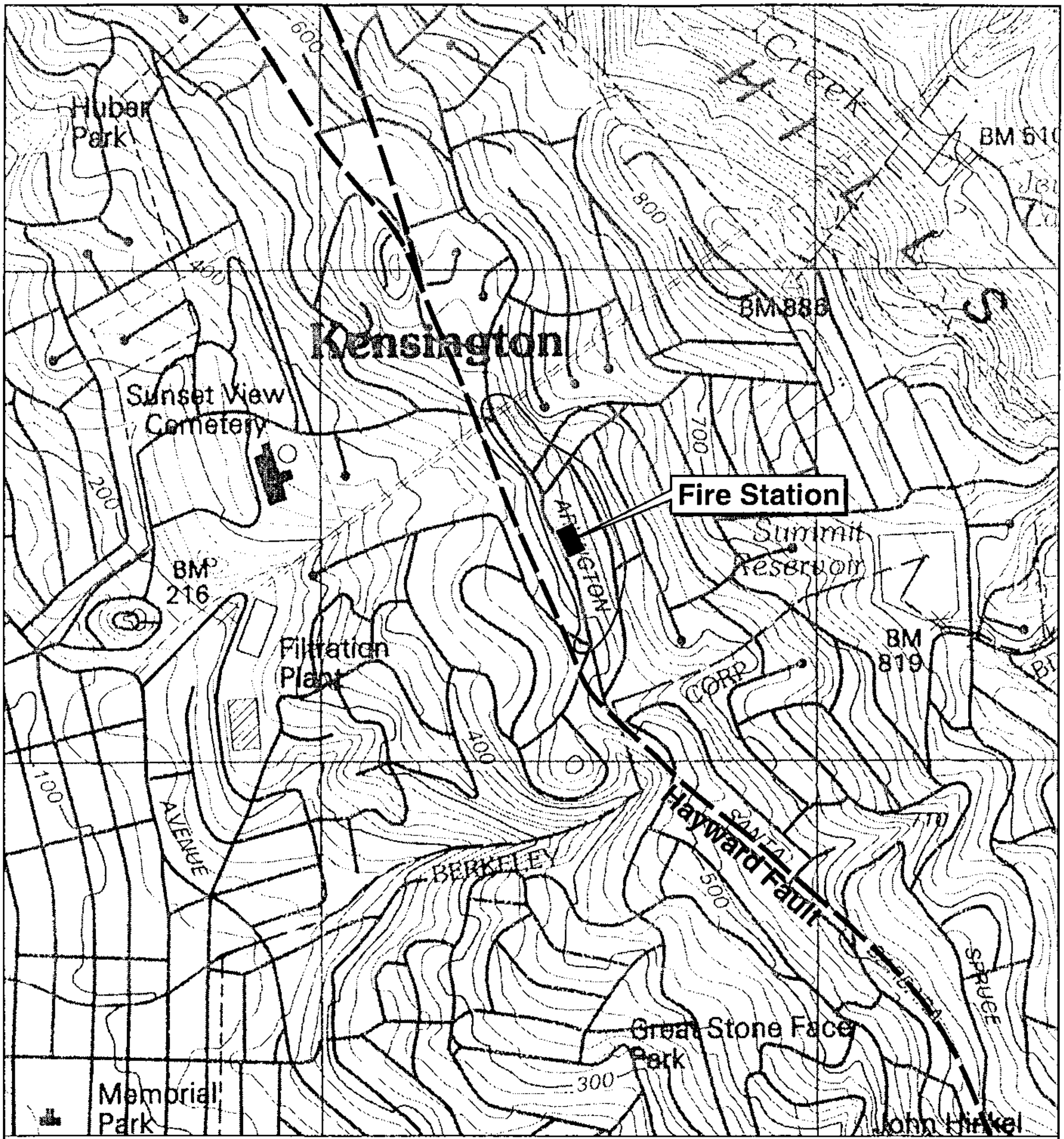


Base map from U.S.G.S. Richmond, California 7.5 minute topographic quadrangle, 1993.

0 1000 ft.

Explanation

▨ Area of slope creep, as indicated by observations of cracked and tilted sidewalks, driveways, and staircases. No reconnaissance was conducted outside of the shaded area.

Note: Hayward fault trace from Lienkaemper (1992).

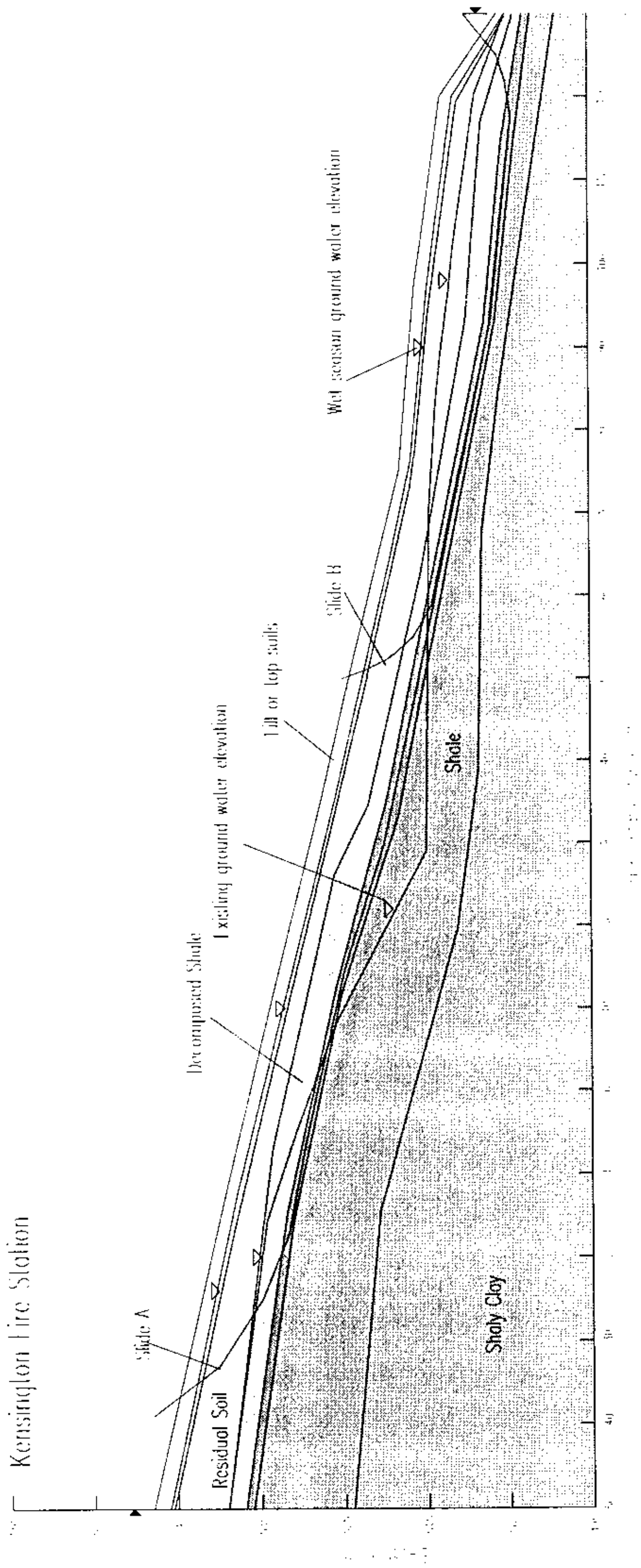
GEOMATRIX

LOCATION OF HAYWARD FAULT AND AREA OF SLOPE CREEP
Kensington Fire Station
Kensington, California

Figure
2

Project No.
4247

4247.001.ai

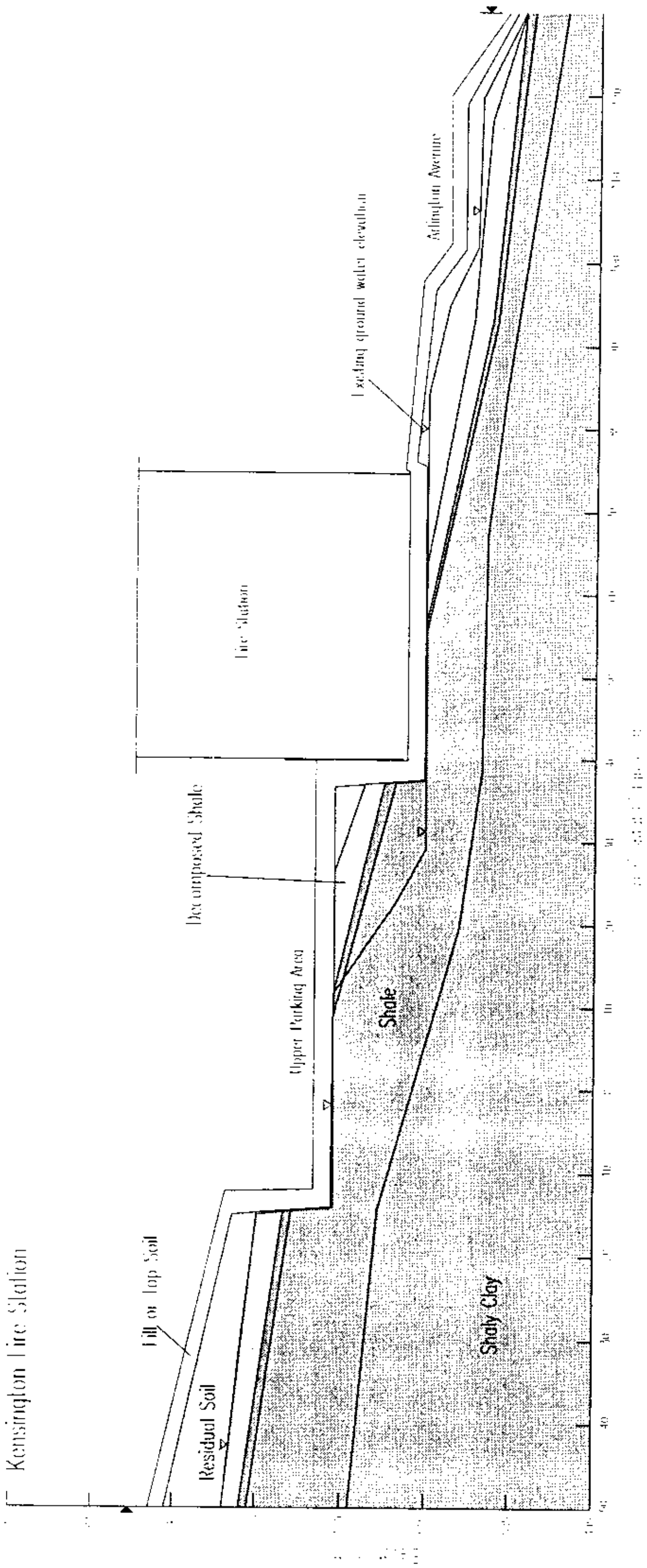


GEOMATRIX

IDEALIZED CROSS-SECTION OF NATURAL SLOPE AT SITE
Kensington Fire Station
Kensington, California

Figure
3

Project No.
4247



GEOMATRIX

LOCATION OF SITE FEATURES ON SLOPE CROSS-SECTION
Kensington Fire Station
Kensington, California

Figure 4
Project No. 4247