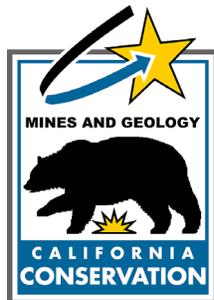


**SEISMIC HAZARD ZONE REPORT FOR THE
REDONDO BEACH 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

1998



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Division of Mines and Geology

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SEISMIC HAZARD ZONE REPORT 031

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REDONDO BEACH 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

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CONTENTS

EXECUTIVE SUMMARY	viii
INTRODUCTION	1
SECTION 1 LIQUEFACTION EVALUATION REPORT Liquefaction Zones in the Redondo 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	6
GROUND-WATER CONDITIONS	8
PART II.....	9
LIQUEFACTION POTENTIAL	9
LIQUEFACTION SUSCEPTIBILITY.....	9
LIQUEFACTION OPPORTUNITY	11
LIQUEFACTION ZONES	12
ACKNOWLEDGMENTS	14
REFERENCES	14

SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT Earthquake-Induced Landslide Zones in the Redondo Beach 7.5-Minute Quadrangle, Los Angeles County, California	17
PURPOSE.....	17
BACKGROUND	18
METHODS SUMMARY.....	18
SCOPE AND LIMITATIONS.....	19
PART I.....	19
PHYSIOGRAPHY.....	19
GEOLOGY	20
ENGINEERING GEOLOGY	24
PART II.....	27
EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL.....	27
EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE	30
ACKNOWLEDGMENTS	32
REFERENCES	32
AIR PHOTOS.....	35
APPENDIX A Source of Rock Strength Data.....	35
SECTION 3 GROUND SHAKING EVALUATION REPORT Potential Ground Shaking in the Redondo Beach 7.5-Minute Quadrangle, Los Angeles County, California.....	37
PURPOSE.....	37
EARTHQUAKE HAZARD MODEL	38
APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS	42
USE AND LIMITATIONS.....	45
REFERENCES	46

ILLUSTRATIONS

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake.	28
Figure 3.1. Redondo Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Firm rock conditions.	39
Figure 3.2. Redondo Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Soft rock conditions.	40
Figure 3.3. Redondo Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration (g)—Alluvium conditions.	41
Figure 3.4. Redondo Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years peak ground acceleration—Predominant earthquake.	43
Figure 3.5. Redondo Beach 7.5-Minute Quadrangle and portions of adjacent quadrangles, 10% exceedance in 50 years magnitude-weighted pseudo-peak acceleration for alluvium - Liquefaction opportunity	44
Table 1.1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.	8
Table 2.1. Summary of the Shear Strength Statistics for the Redondo Beach Quadrangle.	25
Table 2.2. Summary of the Shear Strength Groups for the Redondo Beach Quadrangle.	26
Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Redondo Beach Quadrangle.	30
Plate 1.1. Quaternary Geologic Map of the Redondo Beach Quadrangle.	48
Plate 1.2. Historically Highest Ground Water Contours and Borehole Log Data Locations, Redondo Beach Quadrangle.	49
Plate 2.1. Landslide Inventory, Shear Test Sample Locations, and Areas of Significant Grading, Redondo Beach Quadrangle.	50

EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Redondo 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 only approximately 13 square miles at a scale of 1 inch = 2,000 feet because most of the quadrangle is Pacific Ocean.

The Redondo Beach Quadrangle includes the shoreline of Santa Monica Bay from Redondo Beach southward to the Palos Verdes Peninsula. The low-lying topography in the northeastern corner includes parts of the coastal cities of Hermosa Beach, Manhattan Beach, Redondo Beach and Torrance. The southeastern corner of the map includes parts of the cities of Palos Verdes Estates, Rancho Palos Verdes, and Rolling Hills Estates. Coastal cities were developed on active and inactive coastal sand dunes. The elevated Palos Verdes Peninsula is characterized by a series of stair step-like Pleistocene wave-cut marine terraces. Elevations range from sea level to about 1200 feet near the crest of the Palos Verdes Hills. Access along the northern coastal section of the quadrangle is provided by Pacific Coast Highway (State Highway 1). Palos Verdes Drive and Hawthorne Boulevard provide access on the Palos Verdes Peninsula.

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

In the Redondo Beach Quadrangle the liquefaction zone is restricted to the beach and areas of artificial fill associated with the King Harbor development in Redondo Beach. The steep sea cliffs, canyon walls, edges of marine terraces and existing large landslide deposits in the Palos Verdes Hills constitute most of the earthquake-induced landslide zone. Approximately 10 percent of the land (1,040 acres) in the quadrangle lies within the earthquake-induced landslide hazard zone.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone <http://www.conservation.ca.gov/CGS/index.htm>

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

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

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

INTRODUCTION

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

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

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

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

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

SECTION 1

LIQUEFACTION EVALUATION REPORT

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

By
Richard B. Greenwood

**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 Redondo 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.conservation.ca.gov/CGS/index.htm>

BACKGROUND

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

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

floodplains. 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 portion of the Redondo Beach Quadrangle covers an area of about 13 square miles in southwestern Los Angeles County. The low-lying topography in the northeastern corner includes parts of the coastal cities of Hermosa Beach, Manhattan Beach, Redondo Beach and Torrance. The southeastern corner of the map includes the western portion of the Palos Verdes Peninsula where parts of the cities of Palos Verdes Estates, Rancho Palos Verdes, and Rolling Hills Estates are located.

The quadrangle includes the shoreline of Santa Monica Bay from the City of Redondo Beach southward to the Palos Verdes Peninsula. Coastal cities were developed on active and inactive coastal sand dunes, which locally required extensive placement of artificial fills in the Redondo Beach area. The topography of the elevated Palos Verdes Peninsula is characterized by a series of stair step-like Pleistocene wave-cut marine terraces that are generally covered by a non-marine veneer over thin marine terrace deposits. The lowland areas of the Redondo Beach Quadrangle are covered with modern beach sands and late Pleistocene to Holocene dune sand deposits.

Access along the northern coastal section of the quadrangle is provided by Pacific Coast Highway (State Highway 1). Palos Verdes Drive and Hawthorne Boulevard provide access on the Palos Verdes Peninsula.

GEOLOGY

Surficial Geology

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. A digital map obtained from the U.S. Geological Survey (Tinsley, unpublished) was used as a base to prepare a geologic map of the Redondo Beach Quadrangle for this project. Additional detail was added from a digital map prepared by the Southern California Areal Mapping Project (SCAMP, unpublished) and the California Division of Mines and Geology (Bezore and others, unpublished), which was compiled primarily from Poland and others (1959). Quaternary geologic contacts received minor modifications in accordance with information taken from older 1:20,000-scale U.S. Geological Survey topographic maps (Torrance, 1934), the 1:62,500-scale Redondo Quadrangle (1896; 1944), and an older regional soils map (Nelson and others, 1919). Stratigraphic nomenclature was revised to follow the format developed by SCAMP (Morton and Kennedy, 1989). The revised geologic map that was used in this study of liquefaction susceptibility is included as Plate 1.1.

The oldest Quaternary geologic unit mapped in the Redondo Beach Quadrangle is the Pleistocene San Pedro Formation (Qsp), a predominantly marine sand and gravel deposit exposed in the Palos Verdes Peninsula. A detailed description of the bedrock geology of the Palos Verdes Peninsula is presented in Section 2.

Woodring and others (1946) recognized the early-Pleistocene San Pedro Sand (Qsp) as the oldest Quaternary geologic unit within the Redondo Beach Quadrangle. The San Pedro Formation is a massive, poorly consolidated, light brown, marine sand deposit exposed in the Palos Verdes Hills. Woodring and others (1946) also mapped multiple levels of Pleistocene marine terraces with dense silty sand terrace deposits (Qter/Ooa) in the Palos Verdes Hills. Modern eolian deposits (Qe) form a quarter- to one-half-mile-wide strip along the coastline adjacent to the modern beach. The eolian deposits are composed of very well-sorted, fine- to medium-grained sand that rapidly grade into Pleistocene moderately dense silty sand of older eolian deposits (Qoe). Local drainages are incised and filled with younger alluvium, consisting of soft, locally derived sandy silt and sandy clay of younger alluvium (Qya2). Modern beach deposits (Qm), which consist of well-sorted, medium- to coarse-grained sand, form the shoreline of Santa Monica Bay.

ENGINEERING GEOLOGY

Information on subsurface geology and engineering characteristics of artificial fill and beach sands was obtained from borehole logs collected from reports on geotechnical projects. For this investigation, borehole logs were collected from the files of the

Regional Water Quality Control Board. Also reviewed were DMG files of seismic reports for hospitals, school site files from the State Architect's Office, and local water well logs from the California Department of Water Resources. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to the use of non-standard equipment and incomplete reporting of procedures.

Data from borehole logs were entered into the DMG geotechnical (GIS) database. Locations of all exploratory boreholes entered into the database for consideration in this investigation are shown on Plate 1.2.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit and commonly are used as an index of density. Many geotechnical investigations record SPT data, including the number of blows by a 140-pound drop weight required to drive a sampler of specific dimensions one foot into the soil. Recorded blow counts for non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), were converted to SPT-equivalent blow count values and entered into the DMG GIS. The actual and converted SPT blow counts were normalized to a common reference effective overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

Descriptions of characteristics of geologic units are given below. These descriptions are necessarily generalized, but give the most commonly encountered characteristics of the units (see Table 1.1).

San Pedro Sand (Qsp)

The San Pedro Sand was mapped by Woodring and others (1946) on the Palos Verdes Peninsula. Lower Pleistocene San Pedro Sand is typically composed of cross-bedded to massive sand and silty sand.

Older eolian deposits (Qoe) and marine terrace deposits (Qter/Qoa)

Late Pleistocene eolian deposits comprise most of the eastern Redondo Beach Quadrangle. These older, largely stabilized dune sands form a veneer over late Pleistocene terrace surfaces. Ground water is deep throughout this area, so no extensive effort was made to collect subsurface data. They are generally described as dense to very dense sands and silty sands. Late Pleistocene marine terrace deposits (Qter), mapped in places as Qoa, generally consist of silty sand with local gravels that are found throughout the Palos Verdes Peninsula.

Modern eolian deposits (Qe)

Modern eolian deposits are composed of very well sorted, fine- to medium-grained sand and rapidly grade into Pleistocene moderately dense silty sand of older eolian deposits (Qoe).

Younger alluvium (Qya2)

Younger alluvial deposits consist of locally derived soft silt and clay with some loose to moderately dense silty sand and sand.

Modern beach deposits (Qm)

Modern beach deposits (Qm), which consist of well sorted, medium- to coarse-grained sand, form the shoreline of Santa Monica Bay.

Artificial fill (af)

Artificial fill in the Redondo Beach Quadrangle consists of undifferentiated new and old fills associated with development of the greater Redondo Beach Harbor complex.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
af, artificial fill	sand, silty sand	soft to dense	high
Qm, modern beach deposits	sand	soft	high
Qya2, younger alluvial deposits	silty sand, and sand	soft to moderately dense	high to moderate
Qe, modern eolian deposits	sand	soft	moderate to low
Qoe, older dune sand	silty sand and sand	moderately dense-very dense	low
Qter/Qoa, older marine terrace	silty sand, minor gravel	dense-very dense	low
Qsp, San Pedro Sand	sand, silty sand, minor gravel	loose to moderately dense	low

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

GROUND-WATER CONDITIONS

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

Ground-water conditions were investigated in the Redondo 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 and selected water wells. Turn-of-the-century water-well logs and data (Mendenhall, 1905) were also reviewed but were generally found to be inadequate for the purposes of this study. As noted by Poland and others (1959, p. 90): recent topographic maps differ considerably from the land surface modeled by the 25-foot contour interval of the 1894 base map. Mendenhall (1905) contoured all available water levels--from all aquifers. For the current evaluation the depths to first-encountered water free of piezometric influences were plotted onto a map (Plate 1.2) 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. This map was digitized and used for the liquefaction analysis.

PART II

LIQUEFACTION POTENTIAL

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

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

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to

liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

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

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

San Pedro Sand (Qsp)

The lower Pleistocene San Pedro Sand is typically composed of cross-bedded to massive sand and silty sand. As this unit predates the late Pleistocene age restrictions of the liquefaction susceptibility criteria, low liquefaction susceptibility is assigned.

Older eolian deposits (Qoe) and marine terrace deposits (Qter/Qoa)

Older eolian and marine terrace deposits are composed of dense to very dense sands and silty sands. Liquefaction susceptibility of these units is low.

Modern eolian deposits

Modern eolian deposits are composed of very well sorted, fine- to medium-grained sand that is assumed to be well drained. Liquefaction susceptibility of this unit is low to moderate.

Younger alluvium (Qya2)

Younger alluvial deposits consist of locally derived soft silt and clay with some loose to moderately dense silty sand and sand. Liquefaction susceptibility of this unit, where saturated, is moderate to high.

Modern beach deposits

Modern beach deposits, which consist of well-sorted, medium- to coarse-grained sand, form the shoreline of Santa Monica Bay. Liquefaction susceptibility of this unit is high.

Artificial fill (af)

Artificial fills commonly overlie young beach sand deposits. Because the artificial fills are usually too thin to affect the liquefaction hazard, and the underlying beach sand deposits have a high liquefaction susceptibility, fills are assumed to have a high susceptibility to liquefaction.

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 Redondo Beach Quadrangle, PGAs of 0.39 g to 0.55 g, resulting from an earthquake of magnitude 7.1, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

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

were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the geotechnical borehole logs reviewed in this study (Plate 1.2), six 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.

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 Redondo Beach Quadrangle is summarized below.

Areas of Past Liquefaction

In the Redondo Beach Quadrangle, major effects attributed to liquefaction were noted in Redondo Beach at King Harbor following the 1994 Northridge earthquake. Liquefaction-induced lateral spreading and differential settlement severely damaged the Mole B marina facilities (Stewart and others, 1994) and (Kerwin and Stone, 1997; see Plate 1.2).

Artificial Fills

In the Redondo Beach Quadrangle artificial fill consists of engineered fill primarily around the King Harbor area. The engineered fills are generally too thin to have an impact on liquefaction but overlie beach sand deposits that are susceptible to liquefaction. Areas underlain by artificial fill have been included in liquefaction hazard zones.

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. The San Pedro Sand (Qsp), marine terrace deposits (Qter), and older eolian deposits (Qoe) in the Redondo Beach Quadrangle have dense consistencies and deep ground water was encountered in many of the areas underlain by these units. Accordingly, these geologic units have not been included in a liquefaction hazard zone.

Younger eolian deposits (Qe) are typically very thin and permeable, and therefore, unsaturated. They are not included in liquefaction hazard zones.

Younger alluvial deposits (Qya2) commonly have layers of loose silty sand or sand. Where these deposits are saturated, they are generally included in a liquefaction hazard zone.

Modern beach deposits (Qm) are typically loose saturated sand. They are included in liquefaction hazard zones.

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SECTION 2 EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Redondo 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://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Redondo 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.conservation.ca.gov/CGS/index.htm>.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Redondo 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 Redondo 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 Redondo 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 Redondo Beach Quadrangle covers an area of about 13 square miles in southwestern Los Angeles County. The low-lying topography in the northeastern corner includes parts of the coastal cities of Hermosa Beach, Manhattan Beach, Redondo Beach and Torrance. The southeastern corner of the map includes the

western portion of the Palos Verdes Peninsula where parts of the cities of Palos Verdes Estates, Rancho Palos Verdes, and Rolling Hills Estates are located.

The Redondo Beach Quadrangle lies within the southwestern part of the Los Angeles Basin. The topography of the elevated Palos Verdes Peninsula is characterized by a series of stair step-like Pleistocene wave-cut marine terraces that are generally covered by a non-marine veneer over thin marine terrace deposits. Alluvium and slope wash deposits occur within the major drainages in some areas. A strip of ancient coastal dunes parallels the modern beach along the coastline north of the peninsula. Elevations range from sea level to about 1200 feet near the crest of the Palos Verdes Hills in the south half of the quadrangle

Access along the northern coastal section of the quadrangle is provided by Pacific Coast Highway (State Highway 1). Palos Verdes Drive and Hawthorne Boulevard provide access on the Palos Verdes Peninsula.

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 Redondo 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 that are based on 1963 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1963 as part of residential development were identified on 1:40,000-scale aerial photography flown in 1994 and 1995 (NAPP, 1994). Photogrammetric DEM's covering the graded areas were prepared by the U.S. Bureau of Reclamation with ground control points established by DMG. The photogrammetric DEM's were then merged into the USGS DEM, replacing the areas of out-dated elevation data. Surrounding quadrangle DEM's were merged with the Redondo Beach DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. Plate 2.1 shows those areas where the topography is updated to 1994 grading conditions.

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

GEOLOGY

Bedrock and Surficial Geology

For the Redondo Beach Quadrangle, a bedrock geologic map at a scale of 1:24,000 was released by Woodring and others (1946). Cleveland (1976) also published geologic maps

covering portions of the Palos Verdes Hills at 1:12,000 scale. These sources were compiled, digitized and presented at 1:100,000 scale in Bezore and others (unpublished). This digitized compilation formed the basis of the geologic map used in this investigation. The northern section of coastal alluvium and dunes was taken from Tinsley and others (1985). The digital geologic map was modified to reflect the most recent mapping in the area and to include interpretations of observations made during the aerial photograph landslide inventory and field reconnaissance. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of slope failures was noted.

The bedrock geologic units mapped within the Redondo Beach Quadrangle include the Monterey Formation (Tm) and its three members -- Malaga Mudstone (Tmal), Valmonte Diatomite (Tmv), and Altimira Shale (Tma); the San Pedro Formation (Qsp); and intrusive basalt (Tb). Quaternary units include marine and non-marine terrace deposits (Qter), talus deposits (Qtb), beach sand (Qm/a), dune deposits (Qe), landslide deposits (Qls) and artificial fill (af).

Most of the upland area of the Palos Verdes Hills is underlain by the middle to upper Miocene Altimira Shale member (Tma) of the Monterey Formation, the oldest rocks exposed in the study area. The Altimira Shale consists of siliceous shale, silty and sandy shale, chert shale, chert, siltstone, bituminous shale, diatomaceous shale, diatomite, phosphatic shale, tuffaceous shale, limestone, sandstone, conglomerate, breccia and silicified limestone and shale. Intrusive basaltic rocks (Tb) occur in the lower and middle parts of the Altimira Shale member. The basaltic rocks consist of basalt, andesite, volcanic breccia and tuff breccia that forms sills that are more or less concordant with bedding. These rocks crop out along the sea cliffs from Resort Point south to Long Point. From Long Point to Abalone Cove, the basaltic rocks crop out on the south-facing slope between about elevation 200 and 700 feet. These rocks also crop out along a portion of the sea cliff and areas upslope from Bluff Cove to just north of Flatrock Point.

The upper Miocene Valmonte Diatomite member (Tmv) of the Monterey Formation overlies the Altimira Shale and underlies a portion of the crest of the Palos Verdes Hills in the central part of the uplands. This unit also crops out over a relatively small area to the east and south of Bluff Cove. The Valmonte Diatomite member overlies the Altimira Shale and consists of diatomaceous shale and diatomite. In the Torrance Quadrangle to the east, the Monterey Formation rests unconformably on pre-Cenozoic Catalina Schist, which consists of quartz-chlorite schist, quartz-sericite schist and quartz-glaucophane schist. Catalina Schist forms the basement complex beneath the entire Palos Verdes Peninsula, but is not exposed in the Redondo Beach Quadrangle.

A flight of 13 main emergent marine terraces were mapped in the Palos Verdes Hills by Woodring and others (1946), who numbered the terraces 1 through 13 in ascending order. Intermediate terraces mapped by Woodring and others (1946) include 5a, 7a. The terraces are discontinuous and not all the numbered terraces are exposed everywhere. Cleveland (1976) remapped the terrace distribution in portions of the Torrance Quadrangle and more recent work, as reported in Bryant (1982; 1987), designate several

additional intermediate terraces as 2a, 2b, 3a, 3b, 4a and 4b. The wavecut platforms of the terraces are typically capped with marine sediments, a non-marine cover, or, locally, are simply geomorphic benches without significant sedimentary cover.

Terraces 1 through 10 are exposed in the Redondo Beach Quadrangle. Terraces 1 through 5 are typically capped with upper Pleistocene to Holocene non-marine terrace deposits (Qter) and are the only terraces shown on the geologic map. Throughout the Palos Verdes Peninsula terraces 6 through 10 have lost much, or virtually all, of their original cover through erosion. The upper Pleistocene to Holocene non-marine terrace deposits on the lowest terraces consist of a thin marine basal strata of Palos Verdes Sand overlain by non-marine deposits. The Palos Verdes sand is undifferentiated from the overlying non-marine terrace deposits on the geologic map and consists of a few inches to 15 feet of calcareous sand, shell fragments and scattered small pebbles and cobbles. The overlying terrace deposits consist of poorly sorted to unsorted, crudely stratified sand, rubble and gravel. This unit is as much as 100 feet thick toward the landward part of the terrace, although the exposed thickness is generally less than 50 feet.

Holocene deposits consist of three surficial units that crop out in bands parallel to the coast, and undifferentiated alluvium along some of the stream channels. In the west, along the coast below the sea cliffs is a narrow band of modern marine beach deposits (Qm/a), consisting of arenaceous sand. The beach deposits extend from the northern boundary of the quadrangle, southward to Malaga Cove, and in Lunada Bay, east of Long Point and in Abalone Cove. To the east and inland, is a band of modern eolian dune deposits (Qe) that consist of sand and silty sand. This unit extends from the northern quadrangle boundary southward to King Harbor. Farther east and inland, are older dune deposits (Qoe) that consist of sand and silty sand. The older eolian dune deposits are more densely vegetated and, hence, more stabilized dunes than the modern dune deposits. This unit extends from the northern quadrangle boundary southward to the northern margin of the uplands and eastward to the eastern quadrangle boundary. South of King Harbor, the older eolian dunes extend from the top of the sea cliff face to the eastern quadrangle boundary. Active alluvium (Qal) is identified in scattered deposits along a few of the modern streams and is typically exposed near or just above the top of the sea cliffs. A more detailed description of the late Quaternary geologic units is presented in the liquefaction portion (Section 1) of this report.

Landslide deposits (Qls) are scattered across the quadrangle and typically occur as small to moderate size failures on the slopes of drainages and along the sea cliffs in areas underlain by the Altimira Shale. However, in the southeast corner of the quadrangle part of the large Portuguese Bend landslide complex occurs. Modern artificial fills (af) are mapped at large school sites, residential subdivisions, commercial developments, and along freeway embankments.

Structural Geology

The geologic structure of the Palos Verdes Peninsula is dominated by the Palos Verdes Fault and a large, broad northwest-southeast-trending doubly plunging anticline (Ehlig, 1982a; 1982b), (Bryant, 1987), (Yerkes and others, 1965) and (Rowell, 1982). The

anticlinal form of the peninsula has been uplifted as a horst between the Palos Verdes fault on the northeast and faults on the sea floor to the southwest. The Palos Verdes Fault is a steep, southwest-dipping reverse fault, upthrown on the southwest, that is exposed along the northeast margin of the Palos Verdes Hills and separates the upland area from the flatlands of the Central Plain of the Los Angeles Basin on the northeast. The axis of the anticline forms a concave-to-the-south arc from the northwest corner of the Palos Verdes Peninsula, in the area of Flatrock Point, extending toward the southeast to the vicinity of Whites Point (east of the Redondo Beach Quadrangle). In most places within the anticline the strata are tilted less than 20 degrees.

Other faults and small folds are also present in the Redondo Beach Quadrangle. Woodring and others (1946) mapped a number of other structures, the trends of which change systematically from north to south. In the northwestern corner of the Palos Verdes Peninsula, along the coast at, and inland of, Flatrock Point and Bluff Cove Woodring and others, (1946) mapped two southwest-trending synclines, the southernmost of which was mapped as discontinuous and may be two separate synclines, and one southwest-trending anticline between the synclines. An east-west-trending syncline, on the north, and anticline, on the south, were mapped to the east of Palos Verdes Point. Two synclines, the northern one of which was mapped as discontinuous and may represent two separate synclines, and one anticline were mapped in the southwestern of the Palos Verdes Peninsula, in the area east of Lunada Bay and north of Abalone Cove. These folds are likely undulations in the general anticlinal structure of the Palos Verdes Peninsula.

Bedding in the geologic units strikes approximately parallel to the trend of the structures with dips that range between 5 and 55 degrees.

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Redondo Beach Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and limited field reconnaissance (Haydon, unpublished). All areas containing landslides identified in the previous work of Woodring and others (1946), Cleveland (1976), Ehlig, (1982a and b; 1987), Lass, and Eagen, (1982), Scullin, (1987), and Anderson (1987) were re-evaluated during the aerial photograph interpretation conducted for this investigation. Some of the landslides identified in the previous work were not included in the landslide inventory because in our reevaluation it was concluded the feature was not a landslide, while many additional landslides were identified and the boundaries of many of the landslides were modified from the previous work.

Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of

their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Redondo Beach Quadrangle geologic map were obtained from geotechnical reports prepared by consultants and on file with the local government permitting departments, (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants 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 map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Adverse Bedding Conditions

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

To account for adverse bedding in our slope stability evaluation, we used geologic structural data from previous geologic mapping by Woodring and others (1946) and Cleveland (1976) 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 Monterey Formation, which contains interbedded sandstone and shale, was subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and

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

Existing Landslides

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

The results of the grouping of geologic materials in the Redondo Beach Quadrangle are in Tables 2.1 and 2.2.

REDONDO BEACH QUADRANGLE SHEAR STRENGTH GROUPINGS							
	Formation Name	Number Tests	Mean phi value	Group phi Mean/Median (deg.)	Group C Mean/Median (psf)	Phi Values Used in Stability Analyses	Similar Lithology: no data
GROUP 1	Tma (fbc)	41	36.3				
	Tb	14	37.1	36.5/35	680/300	36	
GROUP 2	Qal	3	32				
	Qter	8	31	31.2/32	394/300	32	Q, Qoe, Tmal
	Tmv	2	31				
GROUP 3	af	22	26.1				
	Qtb	6	26.7	26.2/25.5	493/300	26	Qe, Qm/a, Qsp
GROUP 4	Tma (abc)	47	18.4	18.4/19	570/400	18	
GROUP 5	Qls	25	9.8	9.8/8.5	307/209	10	

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

SHEAR STRENGTH GROUPS FOR THE REDONDO BEACH QUADRANGLE				
GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Tma (fbc)	Q	af	Tma (abc)	Qls
Tb	Qal	Qe		
	Qoe	Qm/a		
	Qter	Qsp		
	Tmal	Qtb		
	Tmv			

Table 2.2. Summary of the Shear Strength Groups for the Redondo 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 Redondo 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:	7.0 to 7.1
Modal Distance:	2.5 to 12.6 km
PGA:	0.33 to 0.51 g

The strong-motion record selected for the slope stability analysis in the Redondo Beach Quadrangle was the Channel 3 (N35°E horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge Earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59 g. 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 0.076, 0.129 and 0.232 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Redondo Beach Quadrangle.

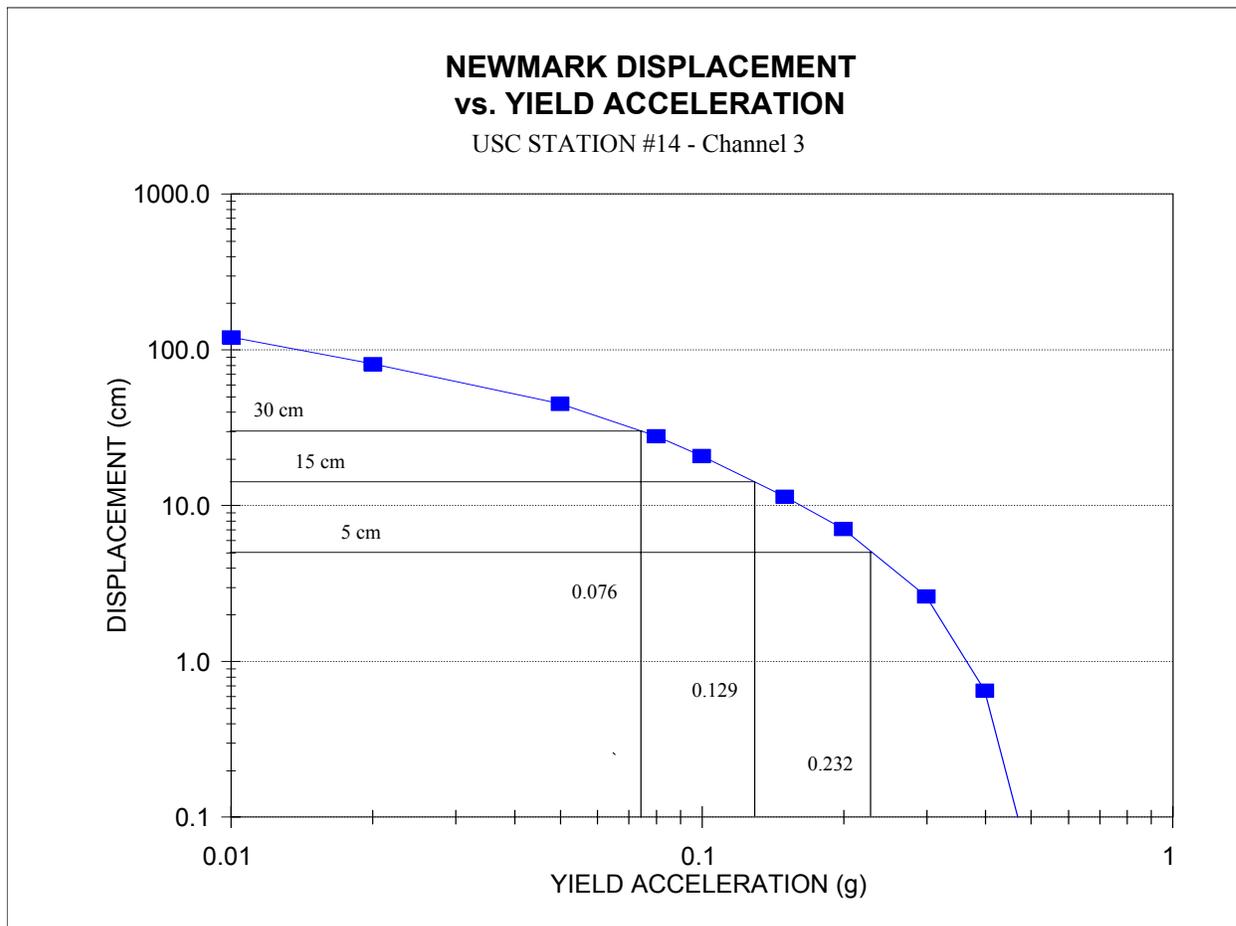


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record from the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

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

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

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

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

1. If the calculated yield acceleration was less than 0.076g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)
2. If the calculated yield acceleration fell between 0.076g and 0.129g, 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 0.129g and 0.232g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)
4. If the calculated yield acceleration was greater than 0.232g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

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

REDONDO BEACH QUADRANGLE HAZARD POTENTIAL MATRIX														
		SLOPE CATEGORY (percent)												
Geologic Material Group	Mean Phi	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
		0-5	6-9	10-19	20-23	24-35	36-37	38-41	42-46	47-48	49-54	55-59	60-64	>64
1	36	VL	VL	VL	VL	VL	VL	VL	VL	L	L	L	M	H
2	32	VL	VL	VL	VL	VL	VL	L	L	L	M	H	H	H
3	26	VL	VL	VL	VL	L	M	M	H	H	H	H	H	H
4	18	VL	VL	L	M	H	H	H	H	H	H	H	H	H
5	10	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 Redondo 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 5 is included for all slope gradient categories. (Note: Geologic Strength Group 5 includes all mappable landslides with a definite or probable confidence rating).
2. Geologic Strength Group 4 is included for all slopes steeper than 9 percent.
3. Geologic Strength Group 3 is included for all slopes steeper than 23 percent.
4. Geologic Strength Group 2 is included for all slopes steeper than 37 percent.
5. Geologic Strength Group 1 is included for all slopes greater than 46 percent.

This results in approximately 10 percent of the land (1,040 acres) in the quadrangle lying within the earthquake-induced landslide hazard zone for the Redondo Beach Quadrangle.

ACKNOWLEDGMENTS

The authors thank staff from the City of Rancho Palos Verdes and County of Los Angeles, Department of Public Works, Material Engineering Division for their assistance in obtaining geotechnical information used in the preparation of this report. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their Geographic Information System operations support. Thanks also go to the Bureau of Reclamation staff who built the DEM's. Tim McCrink and Rick Wilson provided assistance with digitizing terrain in graded areas. Joy Arthur designed and plotted the graphic displays associated with the earthquake-induced landslide zone map, and Lisa Chisholm prepared the landslide attribute tables for input into this report.

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AIR PHOTOS

NAPP, 1994, U.S. Geological Survey-National Aerial Photography Program (NAPP), flight 6862, frames 1-5, 71-73, flown 6/1/94, black and white, vertical, approximate scale 1:40,000.

United States Department of Agriculture (USDA), dated 11-19-52, Flight or Serial number AXJ, Photo numbers 14K-83-88, scale 1:20,000±.

United States Department of Agriculture (USDA), dated 11-4-52, Flight or Serial number AXJ, Photo numbers 4K-123-131, scale 1:20,000±.

APPENDIX A SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Division of Mines and Geology, Environmental Impacts Reports File	64
City of Rancho Palos Verdes, Planning Department	27
County of Los Angeles, Department of Public Works, Materials Engineering Division	77
Total Number of Shear Tests	168

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Redondo Beach 7.5-Minute Quadrangle, Los Angeles County, California

By

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**California Department of Conservation
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PURPOSE

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

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

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

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

EARTHQUAKE HAZARD MODEL

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

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

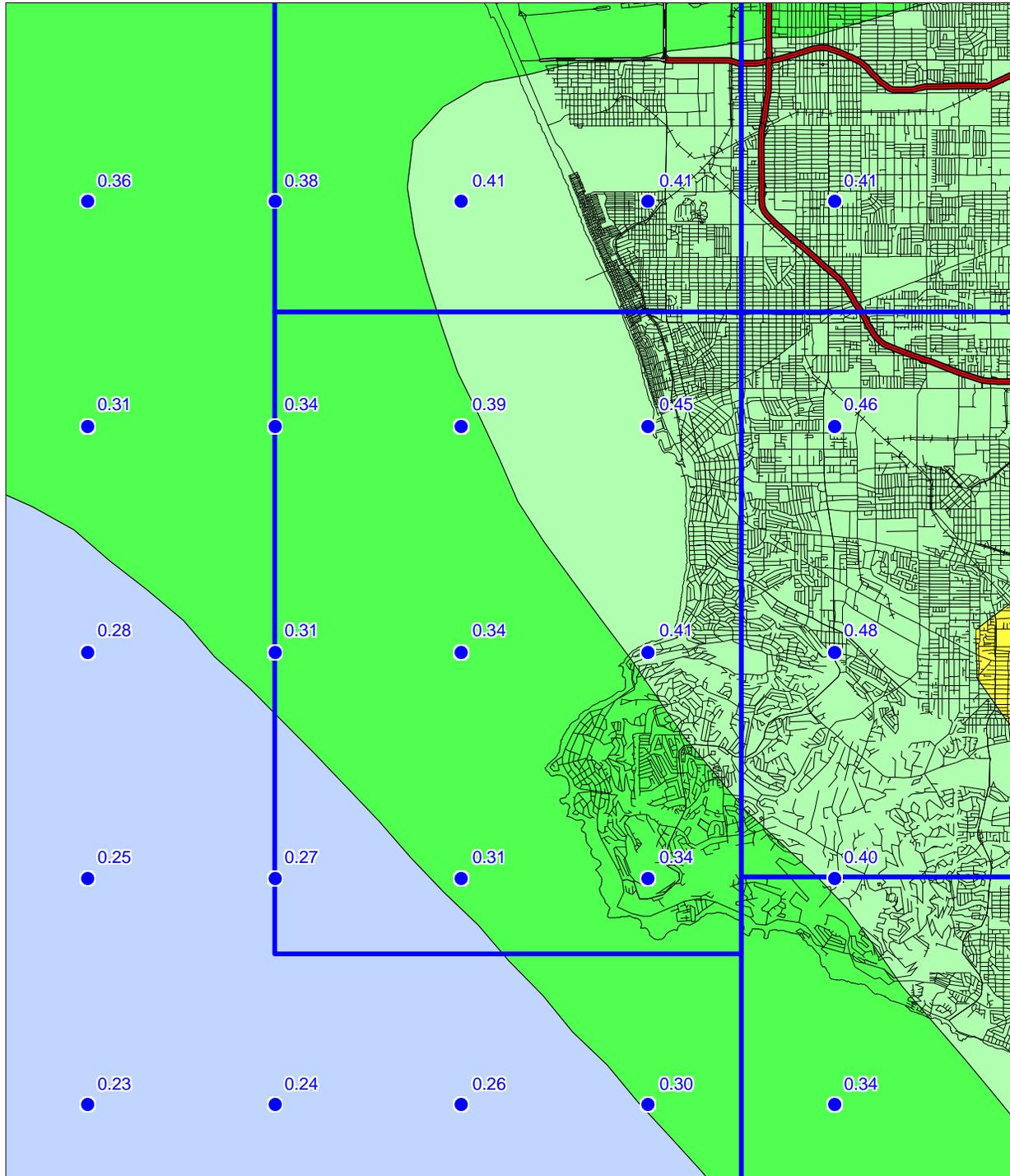
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively.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

REDONDO 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



Department of Conservation
Division of Mines and Geology



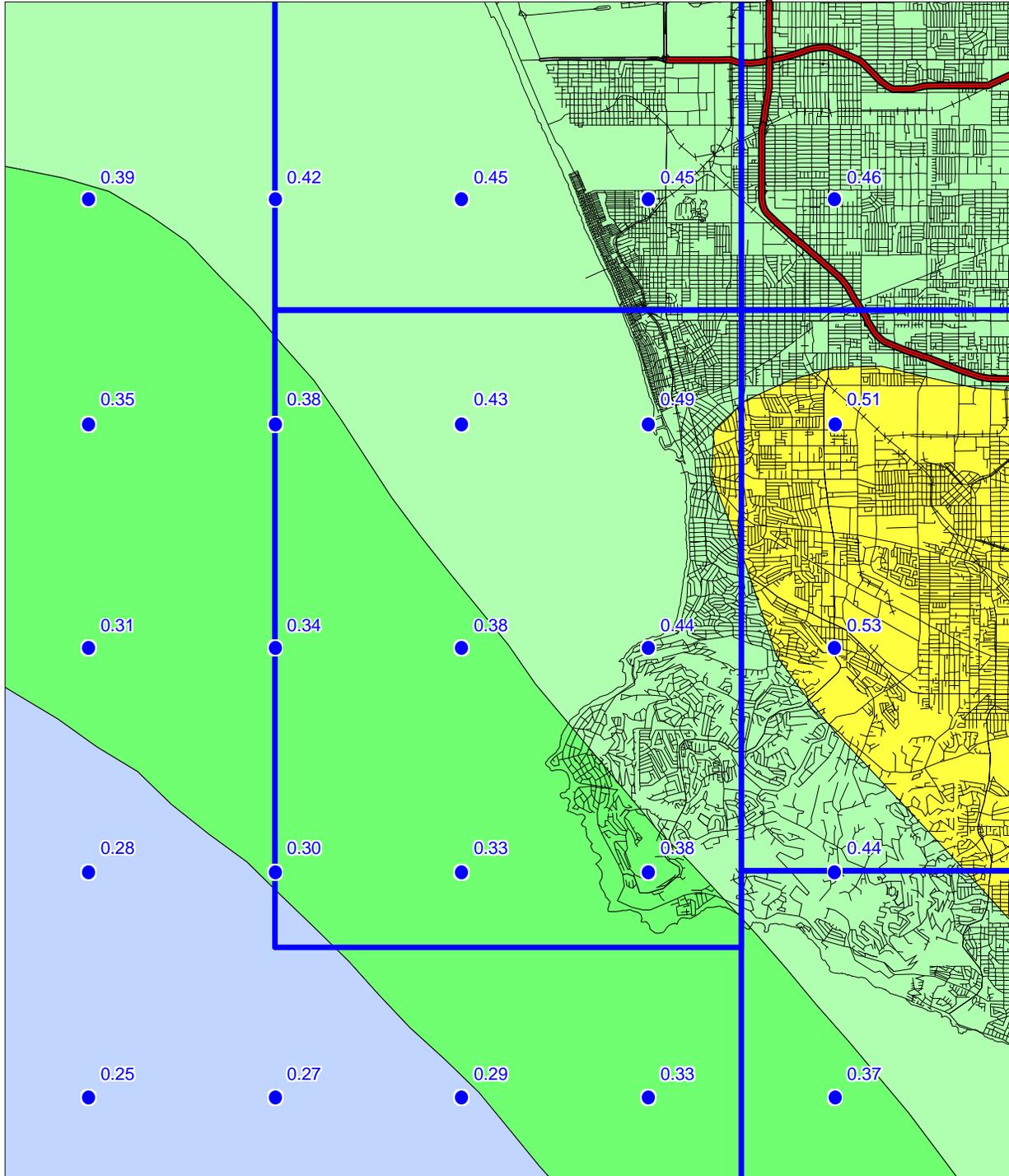
Figure 3.1

REDONDO BEACH 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

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

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation



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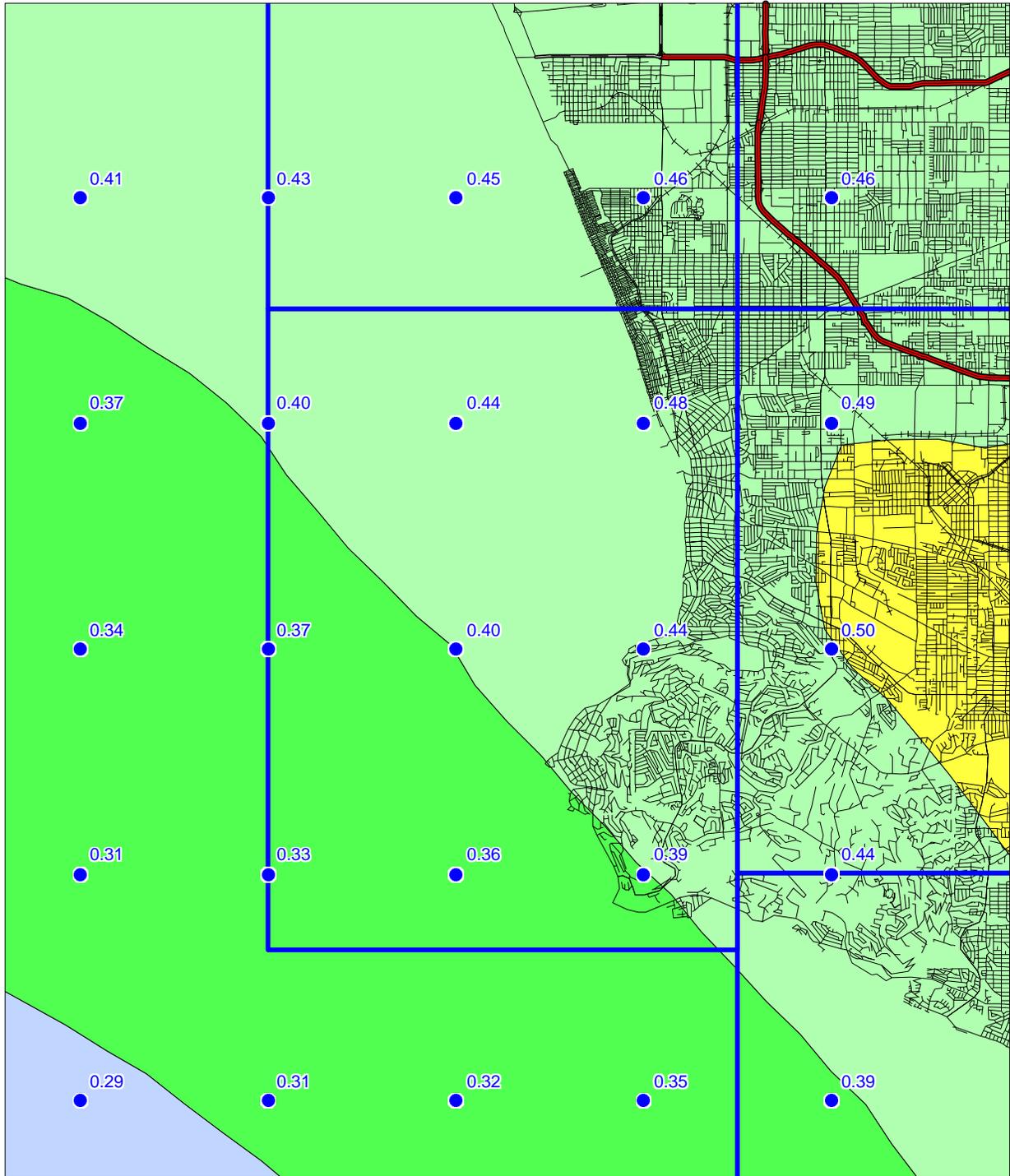
Figure 3.2

REDONDO 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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Division of Mines and Geology



Figure 3.3

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

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

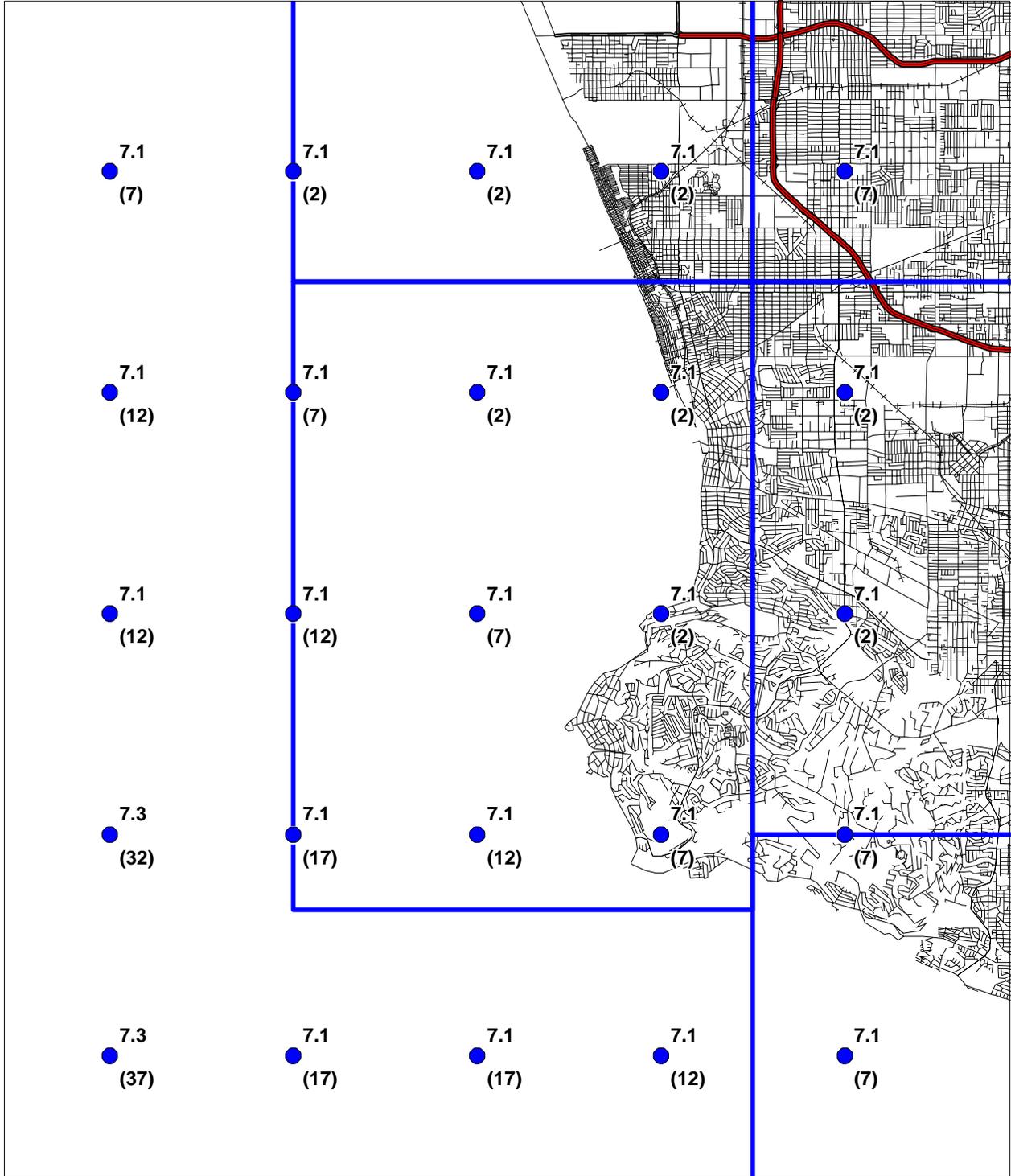
Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value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

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

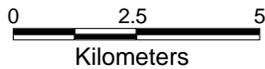
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1)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

SEISMIC HAZARD EVALUATION OF THE REDONDO BEACH QUADRANGLE
REDONDO 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



Department of Conservation
Division of Mines and Geology

Figure 3.4

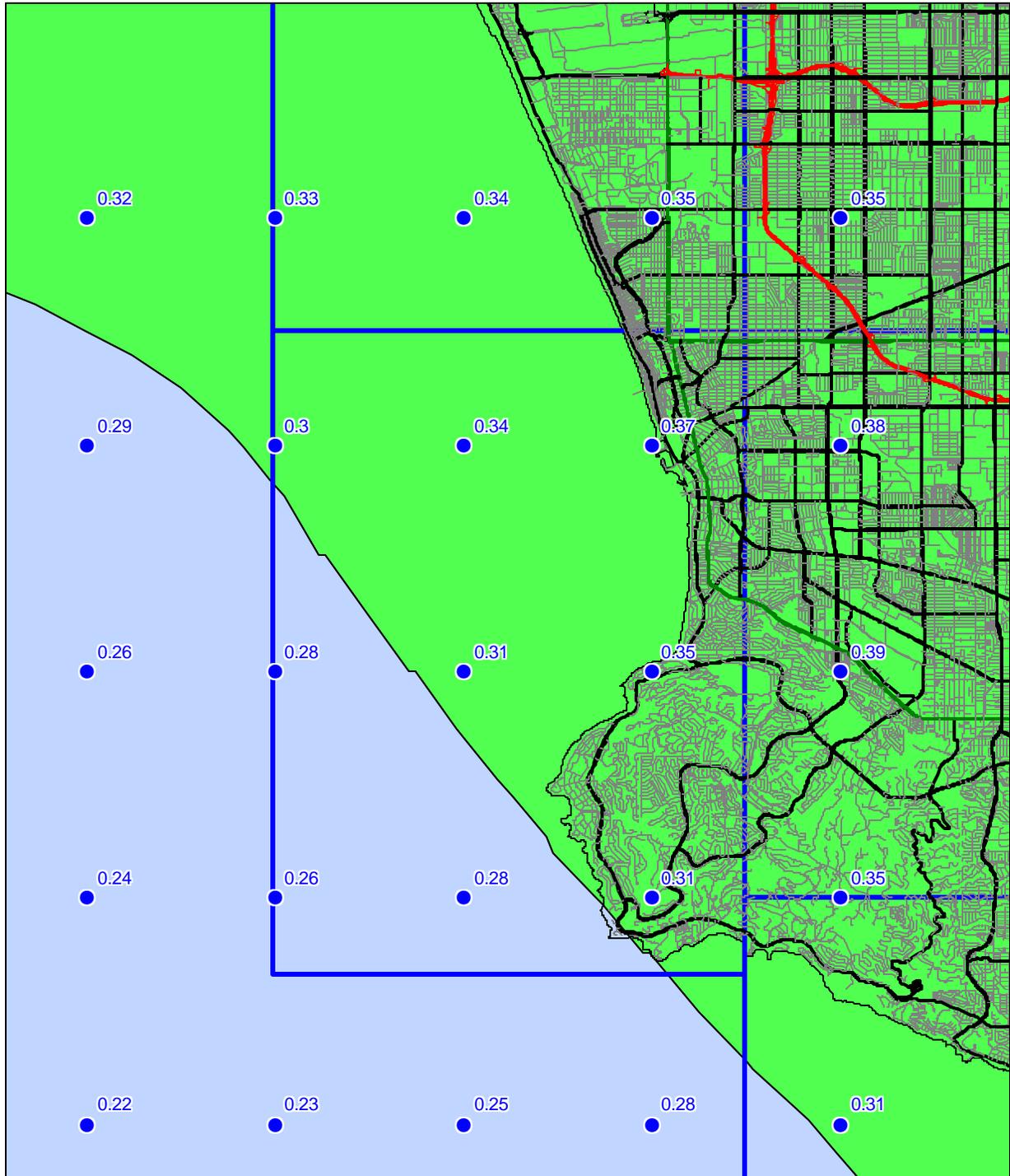


**SEISMIC HAZARD EVALUATION OF THE REDONDO BEACH QUADRANGLE
REDONDO BEACH 7.5-MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES**

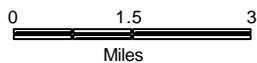
*10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM*

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT



Department of Conservation
California Geological Survey



Figure 3.5

USE AND LIMITATIONS

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

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

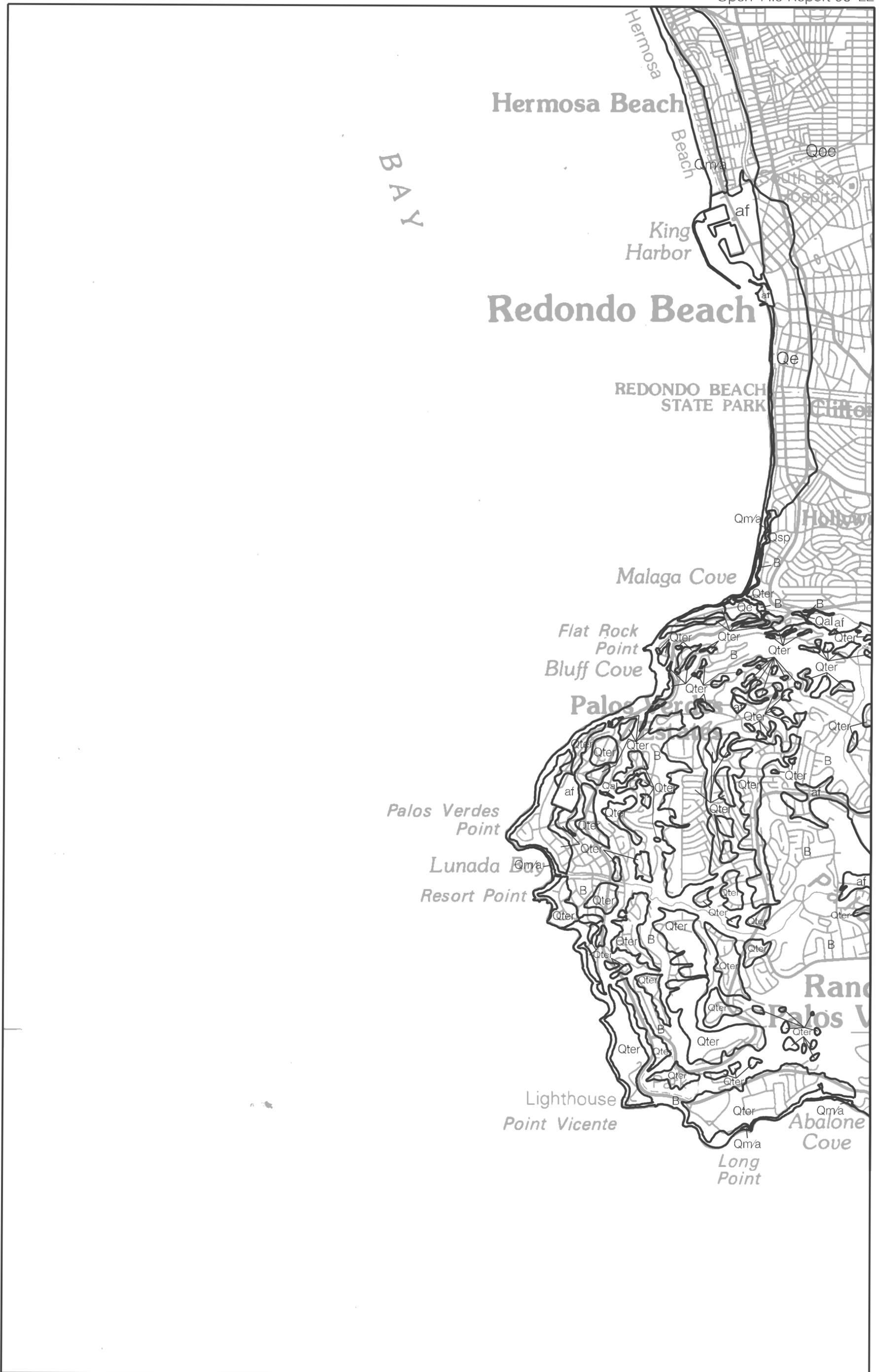
Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific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

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

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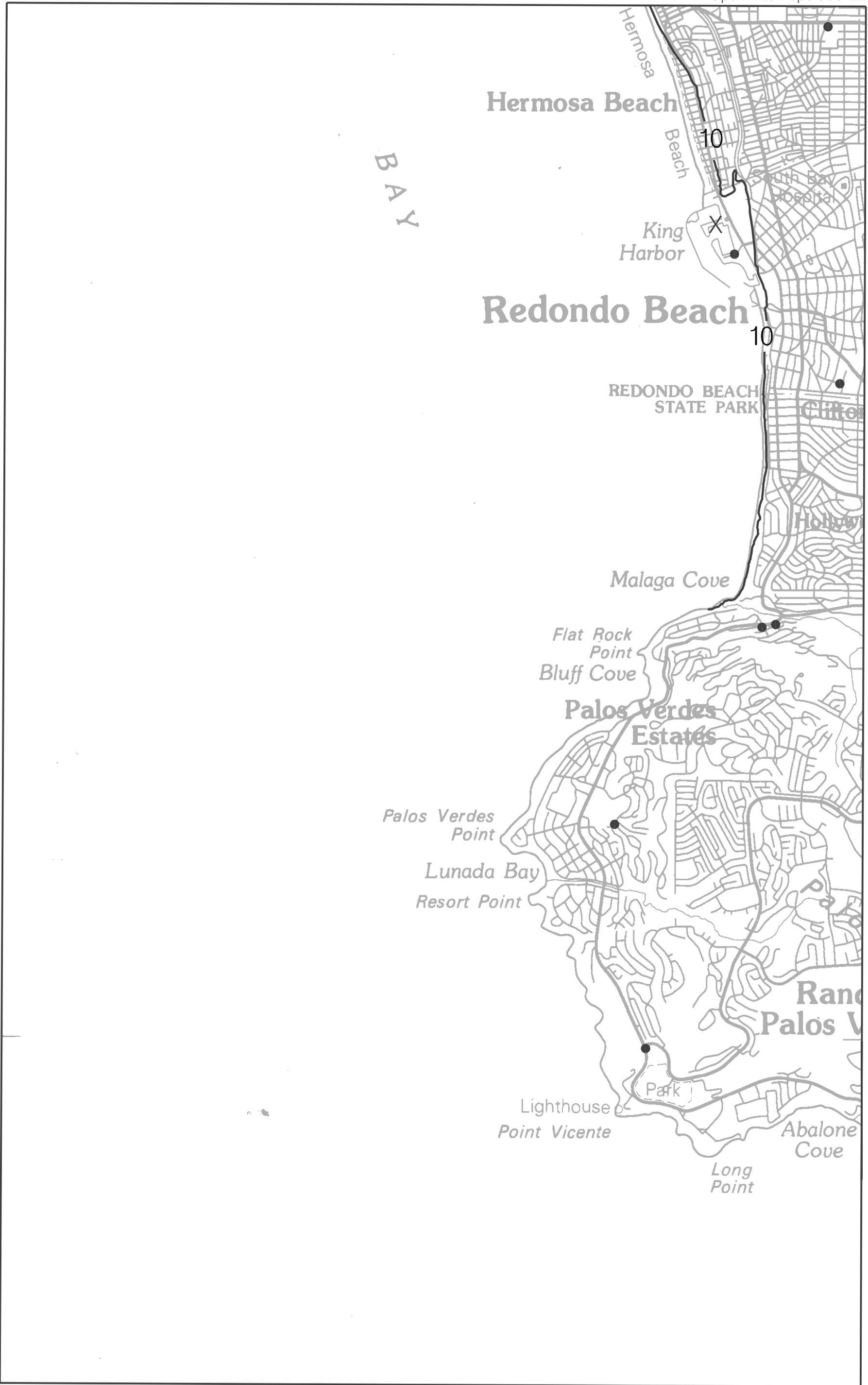
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Base map enlarged from U.S.G.S. 30 x 60-minute series

Plate 1.1 Quaternary Geologic Map of the Redondo Beach Quadrangle.
 See Geologic Conditions section in report for descriptions of the units.
 B = Pre-Quaternary bedrock.

ONE MILE
 SCALE



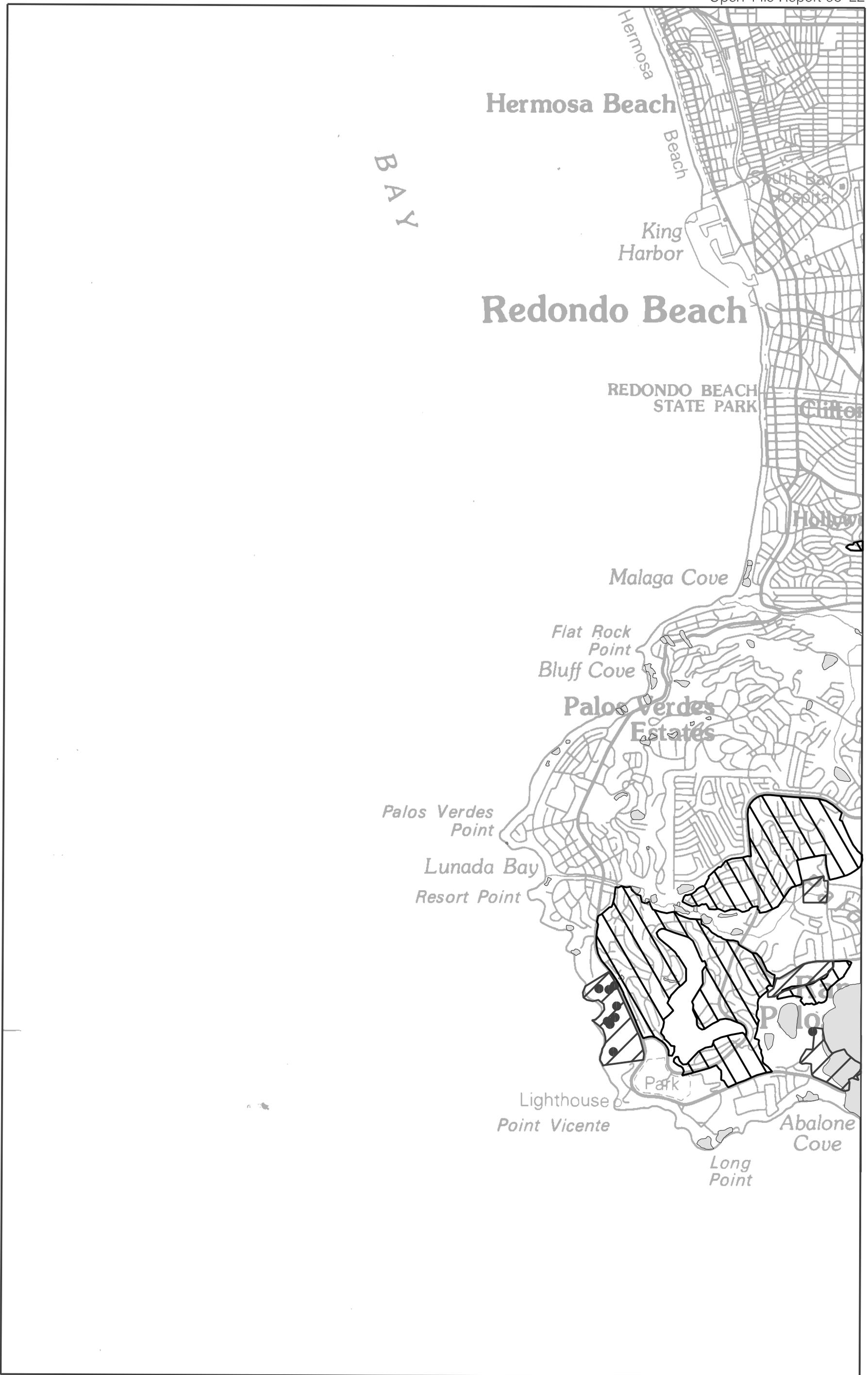
Base map enlarged from U.S.G.S. 30 x 60-minute series

Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Redondo Beach Quadrangle.

● Borehole Site — 30 — Depth to ground water in feet

X Site of historical earthquake-generated liquefaction. See "Areas of Past Liquefaction" discussion in text.

ONE MILE
SCALE



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

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

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

ONE MILE
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