SEISMIC HAZARD ZONE REPORT 057

SEISMIC HAZARD ZONE REPORT FOR THE POINT MUGU 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Point Mugu 7.5-minute Quadrangle, Ventura County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 22 square miles at a scale of 1 inch = 2,000 feet.

Within the unusual-shaped Point Mugu Quadrangle along the Ventura County coast are about 8 square miles of flat-lying lowlands surrounding Mugu Lagoon on the west and the western end of the rugged Santa Monica Mountains on the east. Elevations within the quadrangle range from sea level to 1567 feet on La Jolla Peak. Calleguas Creek, La Jolla Canyon creek, and Big Sycamore Canyon creek are the major drainages in the quadrangle. Pacific Coast Highway (State Route 1) provides the major transportation route. The U.S. Navy administers land use over most of the area within the lowland portion of the quadrangle. The California Department of Parks and Recreation (Point Mugu State Park) and the County of Ventura administer land use in the highland region.

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 Point Mugu Quadrangle liquefaction effects such as sand boils and mud “volcanoes” developed during the 5.9 magnitude1973 Point Mugu earthquake. Essentially, the entire lowland portion of the quadrangle as well as the bottom of Big Sycamore Canyon and the beaches are within the liquefaction zone of required investigation. Landslides are relatively abundant on the coastal bluffs along Pacific Coast Highway, on some of the steep slopes in Sycamore Canyon, and along some of the other steep mountain drainages. Several rock falls occurred along steep bluffs near Point Mugu in the magnitude 5.9 Point Mugu earthquake of 1973. The steep slopes and weak rocks in the Santa Monica Mountains contribute to an earthquake-induced landslide zone of required investigation that covers about 48 percent of the quadrangle or much of the upland region.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet page: http://www.consrv.ca.gov/dmg/shezp/

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

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

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

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

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

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

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

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

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Point Mugu 7.5-Minute Quadrangle, Ventura County, California

By
Ralph C. Loyd

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Point Mugu 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

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

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

METHODS SUMMARY

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

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the 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 Point Mugu Quadrangle consist mainly of low-lying shoreline regions, alluviated

valleys, floodplains, and canyon floors. DMG's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The on-land portion of the unusual-shaped Point Mugu 7.5-minute Quadrangle covers approximately 22 square miles in southern coastal Ventura County. The western half of the quadrangle contains about 8 square miles of flat-lying coastal lowlands surrounding Mugu Lagoon. The eastern half of the map area includes the western end of the rugged Santa Monica Mountains. Elevations within the quadrangle range from sea level along the coastline to 1567 feet on La Jolla Peak. Calleguas Creek, La Jolla Canyon creek, and Big Sycamore Canyon creek are the major drainages in the quadrangle. The Pacific Coast Highway (State Route 1) provides the major transportation route through the quadrangle. Secondary access routes include Las Posas and Arnold roads, along with the several main roads extending through the Navy base. The U.S. Navy administers land use over most of the area within the lowland portion of the quadrangle. The California Department of Parks and Recreation (Point Mugu State Park) and the County of Ventura administer land use in the highland region.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. William Lettis and Associates (1999) provided digital Quaternary geologic mapping for use in this study. Their map was merged with digitized geologic mapping by Dibblee and Ehrenspeck (1990) to provide a common geologic map for zoning liquefaction and earthquake-induced landslides in the Point Mugu Quadrangle. It is presented in this report as (Plate 1.1). Nomenclature for labeling Quaternary geologic units followed that applied by the Southern California Areal Mapping Project [SCAMP] (Morton and Kennedy, 1989). Other sources of geologic information referenced in this study include McCoy and Sarna-Wojcicki (1978), Turner (1975), Turner and Mukae (1975), and Weber and others (1973).

As illustrated on Plate 1.1, Holocene sedimentary deposits cover the lowland surface of the Point Mugu Quadrangle. The alluvial units are divided on the basis of their depositional environment and relative ages, which were established on the basis of geomorphic expression (Table 1.1). For the most part, the young Quaternary sediments in the Point Mugu Quadrangle consist of sandy material deposited in alluvial valley, estuarine, alluvial fan, dune sand, and stream channel (wash) depositional environments associated with Calleguas Creek and a former course of the Santa Clara River.

At least three generations of young Quaternary depositional units are identified in the lowland areas of Plate 1.1. The first generation consists of wash deposits (Qw1) of late Holocene age. The second consists of wash (Qw2), alluvial fan (Qyf2), and alluvial valley (Qya2) deposits of latest Holocene age. The third consists of wash (Qw), estuarine (Qes), dune sand (Qe), colluvium (Qc) and alluvial fan (Qf) deposits of modern age. In addition, it appears that the construction of the Naval base (airfield) within and adjacent to the Mugu Lagoon required the extensive use of artificial fill.

Quaternary sedimentary units in the Santa Monica Mountains consist of alluvial fan deposits (Qf), colluvium (Qc), canyon floor sediments (Qya2), and older alluvium (Qoa).

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qw, Qw2, Qw1	Sandy, silty sand	Stream channels	Very loose to moderately dense	Yes
Qe	Dune (eolian) sand	Coastline	Very loose	Yes
Qf	Sand, silty sand	Active alluvial fans	Loose	Yes
Qes	Sandy Silt and Clay	Marine estuary	Loose, sensitive	Yes
Qc	Clay, rock debris	Slope Wash	Cohesive	Not likely
Qya2	Silty sand, sand,minor clay	Valley deposits	Loose to moderately dense	Yes
Qyf2	Silty sand, sand, minor clay	Young alluvial fan	Loose to moderately dense	Yes
Qoa	Sand, silt, and clay	Older alluvium	Dense to very dense	Not likely

* When saturated.

Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Map Units.

ENGINEERING GEOLOGY

Logs of 8 borehole test sites in the Point Mugu Quadrangle were collected from the Department of Toxic Substances Control and the County of Ventura. These data were entered into the DMG geotechnical GIS database. Locations of the exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections using data reported on the borehole logs enabled staff to relate lithology and soil-engineering properties to the various depositional units, to correlate soil types from one borehole to another, extrapolate geotechnical data into outlying areas containing similar soils, and to evaluate ground-water conditions.

Turner (1975) shows the thickness of Holocene deposits to averages between 200 and 250 feet throughout most of the Oxnard Plain. Borehole log data indicate that in the upper 40 feet of the subsurface these young Quaternary sediments in the Point Mugu Quadrangle are composed of predominantly well-sorted and poorly sorted sand with lesser amounts of silty sand and minor silt and clay. Lithologic descriptions, penetration

tests, and dry density measurements recorded in the borehole logs and posted on computer-generated cross sections developed in this study show that loose, sand and silty sand layers dominate the near-surface deposits within the lowland area of the quadrangle.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of 1 atmosphere (approximately 1 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 $(N_1)_{60}$.

GROUND-WATER CONDITIONS

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

Ground-water conditions were investigated in the Point Mugu Quadrangle to evaluate the depth to saturated materials. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation was based on first-encountered water noted in geotechnical borehole logs acquired from geotechnical boreholes, environmental monitoring wells, and water-well logs. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water (Plate 1.2). Water depths from boreholes known to penetrate confined aquifers were not utilized.

Ground-water hydrology of the Oxnard Plain is summarized in reports by the California Department of Water Resources (1971), Turner (1975), and Turner and Mukae (1975). Near-surface ground water throughout most of the Oxnard Plain is associated with an unconfined aquifer extending from the surface to a depth of about 75 feet. This upper semi-perched ground-water zone is separated from deeper aquifers by a clay-rich zone "clay cap" that averages over 80 feet in thickness. In the Point Mugu Quadrangle, this "clay cap" is missing and sand layers dominate the entire 200-foot plus Holocene section (Turner and Mukae, 1975). Borehole logs collected for this study indicate that the Oxnard Plain within the Point Mugu Quadrangle is marked by relatively consistent historical ground-water depths that range from 0 feet along the coastline to about 5 feet along the quadrangle's northern boundary (Plate 1.2).

PART II

LIQUEFACTION HAZARD 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. DMG's 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.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. DMG's qualitative susceptible soil inventory is summarized on Table 1.1

LIQUEFACTION OPPORTUNITY

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

For the Point Mugu Quadrangle, peak accelerations of 0.54 g to 0.56 g resulting from an earthquake of magnitude 7.3 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

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to

the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 8 geotechnical borehole logs reviewed in the 8-square-mile study area of lowlands (Plate 1.2), 5 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or using average test values of similar materials.

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 Point Mugu Quadrangle is summarized below.

Areas of Past Liquefaction

Several hundred lurch cracks and sand-boil craters were reported and photographed in the bed of Calleguas Creek and Mugu Lagoon following the offshore February 1973 Point Mugu earthquake of magnitude 5.9 (California Division of Mines and Geology, 1976; Morton and Campbell, 1973). The approximate locations of these observed features are shown on Plate 1.2. It is probable that widespread damage to buildings and other structures in Oxnard and the Point Mugu Naval Station caused by the 1973 earthquake were due in part to liquefaction and associated unstable soil conditions.

Artificial Fills

In the Point Mugu Quadrangle, about two of the eight square miles in and adjacent to Mugu Lagoon has been covered by artificial fill. Although it is presumed that the fill material on sites containing building and other structures have been properly prepared for construction purposes, it is unknown to what degree artificial fill elsewhere in the quadrangle has been engineered.

Areas with Sufficient Existing Geotechnical Data

In general, sufficient geotechnical data exist in the alluviated valley areas of the Point Mugu Quadrangle to evaluate potential for liquefaction. The available borehole log data clearly indicate that young Quaternary sediments deposited in the upper 40 feet of the Oxnard Plain are composed of predominantly saturated, loose, sandy soils that are highly susceptible to liquefaction.

Areas with Insufficient Existing Geotechnical Data

Lack of data in the canyon floors of La Jolla and Big Sycamore canyons require the application of SMGB zoning criteria for areas with insufficient geotechnical data. The widespread exposure of sand-rich sedimentary rocks of the Tertiary Vaqueros Formation within these watersheds make it likely that canyon-bottom Quaternary deposits are composed of loose, sandy sediments, that when saturated are potentially liquefiable.

ACKNOWLEDGMENTS

Thanks to Christopher Hitchcock of William Lettis and Associates for providing original mapping of Quaternary geology of the Point Mugu Quadrangle. Appreciation is also extended to managers and staff Ventura County Public Works Agency, Ventura County Environmental Health Division, and California Department of Toxic Substances Control for providing geotechnical data that were critical to the successful completion of this study.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Point Mugu 7.5-Minute Quadrangle, Ventura County, California

By
Michael A. Silva and Mark O. Wiegers

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This Section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Point Mugu 7.5-minute Quadrangle (scale

1:24,000). This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarize 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 DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/.

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 Point Mugu Quadrangle.

METHODS SUMMARY

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

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of DMG probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

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

SCOPE AND LIMITATIONS

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

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Point Mugu 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 Point Mugu 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 Point Mugu 7.5-minute Quadrangle covers approximately 22 square miles in southern Ventura County. Local physiography includes about 8 square miles of flat

coastal lowlands and the rest consisting of the rugged Santa Monica Mountains. Elevations within the quadrangle range from sea level along the coast line to 1567 feet on La Jolla Peak. Calleguas, La Jolla Canyon, and Big Sycamore Canyon creeks are the major drainages in the quadrangle. Highway 1 (Pacific Coast Highway) provides the major transportation route through the quadrangle. Secondary access routes include Las Posas and Arnold roads, along with the several main roads extending through the Navy base. The U.S. Navy administers land use over most of the area within the lowland portion of the quadrangle. The California Department of Parks and Recreation and the County of Ventura administer land use in the highland region.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Point Mugu Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

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

GEOLOGY

Bedrock and Surficial Geology

Bedrock geologic mapping used in this slope stability evaluation was obtained from the Dibblee Geological Foundation (Dibblee and Ehrenspeck, 1990) and digitized by DMG staff for this study. Bedrock units are described in detail in this section. The source of surficial geologic mapping used in this study was an unpublished digitized Quaternary geology map of the Point Mugu 7.5-minute Quadrangle prepared by William Lettis and Associates (2000). Surficial geologic units are briefly described here, and are discussed in more detail in Section 1, Liquefaction Evaluation Report.

The digitized geologic map was modified by DMG geologists in the following ways. 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. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S.G.S. 7.5-minute quadrangle. DMG staff then merged the bedrock contacts on this map with the digital Quaternary geologic map prepared by William Lettis and Associates. Air-photo interpretation and field reconnaissance were performed to assist in adjusting contacts between bedrock and surficial geologic units and to review geologic unit lithology and geologic structure.

Bedrock formations exposed in the Point Mugu Quadrangle consist of Miocene marine sedimentary rocks of the Lower Topanga Formation and Miocene intrusive volcanic rocks of the Conejo Volcanics (Dibblee and Ehernspeck, 1990). The intrusive volcanic rocks occur as plugs, pods, dikes and sills within the sedimentary strata. Surficial deposits in the Point Mugu Quadrangle include alluvial and estuarine sediments underlying the coastal plain surrounding Mugu Lagoon and more limited alluvial sediments in the Santa Monica Mountains, primarily in the vicinity of La Jolla Valley and in Sycamore Canyon (William Lettis and Associates, 2000). Surficial deposits also include beach sand and dune sand along the coast.

The Santa Monica Mountains consist of two distinct geologic terranes that are juxtaposed along the east-west trending Malibu Coast Fault. The Malibu Coast Fault lies offshore to the south of the coastline in the Point Mugu Quadrangle. It extends onshore about three miles east of the Point Mugu Quadrangle at Sequit Point. North of the fault, the basement consists of Santa Monica Slate and granodiorite that is overlain by Upper Cretaceous through upper Miocene rocks. South of the fault, the basement consists of Catalina Schist that is overlain by Miocene and younger rocks. The basement complex and Upper Cretaceous through Upper Oligocene strata are not exposed in the Point Mugu Quadrangle, which is in the terrane north of the fault.

The Cenozoic rocks in the central part of the Santa Monica Mountains east of the Point Mugu Quadrangle are highly deformed and exhibit complex time-transgressive facies changes and intertonguing relationships. This geologic complexity has led to differences in stratigraphic terminology used by some of the geologists who have mapped in the region (Yerkes and Campbell, 1979, 1980; Dibblee and Ehrenspeck, 1990, 1993). The evolution of stratigraphic terminology used in the region is reviewed in detail by Fritsche (1993). For this study, the stratigraphic terminology used by Dibblee and Ehrenspeck (1990, 1993) is adopted.

The predominant bedrock unit exposed in the Point Mugu Quadrangle is the early to middle Miocene Lower Topanga Formation. The Lower Topanga Formation consists of marine clastic rocks that are subdivided into four units (Ttlc, Ttls, Ttlcv, Ttlcs) by Dibblee and Ehrenspeck (1990). Ttlc consists of dark to light gray, thin-bedded micaceous clay shale with a few thin interbeds of hard, semi-siliceous shale or sandstone. Ttls consists of gray to tan, moderately hard sandstone with thin interbeds of gray micaceous shale. Ttlcv and Ttlcs are lithologically identical, respectively, to the other two units but contain fossils of early Miocene age. These two latter units have been mapped previously as the Vaqueros Formation (Yerkes and Campbell, 1979).

Plugs, pods, dikes and sills of the middle Miocene Conejo Volcanics intrude the Lower Topanga Formation. These intrusive volcanic rocks were injected into the Upper Topanga Formation along vents and fissures that fed extrusive rocks of the Conejo Volcanics exposed east of the Point Mugu Quadrangle. The intrusive volcanic rocks include two map units in the map area, designated db and bi (Dibblee and Ehrenspeck, 1990). The unit db consists of gray to dark olive-brown, fine-to coarse-grained diabase that forms many lenticular sills and feeder dikes. The unit bi consists of gray-black, fine-grained basalt in dikes, pods and plugs.

The bedrock units are overlain locally by Pleistocene and Holocene surficial deposits. Pleistocene deposits (Qoa) consist of dissected alluvial gravel, sand and silt located in limited upland areas in the Santa Monica Mountains, primarily in and near La Jolla Valley. Holocene deposits include alluvial, channel and estuarine deposits underlying the coastal plain around Mugu Lagoon, beach sand and dune sand along the coast, and alluvium in Sycamore Valley and along some of the smaller streams in the Santa Monica Mountains. Surficial map units include wash deposits (Qw, Qw1, Qw2), alluvial fan deposits (Qf, Qf2), alluvial valley deposits (Qya2), alluvium (Qa), beach sand (Qs) and dune sand (Qds). Additional discussion of Quaternary units in the Point Mugu Quadrangle can be found in Section 1.

Structural Geology

The Point Mugu Quadrangle is within the Santa Monica Mountains which, along with the northern Channel Islands, forms a structural block known as the western Transverse Range uplift (Dibblee and Ehrenspeck, 1993). The Santa Monica Mountains portion of this uplift has been squeezed up more or less anticlinally along the north side of the east-trending, north-dipping Malibu Coast-Santa Monica Fault Zone. The Malibu Coast-Santa Monica Fault Zone is a dip-slip fault with significant left-lateral offset (Treiman, 1994). The Malibu Coast segment of this fault zone lies offshore south of the coastline in the Point Mugu Quadrangle.

The Point Mugu Quadrangle is at the western end of a prominent fold called the Sequit Anticline. The axis of this anticline extends into the eastern portion of the map area across the lowermost portion of Sycamore Canyon. Most of the mountainous area in the Point Mugu Quadrangle lies on the north limb of this anticline. Beds in the map area dip relatively consistently to the north and northwest. Dips generally range between 10 and 40 degrees. Dip slope conditions are most common on the north side of the map area, where some of the north-facing slopes are underlain by north-dipping beds.

Several faults extend through the mountainous portion of the map area, including the Sycamore Canyon Fault and the southern extension of the Boney Mountain Fault. These faults displace Miocene rocks but are not known to be seismically active or to have Quaternary displacement.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Point Mugu Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published and unpublished landslide mapping (Weber and Wills, 1983; Dibblee and Ehrenspeck, 1990; Irvine, 1994). The areal distribution of landslides identified in the map area is shown on Plate 2.1

Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map several characteristics 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.

In general, landslides are relatively abundant on the coastal bluffs along the Pacific Coast Highway, on some of the steep slopes in Sycamore Canyon, and along some of the other steep mountain drainages. Upland areas along the crest of the Santa Monica Mountains are relatively stable with few landslides. Landslides range from shallow failures such as soil and/or rock creep, rock falls, soil and debris slumps, and debris flows to large rotational and translation bedrock landslides, some of which are relatively old and deeply eroded. Several rock falls occurred along steep bluffs near Point Mugu in the magnitude 6.0 Point Mugu earthquake of 21 February 1973 (California Division of Mines and Geology, 1973).

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. Due to the limited amount of shear-strength data available in the Point Mugu Quadrangle, most of the shear strength data for this quadrangle were derived from the Point Dume and Triunfo Pass quadrangles.

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.

One map unit of the Topanga Formation, Ttlsv, was subdivided further, as discussed below.

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 that are exposed at the ground surface due to a lack of lateral support.

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

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

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if they appear to have been performed appropriately, have also been used. Within the Point Mugu Quadrangle, no strength values for landslide slip surfaces were available. Instead, a phi value of 10° was assumed, and this value is shown in Table 2.1.

POINT MUGU QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	bi	4	34/37	34/36	470/365		34
	db	5	35/40				
	Ttls	3	34/38				
	Ttlsv(fbc)	25	34				
GROUP 2	Qa	6	28/25	28/30	455/425	af, Qc, Qds	28
	Ttlc	26	29/30			Qe, Qes	
	Ttlsv(abc)	17	28/30			Qoa, Qs	
						Qw, Qw1,	
						Qw2, Qya2	
						Qyf2	
						Ttlcv	
GROUP 3	Qls						10
	fbc = Favorable bedding conditions						
	abc = Adverse bedding conditions						
	Formations for strength groups from Dibblee and Ehrenspeck, 1993						

Table 2.1. Summary of the Shear Strength Statistics for the Point Mugu Quadrangle.

SHEAR STRENGTH GROUPS FOR THE POINT MUGU 7.5-MINUTE QUADRANGLE		
GROUP 1	**GROUP 2**	**GROUP 3**
bi	Qa	Qls
db	Qc	
Ttls	Qds	
Ttlsv(fbc)	Qe	
	Qes	
	Qoa	
	Qs	
	Qw	
	Qw1	
	Qw2	
	Qya2	
	Qyf2	
	Ttlc	
	Ttlcv	
	Ttlsv(abc)	
fbc = favorable bedding conditions		
abc = adverse bedding conditions		

Table 2.2. Summary of Shear Strength Groups for the Point Mugu 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 Point Mugu Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.2 to 7.3
Modal Distance:	2.5 to 3.7 km
PGA:	0.50 to 0.62 g

The strong-motion record selected for the slope stability analysis in the Point Mugu Quadrangle was the Southern California Edison (SCE) Lucerne record from the 1992 magnitude 7.3 Landers, California, earthquake. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.80g. Although the distance and PGA values of the Lucerne 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 are used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.142, 0.182, and 0.243 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Point Mugu Quadrangle.

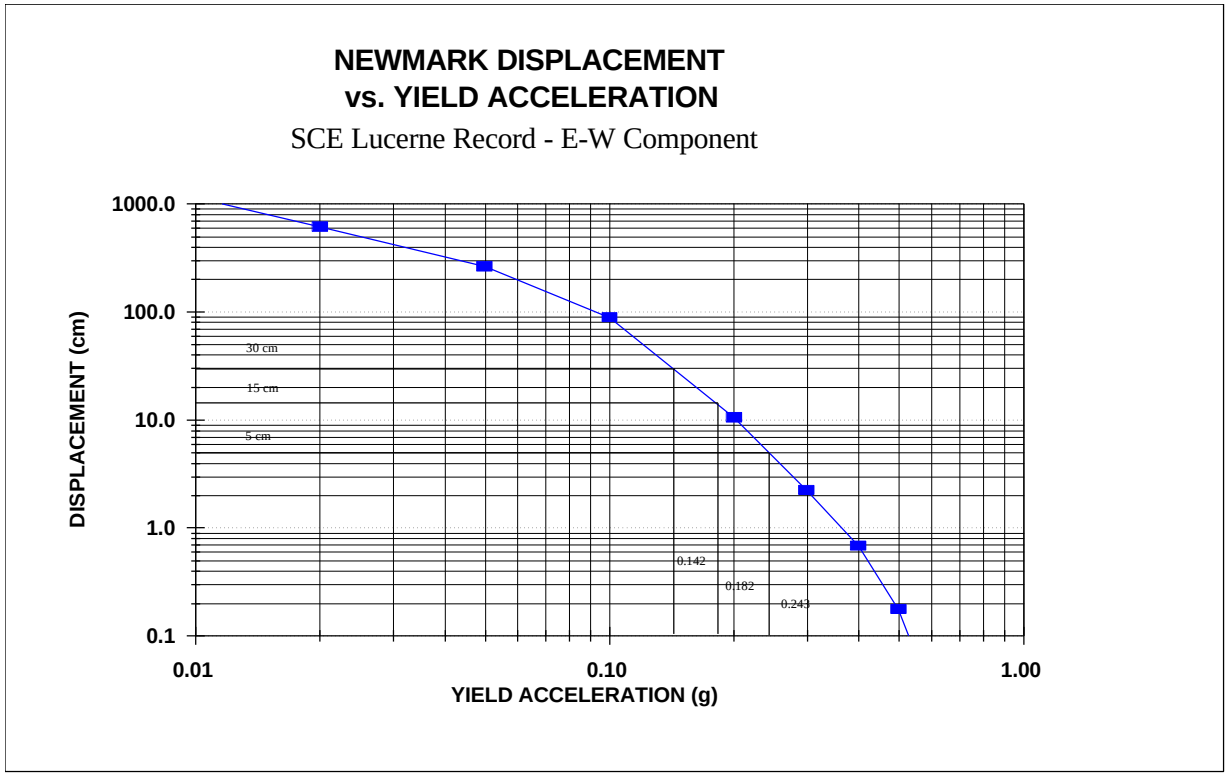

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1992 Landers Earthquake SCE Lucerne Record.

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 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 0.142g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3).

2. Likewise, if the calculated yield acceleration fell between 0.142g and 0182.g, 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 0.182g and 0.243g, 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 0.243g, 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.

POINT MUGU QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)						
		I	II	III	IV	V	VI	VII
		0-28	28-34	34-38	38-42	42-49	49-53	>53
1	34	VL	VL	VL	VL	L	M	H
2	28	VL	L	M	H	H	H	H
3	10	H	H	H	H	H	H	H

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

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

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

Existing Landslides

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

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 3 is included for all slope gradient categories. (Note: Geologic Strength Group 3 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 2 is included for all slopes steeper than 28 percent.

3. Geologic Strength Group 1 is included for all slopes steeper than 42 percent.

This results in 48 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Point Mugu Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the Ventura County Public Works office with the assistance of James O'Tousa, Larry Cardozo, and LaVonne Driver. Pamela Irvine reviewed landslide mapping. Terilee McGuire and Bob Moscovitz provided GIS support. Barbara Wanish and Ross Martin prepared the final landslide hazard zone maps and the graphic displays for this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Ventura County	**4**
Point Dume Quadrangle	**59**
Triunfo Pass Quadrangle	**23**
Total Number of Shear Tests	**86**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Point Mugu 7.5-Minute Quadrangle, Ventura County, California

By

Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, 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) 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://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps),

and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

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

EARTHQUAKE HAZARD MODEL

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

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

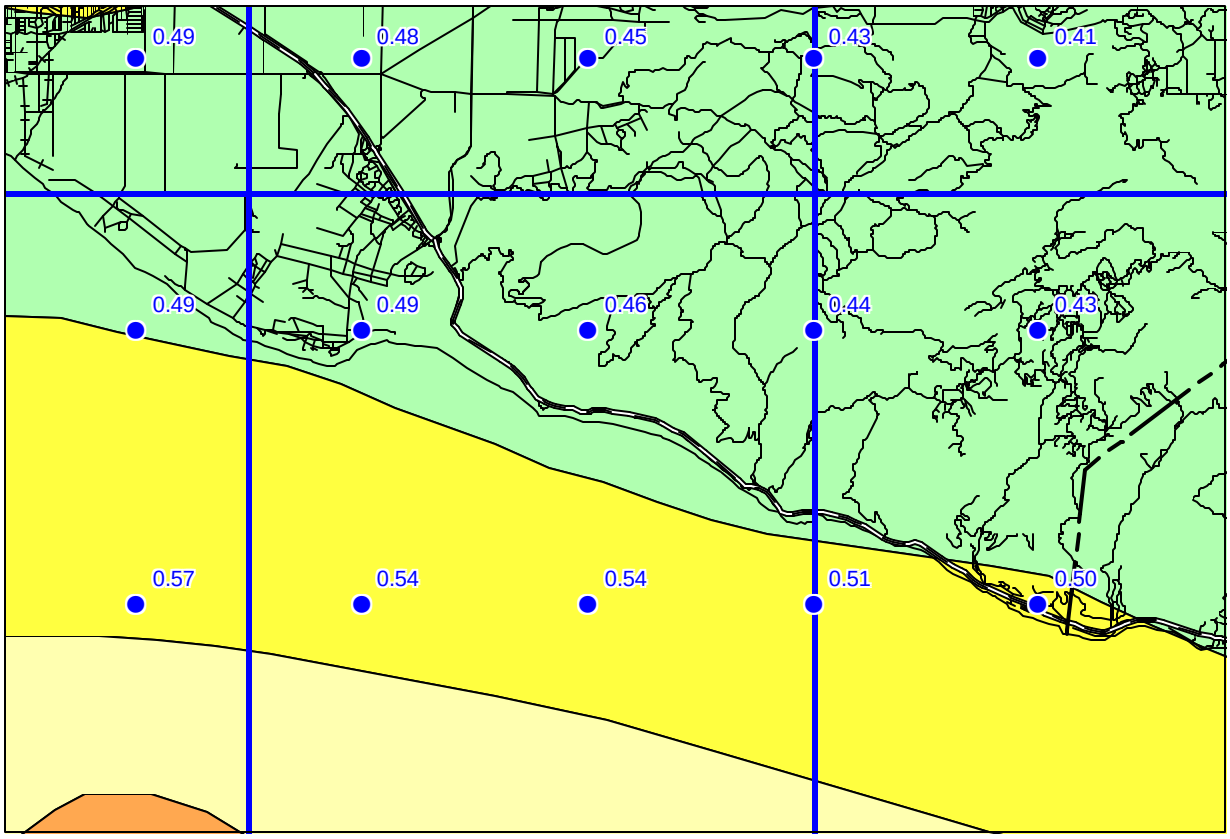
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

POINT MUGU 5X10-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

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Miles

Department of Conservation
Division of Mines and Geology

Figure 3.1

POINT MUGU 5X10-MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS

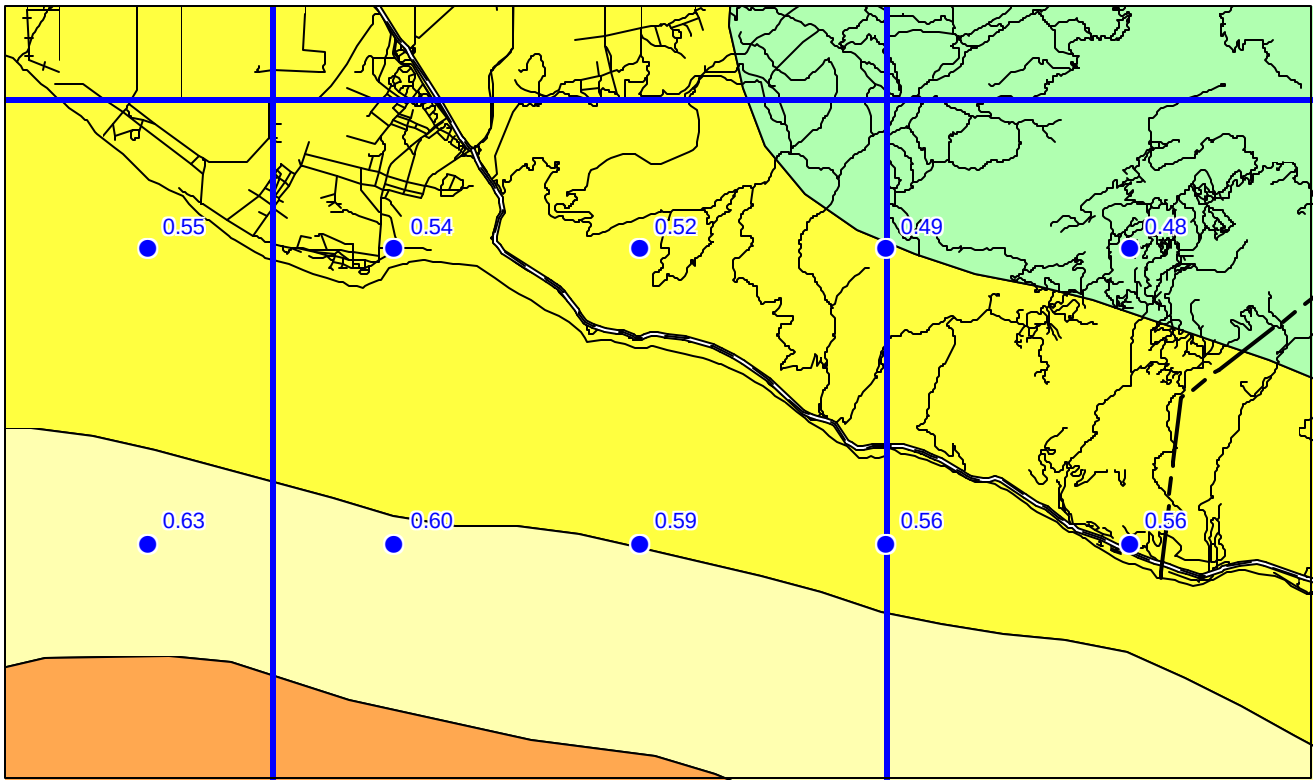

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Figure 3.2

POINT MUGU 5X10 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS

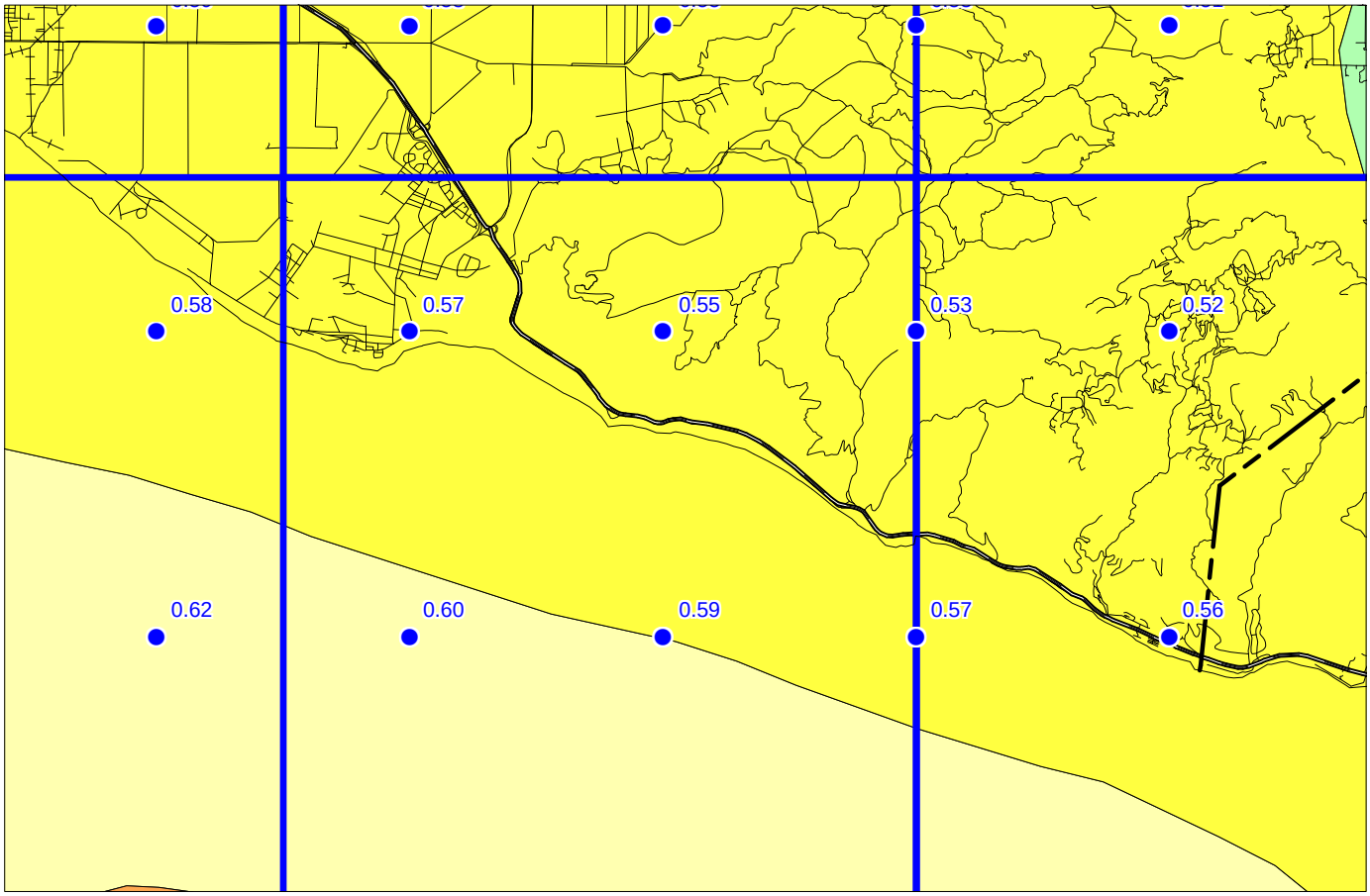

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Figure 3.3

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.

POINT MUGU 5X10 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

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

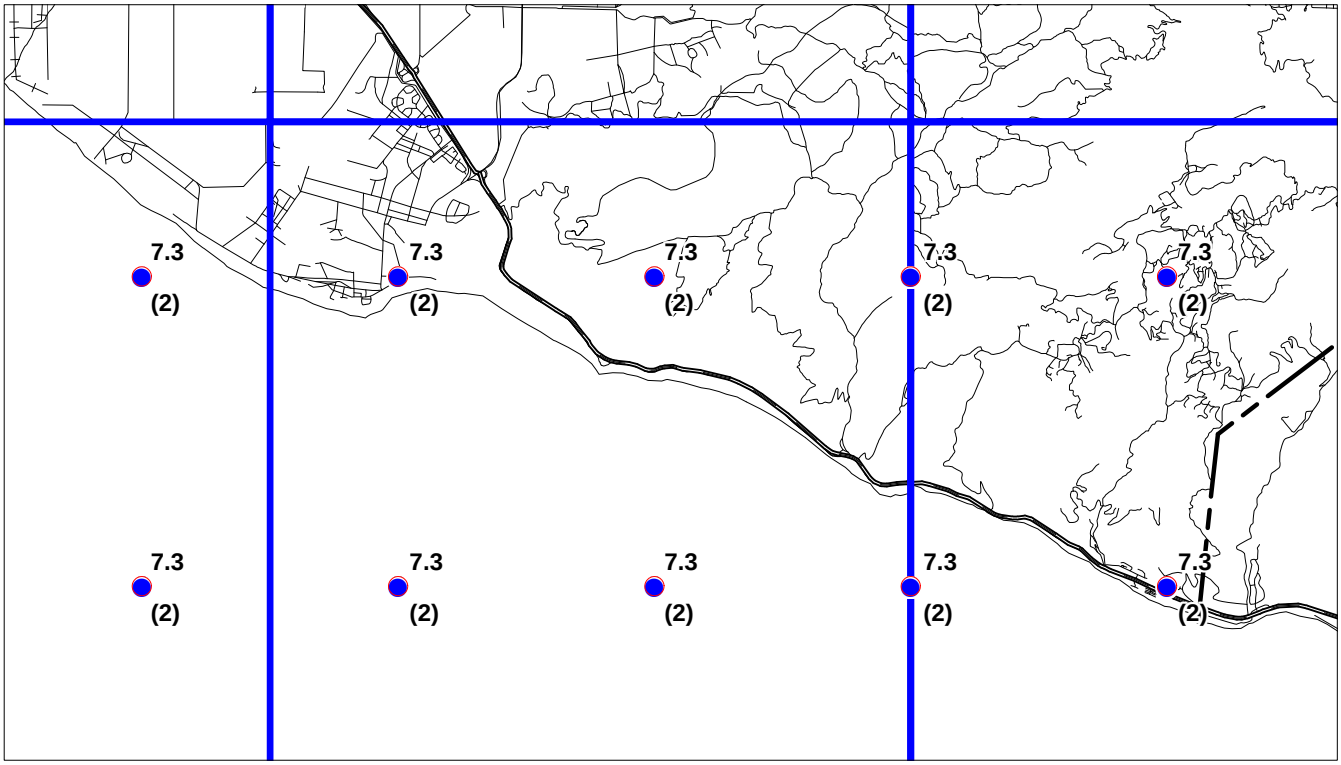

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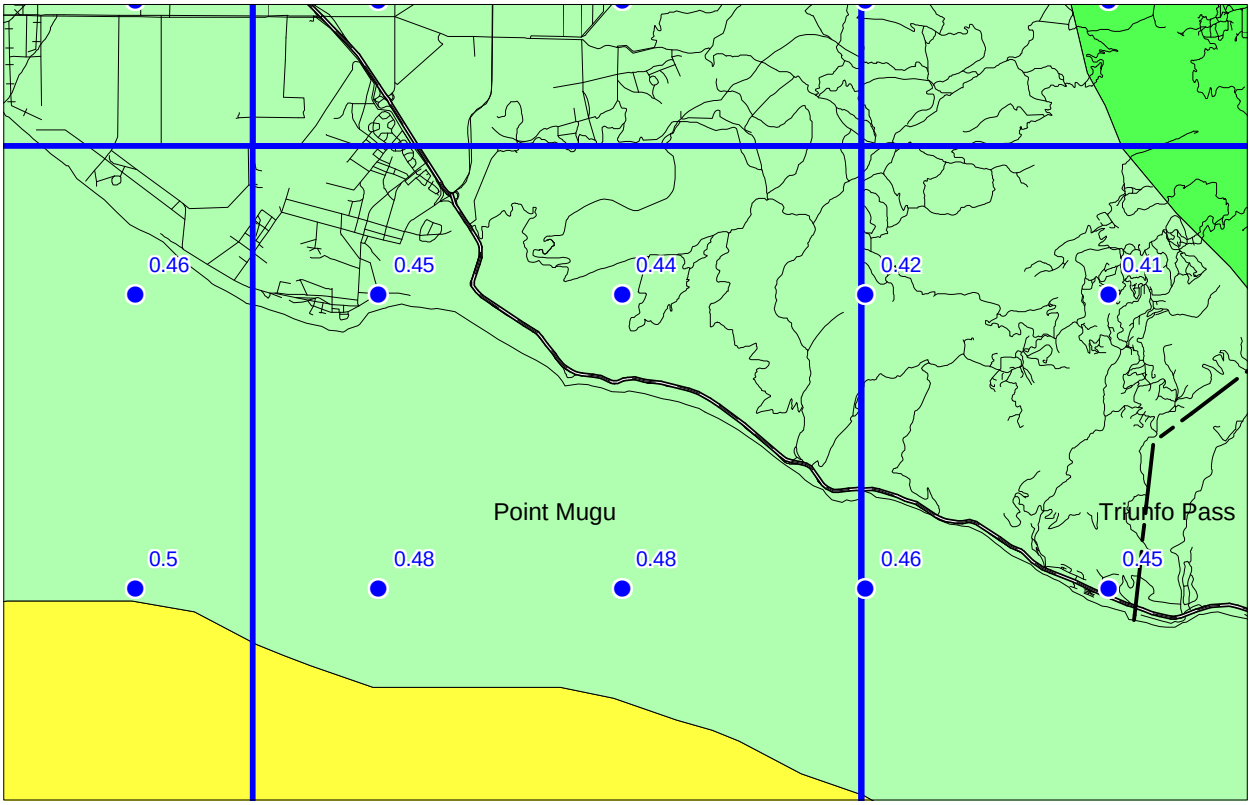
Figure 3.4

POINT MUGU 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



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Division of Mines and Geology

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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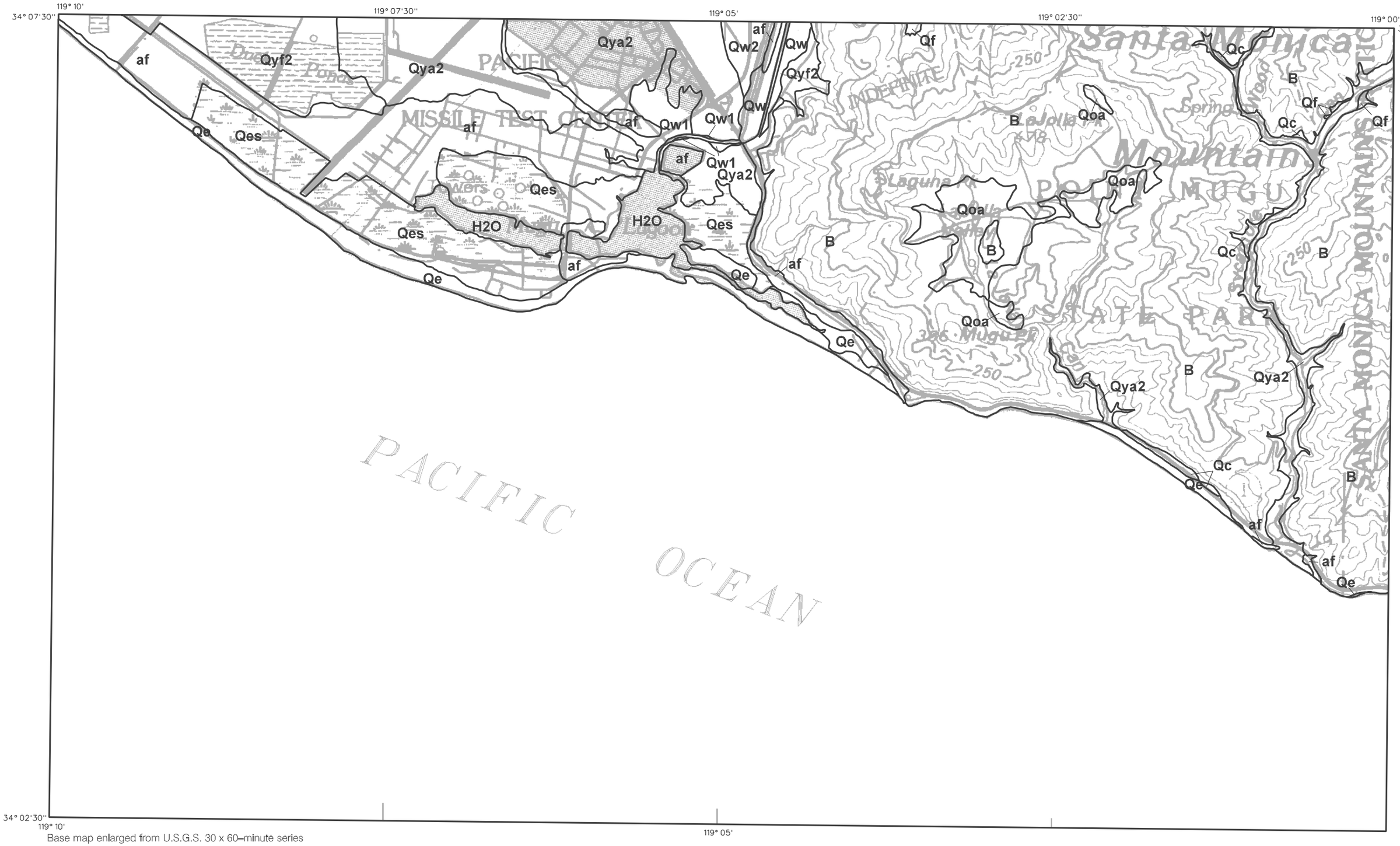

POINT MUGU QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

N

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 Point Mugu 7.5-minute Quadrangle (William Lettis & Associates, 2000).

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

5 Depth to ground water in feet

Alluviated valley boundary

Borehole Site

Approximate location of sand boils and lurch cracks observed following the Point Mugu Earthquake of February 21, 1973.

POINT MUGU QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

N

Plate 1.2 Historically highest ground–water levels and Borehole Locations in the Pt. Mugu 7.5–minute Quadrangle.

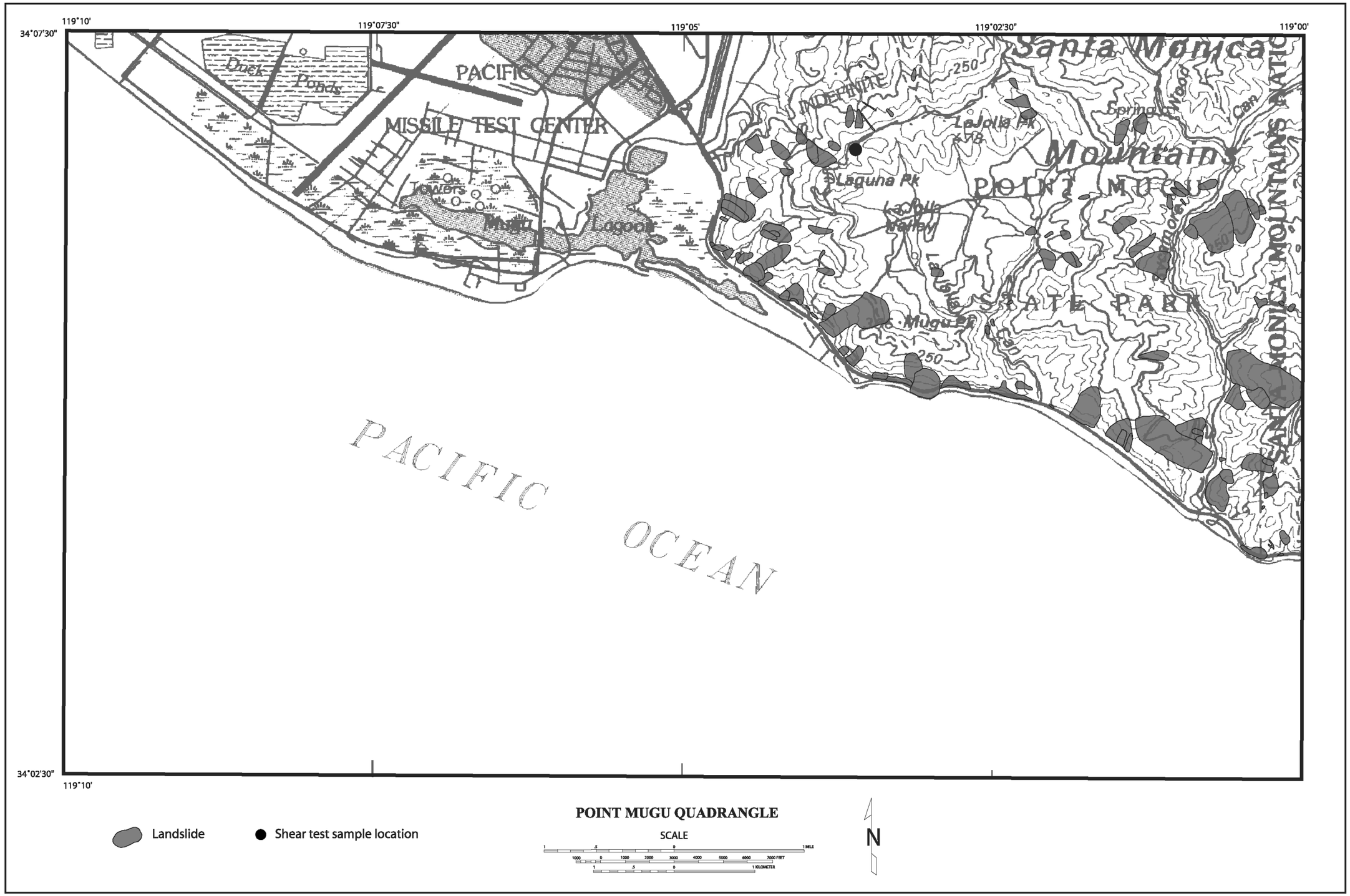

Plate 2.1 Landslide inventory and shear test sample locations, Point Mugu 10 x 5-minute Quadrangle.