SEISMIC HAZARD ZONE REPORT 050

SEISMIC HAZARD ZONE REPORT FOR THE MALIBU BEACH 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

2001

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Division of Mines and Geology

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CONTENTS

EXECUTIVE SUMMARY viii

INTRODUCTION 1

SECTION 1 LIQUEFACTION EVALUATION REPORT Liquefaction Zones in the Malibu Beach 7.5-Minute Quadrangle, Los Angeles County, California 3

PURPOSE 3

BACKGROUND 4

METHODS SUMMARY 4

SCOPE AND LIMITATIONS 4

PART I 5

PHYSIOGRAPHY 5

GEOLOGY 6

ENGINEERING GEOLOGY 9

GROUND-WATER CONDITIONS 9

PART II 10

LIQUEFACTION HAZARD POTENTIAL 10

LIQUEFACTION SUSCEPTIBILITY 11

LIQUEFACTION OPPORTUNITY 11

LIQUEFACTION ZONES 13

ACKNOWLEDGMENTS 14

REFERENCES 15

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT Earthquake-Induced Landslide Zones in the Malibu Beach 7.5-Minute Quadrangle, Los Angeles County, California 18

PURPOSE 18

BACKGROUND 19

METHODS SUMMARY 19

SCOPE AND LIMITATIONS 20

PART I 20

PHYSIOGRAPHY 20

GEOLOGY 22

ENGINEERING GEOLOGY 27

PART II 30

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL 30

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE 34

ACKNOWLEDGMENTS 35

REFERENCES 35

AIR PHOTOS 40

APPENDIX A Source of Rock Strength Data 41

SECTION 3 GROUND SHAKING EVALUATION REPORT Potential Ground Shaking in the Malibu Beach 7.5-Minute Quadrangle, Los Angeles County, California 43

PURPOSE 43

EARTHQUAKE HAZARD MODEL 44

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS 48

USE AND LIMITATIONS 48

REFERENCES 51

ILLUSTRATIONS

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1992 Landers Earthquake SCE Lucerne Record.....32

Figure 3.1. Malibu Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Firm rock conditions. 45

Figure 3.2. Malibu Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Soft rock conditions. 46

Figure 3.3. Malibu Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Alluvium conditions.....47

Figure 3.4. Malibu Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration—Predominant earthquake. 49

Table 1.1. Quaternary map units in the Malibu Beach Quadrangle and their geotechnical characteristics and liquefaction susceptibility 8

Table 2.1. Summary of the Shear Strength Statistics for the Malibu Beach Quadrangle. 29

Table 2.2. Summary of Shear Strength Groups for the Malibu Beach Quadrangle. 30

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Malibu Beach Quadrangle. 33

Plate 1.1. Quaternary geologic map of the Malibu Beach 7.5-minute Quadrangle, California

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

Plate 2.1. Landslide inventory and shear test sample locations, Malibu Beach 7.5-minute Quadrangle

EXECUTIVE SUMMARY

This report summarizes the methodology and sources of information used to prepare the Seismic Hazard Zone Map for the Malibu Beach 7.5-minute Quadrangle, Los Angeles County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of about 45 square miles at a scale of 1 inch = 2,000 feet.

About 70 percent of the Malibu Beach Quadrangle is on land. The quadrangle includes parts of the coastal City of Malibu, a small part of Calabasas and the unincorporated communities of Malibu Lake, Monte Nido, Malibu Bowl, and El Nido. The Malibu Civic Center is about 25 miles west of Los Angeles. The steep and rugged central Santa Monica Mountains, with elevations up to 2828 feet above sea level, dominate the terrain in the quadrangle. The major drainage system consists of Malibu Creek and its tributaries. Malibu Creek flows southeastward in Triunfo Canyon and turns southward in Malibu Canyon in the center of the area. Near the coast the Malibu Creek floodplain and delta form a gently sloping to flat-lying surface upon which is located the Malibu Civic Center. Residential development is primarily concentrated along the beaches and on the coastal bluffs and hillsides within the City of Malibu, which was incorporated in 1991. Much of the undeveloped land in the Malibu Beach Quadrangle is parkland managed by California State Parks, National Park Service, Santa Monica Mountains Conservancy, and Mountains Restoration Trust.

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.

The Malibu Beach Quadrangle is underlain by numerous geological formations that consist of relatively weak strata such as siltstone and shale that have been subject to severe deformation and exist in a deeply dissected terrain. These conditions have produced widespread and abundant landslides with more than 600 being mapped. As a result, earthquake-induced landslide zones cover about 69% of the quadrangle. In the quadrangle liquefaction zones are restricted to canyon areas near the confluence of Liberty and Stokes canyons, the Malibu Creek floodplain and the beach.

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 Malibu Beach 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Malibu Beach 7.5-Minute Quadrangle, Los Angeles County, California

By
Marvin Woods

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 Malibu Beach 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 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 Malibu Beach 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 Malibu Beach Quadrangle consist mainly of low-lying shoreline regions, alluviated

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

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

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

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The onshore part of the Malibu Beach Quadrangle covers approximately 45 square miles in western Los Angeles County. The quadrangle includes parts of two incorporated cities: Malibu, along the coast and Calabasas along the northern edge of the quadrangle. The remainder of the quadrangle is unincorporated Los Angeles County land. Although the City of Malibu stretches for 26 miles along the coastline, it is narrow and typically extends less than a mile inland. Except for a narrow strip of marine-terrace terrain in the western half of the quadrangle and the flatlands near the mouth of Malibu Creek, the remainder of the area lies within the deeply dissected Santa Monica Mountains. The highest elevation within the quadrangle is 2828 feet at Saddle Peak, which is located approximately 2.5 miles north of Carbon Beach.

Malibu Creek and its principal tributaries, Las Virgenes Creek, Stokes Canyon, and Cold Creek, flow in deep canyons and constitute the dominant drainage network in the quadrangle. Although Malibu Creek is typically nearly dry during the summer, its large watershed extends well beyond the Malibu Beach Quadrangle and, thus, often has a large discharge during winter rainstorms. Solstice, Corral, Puerco, Carbon, and Las Flores canyons, all of which are usually dry during the summer months, drain directly into Santa

Monica Bay. A segment of Old Topanga Canyon occurs in the northeastern corner of the quadrangle. The largest flat-lying area within the quadrangle is the coastal floodplain of Malibu Creek, where the City of Malibu Civic Center is located.

Principal travel routes within the Malibu Beach Quadrangle are the Pacific Coast Highway (State Highway 1), Malibu Canyon Road, and Mulholland Highway. The coastal strip within the City of Malibu represents the principal developed (residential) area. Smaller developed areas within the mountains include the unincorporated communities of Monte Nido (near Cold Creek), Malibu Bowl and El Nido (above Corral Canyon), and Topanga Park (Old Topanga Canyon). The entire quadrangle lies within the Santa Monica Mountains National Recreation Area, which includes noncontiguous tracts of public land, the largest of which is Malibu Creek State Park. Other public land areas include Cold Creek Preserve and Solstice Canyon, a former county park that is now managed by the National Park Service.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. To evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the units in the Malibu Beach Quadrangle, we relied on a 1:24,000-scale geologic map published by the U. S. Geological Survey (Yerkes and Campbell, 1980). An earlier, 1:12,000-scale open-file version of this map (Yerkes and others, 1971) was digitized by staff of the Southern California Areal Mapping Project (SCAMP) and incorporated into DMG's GIS. The distribution of Quaternary deposits on this map (summarized on Plate 1.1) was used in combination with other data, discussed below, to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map. Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

Table 1.1 summarizes the Quaternary map units recognized by Yerkes and Campbell (1980) within the Malibu Beach Quadrangle. Omitted from Table 1.1 and also from Plate 1.1 are undivided landslide deposits (Qls) and related debris train deposits (Qdt). Approximately 10 percent of the quadrangle is covered by unconsolidated to moderately consolidated sedimentary deposits of Quaternary age (excluding Qls and Qdt deposits). Within one-half mile of the coast, upper Pleistocene marine and non-marine terrace deposits rest on erosional platforms cut into older bedrock (Qt and Qtm in Table 1.1). Upper Pleistocene stream terrace deposits (Qts) are perched on the flanks of some canyons and valleys. For the most part all of these terrace deposits consist of gravel, sand, and silt that, because of their relatively old age, tend to be compact and dense. Also, because these deposits tend to occur in locally high topographic areas, ground water tends to be relatively deep within them.

The remaining Quaternary deposits are relatively young, considered by Yerkes and Campbell (1980) to be of late Pleistocene to Holocene age. Artificial fill (af), which occurs chiefly along roadways, is, of course, strictly Holocene. The younger Quaternary deposits occur within or immediately adjacent to low-lying valley and canyon floors, or they form beach (Qb) and associated dune (Qd) deposits.

Of particular interest is the prominent coastal embayment filled with floodplain (Qalp) deposits, upon which is situated the City of Malibu Civic Center. This floodplain appears to have received most of its detritus from flooding along Malibu Creek. The canyon of Malibu Creek is, for the most part, occupied by mappable active channel (Qalc) and floodplain (Qalp) deposits, or undifferentiated alluvium (Qal). The same is also true for the other canyons in the quadrangle that drain directly to the ocean, as well as Old Topanga Canyon and the canyons of Las Virgenes Creek and Cold Creek.

Deposits mapped by Yerkes and Campbell (1980) as fan deposits (Qf), considered by them to be related to landslides and consisting "chiefly [of] mudflow deposits, but locally include[ing] some stream deposits (alluvium)," occupy much of Liberty Canyon, Las Virgenes Creek canyon, and lower Stokes Canyon and the unnamed valley into which it empties. Because the source of detritus for these deposits is the widely exposed sandstone and siltstone of the Calabasas Formation, we presume these Qf deposits are also rich in sand and silt. Finally, undifferentiated surficial deposits (Qu), chiefly colluvium and alluvium, occur in small areas in the northwestern quadrant of the quadrangle, notably flanking Mulholland Highway near the western edge of the quadrangle and in Sleeper Canyon.

Structural Geology

The Malibu Beach Quadrangle is within the Santa Monica Mountains, an east-west trending mountain range that has undergone fairly rapid uplift during Quaternary time. Topographic maps of the area depict abundant physiographic evidence for recent uplift. The headwaters of streams such as Malibu Creek and Las Virgenes Creek lie to the north of the crest of the Santa Monica Mountains. This implies that significant uplift has occurred in the area after the flow direction of the streams became well established. Faults across which this uplift has been accommodated include the Malibu Coast Fault, the Las Flores Canyon Thrust Fault, and the Dark Canyon fault, all of which are east-west trending down-to-the-south reverse faults located within the southern Santa Monica Mountains (Yerkes and Campbell, 1980).

Pre-Quaternary bedrock exposed in the Malibu Beach Quadrangle is mostly of Tertiary age. Cretaceous rocks are exposed in the southeastern corner (Yerkes and Campbell, 1980). Upper Pleistocene marine terrace deposits unconformably overlie the youngest Tertiary rocks (upper Miocene). Pliocene and early Pleistocene units are not present within the quadrangle. Yerkes and Campbell (1980) classified the bedrock within the quadrangle into two distinct sequences, separated by the Malibu Coast Fault. All pre-Quaternary rocks are folded and cut by faults.

See the earthquake-induced landslide portion (Section 2) of this report for a detailed discussion of the pre-Quaternary bedrock geology.

Geologic Map Unit	Material Type	Consistency	Age	Liquefaction Susceptibility*
af, artificial fill	variable granular materials	loose to dense	Holocene	very high to low
Qal, alluvium	sand, gravel, & silt	loose	Holocene & Late Pleistocene	very high to high
Qalc, alluvium in active channels	sand, gravel, & silt	loose	Holocene & Late Pleistocene	very high to high
Qalp, alluvium as floodplain deposits	sand, gravel, & silt	loose to firm	Holocene & Late Pleistocene	high to moderate
Qc, colluvium	silt, clay, & sand, locally with abundant rock fragments	loose to firm	Holocene & Late Pleistocene	low
Qb, beach deposits	fine- to medium-grained sand, locally with rounded pebble gravel	loose	Holocene & Late Pleistocene	very high
Qd, dunes	fine- to medium-grained sand	loose	Holocene & Late Pleistocene	high
Qf, fan deposits	mudflow deposits, locally includes stream alluvium; considered a landslide deposit by Yerkes & Campbell	loose to firm	Holocene & Late Pleistocene	moderate
Qu, undifferentiated surficial deposits	chiefly alluvium & colluvium, locally includes cultivated residual soils	loose to firm	Holocene & Late Pleistocene	moderate to low
Qts, stream terrace deposits	gravel, sand, & silt	dense	Late Pleistocene	low to very low
Qt, coastal terrace deposits, non-marine	gravel, sand, silt, & clay	dense to very dense	Late Pleistocene	very low
Qtm, coastal terrace deposits, marine	sand, silty sand, & gravel	dense to very dense	Late Pleistocene	very low

(*when saturated)

Table 1.1. Quaternary map units used in the Malibu Beach Quadrangle by Yerkes and Campbell (1980) and their geotechnical characteristics and liquefaction susceptibility.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of sedimentary deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, 56 borehole logs were collected from the files of the City of Malibu, Los Angeles County Public Works Department, and Caltrans. Data from 56 borehole logs were entered into a DMG geotechnical GIS database (Table 1.1).

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 valleys.

Ground-water conditions were investigated in the Malibu Beach 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 the City of Malibu, Los Angeles County Public Works Department, and Caltrans. The depths to first-encountered unconfined ground water were plotted onto a map of the project area to constrain the estimate of historically shallowest ground water. Water depths from boreholes known to penetrate confined aquifers were not utilized.

We estimated depth to historically high ground water though a process of applying professional judgement, as constrained by basic principles of ground-water and surface-water hydrology and by a conservative bias. For example, in small stream valleys that drain a correspondingly small area, we anticipate that young alluvium deposits will not be saturated except for the several hours or few days during which these streams are in flood during storm events. On the other hand, stream valleys that drain large areas are more

likely to have permanent baseflow within the alluvium even during relatively dry seasons. In many areas where observed ground-water depths were available, we generally simply rounded those depths up to the next higher five-foot increment. We then classified areas of Quaternary deposits into areas of relatively constant historically high ground-water level (Plate 1.2).

The only source of data obtained on ground-water depths within the Malibu Beach Quadrangle is the set of boreholes discussed previously and posted on Plate 1.2. Of the 56 borehole logs acquired, 49 encountered the water table on the date they were drilled. Observed depths to ground water range from 3 feet to 40 feet, over a period of time that ranges from 7/31/1964 to 12/15/1999. Of the seven “dry” boreholes, five had total depths of 40 feet or less. Most ground-water depth observations come from the Malibu Creek coastal floodplain and the beach to the east of there. A few observations came from stream valleys.

Historic high ground-water depths in the Malibu Creek coastal floodplain are estimated to range from approximately five feet in the center to about 10 feet along the flanks. Water depth increases to greater than 40 feet at the north end of the valley, behind the Serra Retreat. Ground-water depth along the beach is estimated to be no greater than 5 feet. Ground-water depth in the small coastal stream canyons is estimated to be approximately 10 feet, with depth increasing in their upper reaches. In the stream valleys within the northern half of the quadrangle where data are scarce, we estimate that historic high ground-water depths are generally approximately 10 to15 feet and increase in their upper reaches and small side canyons to depths generally in excess of the thickness of alluvium.

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. 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.

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 relations between susceptibility and geologic map unit are summarized in 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 Malibu Beach Quadrangle, PGAs of 0.45 g to 0.57 g, resulting from earthquakes of magnitude 6.6 to 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 56 geotechnical borehole logs reviewed in this study (Plate 1.2), 43 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on

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

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the 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 Malibu Beach Quadrangle is summarized below.

Areas of Past Liquefaction

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

Artificial Fills

In the Malibu Beach Quadrangle, most artificial fill areas large enough to show at the scale of mapping (1:12,000) consist of engineered fill for roadways. Because these fills are considered to be properly engineered, zoning for liquefaction in such areas depends not on the fill itself, but rather on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and sufficiently detailed lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data were evaluated for zoning based on the liquefaction potential determined by the Seed-Idriss Simplified Procedure. In Holocene alluvial deposits that cover much of the coastal flat area surrounding the Malibu Civic Center (Malibu Creek floodplain), in beach deposits east of there, and in the valley at the mouth of Stokes Canyon (vicinity of Soka University), most of the borehole logs that were analyzed using the Seed-Idriss Simplified Procedure contain sediment layers that liquefy under the expected earthquake loading. Those areas containing saturated, potentially liquefiable material at depths of up to 40 feet are included in the zone.

Areas with Insufficient Existing Geotechnical Data

Younger alluvium deposited in stream channel areas generally lacks 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 Malibu Beach 7.5-Minute Quadrangle, Los Angeles 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) 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 Malibu Beach 7.5-minute Quadrangle. This section, along with Section 1 (addressing liquefaction), and Section 3 (addressing earthquake shaking), form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet web page: 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 Malibu Beach 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 Malibu Beach 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 Malibu Beach 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 onshore portion of the Malibu Beach Quadrangle covers an area of approximately 45 square miles in southwestern Los Angeles County and includes parts of the cities of Malibu and Calabasas and the unincorporated communities of Malibu Lake, Monte Nido, Malibu Bowl, and El Nido. The Malibu Civic Center is located in the south-central part of the map area, about 25 miles west of the Los Angeles Civic Center. Santa Monica Bay occupies the southern quarter of the quadrangle.

The Malibu Beach Quadrangle is dominated by steep and rugged terrain of the central Santa Monica Mountains. Local elevations range from sea level to 2828 feet at Saddle Peak in the east-central part of the map area. The main crest of the mountain range trends generally east-west across the center of the quadrangle, although the actual drainage divide is located north of the quadrangle boundary in the Simi Hills. Numerous south-trending broad-crested ridges and canyons with narrow channels extend from the range crest to Santa Monica Bay. The east-west-trending Malibu Coast Fault Zone forms the southern boundary of the mainland portion of the mountain range.

The most important drainage system in the quadrangle includes Malibu Creek and its tributaries, Cold Creek, Las Virgenes Creek, Stokes Canyon, and Liberty Canyon, which drain a large area south of the Simi Hills and flow via Triunfo Canyon - Malibu Canyon through the entire mountain range to Santa Monica Bay. The larger canyons in this drainage area are wide and flat-bottomed and form gently sloping to flat-lying terrain near their confluence with Malibu Creek in the northwestern quarter of the map. Malibu Creek flows southeast and then south in Triunfo Canyon -Malibu Canyon through a deeply incised channel near the center of the quadrangle. The Malibu Creek floodplain and delta form a gently sloping to flat-lying surface underlying the Malibu Civic Center near the coast.

The coastline west of Malibu Creek is characterized by broad, gently sloping, relatively continuous terrace surfaces that terminate in moderately steep bluffs above a narrow beach. East of Malibu Creek, the coastline consists of a moderately steep to steep mountain front with a few discontinuous terrace surfaces and a narrow beach.

Development in the Malibu Beach Quadrangle began in the mid- to late 1920’s with the construction of a movie colony and large estates and increased in the early 1930’s following construction of the original coast highway (Roosevelt Highway) and subdivision of Rindge Ranch. Residential development is primarily concentrated along the beaches and on the coastal bluffs and hillsides within the City of Malibu, which was incorporated in 1991. Small residential communities are also present in the unincorporated county area. Other development in the area includes the campuses of Pepperdine University and Soka University, religious retreats and camps, a juvenile detention camp, and minor light commercial and agricultural activity. A substantial portion of the undeveloped land in the Malibu Beach Quadrangle is parkland managed by California State Parks, National Park Service, Santa Monica Mountains Conservancy, and Mountains Restoration Trust.

Major transportation routes in the area include State Highway 1 (Pacific Coast Highway), which follows the east-trending coastline, and U.S. Highway 101, which parallels Highway 1 and is located just north of the quadrangle. Las Virgenes/Malibu Canyon Road is the main north-south artery between Highway 101 and Highway 1. Access within the quadrangle is provided by county roads and private roads in developed areas and by fire roads and trails in undeveloped land.

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 Malibu Beach 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

The primary source of bedrock geologic mapping used in this slope stability evaluation was obtained from the U.S. Geological Survey (Yerkes and Campbell, 1980) and then digitized by Southern California Areal Mapping Project (SCAMP) staff. This source was also used for the surficial geologic mapping for the Malibu Beach Quadrangle because the quadrangle contains relatively few areas of young surficial deposits. Surficial geology is discussed in detail in Section 1 of this 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. Bedrock geology was modified in some areas to reflect more recent mapping (Weber, 1984; Dibblee, 1993; Fellbaum and Fritsche, 1993). Air-photo interpretation and field reconnaissance were performed to assist in adjusting contacts between bedrock and surficial geologic units and to review lithology of geologic units and geologic structure.

Yerkes and Campbell (1979) revised the stratigraphic nomenclature of the central Santa Monica Mountains based on detailed mapping of the unincorporated Los Angeles County portions of the Santa Monica Mountains (Yerkes and others, 1971). They concluded that the Malibu Coast Fault represents the boundary between two different geologic terranes. On the north side of the fault, a basement of Santa Monica Slate and granodiorite is overlain by Upper Cretaceous through upper Miocene deposits and, on the south, a basement of Catalina Schist is overlain by Miocene and younger deposits.

The oldest geologic unit mapped in the Malibu Beach Quadrangle is the Upper Cretaceous Tuna Canyon Formation (Kt), which crops out in Las Flores and Carbon canyons in the southeastern part of the map area. It consists of massive, coarse-grained,

closely jointed and fractured marine sandstone with thin-bedded siltstone representing deposition in a submarine delta-fan complex. The Tuna Canyon Formation is overlain by lower Paleocene and Eocene very fine- to medium-grained, semi-friable to hard, thick-bedded marine sandstone, resistant pebble conglomerate, and conchoidally fractured siltstone of the Coal Canyon Formation (Tcc). The middle Eocene Llajas Formation (Tll) disconformably(?) overlies the Coal Canyon Formation and is composed of very fine-grained, semi-friable marine sandstone, siltstone, pebble conglomerate, and mudstone. The only exposure of the Llajas Formation shown on the map is in Solstice Canyon on the western edge. However, some of the strata mapped as Coal Canyon Formation in Carbon Canyon in the southeast may be equivalent to the basal part of the Llajas Formation (Yerkes and Campbell, 1979).

Overlying the Upper Cretaceous through middle Eocene strata is a sequence of laterally gradational and interfingering nonmarine, transitional, and marine clastic sedimentary rocks assigned to the Sespe, Vaqueros, and Topanga Canyon formations by Yerkes and Campbell (1979). This sequence, which forms a broad arc from the northeast corner to the south-central part of the quadrangle, records deposition during several shoreline transgressions and regressions in late Oligocene to early Tertiary time (Fritsche, 1993). Forming the base of this sequence is the upper Eocene to lower Miocene Sespe Formation (Ts), which consists of alluvial-fan and floodplain deposits of pebble-cobble conglomerate and massive to thick-bedded sandstone interbedded with thin-bedded siltstone and mudstone. The Piuma Member (Tsp) of the Sespe Formation is characterized by thinner beds, finer grained sandstone, absence of pebble-cobble conglomerate, and more interbedded lacustrine or lagoonal siltstone. The Piuma Member intertongues with the upper Oligocene to lower Miocene Vaqueros Formation (Tv), which consists of deltaic and marine strandline deposits of medium- to coarse-grained, thin- to thick-bedded biotitic sandstone interbedded with siltstone and mudstone, and minor pebbly sandstone.

East of Malibu Canyon, the Sespe Formation and Piuma Member are overlain by three intertonguing marine and nonmarine members of the lower to middle Miocene Topanga Canyon Formation, which represents the lowest division of the Topanga Group (Yerkes and Campbell, 1979). The Saddle Peak Member (Tts) of the Topanga Canyon Formation conformably overlies the Piuma Member of the Sespe Formation and consists of thick-bedded to massive, medium- to coarse-grained resistant sandstone, pebbly sandstone, and sandy siltstone deposited in a marginal marine environment. The Fernwood Member (Ttf) conformably overlies and tongues into the Saddle Peak Member and is composed of fluvial and deltaic ledge-forming sandstone, abundant mudstone, and minor interbedded altered tuff and limestone. The Cold Creek Member (Ttc) overlies and intertongues with the Fernwood Member and consists of marine sandstone, silty sandstone, and minor pebbly sandstone. West of Malibu Canyon, the Vaqueros Formation is conformably overlain by the undivided Topanga Canyon Formation (Tt), which is composed of alternating thick and thin sequences of medium- to coarse-grained silty biotitic sandstone, sandy siltstone, and pebbly sandstone.

Overlying the intertonguing marine and nonmarine upper Oligocene to lower Miocene strata are the middle Miocene Conejo Volcanics and Calabasas Formation, which

constitute the middle and upper parts of the Topanga Group. The Conejo Volcanics were erupted into a structurally controlled marine basin from an ancient oceanic volcano complex that eventually emerged to form a land mass as lava flows accumulated and filled the basin (Williams, 1977). In the north half of the quadrangle, the Conejo Volcanics consists of a basal volcanic sandstone with shaly siltstone (Tcos), basaltic pillow breccia, aquagene tuff, and pillow lava (Tcop), basaltic and andesitic flows (Tcof), and andesitic and basaltic breccia (Tcob). In the southwest, three tongues of Conejo Volcanics are interbedded with the Calabasas Formation. The Ramera Canyon Tongue (Tcor) consists of andesitic and basaltic breccia, mudflow breccia and minor volcanic sandstone, the Solstice Canyon Tongue (Tcosc) is composed of basaltic and andesitic flows, breccia, tuff, and volcanic sandstone, and the Malibu Bowl Tongue (Tcom) includes basaltic and andesitic flows and flow breccia. Intrusive rocks (Ti) consist of basaltic and diabasic dikes and sills, which intrude both the older sedimentary rock units and other units within the Conejo Volcanics.

The Calabasas Formation is widely exposed in the north-central and southwestern parts of the quadrangle and consists of a sequence of marine sandstone, siltstone, and sedimentary breccia that intertongues with and overlies the Conejo Volcanics. Yerkes and Campbell (1979) divided the formation into several members. The Dry Canyon Sandstone Member (Tcd), which is composed of sandstone and interbedded siltstone, and the Newell Sandstone Member (Tcn), which consists of sandstone and shaly siltstone with dolomitic concretions, are exposed in the southwest part of the map area and represent turbidite deposition in a submarine fan environment. The Mesa Peak Breccia Member (Tcmp) is exposed in the west-central part of the area and is a sedimentary breccia and conglomerate consisting of angular fragments of basalt and andesite in a matrix of coarse-grained sandstone. The Stokes Canyon Breccia Member (Tcsc) is exposed at the northern edge of the quadrangle and consists of a sedimentary breccia and conglomerate containing clasts of fossiliferous sandstone. Undivided Calabasas Formation (Tc), consisting of sandstone and interbedded siltstone, is exposed in the southeast corner of the map area.

The upper Miocene Modelo Formation (Tmo), which is exposed in the northern part of the quadrangle, unconformably overlies the Calabasas Formation. In the map area, the Modelo Formation is composed of interbedded sandstone, siltstone, shale, and sedimentary breccia and conglomerate representing deposition in a submarine fan environment.

The sequence of bedrock units south of the Malibu Coast Fault, which Yerkes and Campbell (1979) mapped as a separate geologic terrane, consists of the lower to middle Miocene Trancas Formation and Zuma Volcanics and the middle to upper Miocene Monterey Formation. The Trancas Formation (Tr) is exposed in fault slices in the southwest and south-central part of the map area and is composed of marine sandstone, mudstone, silty shale, and claystone. In the Point Dume Quadrangle to the west it contains a distinctive sedimentary breccia unit. The Zuma Volcanics (Tz) crops out in the southwest corner of the area and consists primarily of mudflow breccia. The Monterey Formation (Tm) intertongues with and overlies the Trancas Formation and

Zuma Volcanics and is composed of marine clay shale, laminated to platy siltstone, and interbedded altered vitric tuffs and fine- to medium-grained sandstone.

The Monterey Formation and older bedrock units are unconformably overlain by upper Pleistocene marine and nonmarine coastal terrace deposits (Qtm and Qt) in the southern part of the quadrangle. Scattered remnants of upper Pleistocene stream-terrace deposits (Qts) are present along the flanks of canyons and valleys throughout the map area.

Other Quaternary surficial deposits in the Malibu Beach Quadrangle consist of upper Pleistocene to Holocene undifferentiated surficial deposits (Qu), fan deposits (Qf), landslide deposits (Qls), dunes (Qd), beach deposits (Qb), colluvium (Qc), undifferentiated alluvial deposits (Qal), alluvial floodplain deposits (Qalp), alluvium in active channels (Qalc), and artificial fill (af). Landslides and landslide deposits are not shown on the bedrock/Quaternary geology map, but are included on a separate landslide inventory map (Plate 2.1). Additional discussion of Quaternary units in the Malibu Beach Quadrangle can be found in Section 1.

Structural Geology

Rocks in the Malibu Beach Quadrangle have been complexly folded and faulted during several periods of deformation. The resulting structural complexity is further complicated by the presence of igneous intrusives injected along the faults and lateral facies changes in many of the sedimentary rock units, making mapping and interpretation of the structural geology in this area both difficult and controversial (Campbell and others, 1966).

Campbell and others (1966) postulate that the geologic structure of the central Santa Monica Mountains primarily consists of an autochthon (?) of Cretaceous and Paleocene sedimentary rock and older basement rock overlain by three superimposed detachment thrust sheets that have been folded, faulted, and intruded by mafic to intermediate igneous rock. These detachment thrust sheets, named Tuna Canyon, Zuma, and Malibu Bowl in ascending order, were emplaced by gravity tectonics from north to south along the Tuna Canyon, Zuma, and Malibu Bowl faults in latest middle Miocene time.

The Tuna Canyon thrust sheet contains rocks of the Tuna Canyon and Coal Canyon formations and is inferred (Yerkes and Campbell, 1980) to be exposed locally in a tectonic window southeast of Saddle Peak. The Zuma thrust sheet is widely exposed across the quadrangle and contains rocks of the Sespe and Vaqueros formations and the Topanga Group. The Malibu Bowl thrust sheet consists of rocks belonging to the Topanga Group and is exposed in the southwest part of the map area. The thrust-sheet contacts, seen only in rare exposures, are parallel or nearly parallel to bedding and are characterized by zones of brecciation or igneous intrusion.

East-west-trending anticlinal folding in the southern part of the map area accompanied the emplacement of the thrust sheets and continued afterwards. According to Campbell and others (1966), the north and south branches of the Las Flores thrust faults represent break thrusts associated with the late stages of folding. Structure in the northern half of

the quadrangle is dominated by northwest-trending folds disrupted by several north- and northwest-trending high-angle dip-slip faults.

The gravity detachment fault hypothesis has not been accepted by all geologists (Truex, 1976, 1977; Dibblee 1993; and Dibblee and Ehrenspeck, 1993). For example, Dibblee and Ehrenspeck (1993) noted that, whereas there is some evidence for thrust faulting in the area, they believe that some of the detachment fault contacts mapped by Campbell and others (1966) and Yerkes and Campbell (1980) may instead represent buttress angular unconformities.

The structures described above are truncated on the south by the Malibu Coast Fault Zone, an east-west-trending, north-dipping reverse fault zone that has also had significant left-lateral displacement (Treiman, 1994). The Malibu Coast Fault Zone is part of a larger left-lateral, reverse-oblique fault system that forms the southern boundary of the Transverse Ranges Province. In the Malibu Beach Quadrangle, the fault zone is as much as one-half-mile wide along the coast and is characterized by discontinuous fault splays and branches with associated shearing and brecciation.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Malibu Beach Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published and unpublished landslide mapping. The landslide maps and reports that were reviewed during preparation of the landslide inventory are identified in the References section with an asterisk (*). Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map many 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 abundant in the southern and eastern parts of the Malibu Beach Quadrangle where the sedimentary rocks have been deformed by several episodes of folding and faulting. Landslides in the area range from minor surficial failures resulting from soil and rock creep, rock fall, soil and debris slumps, and debris flows to large rotational and translation landslides, some of which are relatively old and deeply eroded. Landslide identification in the Malibu Beach Quadrangle is difficult due to the structural complexity of the area and the presence of coastal terraces that can be mistaken for landslide morphology. The areal distribution of landslides identified in the map area is shown on Plate 2.1

Rock falls and shallow rockslides are common on the steep mountain front along the Pacific Coast Highway. Rock falls, rock slides, and debris avalanches involving jointed and fractured bedrock of the Sespe and Vaqueros formations and volcanic breccias occur on the steeper slopes within the mountain range. Debris flows are common on moderate

to steep slopes. Individual debris-flow tracks and deposits were not mapped for this study because of the inaccuracies associated with mapping such small features at 1:24,000 scale.

Rotational rock and debris slides are the most common type of slide in the area. Slides involving bedrock, terrace deposits, and artificial fill occur along the coastal terrace bluffs above Corral Beach, Puerco Beach, and Amarillo Beach. Rotational and translational rock and debris slides are also common along the south-trending canyons south of the range crest, especially in the vicinity of faults. Many of the recently active slides occur within older, previously identified landslides.

Several large ancient landslide complexes have been mapped in the Malibu Beach Quadrangle. One of the largest is in the vicinity of Stunts Ranch in the northeast part of the map area. It consists of translational and rotational slides involving Sespe and Topanga Canyon formations that dip moderately to the north and northwest in the general direction of movement. Many of the apparently intact blocks within the landslide, which have been previously mapped as bedrock, may instead represent blocks that slid as coherent units within the larger slide. Several smaller, recently active slides occur within the complex. Other large ancient landslides have been mapped in the southern and eastern parts of the quadrangle. The boundaries of these landslides are often difficult to delineate because the slides have been extensively modified by erosion.

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 sources for the rock shear-strength measurements area geotechnical reports prepared by consultants on file with city and county planning and permitting departments. For the Malibu Beach Quadrangle shear strength data were obtained from the City of Malibu and Los Angeles County (Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

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 unit 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. Within the Malibu Beach Quadrangle, no shear tests were available for Qc, Qd, Qal. Qalc. Qalp, Qu, Tclc, Tcmp, Tcn, Tcob, Tcof, Tcof?, Tcom, Tcsc, Tll and Tmo. Additional shear tests for af, Qa, Qls, Qtm, Tcc, Tcos, Ti, Tm and Tv from the Point Dume Quadrangle were used. For Qc, Qd, Qal. Qalc. Qalp, Qu, Tclc, Tcmp, Tcn, Tcob, Tcof, Tcof?, Tcom, Tcsc, Tll and Tmo were added to existing groups on the basis of lithologic and stratigraphic similarities. A geologic material strength map was made

based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

One geologic map unit, the Vaqueros Formation (Tv) 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 due to a lack of lateral support.

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

The Vaqueros Formation, which contains interbedded sandstone, siltstone and 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 strengths were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). Assigning the lower, fine-grained shear strength value to areas where adverse bedding was identified modified the geologic material strength map. The favorable and adverse bedding shear strength parameters for the Vaqueros Formation are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used. Within the Malibu Beach Quadrangle, 14

direct shear tests of landslide slip surface materials were obtained, and the results are summarized in Table 2.1.

MALIBU BEACH 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	Kt	14	39/40	40/41	367/306		40
	Tcor	4	40				
	Ttf	12	43				
GROUP 2	Tcc	21	37	35/36	592/456	Tcob	35
	Tco	40	34/36			Tcof	
	Ti	12	34/36			Tcof?	
	Tt	2	36				
GROUP 3	Qs	2	34	33	517/400	Tclc	33
	Tcop	5	33			Tcmp	
	Tcos	8	34			Tcom	
	Tcosc	1	35			Tcsc	
	Tm	58	33			Tll	
	Tsp	16	34				
	Tv(fbc)	24	34				
GROUP 4	Qb	3	30/32	31	461/400	Qc	31
	Qf	6	32			Qd	
	Qt	10	31/30			Qal	
	Qts	7	33/30			Qalc	
	Tc	93	32			Qalp	
	Ts	19	29/31			Qu	
	Ttc	4	28/30			Tcn	
	Tv(abc)	17	31/33			Tmo	
	Tz	13	32/31				
GROUP 5	af	24	28	28/27	424/360		27
	Qa	4	31/27				
	Qtm	24	27/28				
	Tcd	26	29/28				
	Tr	41	27/26				
	Tts	1	25				
GROUP 6	Qls	14	17/16	17/16	410/395		16
	fbc = Favorable bedding conditions						
	abc = Adverse bedding conditions						
	Formations for strength groups from Yerkes and Campbell, 1980						

Table 2.1. Summary of the Shear Strength Statistics for the Malibu Beach Quadrangle.

SHEAR STRENGTH GROUPS FOR THE MALIBU BEACH 7.5-MINUTE QUADRANGLE					
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**	**GROUP 6**
Kt	Tcc	Qs	Qb	af	Qls
Tcor	Tco	Tclc	Qc	Qa	
Ttf	Tcob	Tcmp	Qd	Qtm	
	Tcof	Tcom	Qal	Tcd	
	Tcof?	Tcop	Qalc	Tr	
	Ti	Tcos	Qalp	Tts	
	Tt	Tcosc	Qt		
		Tcsc	Qu		
		Tll	Qts		
		Tm	Tc		
		Tsp	Tcn		
		Tv(fbc)	Tmo		
			Ts		
			Ttc		
fbc = favorable bedding conditions			Tv(abc)		
abc = adverse bedding conditions			Tz		

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

Modal Magnitude:	6.8 to 7.3
Modal Distance:	2.5 to 14.4 km
PGA:	0.42g to 0.53g

The strong-motion record selected for the slope stability analysis in the Malibu Beach 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 were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.142, 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 Malibu Beach Quadrangle.

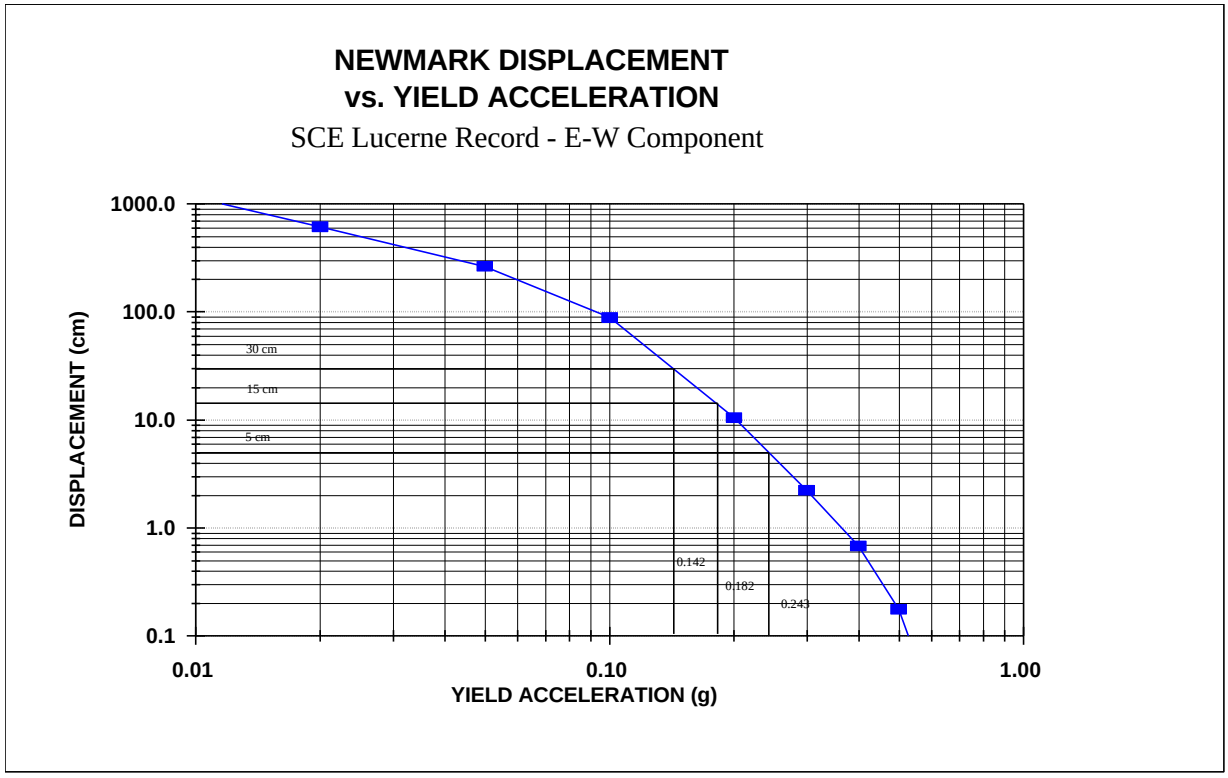

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1992 Landers Earthquake SCE Lucerne Record.

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 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 0.142g, 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 0.142g and 0.182g, 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.

MALIBU BEACH QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)												
		I	II	III	IV	V	VI	VII	VII	IX	X	XI	XII	XIII
		0-10	10-15	15-26	26-32	32-36	36-40	40-46	46-51	51-55	55-58	58-62	62-67	>67
1	**39**	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	**35**	VL	VL	VL	VL	VL	VL	L	L	M	H	H	H	H
3	**33**	VL	VL	VL	VL	VL	VL	L	M	H	H	H	H	H
4	**31**	VL	VL	VL	VL	L	L	M	H	H	H	H	H	H
5	**27**	VL	VL	VL	L	M	H	H	H	H	H	H	H	H
6	**16**	L	M	H	H	H	H	H	H	H	H	H	H	H

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

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

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

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

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

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

Existing Landslides

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

Geologic and Geotechnical Analysis

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

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

1. Geologic Strength Group 6 is included for all slope gradient categories. (Note: Geologic Strength Group 6 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 5 is included for all slopes steeper than 26 percent.

3. Geologic Strength Group 4 is included for all slopes steeper than 32 percent.

4. Geologic Strength Group 3 is included for all slopes steeper than 40 percent.

5. Geologic Strength Group 2 is included for all slopes greater than 40 percent.

6. Geologic Strength Group 1 is included for all slopes greater than 58 percent.

This results in roughly 69% of the land in the quadrangle lying within the landslide hazard zone.

Landslides attributed to the Northridge earthquake covered approximately 139 acres of land in the quadrangle, which is ½ of 1 percent of the total area covered by the map. Of the area covered by these Northridge earthquake landslides, 95% falls within the area of the hazard zone based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Malibu	**395**
County of Los Angeles	**36**
Point Dume Quadrangle	**93**
Robertson, M. S. thesis	**7**
Total Number of Tests	**531**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Malibu Beach 7.5-Minute Quadrangle, Los Angeles 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.

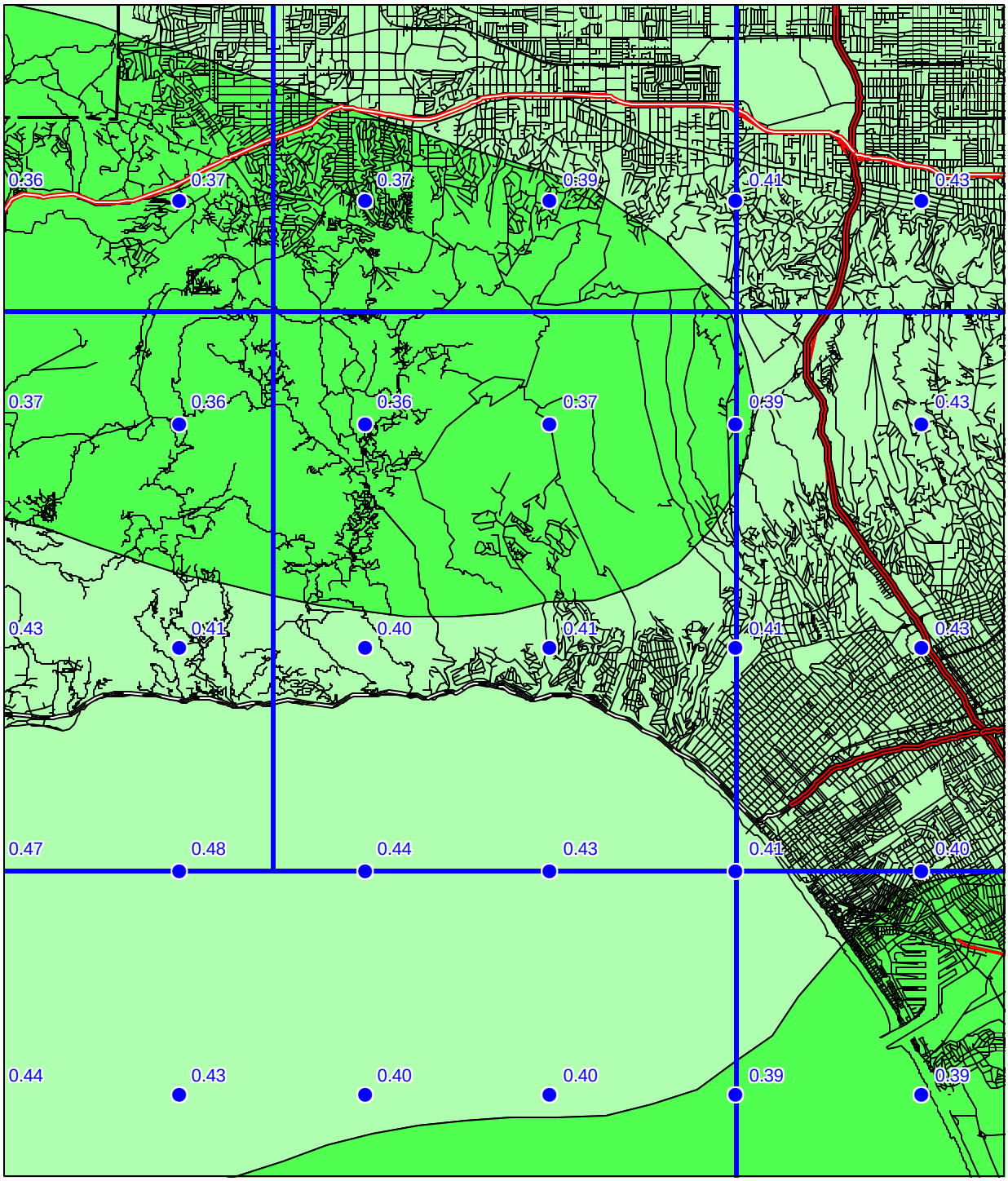
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

MALIBU BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

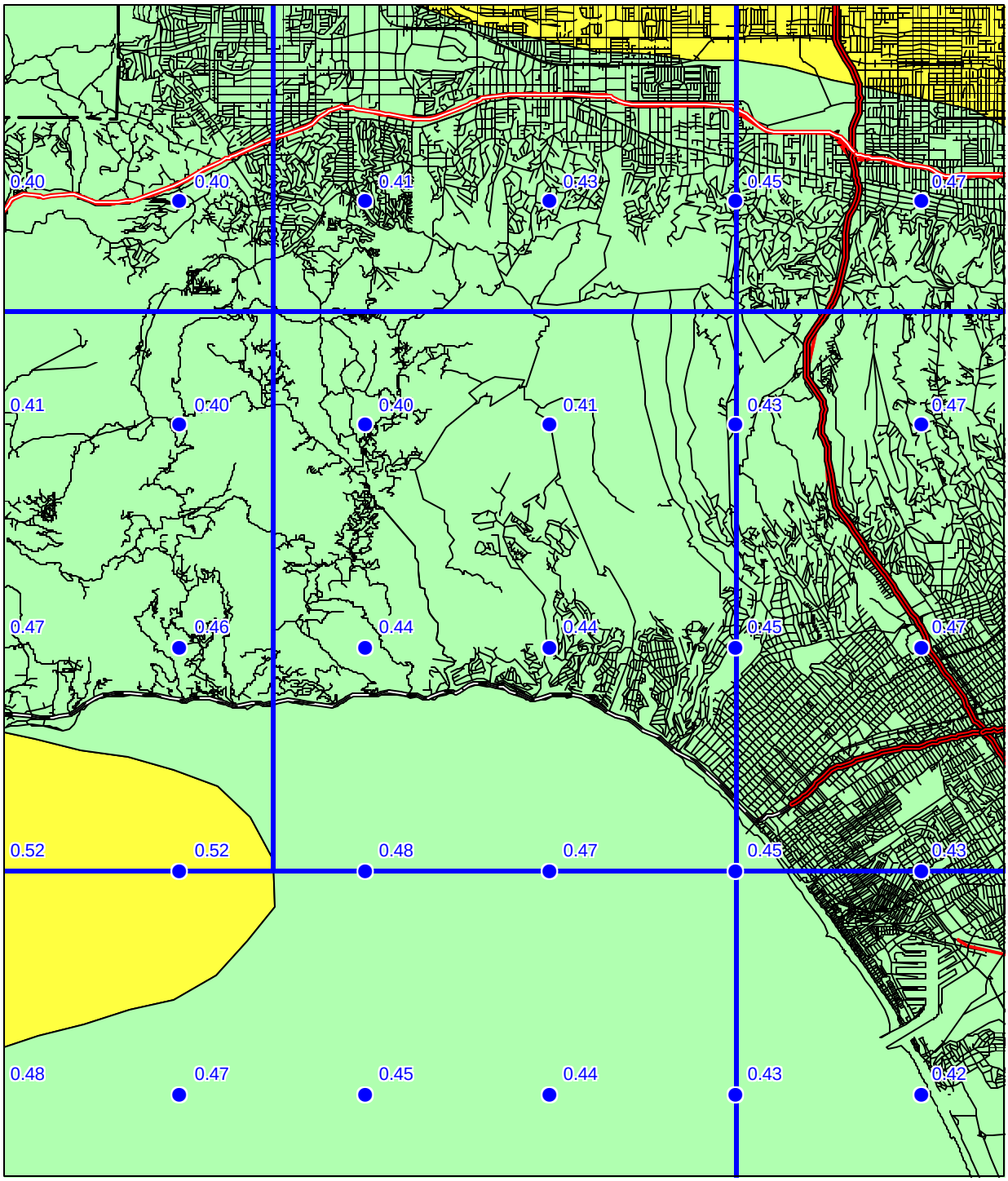
Figure 3.1

MALIBU BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



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Department of Conservation
Division of Mines and Geology

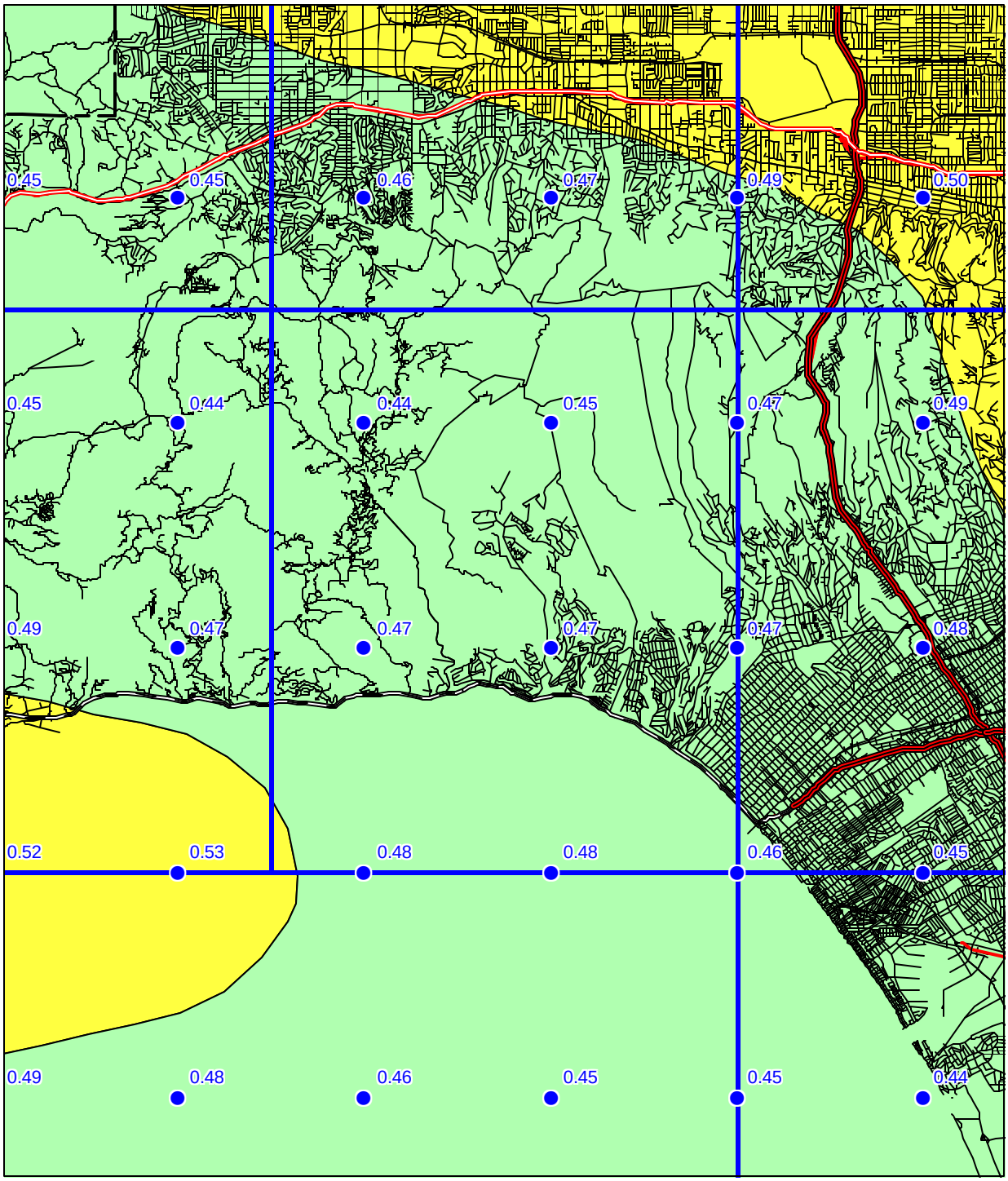
Figure 3.2

MALIBU BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation

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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.

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

MALIBU BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

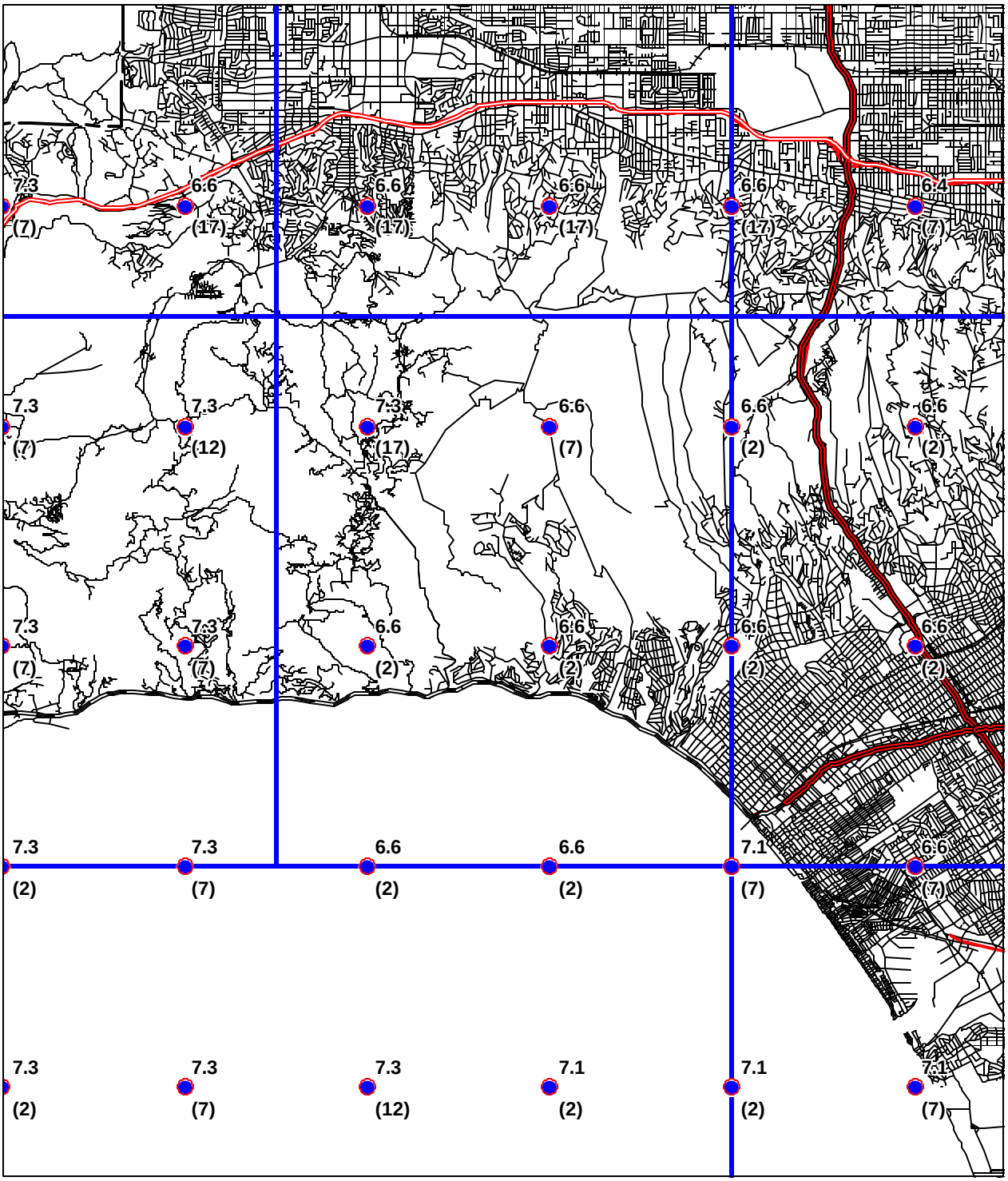
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology
Figure 3.4

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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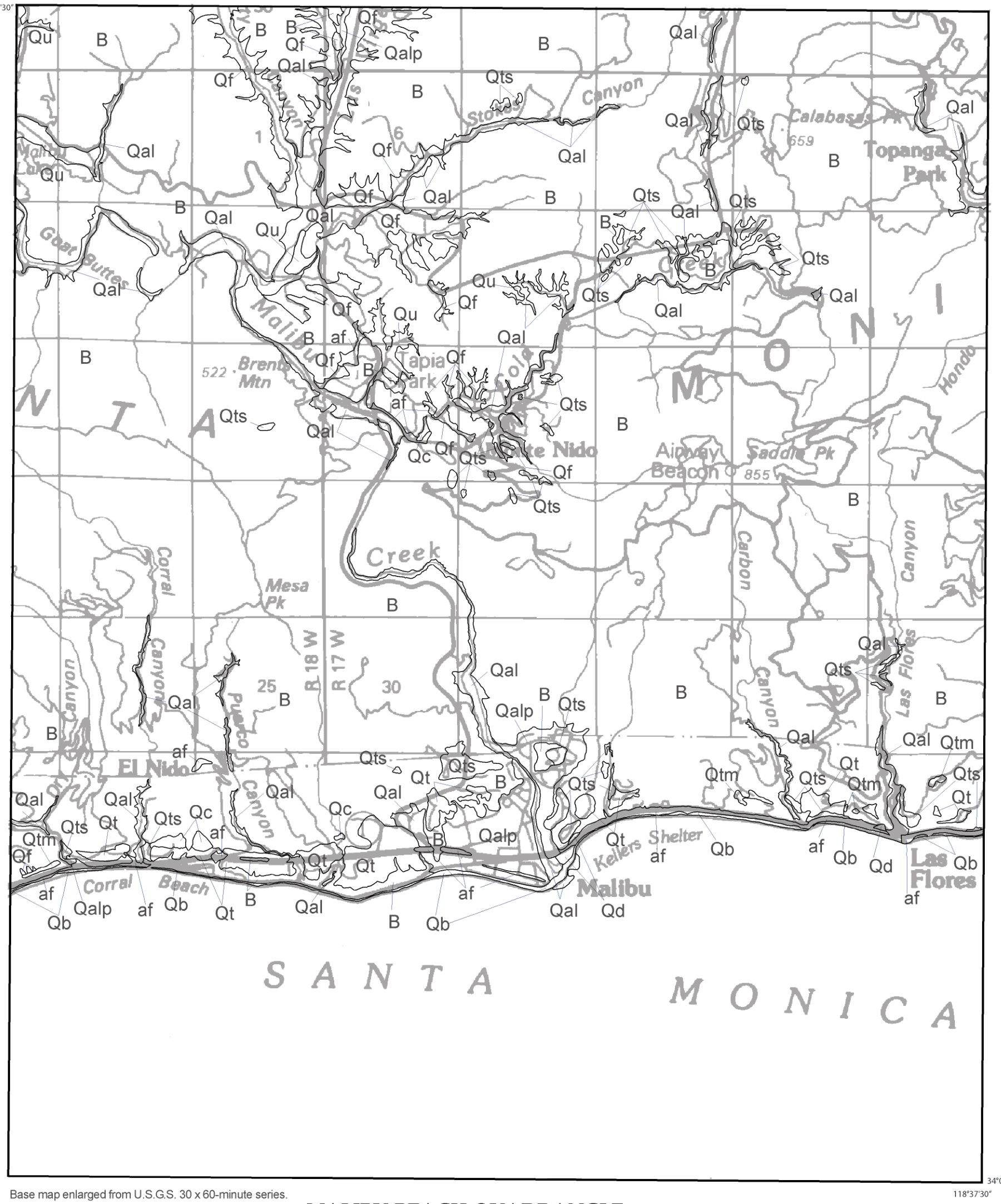


Base map enlarged from U.S.G.S. 30 x 60-minute series.

MALIBU BEACH QUADRANGLE

SCALE

0 1 2 MILES

2000 0 2000 4000 6000 FEET

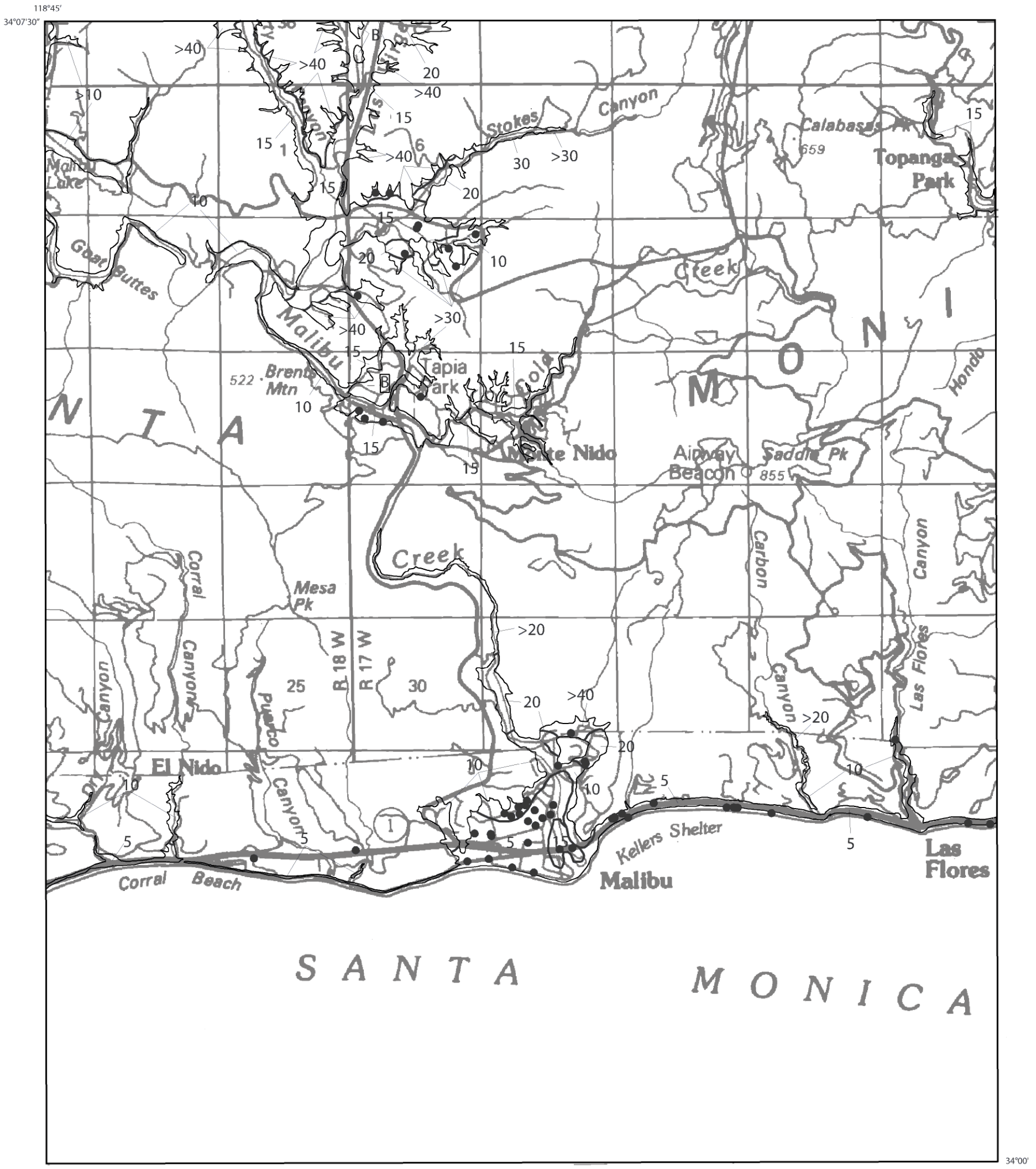
0 1 2 KILOMETERS

N

Lithologic contact

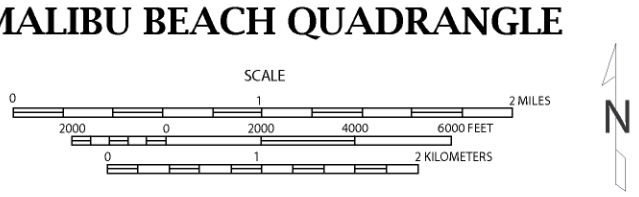
B = Pre-Quarternary bedrock.
See "Bedrock and Surficial Geology in Section 1 of the report for descriptions of the units.

Plate 1.1 Simplified Quaternary Geologic Map of the Malibu Beach 7.5-minute Quadrangle (modified from Yerkes and Campbell, 1980).



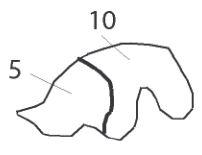
Base map enlarged from U.S.G.S. 30 x 60-minute series

MALIBU BEACH QUADRANGLE



● Borehole Site

B = Pre-Quaternary bedrock



Alluviated valley and areas of approximately constant groundwater depth (in feet)

Plate 1.2 Depth to historically high ground water and borehole locations, Malibu Beach 7.5-minute Quadrangle, California.

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

MALIBU BEACH QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

N

Landslide Inventory

Shear Test Sample Locations

Plate 2.1 Landslide inventory, shear test sample locations, Malibu Beach 7.5-minute Quadrangle.