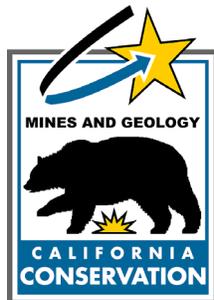


**SEISMIC HAZARD ZONE REPORT FOR THE
EL TORO 7.5-MINUTE QUADRANGLE,
ORANGE COUNTY, CALIFORNIA**

2000



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Division of Mines and Geology

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SEISMIC HAZARD ZONE REPORT 047

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the El Toro 7.5-minute Quadrangle, Orange County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

The El Toro Quadrangle includes part of the southwestern slope of the Santa Ana Mountains and the adjacent gently west-sloping Tustin Plain where all or parts of the cities of Irvine, Lake Forest, and Mission Viejo area located. A small part of the San Joaquin Hills is in the southwestern corner. Elevations range from 200 feet in the southwest to just over 2000 feet near the eastern edge. Residential and commercial development has rapidly spread across the Tustin Plain and onto the slopes and ridges of the foothills. The recent closure of the El Toro Marine Corps Air Station has opened a large tract of land for redevelopment. Major transportation routes include the Santa Ana Freeway (I-5), San Diego Freeway (I-405), Orange County Eastern Transportation Corridor (Route 231), and the Foothill Transportation Corridor.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

In the El Toro Quadrangle the liquefaction zone is located in the bottoms of the major drainages and stream canyons and a few localities along the contact between the mountains and the Tustin Plain where ground water is shallow. The combination of dissected terrain and several weak rock units in the Santa Ana Mountains has produced widespread and abundant landslides. These conditions contribute to an earthquake-induced landslide zone that covers about 22 percent of the El Toro Quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet page: <http://www.conservation.ca.gov/CGS/index.htm>

Paper copies of Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the El Toro 7.5-minute Quadrangle.

Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: <http://www.conservation.ca.gov/CGS/index.htm>

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, including areas in the El Toro Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Construction of shallow ground-water maps showing the historically highest known ground-water levels
- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the El Toro Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The El Toro Quadrangle covers an area of about 62 square miles along the southwestern edge of the Santa Ana Mountains in eastern Orange County. This includes all or parts of the cities of Irvine, Lake Forest, and Mission Viejo as well as unincorporated areas of the county. Major transportation routes traversing the El Toro Quadrangle include the Santa Ana Freeway (I-5), San Diego Freeway (I-405), Orange County Eastern Transportation Corridor (Route 231), Foothill Transportation Corridor, Portola Parkway, Santiago Canyon Road, and El Toro Road.

The topography of the quadrangle consists of the gently west-sloping Tustin Plain that merges to the east with the foothills of the Santa Ana Mountains that are characterized by southwest-trending canyons, washes, and ridges. Exceptions to this are the northwest-trending Loma Ridge, Limestone Canyon, and Santiago Canyon. Along the

southwesternmost edge of the quadrangle is a small portion of the San Joaquin Hills. Elevations within the El Toro Quadrangle range from 200 feet in the southwest to just over 2000 feet near the eastern edge of the study area.

Approximately 70 percent of the quadrangle lies within the San Diego Creek Watershed, a complex system of predominantly southwest-draining canyons and washes that ultimately reach Newport Bay. These include Rattlesnake Canyon, Hicks Canyon, Bee Canyon, Round Canyon, Agua Chinon Wash, Borrego Canyon, Serrano Canyon, San Diego Creek, and several unnamed washes. The southeastern portion of the quadrangle drains to the south and includes Aliso Creek, English Canyon, and Oso Creek. In the northeastern portion of the quadrangle the Santiago Creek drainage system flows to the northwest and includes Modjeska Canyon, Williams Canyon and Silverado Canyon. Limestone Canyon joins Santiago Canyon just to the north of the quadrangle. Large bodies of water within the El Toro Quadrangle include Rattlesnake Reservoir, Siphon Reservoir, Lambert Reservoir, Mission Viejo Lake, and Oso Dam.

Significant residential and commercial development has taken place over the past twenty years on the Tustin Plain and upon the slopes and ridges of the foothills. Although most of the residential development involves minor lot grading, some of the larger projects in the upland areas have required substantial grading and drainage modification. The recent closure of the El Toro Marine Corps Air Station has opened up a large tract of land for redevelopment. The active Frank R. Bowerman Landfill is located in Bee Canyon.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. The generalized Quaternary geology of the El Toro Quadrangle is shown in Plate 1.1. The main sources for this map include geologic maps by Tan and others (1984) and Fife (1974), both of which were originally produced at a scale of 1:12000 for use in assessing engineering geologic conditions. These maps were digitized and compiled with new mapping by the U.S. Geological Survey (Morton, 1999). Map unit nomenclature follows the format developed by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989) and is presented in Table 1.1.

The mapping is based on stratigraphic, geomorphic, and pedologic criteria, namely relative stratigraphic position, environment of deposition, relative degree of erosion, soil type and development, as well as texture (grain size). This geologic map was used in evaluating liquefaction susceptibility of Quaternary sedimentary deposits of the El Toro Quadrangle. The bedrock exposed in this portion of the Santa Ana Mountains is chiefly composed of sandstone, shale and conglomerate and is discussed in detail in Section 2 of this report.

The map shows that approximately 35% of the study area is covered by alluvial sediments of Quaternary age. These deposits have been divided into several subunits that

reflect dominant grain size and depositional environment (Table 1.1). Quaternary deposits of older alluvium flank the lower slopes of the foothills and occur upon dissected terraces in canyons. The younger alluvium occurs within the canyons and washes and covers most of the Tustin Plain. Colluvium is a ubiquitous surface unit and it is shown on the map in areas where it is significantly developed.

Map Unit	Environment of Deposition	Age
Ql	lacustrine	Holocene
Quc	colluvium/ slopewash	undifferentiated Holocene to late Pleistocene
Qyfa, Qyfac, Qyfsa	alluvial fans	Holocene to late Pleistocene
Qya, Qyaa	axial channel/ valley deposits	Holocene to late Pleistocene
Qvofa, Qvofsa	alluvial fans	middle to early Pleistocene
Qvoaga, Qvoaa	axial channel/ valley deposits	middle to early Pleistocene

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the El Toro Quadrangle.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, more than 500 borehole logs were collected from Leighton and Associates; the California Department of Transportation (Caltrans); the Hazardous Material Management Section of the Orange County Health Care Agency; and the Materials Laboratory of the Orange County Public Facilities & Resources Department. Additional data for this study came from DMG files of seismic reports for hospital and school sites and the database compiled by Sprotte and others (1980) for previous ground response studies.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG

GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Lithologic, soil test, and related data from 376 logs were entered into the DMG (Geographic Information System) database. The remaining logs were reviewed during this investigation to aid with the stratigraphic correlation. Locations of all exploratory boreholes in the database for the El Toro Quadrangle are shown in Plate 1.2. Cross sections were constructed from borehole data to correlate soil types and engineering properties, and to extrapolate geotechnical data into outlying areas containing similar soils.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized but give the most commonly encountered characteristics of the units (see Table 1.2).

Very old axial channel/alluvial valley deposits (Qvoaa, Qvoaga)

Subsurface data were not extensively collected for this unit. Borehole data show it to consist of alternating beds of reddish-brown, very dense gravel, silty sand, silt and clay.

Very old fan deposits (Qvofa, Qvofsa)

Subsurface data were not extensively collected for this unit. Borehole data show it to predominantly consist of reddish-brown dense to very dense silty sand interbedded with silt and clay.

Young axial channel/alluvial valley deposits (Qya, Qyaa)

Borehole logs for this unit indicate it is predominantly composed of gray gravel, sand, and silt. Compactness of sand layers ranges from loose to medium dense as indicated by both lithologic descriptions and penetration tests performed during drilling.

Young alluvial fan deposits (Qyfa, Qyfac, Qyfsa)

Borehole logs for this unit indicate it is predominantly composed of sand, sandy silt, and silt and clay mixtures. Compactness of sand layers ranges from loose to medium dense as indicated by both lithologic descriptions and penetration tests performed during drilling.

Lacustrine deposits (Ql)

These deposits occur in lakes and reservoirs and behind flood control structures. No effort was made to collect subsurface information for these units. They generally consist of soft, wet, silt to silty sand deposits.

Colluvial deposits (Quc)

Colluvium, also known as slope wash, occurs in small drainages, upstream portions of major drainages and bottom portions of slopes. It interfingers and is gradational with other alluvial units. Borehole logs within the colluvium indicate it consists of loose gravel, sand, silt and clay. Its composition is highly variable and dependent on adjacent bedrock sources.

Artificial fill (Qaf)

These deposits consist of fill resulting from construction and grading activities. No subsurface data were collected for these units.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Quc	gravel, sand, silt, clay	colluvium/ slopewash	loose	yes
Ql	silty sand, silt	lacustrine	loose	yes
Qyfa, Qyfac, Qyfsa	sand, sandy silt, silt, clay	alluvial fan	loose to medium dense	yes
Qya, Qyaa	gravel, sand, silt	axial channel/ valley deposits	loose to medium dense	yes
Qvofa, Qvofsa	silty sand, silt, clay	alluvial fan	dense to very dense	no
Qvoaa, Qvoaga	gravel, silty sand, silt, clay	axial channel/ valley deposits	very dense	no

* When saturated.

Table 1. 2. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. DMG uses the highest known ground-water levels because water levels during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. A historical-high ground-water map differs from most ground-water maps, which show the actual water table at a particular time. Plate 1.2 depicts a hypothetical ground-water table within alluviated areas.

Ground-water conditions were investigated in the El Toro Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). Ground-water depth data were obtained from Singer (1973), geotechnical boreholes, and

water-well logs. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

Due to limited records of historical high water for the El Toro Quadrangle canyon areas, ground water was assumed to be 10 to 15 feet higher than the measured ground-water values to take into account the potential for seasonal rises in ground-water level. This is considered a reasonable assumption for severe wet-weather conditions. In the alluvial fan areas that open onto the Tustin Plain, the measured ground-water values were not adjusted because of the coarse-grained and unconfined nature of the alluvium. The assumed historical high ground-water levels used for this evaluation are shown on Plate 1.2.

The young alluvial fan deposits that comprise the Tustin Plain consist mainly of sand, gravel, and silt. Generally, the coarser-grained sediments were deposited near mouths of the canyons and washes. Within the El Toro Quadrangle these upper fan areas are interpreted to be intake areas for the recharge of deeper aquifers beneath the Tustin Plain. Because of the coarse-grained nature of these materials, shallow perched water was not encountered nor anticipated within these areas.

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. This method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. DMG's qualitative susceptible soil inventory is summarized on Table 1.2.

Older alluvium (Qvofa, Qvofsa, Qvoaa, Qvoaga)

Most of the older Quaternary sedimentary deposits of the El Toro Quadrangle are described in borehole logs as being dense to very dense sand, silt, and clay. In general, these deposits are considered to have a low liquefaction susceptibility.

Younger alluvium (Qya, Qyaa, Qyfa, Qyfsa, Qyfac)

Younger alluvial deposits within the El Toro Quadrangle consist largely of sand, silt, and gravel, and lesser occurrences of clay. Most test boreholes drilled in these units report the presence of loose to medium dense sand and silt. Some deposits consist of very loose sand. Where anticipated ground-water levels are within 40 feet of the surface, these deposits are judged to be susceptible to liquefaction.

Colluvium (Quc)

Colluvial deposits within the El Toro Quadrangle consist of gravel, sand, silt and clay. The composition of this unit is highly variable and dependent on adjacent bedrock sources. Borehole logs indicate that it is typically loose and interfingers with the other alluvial units. Where anticipated ground-water levels are within 40 feet of the surface, these deposits are judged to be susceptible to liquefaction.

Lacustrine Deposits (Ql)

Lacustrine deposits (Ql) within the El Toro Quadrangle occur in lakes and reservoirs and behind other flood-control structures. These units were not included in the hazard zone evaluation and no effort was made to collect subsurface information for them. In general, they consist of soft, wet, silt to silty sand deposits. Liquefaction susceptibility of this unit is high.

Artificial fill (af)

In the El Toro Quadrangle artificial fill consists of engineered fill associated with reservoirs, embankment dams, and freeways. Artificial fill sites are considered to be properly engineered, therefore the liquefaction susceptibility in such areas depends on soil and anticipated ground-water conditions in underlying strata.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in DMG's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the El Toro Quadrangle, PGAs of 0.29 g to 0.38 g resulting from an earthquake of magnitude 6.8 to 6.9 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-

generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: $FS = (CRR / CSR) * MSF$. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 376 geotechnical borehole logs reviewed in this study (Plate 1.2), 248 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes
2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated
3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable
4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

- a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or
- b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or
- c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the El Toro Quadrangle is summarized below.

Areas of Past Liquefaction

In the El Toro Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the El Toro Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for reservoirs, embankment dams, and freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. In Holocene alluvial deposits, most of the borehole logs that were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that may liquefy under the expected earthquake loading. These areas containing saturated potentially liquefiable material are included in the zone.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel areas generally lack adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these deposits are assumed to be similar to deposits where subsurface information is available. The stream channel deposits, therefore, are included in the liquefaction zone for reasons presented in criteria item 4a above.

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SECTION 1

LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the El Toro 7.5-Minute Quadrangle, Orange County, California

By
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**California Department of Conservation
Division of Mines and Geology**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997; also available on the Internet at <http://www.conservation.ca.gov/CGS/index.htm>).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the El Toro 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996).

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the El Toro 7.5-Minute Quadrangle, Orange County, California

By

Florante G. Perez, Allan G. Barrows, Siang S. Tan, and Rick I. Wilson

**California Department of Conservation
Division of Mines and Geology**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the El Toro 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California: <http://www.conservation.ca.gov/CGS/index.htm>.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the El Toro Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area
- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared
- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area
- Seismological data in the form of DMG probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the El Toro Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the El Toro Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The El Toro Quadrangle covers an area of about 62 square miles along the southwestern edge of the Santa Ana Mountains in eastern Orange County. This includes all or parts of the cities of Irvine, Lake Forest, and Mission Viejo as well as unincorporated areas of the county. Major transportation routes traversing the El Toro Quadrangle include the Santa Ana Freeway (I-5), San Diego Freeway (I-405), Orange County Eastern Transportation Corridor (Route 231), Foothill Transportation Corridor, Portola Parkway, Santiago Canyon Road, and El Toro Road.

The topography of the quadrangle consists of the gently west-sloping Tustin Plain that merges with the southwest-trending canyons, washes, and ridges of the foothills of the Santa Ana Mountains. Exceptions to this are the northwest-trending Loma Ridge, Limestone Canyon, and Santiago Canyon. Along the southwesternmost edge of the quadrangle is a small portion of the San Joaquin Hills. Elevations within the El Toro Quadrangle range from 200 feet in the southwest to just over 2000 feet near the eastern edge of the study area.

Approximately 70 percent of the quadrangle lies within the San Diego Creek watershed, a complex system of predominantly southwest-draining canyons and washes that ultimately reach Newport Bay. These include Rattlesnake Canyon, Hicks Canyon, Bee Canyon, Round Canyon, Agua Chinon Wash, Borrego Canyon, Serrano Canyon, San Diego Creek, and several unnamed washes. The southeast portions of the quadrangle drains to the south and includes Aliso Creek, English Canyon, and Oso Creek. In the northeastern portion of the quadrangle the Santiago Creek drainage system flows to the northwest and includes Modjeska Canyon, Williams Canyon and Silverado Canyon. Limestone Canyon joins Santiago Canyon just to the north of the quadrangle. Large bodies of water within the El Toro Quadrangle include Rattlesnake Reservoir, Siphon Reservoir, Lambert Reservoir, Mission Viejo Lake, and Oso Dam.

Significant residential and commercial development has taken place over the past twenty years within the Tustin Plain and onto the slopes and ridges of the foothills. Although most of the residential development involves minor lot grading, some of the larger projects in the upland areas required substantial grading and drainage modification. The recent closure of the El Toro Marine Corps Air Station has opened a large tract of land for redevelopment. The active Frank R. Bowerman Landfill is located in Bee Canyon.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the El Toro Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1967 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading as a part of residential development and recent highway construction in the hilly portions of the El Toro Quadrangle were updated to reflect the new topography. Using 1:40,000-scale NAPP photography taken in 1994 and 1995, photogrammetric DEMs covering the residential graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by DMG. Digital files of new topographic contours from the construction of the Eastern and Foothill transportation corridors were obtained from the Silverado Construction Company and used to update topography in those areas. The photogrammetric DEMs and DEMs from the highway contour files were merged into the USGS DEM, replacing the areas of out-

dated elevation data. Plate 2.2 shows those areas where the topography is updated to 1994-95 grading conditions.

A slope map was made from the combined DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

For the El Toro Quadrangle, a geologic map was compiled and digitized by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989) from original mapping by Tan and others (1984) and by Fife (1974). The digital geologic map obtained from SCAMP was modified to reflect the most recent mapping in the area. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The oldest rocks mapped in the El Toro Quadrangle are the Jurassic Bedford Canyon Formation (Jbc) and the Santiago Peak Volcanics (Jsp), which are often referred to as the basement complex or subjacent series. They are exposed in the northeastern corner of the quadrangle and probably supplied much of the source material for the younger formations that overlie them to the west. The Bedford Canyon Formation, which consists of dark argillite, quartzite, meta-sandstone, and conglomerate, is separated by an erosional unconformity from the overlying slightly metamorphosed andesite flows, flow breccia, and volcanic sediments of the latest Late Jurassic (Fife and others, 1967) Santiago Peak Volcanics.

Overlying these rock units, exposed in a moderately west-dipping homocline, is a thick sequence of Upper Cretaceous sedimentary rocks that begins with the Trabuco Formation (Kt). Trabuco Formation is made up of nonmarine reddish fanglomerates that rest directly upon the Jurassic rocks. Kt is exposed along White Canyon. It grades upward into the lower conglomerate layers of the marine Ladd Formation called the Baker Canyon Conglomerate Member (Klb-cg). This conglomerate member is overlain by and interfingers with a coarse sandstone member (Klb-sd) with interbedded shale that ultimately grades into the Holz Shale Member (Klh) of the Ladd Formation. Layers of sandstone (Klh-sc) that locally contain resistant calcareous fossil beds mark the top of the Holz Shale Member. The Williams Formation overlies the Ladd Formation and consists of a lower conglomeratic sandstone, the Schulz Ranch Sandstone Member (Kws), and an upper, fine-grained, shaly sandstone, the Pleasants Sandstone Member (Kwp-f) that in places is sandy and conglomeratic (Kwp-sc). The uppermost layers of the Pleasants Sandstone Member mark the top of the marine Upper Cretaceous sedimentary rocks.

The oldest Tertiary unit in the area is the Paleocene Silverado Formation (Tsi). It is characterized by an unsorted basal conglomerate (Tsi-sc) that continues upward into

arkosic, micaceous sandstone layers and two persistent and distinctive clay beds named the Claymont Clay Bed and Serrano Clay Bed. The Serrano Clay Bed is a white sandy clay that was mined for its kaolinite clay beginning in the 1920's. The top of this bed is chosen, where it is exposed, as the boundary between the Silverado Formation and the overlying Eocene Santiago Formation (Tsa). Elsewhere, the Santiago Formation contact has been mapped at the beginning of a repetitious series of massive sandstone beds, which are separated by greenish gray shaly siltstone beds.

In the El Toro Quadrangle, the Sespe Formation (Ts) of late Eocene to early Miocene age and the Vaqueros Formation (Tv) of early Miocene age are typically interbedded. However, the lower sequence consisting mainly of nonmarine sedimentary rocks is generally attributed to the Sespe Formation and the upper sequence, consisting mostly of marine sedimentary rocks, to the Vaqueros Formation. The combined Vaqueros and Sespe formations (Tvs) are the most widespread among the bedrock units in the quadrangle. The Vaqueros Formation is conformable and transitional with the overlying Miocene Topanga Formation (Tt), which, in turn, is conformably overlain by the Puente Formation that consists of two members, the La Vida Member (Tpl) and Soquel Member (Tps). The La Vida Member of the Puente Formation and the Monterey Formation (Tm) both have a similar stratigraphic position and are composed of siltstone, thin-bedded sandstone and calcareous beds. The Monterey Formation also contains diatomaceous and siliceous shale and siltstone beds. The Soquel Member consists of sandstone (Tps-sc), interbedded siltstone (Tpst), and local conglomerate (Tps-cg) and conformably overlies the La Vida Member. In many areas, the two members have gradational contacts.

The late Miocene to early Pliocene Oso Member (Tco) of the Capistrano Formation (Tc) is characterized by massive white sandstone and generally has a sharp boundary with the underlying Soquel Member of the Puente Formation. The Niguel Formation (Tn) of late Pliocene age is only found in the southern part of the area where it overlies the Monterey Formation and Capistrano Formation. It is composed mainly of conglomerate and sandstone.

Approximately one third of the quadrangle is covered by alluvial deposits of Quaternary age. Younger alluvial deposits (Qyfa, Qyfac, Qyfsa, Qya, Qyaa) occur within the canyons and washes and cover most of the Tustin Plain. Colluvium/slopewash (Quc) generally occupies the upstream sections of canyons and the bases of slopes. Modern lacustrine sediments (Ql) are accumulating in several reservoirs and behind flood-control structures. Older alluvial sediments (Qvofa, Qvofsa, Qvoaga, Qvoaa) flank the lower slopes of foothills and occur upon dissected terraces along the sides of canyons. A more detailed discussion of the Quaternary deposits in the El Toro Quadrangle can be found in Section 1.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the El Toro Quadrangle was prepared by reviewing published maps and reports showing or discussing landslides, such as Tan and others (1984) and Fife (1974), and combining field observations, analysis of aerial photos (see Air Photos in References for a list), and

interpretation of landforms on current and older topographic maps. The most landslide-prone bedrock units in the quadrangle are the Sespe, Vaqueros and Puente formations and the Holz Shale Member of the Ladd Formation. The most stable are the Bedford Canyon Formation and the Santiago Peak Volcanics. Most of the landslides inventoried are debris slides and rock slides. Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the El Toro Quadrangle geologic map were obtained from the cities of Lake Forest and Mission Viejo (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1. When available, shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information. For the El Toro Quadrangle, a large number of shear test values were obtained from the adjacent Black Star Canyon Quadrangle (Appendix A), related to the construction of the Highway 241 Corridor.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average ϕ) and lithologic character. Average (mean and median) ϕ values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The formations, which contain interbedded sandstone and shale, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the formations are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

The results of the grouping of geologic materials for the El Toro Quadrangle are shown in Tables 2.1 and 2.2.

EL TORO QUADRANGLE SHEAR STRENGTH GROUPS STATISTICS							
	Formation Name	Number Tests	Unit Phi Mean/Median (deg)	Group Phi Mean/Median (deg)	Group C Mean/Median (psf)	No data: Similar Lithology	Phi Values: Used in Stability Analyses
Group 1	Klb-cg/Klb-sd	2	<i>38.5/38.5</i>				
	Klh(fbc)/Klh-sc	6	<i>39/39</i>				
	Kwp-sc	6	<i>36/33.5</i>			Jbc, Jsp	
	Kws(fbc)	2	<i>40/40.5</i>	39/44	727/600	Kt	39
	Tsi-sc	14	<i>36.7/37</i>			Tsi(fbc)	
	Tvs(fbc)	11	40/44				
Group 2	Qvofoa	2	32/32				
	Tc(fbc)	1	30/30			Klh(abc), Kwp(abc)	
	Tco(fbc)	12	33.5/35			Kwp-f, Qvoaa	
	Tps(fbc)	7	34/36	34.7/35	757/410	Qvoaga, Tn	34
	Tsa	11	<i>34.535</i>			Qvofoa, Tv(fbc)	
	Tt(fbc)	6	36/36			Tps-cg, Tps-sc	
	Tvs(abc)	54	<i>35.6/36</i>			Ts(fbc), Tsi(abc)	
Group 3	Kws(abc)	3	<i>28/29</i>				
	Qaf	7	31.2/29				
	Quc	1	30/30			Qya	
	Qyaa	1	28/28			Qyfac, Qyfsa	
	Qyfa	5	28/29	28.6/29.5	487/317	Tc(abc)	29
	Tco(abc)	1	31/31			Tpst	
	Tm(fbc)	3	31/33			Ts(abc), Tv(abc)	
	Tpl(fbc)	1	31/31				
Tps(abc)	2	30/30					
Group 4	Tm(abc)	11	26.7/28	26.2/27.5	611/600	Tt(abc)	25
	Tpl(abc)	7	25.4/23				
Group 5	Qls	2	18/18	18/18	980/980		18

(abc) - adverse bedding condition
(fbc) - favorable bedding condition
italicized phi values are from Black Star Canyon Quadrangle

Table 2.1. Summary of the Shear Strength Statistics for the El Toro Quadrangle.

EL TORO QUADRANGLE SHEAR STRENGTH GROUPS				
Group 1	Group 2	Group 3	Group 4	Group 5
Jbc, Jsp	Klh(abc), Kwp(abc)	Kws(abc), Qaf	Tm(abc)	Qls
Klb-cg, Klb-sd	Kwp-f, Qvoaa	Quc, Qya	Tpl(abc)	
Klh(fbc), Klh-sc	Qvofa	Qyaa, Qyfa	Tt(abc)	
Kt, Kwp-sc	Qvoaga, Qvofsa	Qyfac, Qyfsa		
Kws(fbc), Tsi(fbc)	Tc(fbc), Tco(fbc)	Tc(abc), Tco(abc)		
Tsi-sc, Tvs(fbc)	Tn, Tps(fbc)	Tm(fbc), Tpl(fbc)		
	Tps-cg, Tps-sc	Tps(abc), Tpst		
	Ts(fbc), Tsa	Ts(abc), Tv(abc)		
	Tsi(abc)			
	Tt(fbc), Tv(fbc)			
	Tvs(abc)			

Table 2.2. Summary of the Shear Strength Groups for the El Toro Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity.” For the El Toro Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8
Modal Distance:	8.8 to 26.3 km.
PGA:	0.29g to 0.45 g

The strong-motion record selected for the slope stability analysis in the El Toro Quadrangle was the Channel 3 (north horizontal component) Pacoma-Kagel Canyon Fire Station recording from the magnitude 6.7 January 1994, Northridge earthquake (Shakal and others, 1994). This record had a source to recording site distance of 2.6 km and a peak ground acceleration (PGA) of 0.44g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.074, 0.13 and 0.21g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the El Toro Quadrangle.

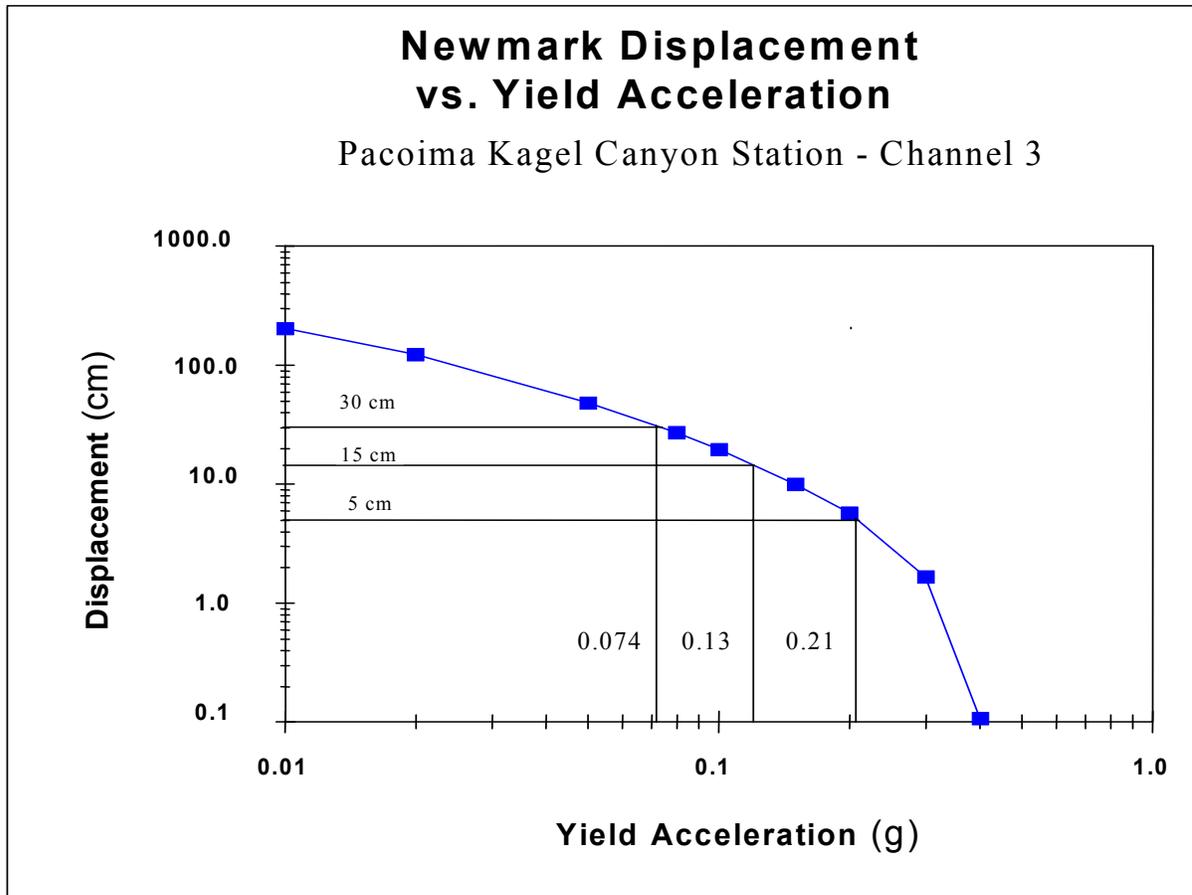


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Pacoima-Kagel Canyon Strong-Motion Record from the January 1994 Northridge, California Earthquake. Record from California Strong Motion Instrumentation Program (CSMIP) Station 24088.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.074g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)
2. If the calculated yield acceleration fell between 0.074g and 0.13g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)
3. If the calculated yield acceleration fell between 0.13g and 0.21g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)
4. If the calculated yield acceleration was greater than 0.21g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

El Toro Quadrangle Hazard Potential Matrix								
Geologic Strength Group	SLOPE GRADIENT CATEGORY							
	I 0 to 18 0 to 10	II 19 to 24 11 to 14	III 25 to 33 15 to 18	IV 34 to 43 19 to 23	V 44 to 56 24 to 29	VI 57 to 65 30 to 33	VII 66 to 70 34 to 35	VIII >71 >36
1	VL	VL	VL	VL	VL	L	M	H
2	VL	VL	VL	VL	L	M	H	H
3	VL	VL	VL	L	M	H	H	H
4	VL	VL	L	M	H	H	H	H
5	L	M	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the El Toro Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by DMG (McCrink and Real, 1996), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 4 is included for all slopes steeper than 24 percent.
3. Geologic Strength Group 3 is included for all slopes steeper than 33 percent.
4. Geologic Strength Group 2 is included for all slopes steeper than 43 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 56 percent.

This results in roughly 22 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the El Toro Quadrangle.

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AIR PHOTOS

Orange County Planning Department, E.L.Pearsons & Associates/Robert J. Lung & Associates July/August 1970 Aerial Photographs, flight 27, frames 18-22, flight 28, frames 16-22, flight 29, frames 16-26, flight 30, frames 15-29, flight 31, frames 14-27, flight 32, frames 15-27, flight 33, frames 21-29, flight 34, frames 24-28, flight 35, frames 27-29, black and white, vertical, approximate scale 1:14000.

USGS (U.S. Geological Survey), NAPP Aerial Photography, June 1, 1994, flight 6866, frames 90-94, frames 135-139, black and white, vertical, approximate scale 1:40000.

APPENDIX A SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Lake Forest	51
City of Mission Viejo	63
Corridor Design Management Group (Black Star Canyon Quadrangle)	216
Total Number of Shear Tests	330

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the El Toro 7.5-Minute Quadrangle, Orange County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided

herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions *for the analysis of ground failure* according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage:

<http://www.conservation.ca.gov/CGS/index.htm>

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

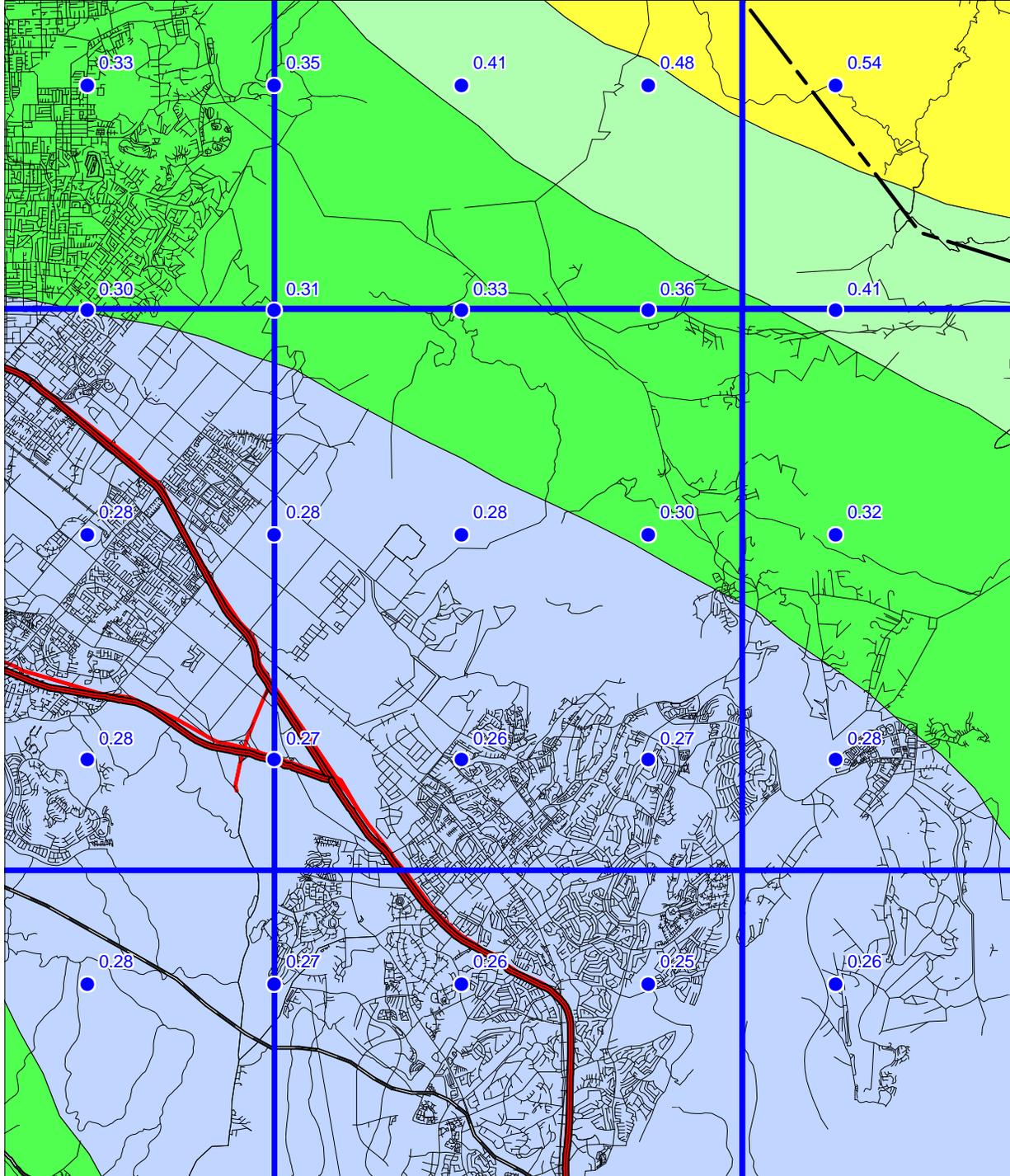
The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

FIRM ROCK CONDITIONS



Base map modified from Mapinfo StreetWorks © 1998 Mapinfo Corporation



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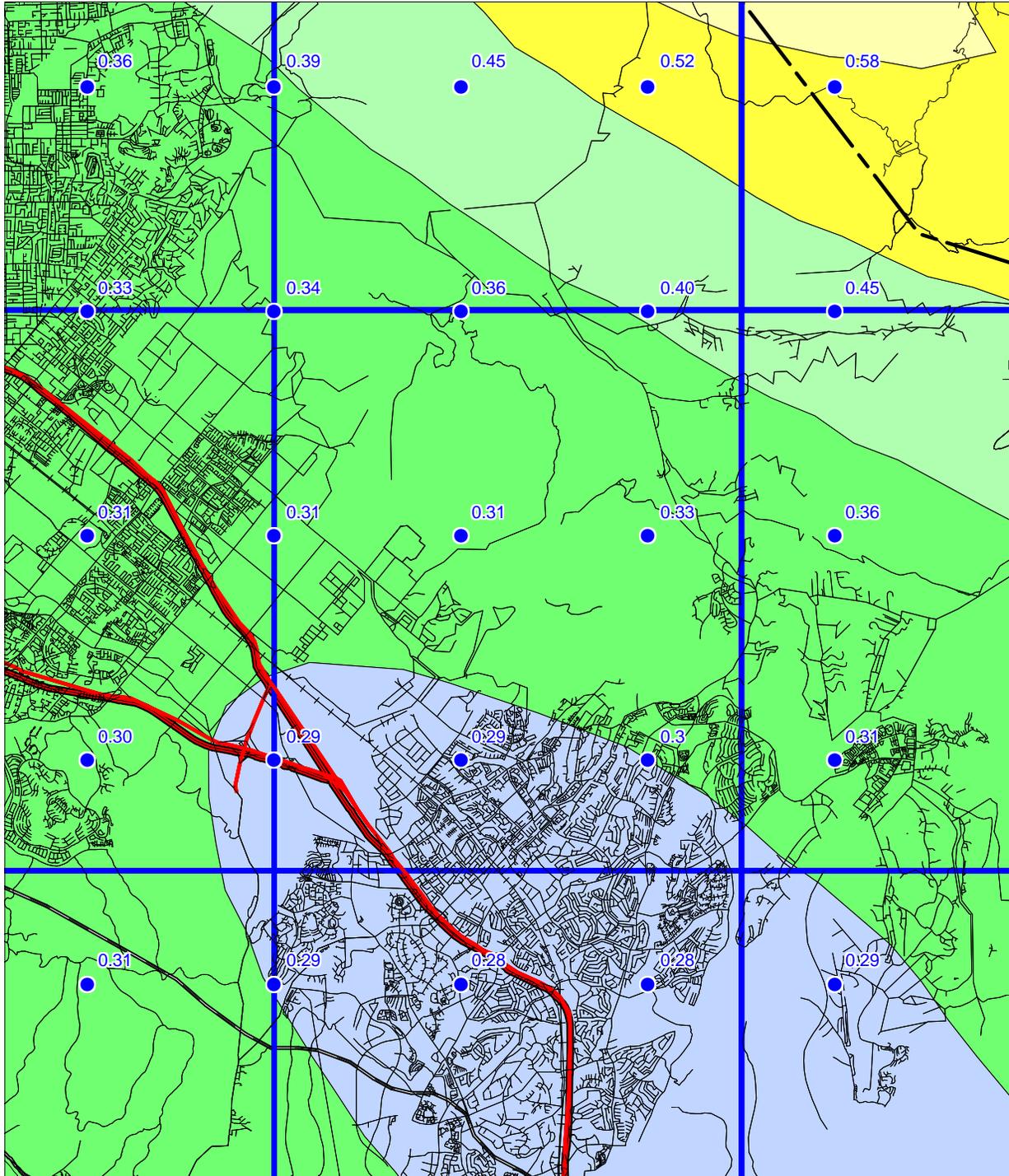
Figure 3.1

EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

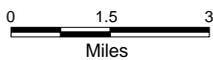
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from Mapinfo StreetWorks © 1998 Mapinfo Corporation



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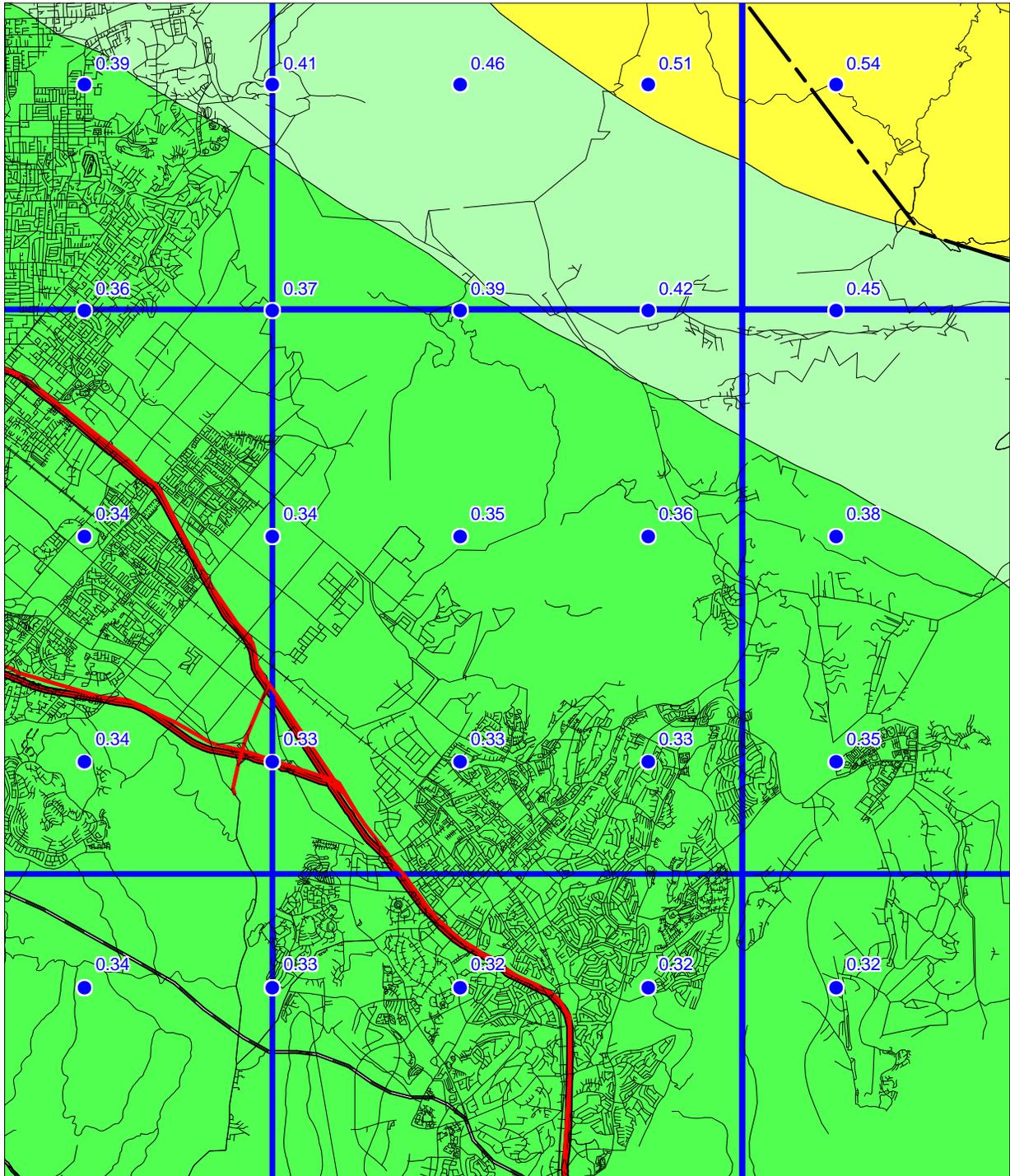


Figure 3.2

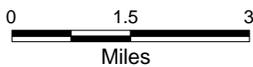
EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation



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Division of Mines and Geology



Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

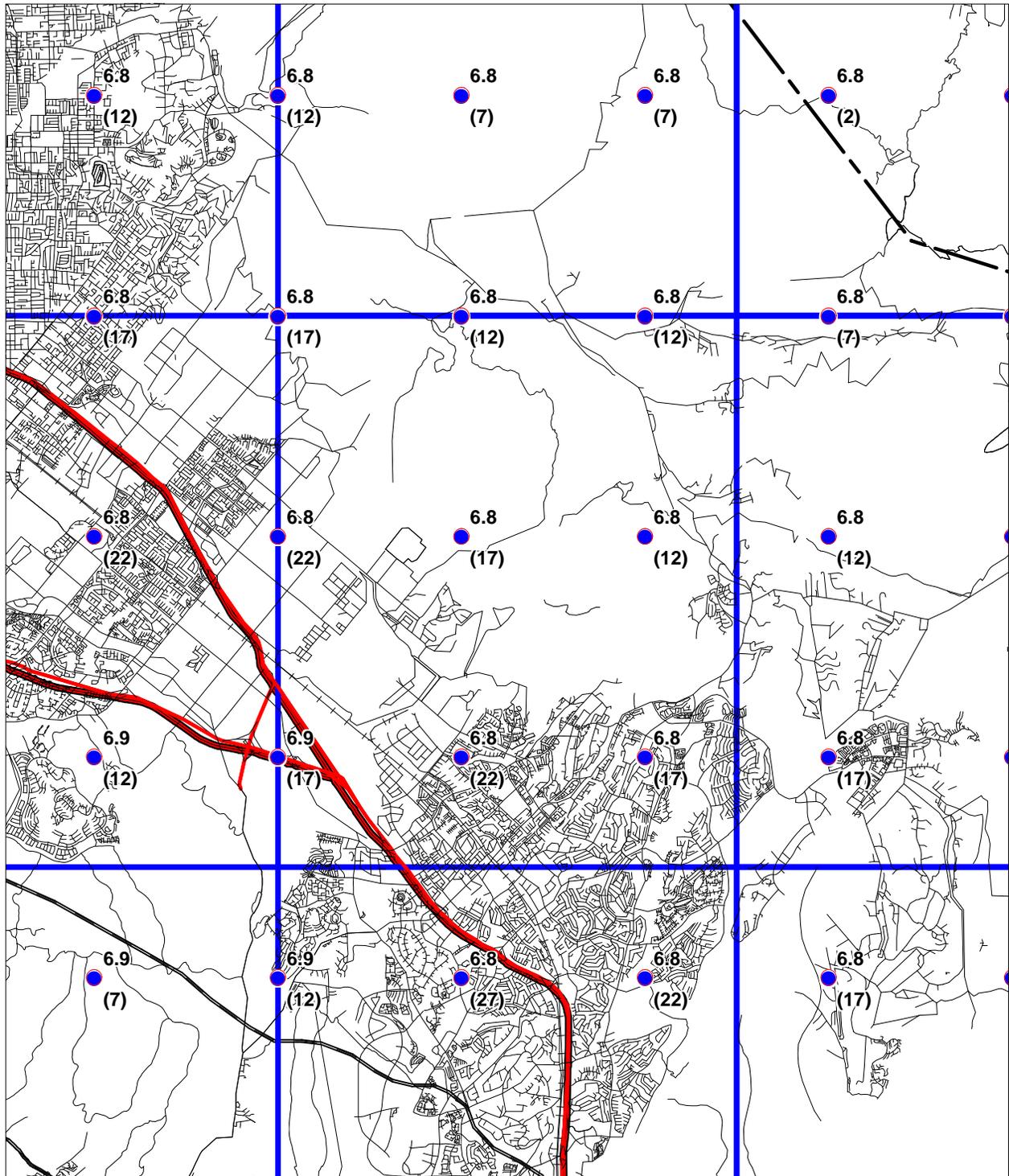
SEISMIC HAZARD EVALUATION OF THE EL TORO QUADRANGLE
EL TORO 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation



Department of Conservation
Division of Mines and Geology

Figure 3.4

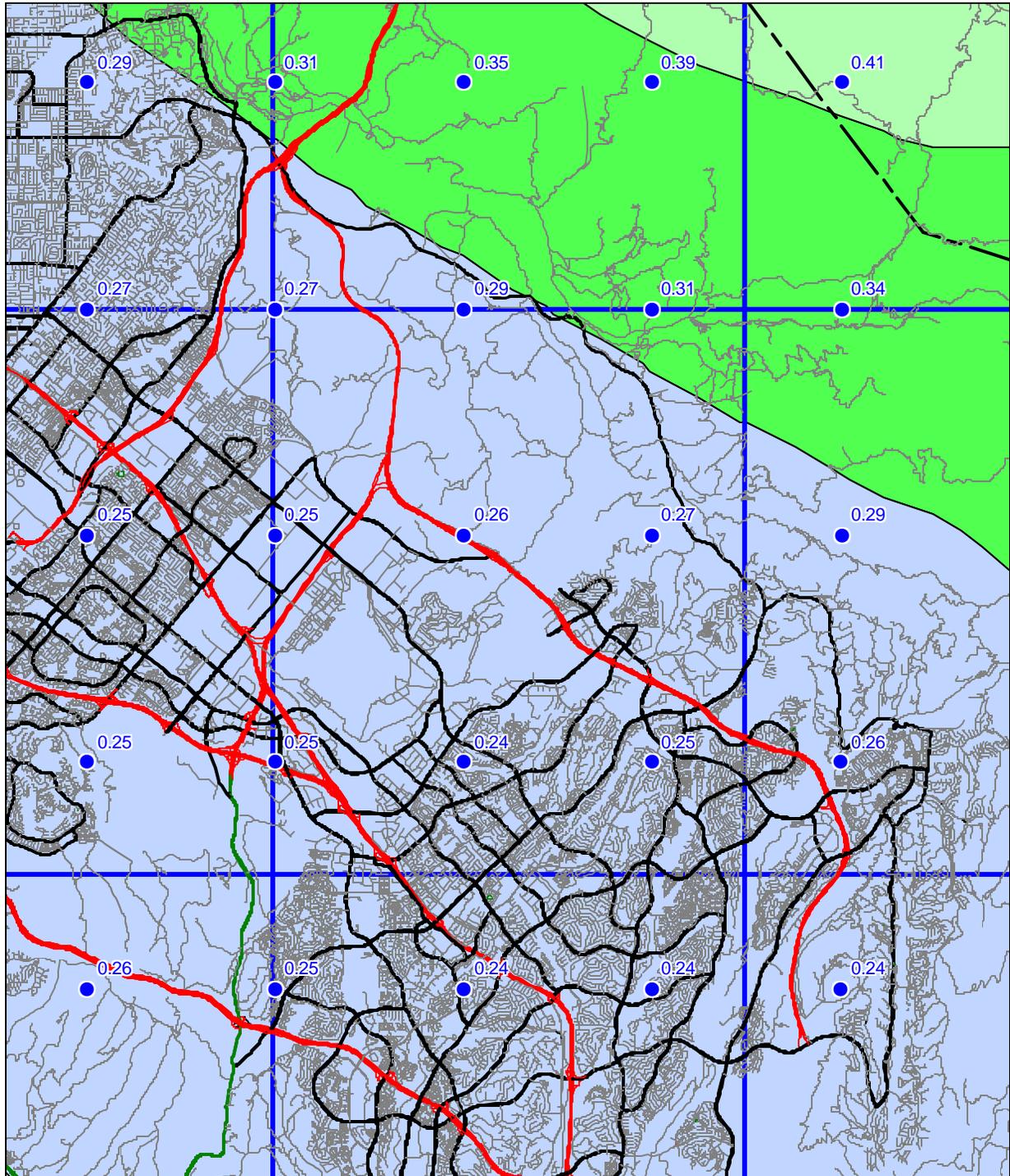


SEISMIC HAZARD EVALUATION OF THE EL TORO QUADRANGLE
EL TORO 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

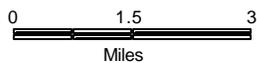
10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT



Department of Conservation
California Geological Survey



Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is *not appropriate for site specific structural design applications*. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.
2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours.*
3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).
4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.
5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

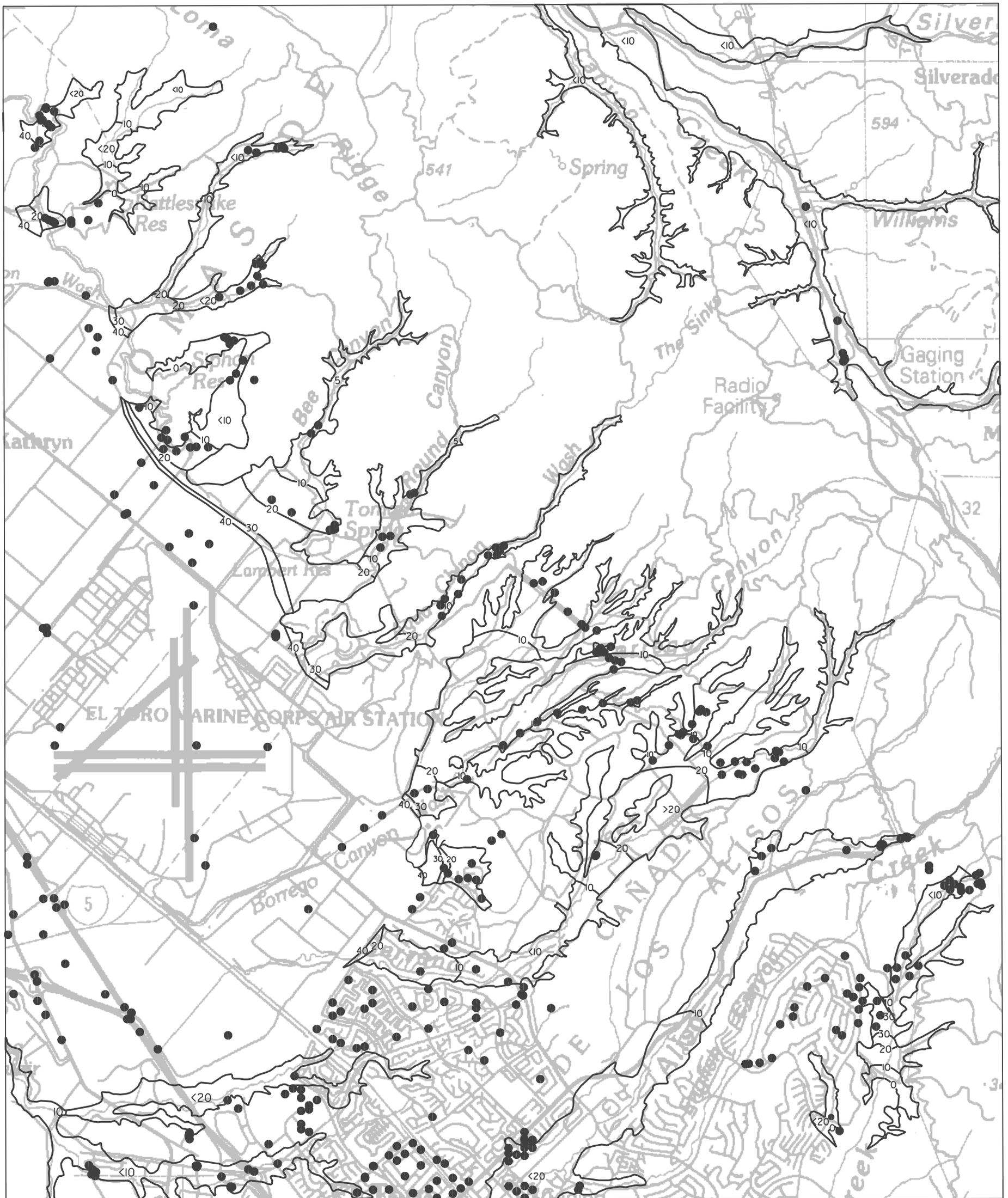
Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the

recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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Base map enlarged from U.S.G.S. 30 x 60-minute series

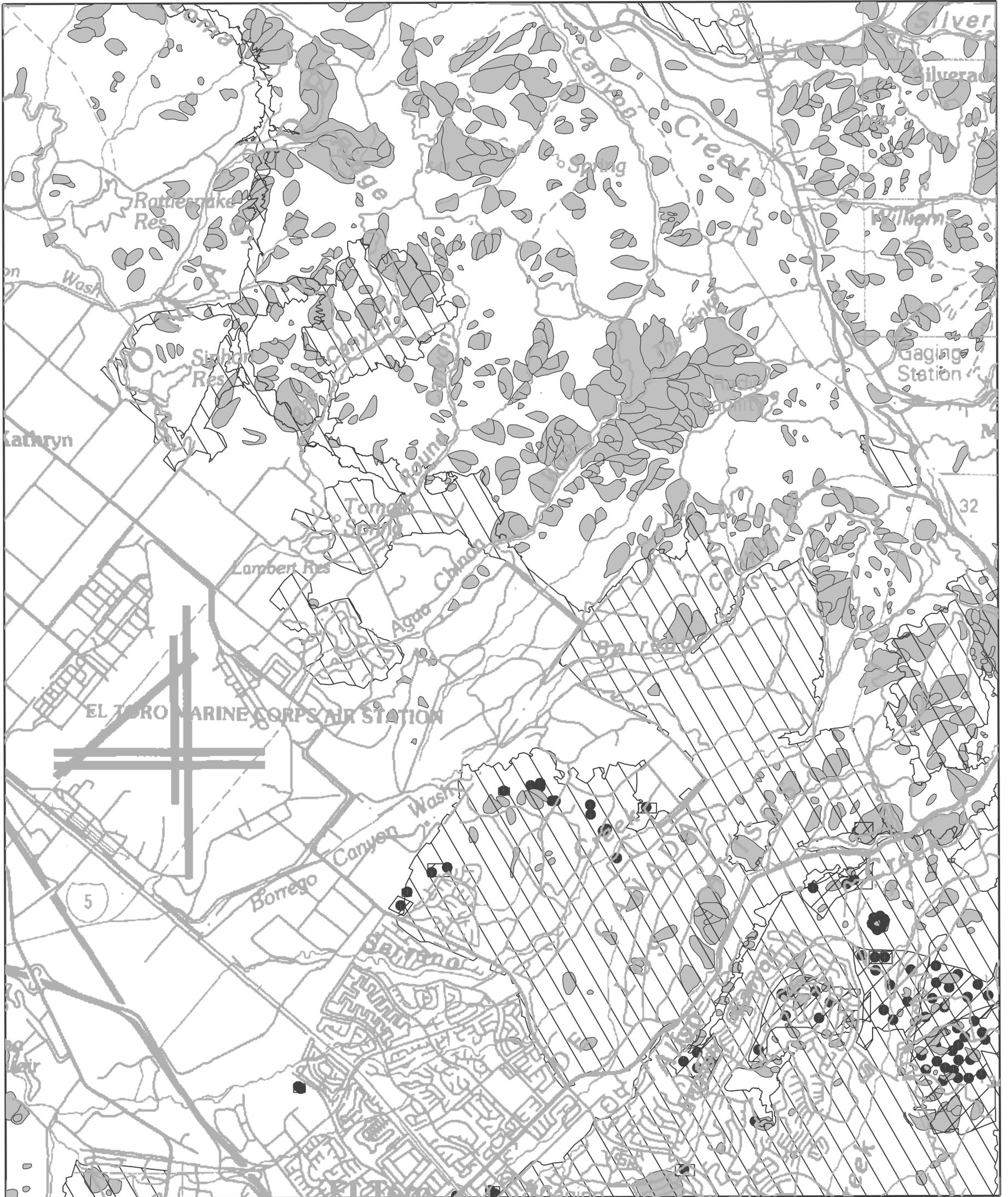
Plate 1.2 Anticipated high ground water levels in the El Toro Quadrangle, Orange County.

● Borehole Site

— 30 — Depth to ground water in feet

ONE MILE

Scale



Base map enlarged from U.S.G.S. 30 x 60-minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, and Areas of Significant Grading, El Toro Quadrangle.

- shear test sample location
- landslide
- ▨ areas of significant grading
- ▨ tract report with multiple borings

ONE MILE
SCALE