SEISMIC HAZARD ZONE REPORT 062

SEISMIC HAZARD ZONE REPORT FOR THE SAN CLEMENTE 7.5-MINUTE QUADRANGLE, ORANGE COUNTY, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
California Geological Survey

CALIFORNIA GEOLOGICAL SURVEY

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the San Clemente 7.5-minute Quadrangle, Orange County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides only within the Orange County portion of the quadrangle, which covers an area of approximately 28 square miles at a scale of 1 inch = 2,000 feet.

Within the Orange County part of the San Clemente Quadrangle the City of San Clemente borders the Pacific Ocean on the southwest and a small part of the City of San Juan Capistrano extends into the northwestern corner of the quadrangle. The remainder is unincorporated Orange County land. The elevated, deeply dissected, rugged terrain in the eastern part of the quadrangle is within the southern Santa Ana Mountains. The western half of the quadrangle, including San Clemente, is characterized by rolling hills and canyons and a narrow strip of coastal plain with marine terraces that borders the ocean. Elevations range from sea level at the beach to more than 1,000 feet. Access to the densely developed coastal plain is primarily by the San Diego Freeway (Interstate 5) and El Camino Real. Residential development is underway in the highlands, most notably within the City of San Clemente.

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 San Clemente Quadrangle the liquefaction zone is restricted to the bottoms of the major canyons and the beach. Landslides are very abundant in the weak Capistrano and Monterey formation bedrock in the area west of the Cristianitos Fault, which strikes north northwesterly across the western part of the area. The deeply dissected terrain in the Santa Ana Mountains near the eastern boundary of Orange County is also within an earthquake-induced landslide zone. Approximately 41 percent of the Orange County portion of the San Clemente Quadrangle lie within the earthquake-induced landslide hazard zone.

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 California Geological Survey's Internet page: http://www.conservation.ca.gov/CGS/index.htm

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, 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 CGS 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) [now called California Geological Survey (CGS)] 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 CGS 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 San Clemente 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the San Clemente 7.5-Minute Quadrangle, Orange County, California

By
Cynthia L. Pridmore

California Department of Conservation
California Geological Survey

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) [now called California Geological Survey (CGS)] 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 CGS 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). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC).

The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the San Clemente 7.5-minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.conservation.ca.gov/CGS/index.htm

BACKGROUND

Liquefaction-induced ground failure historically has 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 San Clemente 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 CGS 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 State Mining and Geology Board (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 San Clemente Quadrangle consist mainly of low-lying shoreline regions, alluviated valleys, floodplains, and canyons. CGS'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. PART I includes physiographic, geologic, engineering, and hydrologic conditions. PART II includes liquefaction and zoning evaluations.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The San Clemente Quadrangle covers an area of about 56 square miles in southeastern Orange County and adjacent San Diego County. The Orange County portion of the quadrangle, which is evaluated herein, covers about 28 square miles. The rest of the quadrangle lies in San Diego County or extends into the Pacific Ocean. The City of San Clemente borders the Pacific in the southwestern part of the quadrangle. A small part of the City of San Juan Capistrano extends into the northwestern corner of the quadrangle. The remainder of the evaluated part of the quadrangle is unincorporated Orange County land.

The elevated, deeply dissected, rugged terrain in the eastern part of the quadrangle is part of the southern Santa Ana Mountains. The western half of the quadrangle, including the City of San Clemente, is characterized by rolling hills, canyons, coastal terraces and a band of sandy shoreline. Elevations range from sea level to more than 1,000 feet in the northeastern corner of the map area.

Along the densely developed coastline, the San Diego Freeway (Interstate 5) and El Camino Real provide access to the area. The inland areas within Orange County are accessible via Avenida Pico and a network of local roads. Residential development is underway in the highlands, especially within the City of San Clemente.

GEOLOGY

Bedrock and Surficial Geology

Geologic units generally susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. For this evaluation, recent 1:24,000-scale geologic mapping by Tan (in preparation [a]) was digitized by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989). Nomenclature for the Quaternary geologic units follows that applied by SCAMP. Additional linework and nomenclature modifications were done by CGS. Plate 1.1 shows the generalized Quaternary geologic map of the San Clemente Quadrangle that was used in combination with other data to evaluate liquefaction potential and develop the Seismic Hazard Zone Map.

Within the study area, approximately 25 percent of the map is covered by alluvial deposits of Quaternary age. The remainder of the quadrangle is underlain by marine and nonmarine sedimentary strata ranging in age from Late Cretaceous through Pliocene (refer to the Earthquake Induced Landslide portion, Section 2, of this report for further details on the bedrock). The Pleistocene through Holocene surficial deposits that unconformably overlie the bedrock are summarized in Table 1.1 and discussed below.

Early to middle Pleistocene marine and nonmarine terrace deposits (Qvom) rest upon now-elevated marine wave-cut platforms in the upland areas of the quadrangle. The ages of these platforms are estimated to be greater than 500,000 years based on correlations made for similar units in the Dana Point Quadrangle (Kern and others, 1996; Tan, in preparation [b]). These units can be up to 50 feet thick and often have a basal gravel that overlies a gently sloping bedrock surface (Edgington, 1974). At lower elevations, middle to late Pleistocene marine and non-marine terrace deposits (Qom), occur above marine wave-cut platforms located on top of the coastal bluffs. Based on similar units mapped in the Dana Point Quadrangle, the ages of these platforms are estimated to range between

450,000 years to 120,000 years (Kern and others, 1996; Tan, in preparation [b]). Qom is also mapped near Interstate 5 and Avenida Pico adjacent to younger alluvium.

Older alluvial channel and valley fill deposits that are of early to middle Pleistocene age (Qvoa) or middle to late Pleistocene age (Qoa) are located above and within Sequnda Deshecha Canada, Talega Canyon, Gabino Canyon, La Paz Canyon, Cristianitos Canyon, and other major drainages. All of these terrace deposits are well dissected.

The remaining younger alluvial units consist of channel deposits (Qya, Qw), slopewash and colluvial debris (Qc), beach sediment (Qm), lacustrine deposits (Ql), landslide debris, and artificial fill materials. Landslides are not shown on the generalized geologic map (Plate 1.1) but are specifically addressed in Section 2. The late Pleistocene through Holocene channel/alluvial valley deposits (Qya) occur within all the major canyons and in the downstream portions of other smaller drainages. Within the San Clemente Quadrangle wash deposits (Qw) are mapped in Gabino and Talega canyons and represent modern alluvium in active and recently active washes. Due to the scale of the map, Qw is shown combined with Qya in Plate 1.1. Colluvium (Qc), also known as slope wash, occurs in small drainages, upstream portions of major drainages, and along gentle to moderate slopes. This unit is gradational with other alluvial units. Colluvium ranges in age from late Pleistocene to Holocene. Most of the colluvium mapped within the quadrangle is derived from the creep- and landslide-prone bedrock units. The modern beach sands (Qm) are the youngest of all the marine deposits and are distributed parallel to the coastline. Within the San Clemente Quadrangle small reservoirs that occur behind small earthen dams are mapped as lacustrine deposits (Ql). These occur within the upper reaches of Trampas Canyon and Talega Canyon. Artificial fills resulting from grading and construction activities and the previously mentioned reservoirs, are present within the study area but are not shown on Plate 1.1.

Map Unit	Environment of Deposition	Age
Qvom	marine and non-marine	early to middle Pleistocene
Qom	marine and non-marine	middle to late Pleistocene
Qvoa	channel/ valley deposits	early to middle Pleistocene
Qoa	channel/ valley deposits	middle to late Pleistocene
Qya	channel/ valley deposits	late Pleistocene and Holocene
Qc	colluvium/ slopewash	late Pleistocene and Holocene
Qm	Marine	late Holocene
Qw	Wash	modern
Ql	Lacustrine	modern

Table 1.1. Quaternary Units of the Southern California Areal Mapping Project (SCAMP) Nomenclature Used in the San Clemente Quadrangle.

Structural Geology

The San Clemente Quadrangle lies within the foothills of the southern Santa Ana Mountains, which are within the Peninsular Ranges geomorphic province of southern California. Members of the San Andreas Fault System border this province. The study area lies within a block bound on the northeast by the Elsinore Fault and on the south by the offshore southern extension of the Newport-Inglewood Fault Zone. Exposed in the area between the two northwest-trending right-lateral strike-slip faults is a sequence of mostly west-dipping rocks that range in age from Jurassic and Cretaceous through the Tertiary. A relatively thin section of flat-lying Quaternary terrace deposits occurs near the coastline, adjacent to modern drainages, and at isolated localities in upland areas. A more detailed discussion of the structural geology can be found in Section 2.

ENGINEERING GEOLOGY

CGS conducted a subsurface investigation of Quaternary sedimentary deposits in the San Clemente Quadrangle using borehole and trench logs from the files of the following agencies and organizations: Orange County Planning and Development; the Hazardous Material Management Section of the Orange County Health Care Agency; California Department of Transportation; California Department of Water Resources; City of San

Clemente; Leighton and Associates; and Goffman, McCormick & Urban, Inc. The locations of the exploratory boreholes and trenches used in this investigation are shown on Plate 1.2.

Out of approximately 100 logs that were collected and reviewed for this evaluation, 87 logs were entered as data into the CGS's geotechnical GIS. This database allowed effective examination of subsurface geology through the construction of software-generated cross sections. Staff examined the nature and distribution of various depositional units in the subsurface, correlated soil types where feasible, extrapolated geotechnical data into outlying areas containing similar soils and evaluated historical ground-water depths.

For this evaluation 47 of the 87 logs evaluated contained Standard Penetration Test (SPT) results or normalized SPT results that provided information on the density, or compactness, of Quaternary sedimentary layers penetrated by the borehole. This test, along with the results of other engineering tests (dry density, moisture content, sieve analysis, etc.) are used in the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971) to evaluate liquefaction potential of a site (see Part II - Quantitative Liquefaction Analysis). The results of the liquefaction analysis performed on the geotechnical data were posted onto the cross sections and aided in the overall three-dimensional evaluation of the Quaternary deposits.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. This is because saturated conditions in near-surface sediments reduce the effective normal stress thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS liquefaction evaluations incorporate the historically highest known ground-water levels since depth to ground water during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. Thus, CGS develops a hypothetical ground-water table map within alluviated areas based on the estimated shallowest depths that have occurred during historic time. Accordingly, this map differs from conventional ground-water contour maps that show the measured water table for a particular year or season.

The ground-water evaluation of the San Clemente Quadrangle was based on first-encountered water noted in geotechnical borehole logs. The depths to first-encountered water, free of piezometric influences, were evaluated by CGS to develop a map of the project area showing depths to historically shallowest ground water (Plate 1.2).

Measured depth-to-ground water ranges from 6 to more than 40 feet. Due to limited records in the canyon areas, depth to historically high ground water was assumed to be from 5 to 10 feet based on the shallowest water encountered along the length of the drainage. Similarly in the coastal and upland terraces (Qom, Qoa) historically high ground water depths was assigned values of 10 to 20 feet based on what was encountered in boreholes and trenches. These assumptions are considered reasonable based upon measured and expected seasonal variations in ground-water level. Water was not encountered in the oldest (Qvom, Qvoa) terrace sediments.

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 State Mining and Geology Board (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.

CGS'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. CGS's qualitative relations between geologic map unit and susceptibility are summarized in Table 1.2.

Discussion of map units

Most Holocene materials where water levels are within 30 feet of the ground surface have susceptibility assignments of high to very high. Although some Holocene units may be fine grained, many may contain lenses of material with higher liquefaction susceptibility. Within the San Clemente Quadrangle the young channel/alluvial valley deposits (Qya), wash deposits (Qw), and marine beach sands (Qm) are all considered highly susceptible. Borehole and trench logs for Qya and Qw generally encountered intervals of clean-sorted sands with intervals of gravelly, silty and clayey sand, silt and clay. Materials were generally loose to medium dense as recorded in both descriptions and blow count data. Although no borehole logs were collected for Qm within the San Clemente Quadrangle, borehole data from the adjacent Dana Point Quadrangle indicate that the active or recently active beach deposits are composed of loose unconsolidated sand.

Throughout the San Clemente Quadrangle colluvium (Qc) occurs extensively. However, for this study only the colluvial units mapped in relatively flat-lying areas were considered for liquefaction evaluation. Borehole and trench logs collected show that the colluvium within these areas is laterally and vertically transitional with, and sometimes indistinguishable from, Qya and Qw deposits. Compositionally, colluvium is highly variable and dependent on adjacent bedrock sources. Within the San Clemente Quadrangle, borehole logs within this unit encountered loose to medium dense, gravel, sand, silt and clay. Liquefaction susceptibility for this unit is moderate to high.

There are only two areas mapped as lacustrine deposits (Ql) within the San Clemente Quadrangle. No borehole logs were collected for this unit. Typically the materials range in grain size from sand to clay. Within the unit, the distribution of cohesionless sediments is expected to be variable. Liquefaction susceptibility for this unit is considered to be moderate to high.

Just inland along Avenida Pico and near Interstate Highway 5, three areas of old marine sediments (Qom) are mapped at elevations just above and adjacent to Qya. Seven borehole logs within this unit showed a wide range of materials and density. Materials encountered varied from very dense sands with concretions to those with intervals of over forty feet of loose sands. These sands may represent reworked older marine materials and/or unmapped channels of Qya. For the purposes of this study, these local areas of Qom considered moderate to highly susceptible.

Borehole data for the elevated coastal terraces capped by Qom penetrated interbedded layers of sand, silty sand, clayey sand, silt and clay. Alluvial deposits of this age are generally considered not susceptible to liquefaction and data collection for this unit was not extensive. Among 19 logs reviewed, Qom sand layers show a ranged of consolidation characteristics, from loose to medium dense based on both recorded blow count data and detailed descriptions. Where these older marine sands were both loose and saturated by perched ground water, they are described as exhibiting moderate to excessive caving. However, the likelihood that cohesionless Pleistocene sediments when saturated would be susceptible to liquefaction is considered very low (Youd and Hoose, 1977; Youd and Perkins, 1978).

Boreholes for inland terraces capped by older alluvium (Qoa) encountered medium-dense to dense clayey gravel, silty sand, silt and clay. Because of their age and subsurface characteristics these units are considered not likely to be susceptible to liquefaction.

In the San Clemente Quadrangle, relatively little geotechnical data were collected for both the very old marine deposits (Qvom) and very old channel/alluvial valley deposits (Qvoa). Alluvial deposits of this age are generally considered not susceptible to liquefaction due largely to age-related processes that act to densify the materials. Logs penetrating these units record materials consisting of dense to weakly cemented, clayey sands, silts, and gravels.

Subsurface data were not collected for any fill units. Artificial fill areas consist of engineered fill for elevated freeways and small earthen dams. Since these fills are generally considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Geologic Map Unit	Sediment Type	Consistency	Age	Susceptible to Liquefaction?*
Qvom	gravel, sand, silt, clay	weakly cemented	early to middle Pleistocene	no
Qom	sand, silt, clay	loose to medium dense	middle to late Pleistocene	not likely on coastal terraces
Qm	sand	loose	late Holocene	yes
Qvoa	gravel, sand, silt, clay	weakly cemented	early to middle Pleistocene	no
Qoa	gravel, sand, silt, clay	medium to very dense	middle to late Pleistocene	not likely
Qya	gravel, sand, silt, clay	loose to medium dense	late Pleistocene and Holocene	yes
Qc	gravel, sand, silt, clay	loose to medium dense	late Pleistocene and Holocene	yes
Qw	gravel, sand	loose	modern	yes
Ql	silts and clays	loose	modern	yes

Table 1.2. Geotechnical Characteristics and Liquefaction Susceptibility (*when saturated) of Quaternary Map Units Used in the San Clemente 7.5 Minute Quadrangle.

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 CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the San Clemente Quadrangle, PGAs of 0.30 to 0.34 g, resulting from earthquakes 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 portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

CGS 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).

Standard Penetration Tests (SPTs) provide a standardized measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). 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), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are 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 $(N_1)_{60}$.

The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS'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. CGS 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 CGS 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 program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. 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.

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; Evans and Seed, 1987; 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 California State Mining and Geology Board (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 San Clemente Quadrangle is summarized below.

Areas of Past Liquefaction

In the San Clemente Quadrangle, no areas of documented historical liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the San Clemente Quadrangle, artificial fill areas for elevated freeways and small earthen dams were not shown at the scale of mapping. Since freeway and highway fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted and the material varies in size and type.

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 with corresponding depths as shown in Table 1.2 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 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the San Clemente 7.5-Minute Quadrangle, Orange County, California

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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) [now called California Geological Survey (CGS)] 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 CGS 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). The text of this report is on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the San Clemente 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which 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 can be accessed on CGS's Internet web page: 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 San Clemente 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 CGS 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 CGS 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 San Clemente 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 San Clemente 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 San Clemente Quadrangle covers an area of about 56 square miles in southeastern-most Orange County and adjacent San Diego County. The Orange County portion of the quadrangle, which is evaluated herein, covers about 28 square miles. The southeasterly portion of the quadrangle lies in San Diego County, and the southwestern corner covers the Pacific Ocean. The City of San Clemente borders the Pacific Ocean in the southwestern part of the quadrangle and a small part of the City of San Juan Capistrano extends into the northwestern corner of the quadrangle. The remainder of the evaluated part of the quadrangle is unincorporated Orange County land.

The elevated, deeply dissected, rugged terrain in the eastern part of the quadrangle is part of the southern Santa Ana Mountains. The western half of the quadrangle, including the City of San Clemente, is characterized by rolling hills and canyons, and a narrow strip of coastal plain with marine terraces that borders the ocean. Elevations range from sea level at the beach to more than 1,000 feet in the northeastern-most corner of the map area.

Access to the area along the densely developed coastal plain, is provided primarily by the San Diego Freeway (Interstate 5) and El Camino Real. The inland areas within Orange County are accessible via a network of local roads, especially Avenida Pico. Residential development is underway in the highlands, most notably within the City of San Clemente.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the San Clemente Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS. This DEM, which was prepared from the 7.5-minute quadrangle topographic contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. A peak and pit smoothing process was then performed to remove errors in the elevation points.

Areas that have undergone large-scale grading as a part of residential development and recent highway construction in the hilly portions of the San Clemente Quadrangle were updated to reflect the new topography. Using 1:40,000-scale NAPP photography taken in

1994 and 1995, photogrammetric DEMs covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control obtained by CGS. The photogrammetric DEM was 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-gradient map was made from the combined DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). This map was used in conjunction with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was obtained from a 1:24,000-scale map by Tan (in preparation) and then digitized by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989). This source was also used for the surficial, or Quaternary, geologic map within the San Clemente Quadrangle. Surficial geology is discussed in detail in Section 1 of this report.

Prior to use in preparing the zone map, the digitized geologic map was evaluated and modified by CGS geologists. 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 slope failures was noted. Contacts between bedrock and surficial deposits were revised to better conform to the topographic contours of the 7.5-minute quadrangle. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. Air-photo interpretation and field reconnaissance were also performed to assist in adjusting contacts between bedrock and surficial deposits and to help with the review of lithology and geologic structure.

The following discussion of the geologic units is restricted to the portion of the San Clemente Quadrangle evaluated in the current study. Unit descriptions are based upon Tan (in preparation), Morton and Miller (1981), and Blanc and Cleveland (1968).

The oldest rocks exposed in the San Clemente Quadrangle belong to the Trabuco Formation (Kt) of Late Cretaceous age. A few extremely small exposures of Trabuco Formation occur as windows in the widespread Shulz Ranch Member (Kws) of the Williams Formation near the county line in the eastern part of the quadrangle. The Trabuco Formation consists of deeply weathered, reddish, cobbly to bouldery, nonmarine fanglomerate.

The Williams Formation, also of Late Cretaceous age, is widely distributed in the eastern half of the quadrangle where it covers a 2-mile-wide swath between the Mission Viejo Fault and the eastern boundary of the map. The Williams Formation includes two members: the Schulz Ranch Member (Kws), composed of marine siltstone and marine (?)

conglomeratic sandstone, and the Pleasants Sandstone Member (Kwp), composed of marine siltstone and sandstone.

The oldest Tertiary unit, the Silverado Formation (Tsi) of Paleocene age, is exposed adjacent to and west of the Mission Viejo Fault and east of Cristianitos Canyon, primarily north of Gabino Canyon. It consists of two subunits. The lower unit is comprised of nonmarine, interbedded, arkosic sandstone, pebble conglomerate, siltstone, distinctive multi-colored kaolinitic and pisolitic clay beds and a basal conglomerate. The upper unit is of marine origin and contains medium- to fine-grained sandstone, conglomerate, siltstone, and shale.

Unconformably overlying the Silverado Formation is the Santiago Formation (Tsa) of Eocene age, which is exposed in a 2-mile swath between the Cristianitos Fault and the Mission Viejo Fault. The Santiago Formation consists of marine conglomeratic and silty and clayey sandstone.

Undifferentiated Sespe and Vaqueros formation (Tsv) rocks are present in a small exposure adjacent to the Cristianitos Fault on the ridge top at the head of Trampas Canyon, about one mile south of the northern quadrangle boundary. The rocks range in age from late Eocene to early Miocene. In this area they rest gradationally upon the Santiago Formation and are composed predominantly of nonmarine, conglomeratic, coarse sandstone and conglomeratic sandstone and marine interbedded siltstone, mudstone, and sandstone.

The San Onofre Breccia (Tso) crops out along a ridge on the west side of the Cristianitos Fault for about one mile south of the northern boundary and downslope to the west as far as the Forster Fault (Blanc and Cleveland, 1968). The middle Miocene marine San Onofre Breccia is a coarse breccia and conglomerate with siltstone lenses and interbeds. It is very distinctive because it contains large slabs and blocks of blue-green glaucophane schist (Catalina Schist) and other rock types in a matrix of red and gray sandstone. It typically forms steep slopes and is covered by dense vegetation and rocky soil.

Monterey Formation (Tm) of late Miocene age is widespread west of the Cristianitos fault. It rests upon the San Onofre Breccia west of the Cristianitos Fault. Monterey Formation consists of marine, white to yellowish-gray, thin-bedded, soft, diatomaceous siltstone, mudstone, and shale. Monterey Formation forms rounded, grass and mustard-weed covered slopes, is typically unstable and hosts abundant landslides.

Capistrano Formation (Tcs) of late Miocene to Pliocene age gradationally overlies the Monterey Formation. It is widely distributed in the western part of the area, especially within the cities of San Clemente and San Juan Capistrano. Capistrano Formation consists of marine siltstone, mudstone, silty and diatomaceous shale. This poorly consolidated and poorly bedded unit forms gradual slopes and is notorious for the abundance of landslides it hosts.

San Mateo Formation (Tsm) is exposed in bluffs along the coast at San Clemente State Beach and inland in the hills that face the ocean above the marine terraces in the City of

San Clemente. Woodford (1925) originally mapped this pale grayish-brown, poorly bedded arkosic sandstone, with abundant material derived from the San Onofre Breccia. There are currently two interpretations on the origin and age of the San Mateo Formation. It either unconformably overlies the Capistrano Formation and is of Pleistocene (?) age (Blanc and Cleveland, 1968, Plate 1). Or it is a "turbidite facies" of the Capistrano Formation of Pliocene age (Morton and Miller, 1981).

Tan (in preparation) mapped 19 Quaternary units in the San Clemente Quadrangle including: very old marine and nonmarine terrace deposits (Qvomt); older marine and nonmarine terrace deposits (Qomt); very old alluvial river deposits (Qvoa); old alluvial river deposits (Qoa); younger colluvial and stream deposits (Qycas [sandy silt]) and (Qycga [gravelly sand]); younger alluvial flood plain deposits (Qyaas [sandy silt]) and (Qyaga [gravelly sand]); active marine beach deposits (Qmba); and active channel and wash deposits (Qwga). On the geologic map, Tan added numbers to particular old alluvial and marine terrace units to indicate specific, named, marine terraces. It should be noted that the different alluvial deposits mapped by Tan were combined to form two groups within the shear strength groupings of Table 2.1 (see foot notes on Table 2.1). For these shear strength group purposes alluvium was either designated as "Qya" for young alluvial deposits, or "Qoa" for old alluvial deposits. Tan's geologic map also depicts landslide deposits (Qls). These will be discussed in more detail in a later section of this report.

Structural Geology

The structural framework of Orange County reflects the effects of broad regional crustal shortening from a southwest to northeast direction. Southern Orange County is bounded on the northeast by the Elsinore Fault and on the south by the offshore extension of the Newport-Inglewood Fault Zone. In the area between the two bounding strike-slip fault zones a homoclinal sequence is exposed that consists of primarily westerly dipping rocks of Jurassic, Cretaceous, and Tertiary age. The western margin of the homocline is gently warped into a north-trending broad syncline, generally referred to as the Capistrano syncline, comprised primarily of Tertiary sedimentary bedrock. A portion of the very eastern limb of the syncline is exposed within the western margin of the San Clemente Quadrangle.

Within the mapped portion of the quadrangle two predominantly north-trending faults interrupt the homoclinal sequence. The Mission Viejo Fault and Cristianitos Fault are vertical to very steep, westerly dipping normal faults that progressively offset younger strata to the southwest as much as 1,000 and 2,500 feet, respectively. The Cristianitos Fault is composed of a complex system of sub-parallel anastomosing shears or branches. The largest of the fault branches, the Forster Fault, trends in a northwest direction departing from the main trace of the Cristianitos Fault in the northwestern quarter of the San Clemente Quadrangle. The Mission Viejo and Cristianitos faults bound three geologically distinct areas. The eastern area is underlain primarily by Upper Cretaceous Williams Formation rocks. The central area is underlain mostly by Paleocene Silverado Formation and Eocene Santiago Formation. The western area is underlain by middle

Miocene San Onofre Breccia and Monterey Formation and Pliocene Capistrano Formation.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the San Clemente Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. 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.

More than 80 percent of the nearly 300 landslides mapped within the quadrangle are west of the Cristianitos Fault where the underlying rocks are predominantly weak, fine-grained, middle Tertiary and younger rocks. These landslides are distributed throughout the area, but are far more abundant north of Interstate Highway 5. Landslides range from several tens of feet across to approximately one mile in greatest dimension. Deep rock slides are the dominant type of landslide, but debris flows and debris slides occur in some areas where the rock may be coarse-grained or well indurated. Although there are many individual landslides, often landslides occur as clusters or compound slides. Some landslide complexes form amphitheaters at the heads of small drainages. Due to the weakness of the Monterey and Capistrano formations, internal deformation appears to be common, especially in larger landslides. Although some of the older landslides show evidence of recent activity, most are older features.

Fewer than 20 percent of the landslides mapped within the quadrangle are east of the Cristianitos Fault. With the exception of the clay strata within the Santiago Formation, rock units east of the fault support steeper slopes than west of the fault. Consequently, debris slides and debris flows are relatively more common in comparison to deeper rock slides. Debris slides and debris flows showing various degrees of activity are widespread, but they were typically not included in the map due to their small size and the scale of the map used. Rock slides are typically smaller east of the Cristianitos Fault, and usually occur as individual slides or as a cluster of several slides along a drainage. The majority of rock slides occur in close proximity to the Cristianitos Fault or within the triangular area defined by Cristianitos Canyon, Gabino Canyon, and the northern boundary of the quadrangle.

The landslides mapped for this study correspond generally with landslide deposits mapped by Blanc and Cleveland (1968) in the western portion of the San Clemente Quadrangle and those mapped by Sowma (1983) in the eastern portion of the quadrangle. Sowma mapped fewer than ten landslides in this area, virtually all on the eastern slope of

Cristianitos Canyon. Blanc and Cleveland did not include source, or main scarp, areas within their mapped landslides and often did not delineate individual landslides within larger slide complexes. They designated other areas as “ancient landslide terrain” where geomorphic features were subdued or landslide boundaries were indistinct. To facilitate seismic hazard zoning, an attempt has been made to identify landslide boundaries to the extent practicable and source areas have been included within landslide boundaries.

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 San Clemente Quadrangle geologic map were obtained from Orange County Office of Planning and Development Services, the City of San Clemente Engineering Department, and the California Division of Mines and Geology Environmental Review Program’s files (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. Shear tests from neighboring quadrangles (Canada Gobernadora, Dana Point, San Juan Capistrano, El Toro, and Santiago Peak) were used to augment data for several geologic formations for which little or no shear test information was available within the San Clemente Quadrangle.

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 phi) and lithologic character. Average (mean and median) phi 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.

Accompanying the digital geologic map were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used the structural geologic information provided with the digital geologic map to categorize areas of common stratigraphic dip direction and magnitude, similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

After completing this analysis for the Orange County portion of the San Clemente Quadrangle it was found that no bedding dipping greater than 25 percent could be identified. Accordingly, an adverse bedding map was not prepared. However, material strength groups reflecting the fine-grained and coarse-grained strengths were maintained in order to be consistent with their treatment in adjacent quadrangles.

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. Within the San Clemente Quadrangle 10 direct shear tests of landslide slip surface materials were obtained and the results are summarized in Table 2.1.

SAN CLEMENTE QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Kwp $Tsa_{(fbc)}$	4 28	37/36 36/35	36/35	343/183	$Tsv_{(fbc)}$, Kt	36
GROUP 2						$Kws_{(fbc)}$, $Tsv_{(abc)}$, Tso, $Tt_{(fbc)}$, $Tsi_{(fbc)}$, Qoa, Qya, Qsw	32*
GROUP 3	$Tsa_{(abc)}$ Tm Tcs Tsm Qt	15 53 58 7 13	24/26 25/25 27/27 24/25 28/28	26/26	410/300	$Kws_{(abc)}$, $Tsi_{(abc)}$, $Tt_{(abc)}$, Qc	26
GROUP 4	af	12	21/20	21/20	575/565		20
GROUP 5	Qls	10	13/13	13/13	385/380		13

Formational Subunits on Map Combined in Analysis**
Tcs = Tc
Qt = Qm, Qom, Qomt1-2sa, Qomt2-6sa, Qomt6sa, Qomt7sa, Qvom, Qvomt12-15sa
Qoa = Qoa1-2ga, Qoa2-6ga, Qoa6ga, Qoa7ga, Qoa7sa, Qvoa, Qvoa13ga, Qvoa14ga, Qvoa15ga
Qya = Qyaas, Qyaga, Qycas, Qyf, Qyfsa
Qsw = Qw, Qwga, Qc
Qls = Qls?
*** = indicates that the shear strength value is based on data from surrounding quadrangles**
**** = Quaternary map units/subunits are not necessarily the same nomenclature used in the liquefaction portion (Section 1) of this report**
abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the Shear Strength Statistics for the San Clemente Quadrangle.

SHEAR STRENGTH GROUPS FOR THE SAN CLEMENTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Kwp, $Tsa_{(fbc)}$, Tsv(fbc), Kt	Kws(fbc), Tsv(abc), Tso, Tt(fbc), Tsi(fbc), Qoa, Qya, Qsw	Tsa(abc), Tm, Tcs, Tsm, Qt, Kws(abc), Tsi(abc), Tt(abc), Qc	af	Qls

Table 2.2. Summary of Shear Strength Groups for the San Clemente 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 San Clemente 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 CGS 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 to 6.9
Modal Distance:	6.5 to 26.6 km
PGA:	0.27 to 0.34 g

The strong-motion record selected for the slope stability analysis in the San Clemente Quadrangle was the USC-14 record (Trifunac and others, 1994) from the magnitude 6.7 Northridge earthquake of January 17, 1994. This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59g. Although the magnitude and PGA from the USC-14 record do not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. 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 CGS 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 {0.076, 0.129 and 0.232}g. 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 San Clemente Quadrangle.

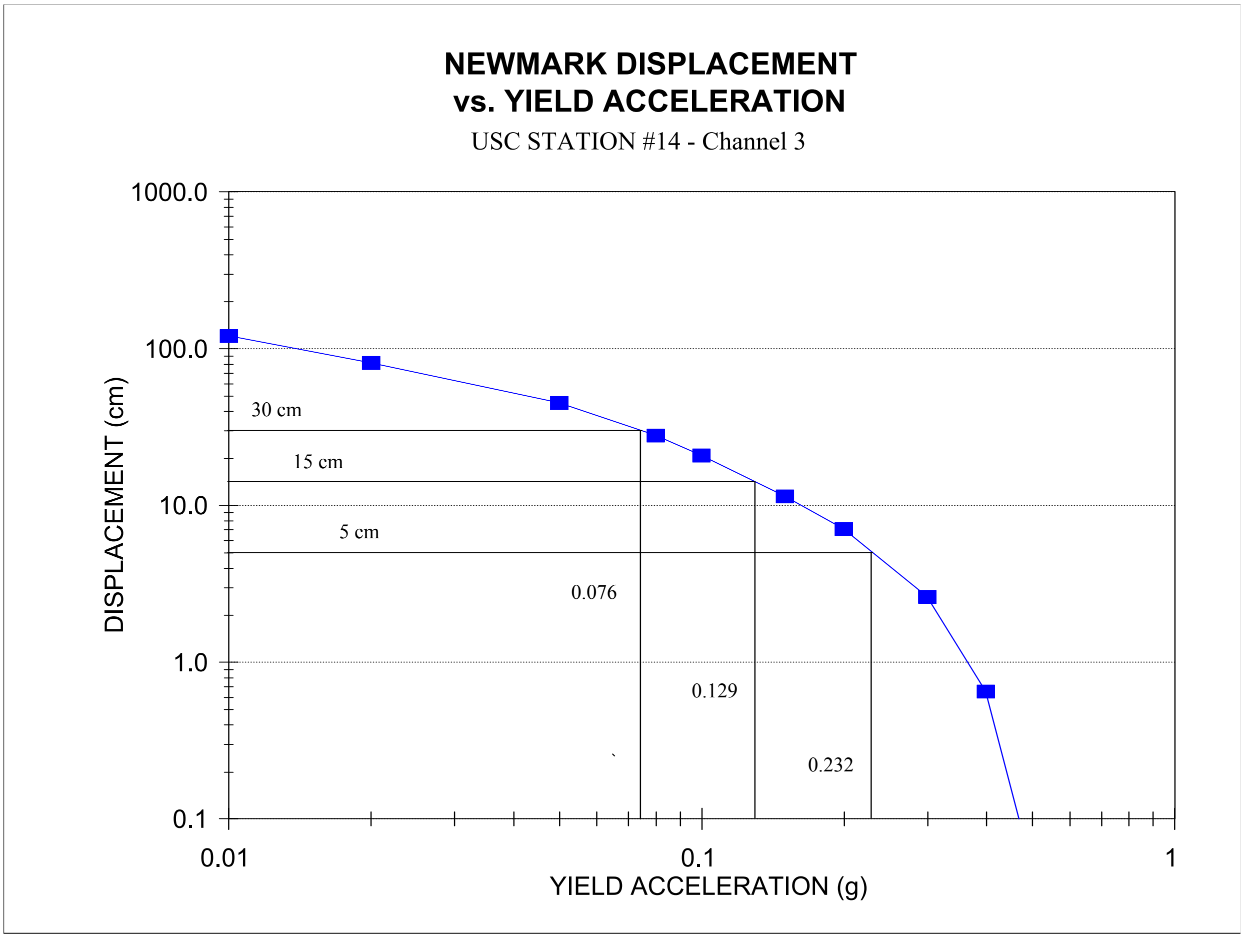

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

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 0.076g, 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 0.129g and 0.076g, 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 0.232g and 0.129g, 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 0.232g, 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.

SAN CLEMENTE QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	Mean Phi	SLOPE CATEGORY (% SLOPE)								
		I	II	III	IV	V	VI	VII	VIII	IX
		0 to 13%	14 to 15%	16 to 24%	25 to 27%	28 to 37%	38 to 46%	47 to 53%	54 to 63%	>63%
1	**36**	VL	VL	VL	VL	VL	VL	L	M	H
2	**32**	VL	VL	VL	VL	VL	L	M	H	H
3	**26**	VL	VL	VL	L	M	M	H	H	H
4	**20**	VL	L	L	M	H	H	H	H	H
5	**13**	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the San Clemente 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 CGS (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 greater than 13 percent.
3. Geologic Strength Group 3 is included for all slopes greater than 24 percent.
4. Geologic Strength Group 2 is included for all slopes greater than 37 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 46 percent.

This results in 41 percent of the mapped portion of the San Clemente Quadrangle lying within the earthquake-induced landslide hazard zone.

ACKNOWLEDGMENTS

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AIR PHOTOS

USGS (U.S. Geological Survey), NAPP Aerial Photography, 1994, flight 6866, frames 77-81, black and white, vertical, approximate scale 1:40000.

APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
CGS Environmental Review Documents	10
City of San Clemente Engineering Department	143
Orange County Office of Planning and Development Services	49
Total Number of Shear Tests	202

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the San Clemente 7.5-Minute Quadrangle, Orange County, California

By

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California Department of Conservation
California Geological Survey
***Formerly with CGS, now with U.S. Geological Survey**

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) [now called California Geological Survey (CGS)] 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 CGS'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, California geological Survey, 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.

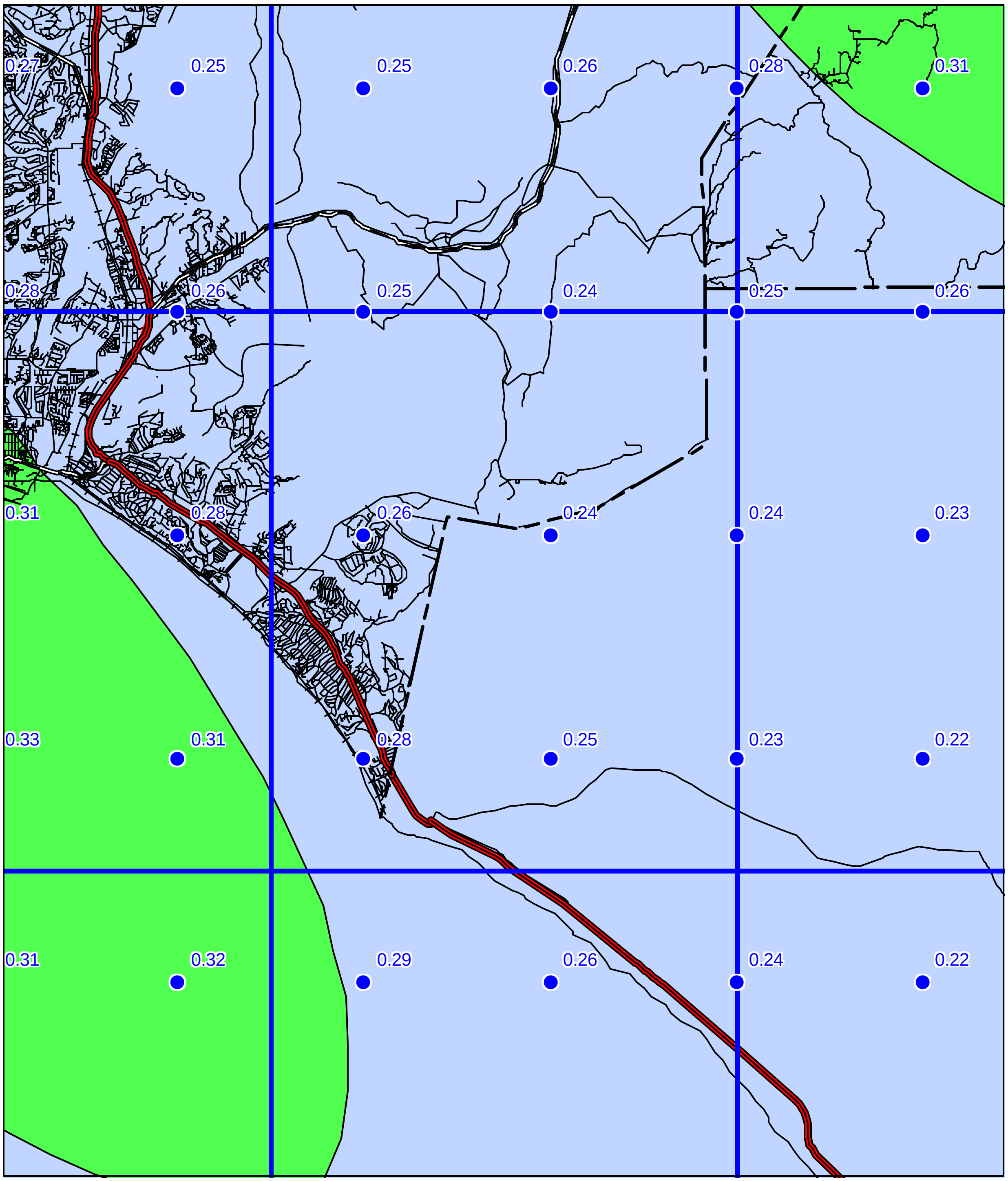
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. 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

SAN CLEMENTE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



0 1.5 3
Miles

Department of Conservation
California Geological Survey

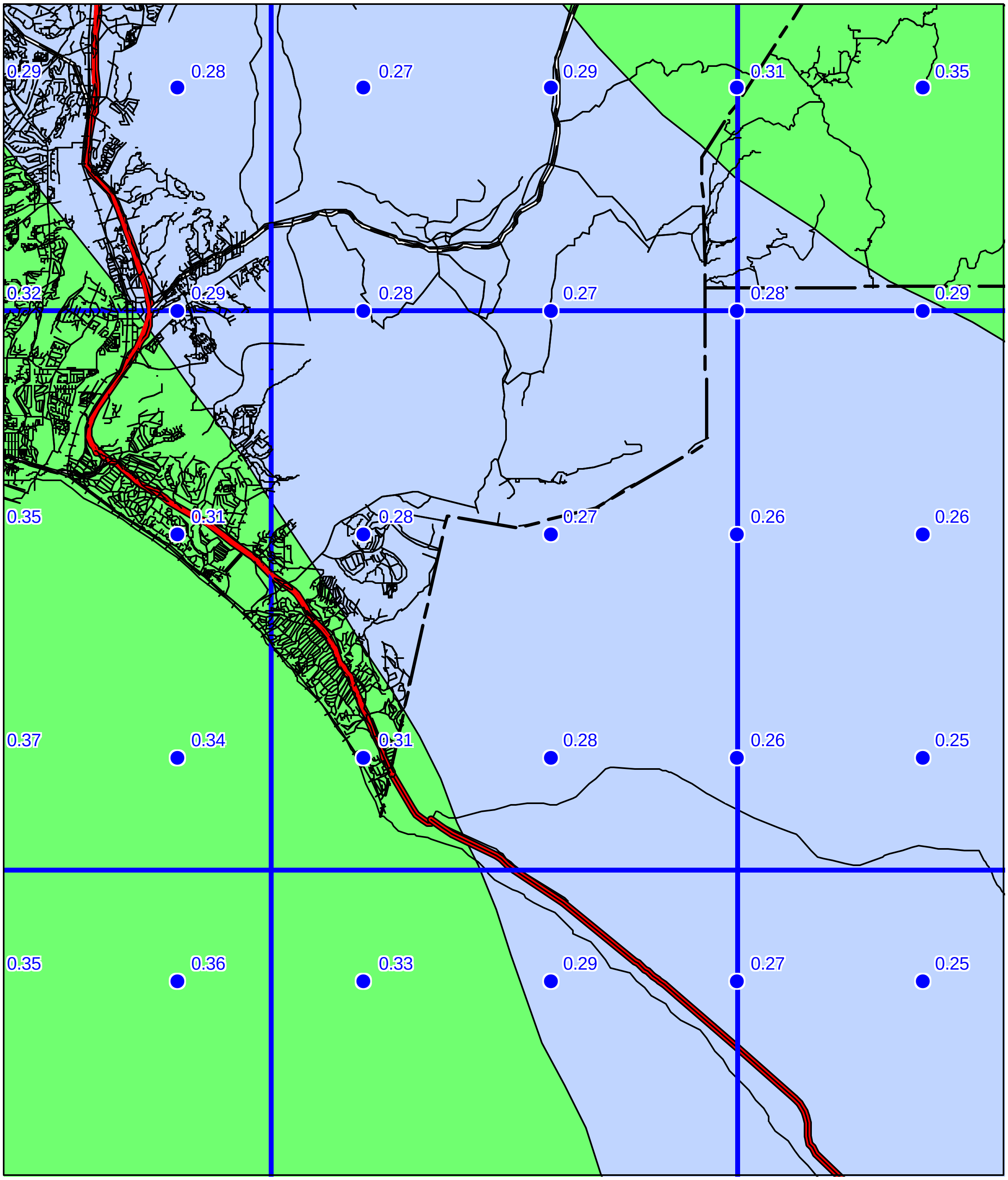
Figure 3.1

SAN CLEMENTE 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

0 1.5 3

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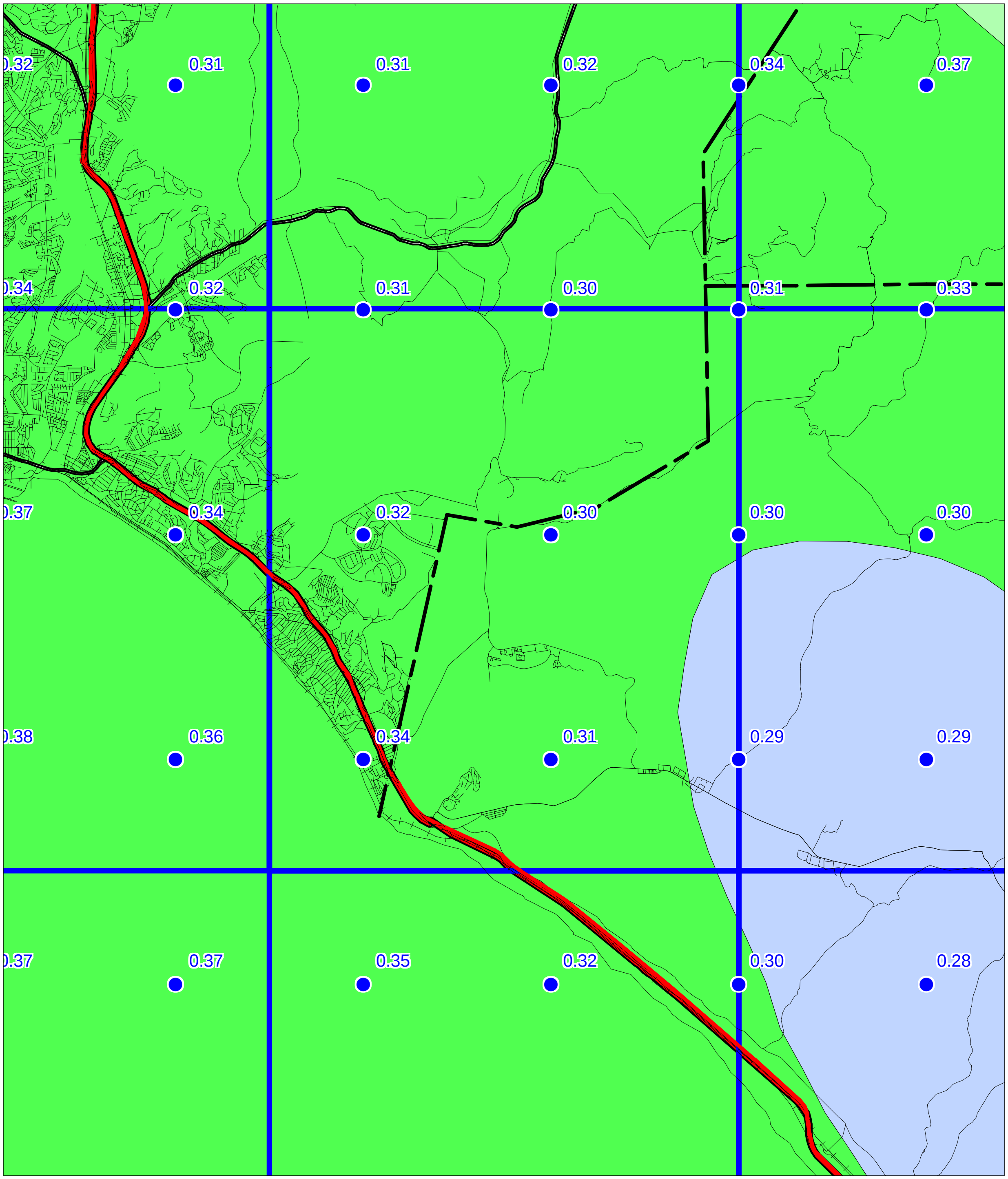
Figure 3.2

SAN CLEMENTE 7.5-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

2001

ALLUVIUM CONDITIONS



0 1.5 3

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Department of Conservation
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.

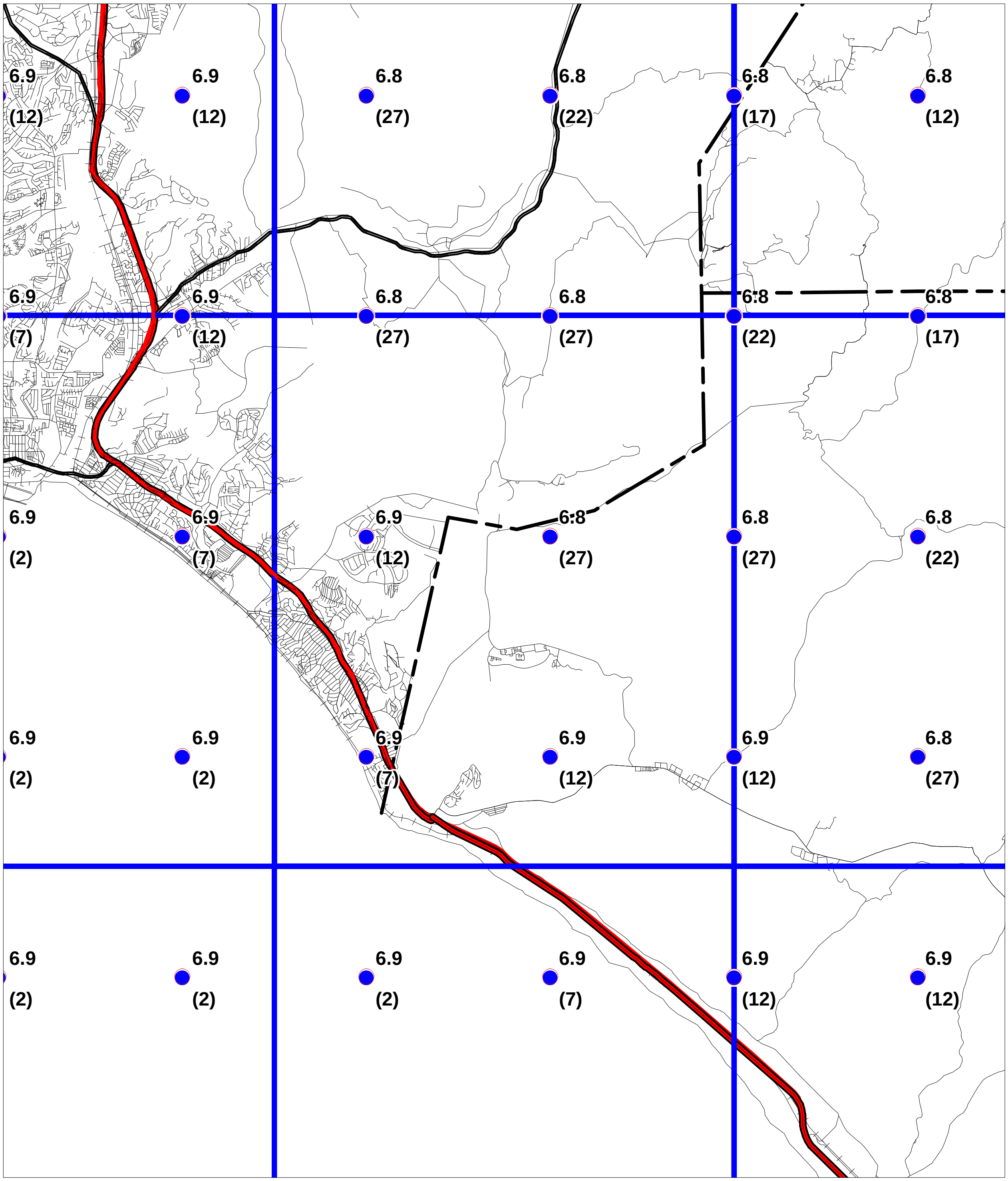
A preferred method of using the probabilistic seismic hazard model and the "simplified Seed-Idriss method" of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a "magnitude-weighted" ground motion (liquefaction 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.

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
California Geological Survey

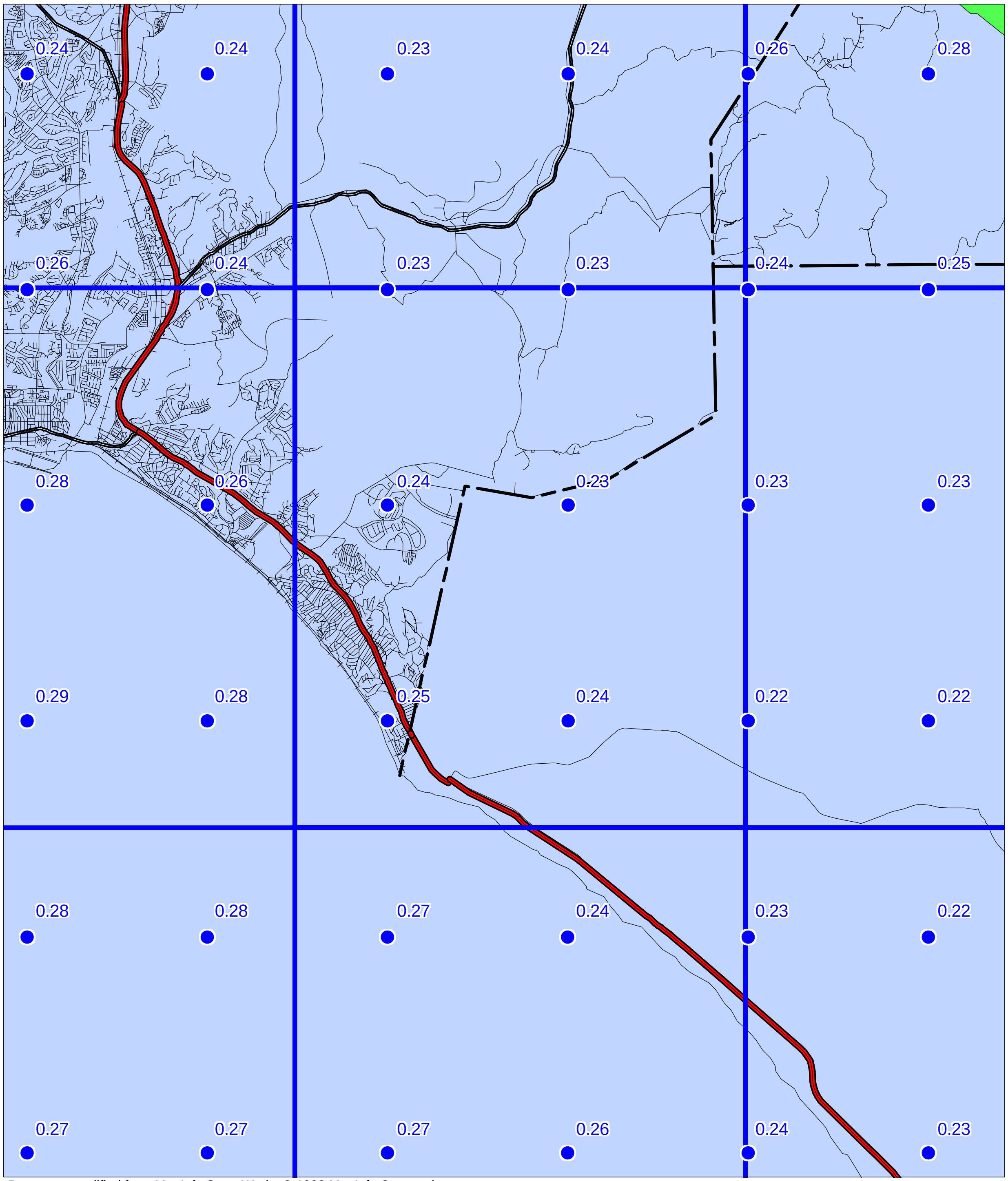
Figure 3.4

SAN CLEMENTE 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

2001

LIQUEFACTION OPPORTUNITY



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

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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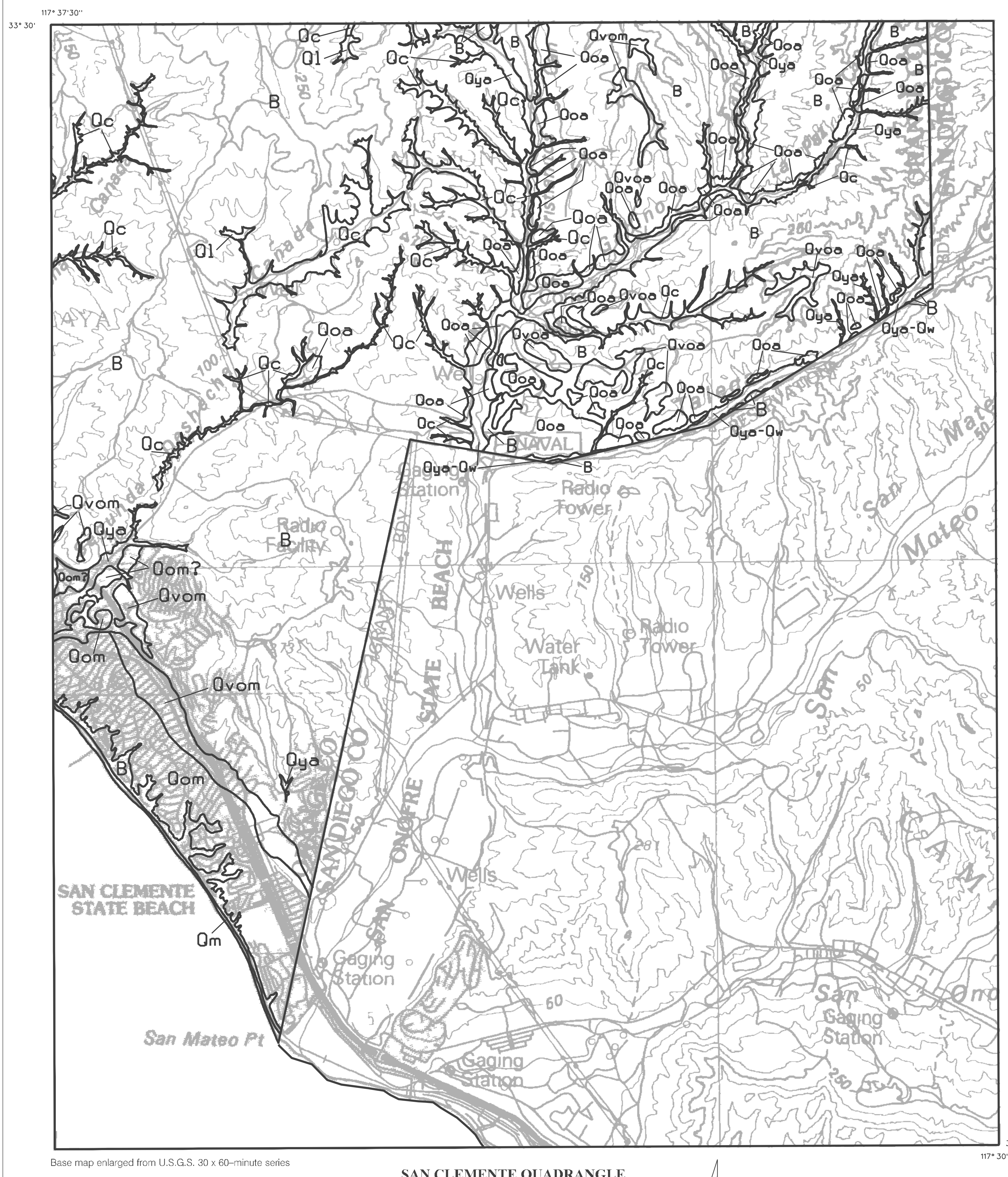


Base map enlarged from U.S.G.S. 30 x 60-minute series

SAN CLEMENTE QUADRANGLE

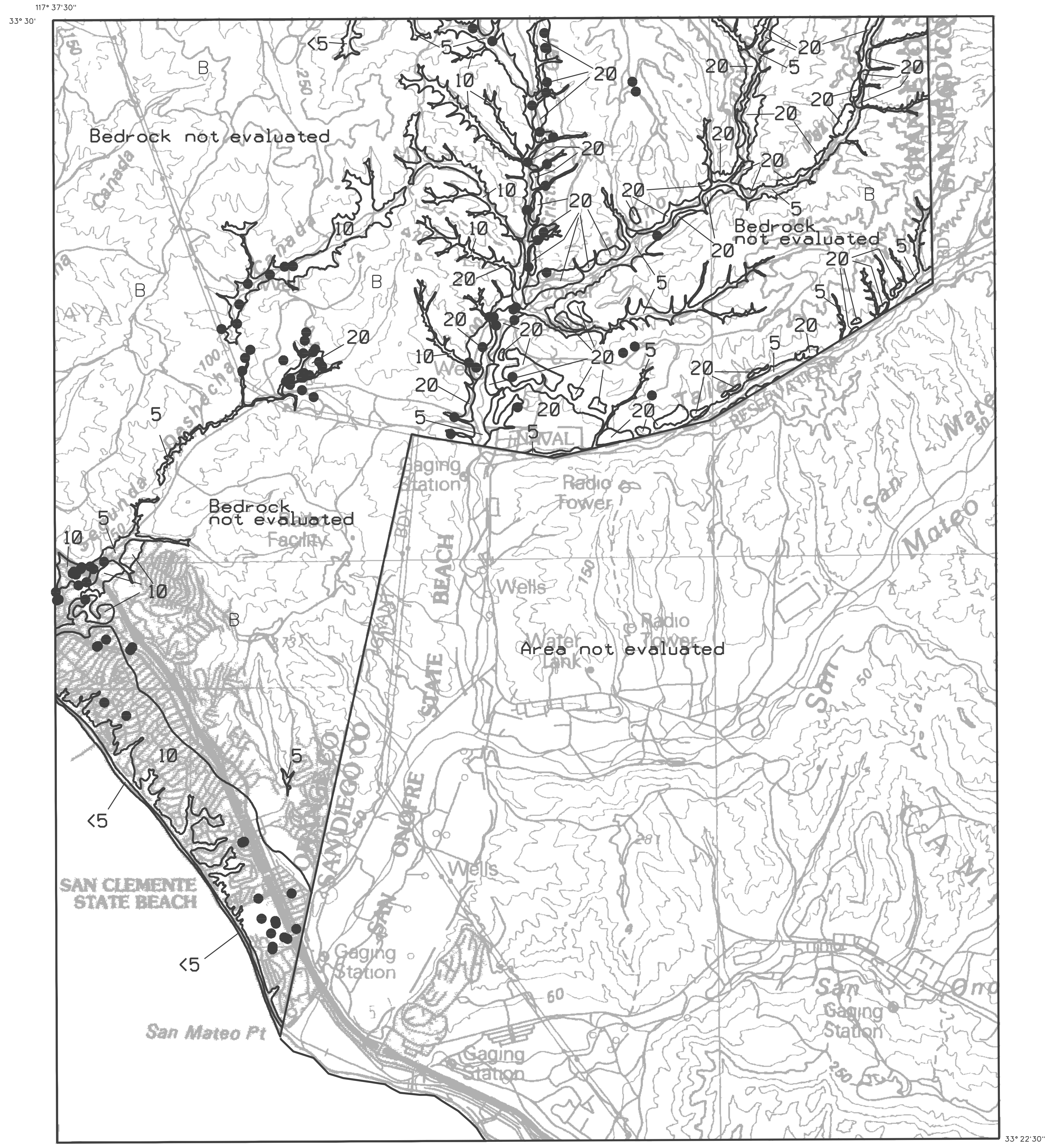
SCALE

1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER

B = Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of units.

Plate 1.1 Quaternary Geologic Map of the San Clemente 7.5-minute Quadrangle. Modified from geologic mapping of Tan (in preparation) and Morton and Miller (1961).



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

SAN CLEMENTE QUADRANGLE

SCALE

1 .5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

— 50 — Depth to ground water, in feet

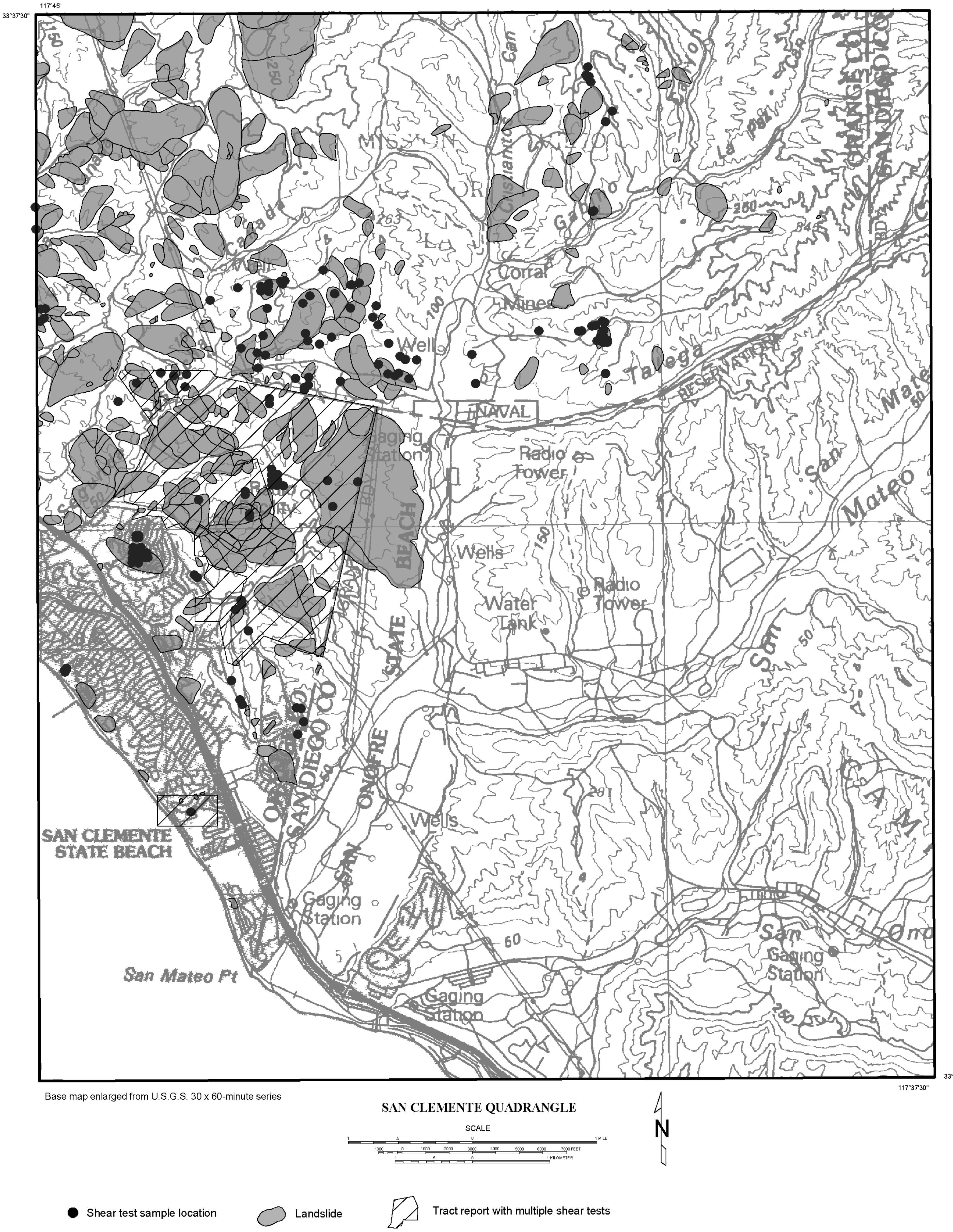
B = Pre-Quaternary bedrock.
See "Bedrock and Surficial Geology"
in Section 1 of report for descriptions of units.

● Geotechnical borings used in liquefaction evaluation

Plate 1.2 Depth to historically highest ground water, and location of boreholes used in this study, San Clemente 7.5-minute Quadrangle, California

CALIFORNIA GEOLOGICAL SURVEY
JAMES F. DAVIS, STATE GEOLOGIST

STATE OF CALIFORNIA-GRAY DAVIS, GOVERNOR
THE RESOURCES AGENCY-MARY D. NICHOLS, SECRETARY
DEPARTMENT OF CONSERVATION-DARRYL W. YOUNG, DIRECTOR



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

SAN CLEMENTE QUADRANGLE

SCALE

● Shear test sample location

Landslide

Tract report with multiple shear tests

Plate 2.1 Landslide inventory, shear test sample locations, San Clemente 7.5-Minute quadrangle.

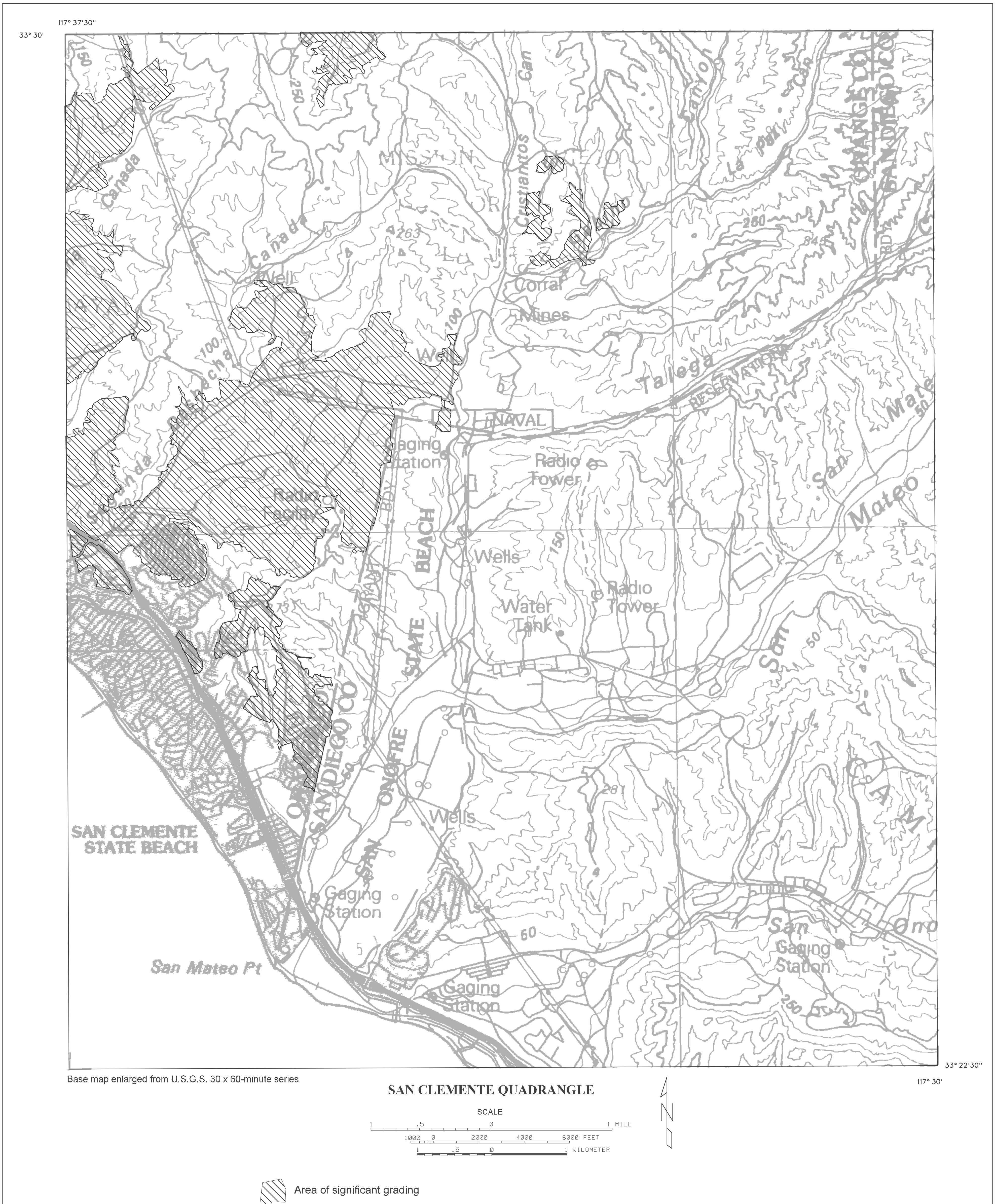


Plate 2.2 Areas of significant grading, San Clemente 7.5-minute quadrangle.