PLANNING SCENARIO

FOR A MAJOR EARTHQUAKE ON THE NEWPORT-INGLEWOOD FAULT ZONE

SPECIAL PUBLICATION 99

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CALIFORNIA DEPARTMENT OF CONSERVATION

DIVISION OF MINES AND GEOLOGY

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PLANNING SCENARIO FOR A MAJOR EARTHQUAKE ON THE NEWPORT-INGLEWOOD FAULT ZONE

By

CALIFORNIA DEPARTMENT OF CONSERVATION

DIVISION OF MINES AND GEOLOGY

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1988

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DIVISION OF MINES AND GEOLOGY

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FOREWORD

- During the past 130 years, California has been struck by five major destructive earthquakes of magnitude about 7 or greater: in northern California, the 1868 Hayward and 1906 San Francisco earthquakes; in central and southern California, the 1857 Fort Tejon, 1872 Owens Valley, and 1952 Kern County earthquakes. Most of these occurred while California was still sparsely populated.

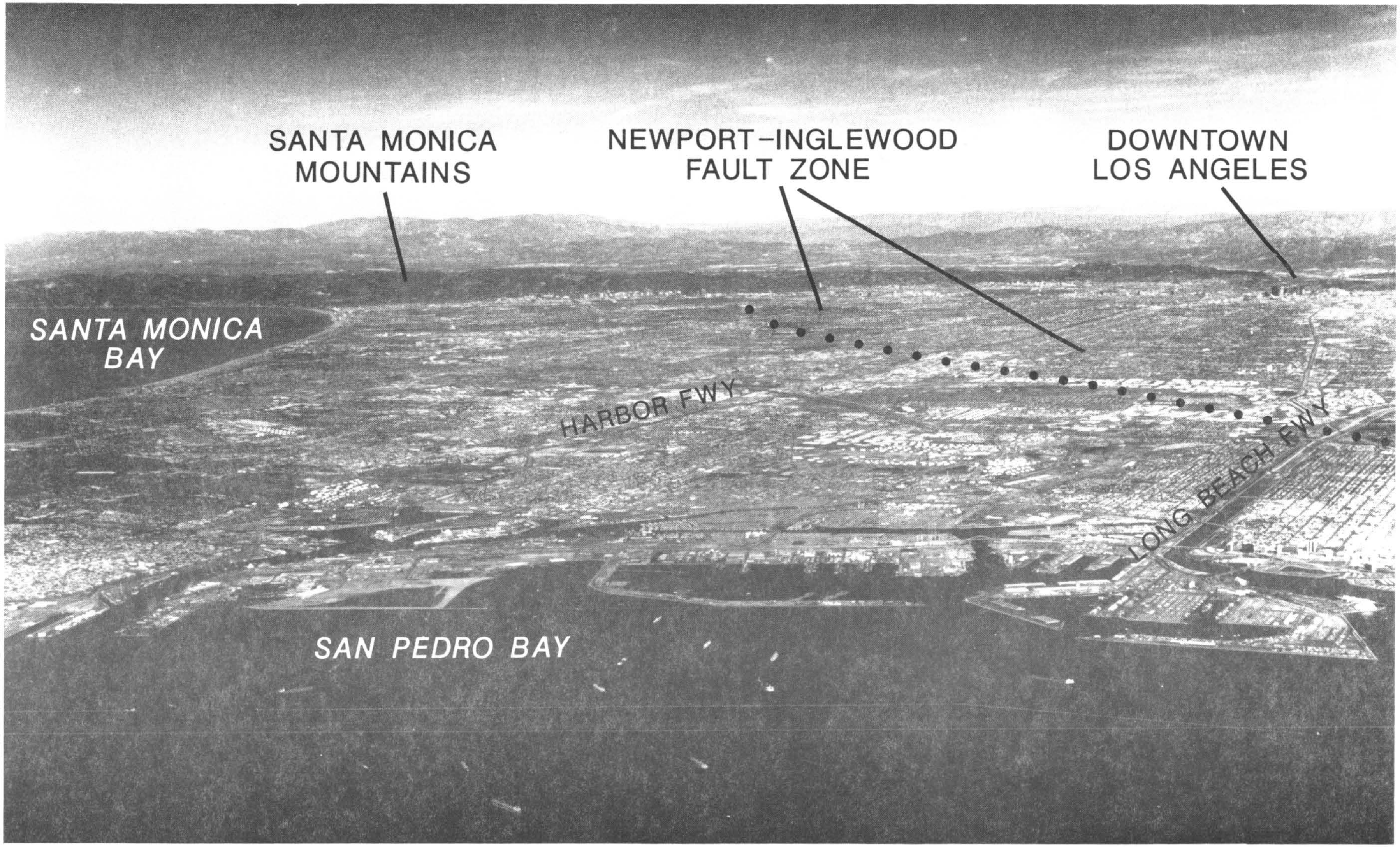
- More than 500 potentially damaging earthquakes (magnitude greater than 5) have occurred in California or near its borders since 1769. These earthquakes have been responsible for the deaths of several thousand people and $2 billion in property damage.

- Scientists agree that during the next 50 years California can expect at least one great earthquake (magnitude about 8) and several smaller destructive earthquakes.

- Earthquakes of magnitude about 6 or greater have caused significant loss of life and property in California during the last 20 years: 1968 Borrego Desert, 1971 San Fernando, 1975 Oroville, 1979 Imperial Valley, 1979 Coyote Lake, 1980 Livermore, 1980 Mammoth Lakes, 1980 offshore Humboldt County, 1983 Coalinga, 1984 E. of San Jose, 1984 NW of Bishop, 1986 Palm Springs, 1986 Chalfant (Mono County), 1987 Whittier Narrows, and 1987 Superstition Hills (Imperial County).

- The Newport-Inglewood Fault Zone (NIFZ) was the source of the destructive 1933 Long Beach earthquake (magnitude 6.3), which took 120 lives.

- A major earthquake (magnitude about 7) on the NIFZ within the highly urban Los Angeles Metropolitan area poses one of the greatest hazards to lives and property in the nation. This scenario portrays many of the consequences of such an earthquake. Hopefully, increased awareness of specific damage effects will stimulate regional planning programs to cope with this eventuality.



Photograph 1. Northerly view of Metropolitan Los Angeles from the Harbors to the Santa Monica Mountains. Photo courtesy of Port of Los Angeles.

EXECUTIVE SUMMARY

The Earthquake Threat

The Newport-Inglewood Fault Zone (NIFZ) was the source of the destructive 1933 Long Beach earthquake of magnitude (M) 6.3. Other damaging earthquakes have occurred on the NIFZ, both before and after 1933.

The northwestern end of the NIFZ is near Beverly Hills. The NIFZ extends southeasterly to include the epicenter of the 1933 earthquake offshore from Newport Beach, and beyond. A major earthquake (M about 7) on the NIFZ would strongly affect the Los Angeles metropolitan area. The impact of such an event on the network of lifelines is addressed in this scenario.

The Scenario Earthquake

The scenario earthquake of M about 7 assumes subsurface faulting on the NIFZ from near Beverly Hills to offshore Laguna Beach (75 km or 45 mi). Surface displacements averaging 1 m or 3 feet (maximum 2 m or 6 feet) occur on the discontinuous segments of active (Holocene) faults in the NIFZ. Potentially damaging shaking continues for about 25 seconds within 40 km (25 mi) of the NIFZ. Aftershocks occur for weeks, with a few of magnitude comparable to the Whittier Narrows earthquake (M 5.9) of 1 October 1987.

Because large earthquakes occur less frequently than small ones, the likelihood of occurrence of the scenario earthquake is in general lower than that of a M 6.3 event such as occurred in 1933. The scenario event provides a possible worst case for emergency planning.

Seismic Intensity Distribution

Intensity VIII or greater Modified Mercalli (damage to ordinary buildings and partial collapse of weak structures) extends throughout the alluvial sections of the Los Angeles basin to Monrovia and San Fernando, and coastal Orange County to San Juan Capistrano.

Intensity IX (considerable damage and partial collapse of ordinary buildings) occurs in the alluvial areas within 5 miles of the NIFZ.

Ground breakage could produce intensities greater than IX, in the 2 km wide NIFZ, in areas of potential liquefaction such as the harbors, and in areas of potential landslides such as the Santa Monica Mountains and Palos Verdes Hills.

Comparison to M 8 Earthquake on the San Andreas Fault

The NIFZ is located within the Los Angeles metropolitan area, whereas the San Andreas fault (SAF) is more than 30 miles distant. Consequently, in the Los Angeles metropolitan area, the impact of an earthquake of M 7 on the NIFZ is stronger than the impact of a M 8 earthquake on the SAF.

Hospitals

Of the 155 acute care hospitals in Los Angeles and Orange counties, 143 are located in the planning area within 25 miles of the NIFZ, including 55 hospitals located within 5 miles of the NIFZ. It is estimated that 7,439 of the 13,000 beds within 5 miles of the NIFZ, will be unavailable due to damage, restricted access, and loss of utilities. In the zone from 5 to 25 miles from the NIFZ, bed loss is estimated at 25%. No bed loss occurs in the 12 hospitals (2,000 beds) at distances greater than 25 miles from the NIFZ. The total bed loss in Los Angeles and Orange counties is 14,439 of 43,000 beds available, or 34%.

Highways

Route 1 is damaged by a landslide at Pacific Palisades near Santa Monica, and by liquefaction at Marina Del Rey. Route 1 is open to emergency traffic in Long Beach, but closed south of there.

Route 22 (Garden Grove Freeway) is damaged at the interchange with Route 405 (San Diego Freeway).

Route 39 (Beach Boulevard) is damaged at the interchanges with Routes 405 and 22.

Liquefaction on Terminal Island has damaged the approaches of 3 bridges: Vincent Thomas, Gerald Desmond, and Schuyler Heim.

Route 101 (Hollywood Freeway) is blocked at the Hollywood Boulevard and Sunset Boulevard over-crossings.

Rupture of the roadway and utility pipelines near the Route 110 (Harbor Freeway)/El Segundo Boulevard interchange necessitates a lengthy detour.

Route 405 is blocked by a landslide in Sepulveda Canyon. Route 405 is closed from Route 110 to Route 605 (San Gabriel River Freeway), and from Route 22-East to Irvine.

Route 605 is partially closed south of the interchange with Route 91 (Artesia Freeway).

Route 710 (Long Beach Freeway) is closed between Route 91 and Long Beach.

<u>Airports</u>

Los Alamitos Armed Forces Reserve Center sustains significant damage to runways, fuel tanks, and other structures.

Long Beach International sustains significant damage to the control tower and other facilities, but the runways remain functional. Freeway damage (I-405) will impair access from the south.

Orange County (John Wayne) sustains damage to the control tower, runway, fuel tanks, and other structures. The runway damage may be repairable in 24 hours. Access will be limited by damage to State 55 and 73 and I-405.

Los Angeles International (LAX) sustains some damage to structures and facilities, but the runways remain functional. Damage to access routes, including the Century Boulevard/Sepulveda Boulevard interchange, will reduce the capacity of LAX to 30% for two days.

Railroads

Ground and rail failures occur in the Wilmington, Long Beach, and Seal Beach areas. The rail bridge to Terminal Island is closed.

The Los Angeles to Santa Monica line is closed by faulting at the bridge over Ballona Creek.

The lines from Los Angeles and from Watts to El Segundo are closed due to faulting and shaking damage to bridges.

Faulting closes the line from Compton to East Long Beach. The bridge at the Route 710 crossing just west of the Los Angeles River is damaged.

The line into Seal Beach Naval Weapons Station is closed by faulting and liquefaction.

The Orange to San Diego line is closed due to liquefaction.

Los Angeles - Long Beach Harbor

Access to Terminal Island is limited to Ocean Boulevard across Gerald Desmond Bridge, because of approach failures at Vincent Thomas, and Schuyler Heim bridges.

In Long Beach, Route 710 is closed due to liquefaction, and access to the southeast basin is limited to Queensway Bridge. Liquefaction and settlement severely restrict rail access, and damage many rail-mounted gravity cranes.

Utility lines, oil pipelines, and waste water lines are extensively damaged, reducing the harbor operations to 25 percent for one week.

Fires occur in the harbor area; these and ruptured oil storage facilities pose the threat of a major fire.

Oscillatory water waves in enclosed bodies of water (seiches) have damaged ships and moorings in the harbor areas from Santa Monica to Newport Beach.

Communications

Within 25 miles of the NIFZ, telephone lines designated for essential services are 25% usable in the first day, 50% usable in the second day, and 75% usable at the end of the third day. The availability of telephone communications for the public is significantly lower.

Electric Power Facilities

Five power plants: Harbor, Long Beach, Alamitos, Haynes, and Huntington Beach are shut down for more than 3 days. A post-earthquake inspection at the San Onofre nuclear power plant indicates no damage.

Five major transmission substations in the Culver City-Compton area are out of service for more than 3 days, making it difficult to reroute power into the area.

The 3 major substations serving coastal Orange County are out of service for more than 3 days, making it difficult to reroute power into the area.

Water Supply

The flow of water in primary transmission lines crossing or within the fault zone is reduced by half for the first day and will return to normal in a week. Areas to the southwest of the NIFZ, from Huntington Beach to Inglewood, must rely on local storage or tank trucks for drinking water.

Waste Water

The principal treatment plants in Los Angeles County, at El Segundo and Carson, are damaged and operate at less than 50% capacity. The main Orange

County plant is in the NIFZ north of Newport Beach and is severely damaged; it will be inoperable for several months.

Main waste water lines into the Carson treatment plant from the north (San Gabriel Valley) and the east (Long Beach) are heavily damaged at the fault crossing between Compton and Long Beach.

Damage and lack of fresh water for treatment and of electrical power for pumping, results in sewage flowing into soils, channels, and streets, contaminating the ground water and the coastline.

Natural Gas

Along the NIFZ there are thousands of damaged mains, valves, and service connections. There are numerous fires in streets at broken gas lines, and in structures at broken houseline connections. Faulting causes breaks in major transmission pipelines at three locations: Slauson Avenue, 104th Street, and along the Los Angeles River.

Ground failures cause breaks in transmission lines in Sepulveda Canyon and Marina Del Rey.

In Long Beach Harbor the trunk line crossing at the Heim Bridge is broken due to ground failure.

The high pressure gas line to the Huntington Beach power plant breaks where it crosses the marshlands east of Bolsa Chica State Park.

Petroleum

A major fire rages for several days at one of the refineries in the Carson-Wilmington area.

Many fuel lines rupture at the fault crossings, between Baldwin Hills and Huntington Beach.

In Los Angeles Harbor, ground failures rupture oil pipelines and storage facilities, discharging oil into the Channel. A fire on Mormon Island poses the threat of a major conflagration.

The fuel line to LADWP's power plant in East Long Beach is ruptured by faulting.

In Seal Beach, ground failures have damaged storage facilities and piping, with consequent fuel spillage into Alamitos Bay.

The fuel line to Huntington Beach Power Plant is damaged by faulting.

PREVIOUS WORK

Following the devastating eruption of Mount St. Helens in 1980, President Carter requested the National Security Council to consider the implications of the occurrence of a large damaging earthquake in California. The results of this analysis were presented by the Federal Emergency Management Agency (FEMA) in 1981. One of the major conclusions was that it is unlikely that the collective emergency response capabilities of all levels of government and the private sector would be adequate to cope with a major destructive earthquake in a metropolitan area.

In response, the Governor's Emergency Task Force on Earthquake Preparedness was established in February 1981. Some 30 committees were formed to deal with improvement of the many emergency response functions that would be needed in such an emergency; e.g., communications, search and rescue, fire services, medical services, air transport, etc. A Threat Assessment Committee was also created to characterize the consequences of credible great earthquakes as a basis for these emergency response planning efforts. Working with the Task Force, the Department of Conservation's Division of Mines and Geology developed two earthquake planning scenarios (Davis and others, 1982a, 1982b). These scenarios were based on a repeat of the 1906 San Francisco earthquake (M about 8) on the northern San Andreas fault and a repeat of the 1857 Fort Tejon earthquake (M about 8) on the southern San Andreas fault. These analyses expanded and updated much of the information compiled in two earlier reports covering earthquake losses in northern and southern California (NOAA, 1972 and 1973).

While these two planning scenarios for the northern and southern San Andreas fault are basic for emergency planning, it was apparent that similar analyses were needed for other faults in metropolitan areas. Of paramount consideration is the possibility of major earthquakes (magnitude 7 or greater) on the Newport-Inglewood fault zone (NIFZ) and on the Hayward fault.

The Division of Mines and Geology, in collaboration with structural engineer Karl V. Steinbrugge and others, undertook development of planning scenarios for the Hayward fault (Steinbrugge and others, 1987) and for the Newport-Inglewood fault zone (this scenario).

Scenarios have previously been completed for various earthquakes, including an event of M 7.5 on the NIFZ (NOAA, 1973). The present scenario for an earthquake of M about 7 significantly augments and updates much of the information contained in the 1973 NOAA report.

Certain effects of earthquakes on the NIFZ were also addressed in several recent reports. Ziony and others (1985) predict the geologic and seismologic effects of a M 6.5 earthquake on the NIFZ. An Orange County report (1986) shows the intensity and ground failure map for a M 7.5 earthquake on the NIFZ, but does not specify the effects on lifelines or other facilities. The City of Los Angeles PEPPER report (Pre-Earthquake Planning for Post-Earthquake Rebuilding, 1987) discusses the effects on buildings, not lifelines, of a repeat of the M 6.3 Long Beach earthquake of 1933.

The Earthquake Engineering Research Institute sponsored a seminar on "Future Earthquake Losses in the Los Angeles, California Region". The proceedings can be obtained from EERI, 6431 Fairmount Avenue, Suite 7, El Cerrito, California 95430. One of the papers treated fire losses from earthquakes. A model for post-earthquake fire applied to a M 6.5 earthquake on the NIFZ indicated losses of several billion dollars.

Steinbrugge and others (1981) estimated the number of deaths, resulting from an earthquake of M 7.5 on the NIFZ to range from 4,000 to 21,000 depending on the time of occurrence. Hospitalized casualties were estimated at 4 times the number of deaths, and significant non-hospitalized casualties at 30 times the number of deaths. The scenario earthquake is smaller (M about 7), and the deaths and injuries resulting from it should be less than those estimated for the M 7.5 event.

While no scenario is accurate in detail, it provides planners with a regional pattern of the degree and types of problems that will confront emergency response personnel. When more detailed engineering and geologic data become available, these scenarios can be periodically updated.

This planning scenario is intended to contribute to the efforts of the following users:

- o Local, state, and federal officials with emergency planning responsibilities.
- o Elected officials who should visualize the threat in order to commit themselves to the leadership roles needed to cope with destructive earthquakes.
- o Private sector managers and planners who must understand the scope of the hazard in order to prepare for it.
- o Educators, journalists, and others who must communicate the character of the threat to motivate citizens to prepare for it.
- o The general public who need to support public mitigation efforts and develop personal strategies in order to minimize the effects of the earthquake on themselves and their families.

Photograph 2. House in the Long Beach-Compton area, displaced off its foundation in the 1933 earthquake.
Photo by Olaf P. Jenkins.

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NEWPORT-INGLEWOOD EARTHQUAKE PLANNING SCENARIO

INTRODUCTION

The Planning Area

The planning area for this study is centered in the Los Angeles metropolitan area. The area is approximately 30 miles (50 km) wide and is bounded by the Pacific coast from Santa Monica to San Juan Capistrano on the west and includes the cities of San Fernando, Pasadena, and Orange on the east. The area encompasses the vast majority of the 10 million people in Los Angeles and Orange counties. It encompasses virtually all of the area likely to experience Modified Mercalli intensities of VIII or greater resulting from this scenario earthquake and, thus, all areas within which significant structural damage can be expected.

The planning area for this study is designated "Planning Area 5". Planning Areas 1 and 2 designate the areas encompassed in previous scenarios based upon M 8.3 earthquakes on the San Andreas fault in northern and southern California (Division of Mines and Geology Special Publications 61 and 60, respectively). Planning Area 3 covers a M 7.5 earthquake on the Hayward fault (DMG Special Publication 78). Planning Area 4 covers a M 6.8 earthquake in the San Diego area.

Earthquake Planning Scenario Maps

Eight EARTHQUAKE PLANNING SCENARIO maps are included in this report. These maps show the locations of major transportation and utility lifelines and principal medical care facilities. One map (Map 5-S) summarizes the regional geologic and seismological basis for development of the damage assessments. This basic geotechnical information includes the location of the Newport-Inglewood fault zone (NIFZ), the predicted shaking intensity distribution, the areas with high potential for ground failure (notably liquefaction), and areas subject to seismically induced landslides. This information enables the reader to visualize the extent to which particular facilities are exposed to ground failure hazards and to the predicted shaking intensities.

The EARTHQUAKE PLANNING SCENARIO maps demonstrate that earthquake damage will not be uniform across the planning area. Damage will be related to the design of structures, the geologic ground conditions upon which they are built, their distance from the fault, and the character of the earthquake shaking.

The ground surface in areas of competent bedrock is not likely to suffer permanent deformation, except for fault rupture and warping along the NIFZ, and landslides in the mountains. Structures located on compressible deposits where the water table is high, are subjected not only to the effects of relatively low frequency, high amplitude vibrations, but possibly also to disruption caused by differential settlement, lateral spreading or liquefaction. These considerations are reflected in the damage assessments.

Damage Assessments

For planning purposes, damage assessments have been hypothesized for various individual facilities. These damage assessments are based largely upon the predicted intensity distribution and areas of potential ground breakage as shown on the EARTHQUAKE PLANNING SCENARIO maps. The assessments are based on the effects of past earthquakes, comments by engineers and public agency officials, and judgments by the authors. Users of these data must recognize that assessments of the performance of individual facilities are hypothetical and are not the result of site-specific evaluations. They are intended to portray, for planning purposes, some of the types of earthquake effects that may occur, thereby providing emergency planners and other users with a reasonable perspective on the impact of this scenario earthquake. Future corrective measures could revise some assessments.

Use and Limitations of Scenario Maps and Damage Assessments

The approach in formulating damage assessments was, first, to evaluate the regional pattern of ground shaking and ground deformation and, second, to interpret the resulting performance of various major facilities. The effects of the scenario earthquake on individual bridges, power plants, or other lifeline elements, are based mainly on the authors' judgments. It is, therefore, improper to use the earthquake scenario for any purpose other than emergency response and preparedness planning. For example, decisions on whether to replace or retrofit lifeline components must be based on detailed investigations of the components and their geologic settings. This scenario does, however, identify high risk areas where such detailed evaluations should be given priority.

Some damage predictions, such as those resulting from surface faulting, have a relatively high likelihood of occurring (given this scenario earthquake). Others are more speculative. The damage assessments also vary in completeness. For example, information was developed for all seven major airports. On the other hand, developing information for all major water or electrical power facilities is beyond the scope of this report.

The damage assessments for specific transportation and utility lifeline facilities (except highways) are keyed to the appropriate EARTHQUAKE SCENARIO map, using a map number.

The Earthquake Planning Scenario maps and related damage assessments illustrate a regional damage pattern that is likely to result from this specific scenario earthquake, i.e., an earthquake of magnitude about 7 resulting from subsurface rupture of a 45-mile (75 km) length of the NIFZ. An earthquake of significantly different magnitude on this fault or an event on any one of many other faults in the planning area would result in a markedly different intensity pattern and consequent damage.

The predicted seismic intensity distribution from which the damage is assessed, is based upon a particular model. There is no general agreement as to the most realistic model to be used for predicting intensity distribution, and a different model would yield a different intensity pattern. In addition, the quality of available information upon which the seismic intensity distribution map is based varies throughout the planning area. Only general geologic information is available for most lifeline elements. Modeling of ground shaking on a regional basis using this generalized geologic information can produce plausible damage conclusions appropriate only for emergency planning. Conclusions regarding specific structures, such as the desirability of upgrading seismic resistance, require detailed site-specific geologic information as well as engineering analysis.

Section 1.

GEOLOGY

AND SEISMOLOGY

THE NEWPORT-INGLEWOOD FAULT ZONE

The Newport-Inglewood fault zone (NIFZ) is familiar to most southern California geologists. Such familiarity is probably not as widely shared by professionals in the realm of emergency response planning. To acquaint these professionals with the NIFZ, we include the following excerpts from California Division of Mines and Geology Special Report 114, "A Review of the Geology and Earthquake History of the Newport-Inglewood Structural Zone, Southern California" by Allan G. Barrows (1974).

Physiographic Features

It is the easily observable alignment of hills and mesas (Figure 1) from Newport to north of Inglewood that first suggested and still supports the concept that the uplifted features are related to a common, linear, underlying structural element which has been called the "Newport-Inglewood fault." The landforms themselves have resulted from a combination of different rates of uplift and the effects of different agents of erosion at various localities along the zone. Particular emphasis is placed upon the effects of faulting on these landforms.

CHEVIOT HILLS

Late Pleistocene marine deposits are exposed on the surface of these low, rolling hills which range in elevation from 175 to 250 feet. Except in the vicinity of Century City, these are completely surrounded by south or east-sloping alluviated terrain. The name Cheviot Hills is preferred over the name Beverly Hills (Poland and others, 1956; 1959) because there is good evidence that the Newport-Inglewood structural trend does not underlie the old Beverly Hills oil field as was once assumed but veers, instead, westward in the vicinity of the Cheviot Hills oil field (Crowder, 1968). Poland and others (1959, p. 76) tentatively extended the Inglewood fault (see below, Baldwin Hills) northward across Ballona Creek and suggested that it lay along an eastward-facing escarpment in the vicinity of Beverly Drive and Hillsboro Avenue in the Cheviot (Beverly) Hills.

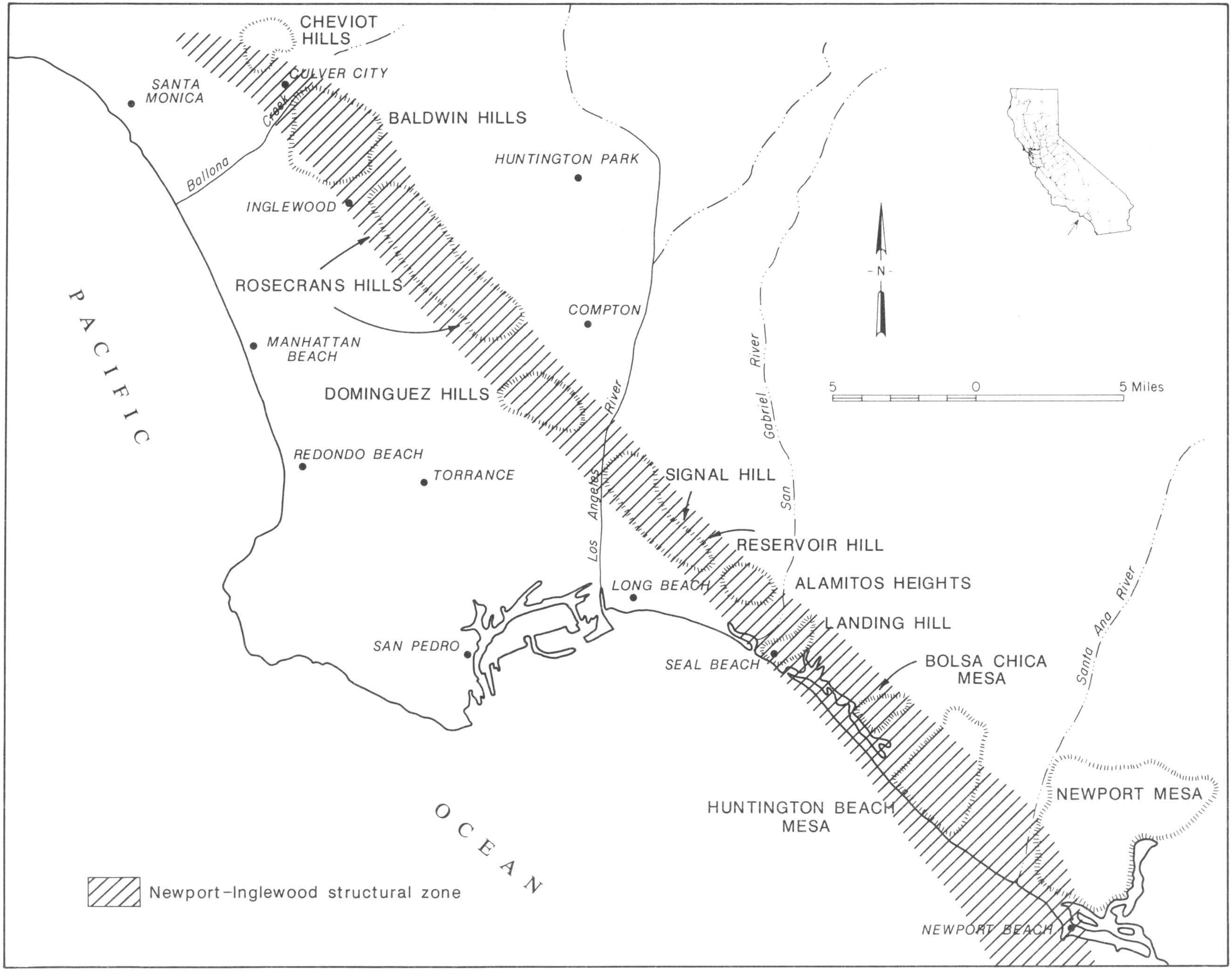


Figure 1. Hills and mesas along the Newport-Inglewood fault zone, southern California. (Modified from Barrows, 1974).

BALDWIN HILLS

The highest elevation of any uplift along the Newport-Inglewood fault zone is attained by the Baldwin Hills, which rise 511 feet above sea level. There is about 400 feet of relief between the summit of the hills and the Ballona Creek valley to the north.

The central portion of the Baldwin Hills is transected by a graben. The eastern side of this depression is bounded by a west-facing fault-line scarp ranging in height from 75 to 150 feet. This scarp is the surface expression of the Inglewood fault (Driver, 1943, p. 308). On the southeast side of the Baldwin Hills, there is an east-facing scarp which may represent the northern continuation of the Potrero fault. This scarp is as much as 50 feet high east of Centinela School.

ROSECRANS HILLS

The Rosecrans Hills (Figure 1) extend for about 8 miles from Centinela Creek to the Dominguez Hills as a tract of elongate, gently rising land.

The steeper northern escarpment, crossing Inglewood Park Cemetery and the grounds of Hollywood Park race track, represents a fault- line scarp along the Potrero fault.

DOMINGUEZ HILLS

Although commonly referred to as the Dominguez Hills, the simple domal form is more properly a single hill.

Minor faults known to exist in the underlying oil field are not exposed at the surface. However, exposures created during construction in 1969 along the east-facing bluff revealed several south-dipping reverse faults that displaced the marine sands beneath the soil near the top of the hill.

SIGNAL HILL AND RESERVOIR HILL

Signal Hill is the most distinctive topographic feature along the entire Newport-Inglewood structural zone. The hill rises abruptly more than 300 feet above the surrounding nearly level plain. Nearby Reservoir Hill is flat-topped and exhibits much lower relief rising only about 100 feet above the adjacent lowlands. In addition to Signal Hill and Reservoir Hill, the low, rolling topography in the vicinity of Los Cerritos, immediately southeast of the Los Angeles River, belongs to the same tectonic uplift.

ALAMITOS HEIGHTS AND LANDING HILL

The topographic expression of the Seal Beach dome has been breached by erosion along the San Gabriel River. Remnants of the structure at the surface are the semi-ellipsoidal, truncated landforms of Alamitos Heights and Landing Hill.

BOLSA CHICA MESA

About 3,000 feet inland from the shoreline, Bolsa Chica Mesa is separated into two parts by a linear, west-facing escarpment. This feature is the surface expression of the single major fault of the Newport-Inglewood structural zone that reaches the surface of Bolsa Chica Mesa. The northwestward dip of the mesa surfaces is attributed to the underlying northwestward-plunging Huntington Beach anticline.

HUNTINGTON BEACH MESA

The surface of Huntington Beach Mesa is divided into three portions, the boundaries of which parallel the coastline. While not scarp-like, these boundaries represent the surface expression of faults of the Newport-Inglewood zone. The highest elevation is not bounded by an abrupt scarp but by a ramplike landform. This high point is one of a series of aligned hills along whose seaward side lies the trace of the north branch of the Inglewood fault (also called High School fault).

NEWPORT MESA

Newport Mesa is characterized by an upper surface sloping very gently inland from an 85 to 105 feet high cliff that faces the sea along its southern edge. The Newport-Inglewood structural zone trends out to sea beneath the southwestern corner of the mesa.

Subsurface Features of NIFZ

The NIFZ is expressed at the surface by a northwest-trending zone of faulted anticlines. According to Yeats (1973), "All these anticlines are sites of oil fields; from northwest to southeast, these are the Cheviot Hills, Inglewood, Potrero, Howard Townsite, Rosecrans, Dominguez, Long Beach, Seal Beach, Sunset Beach, Huntington Beach, and West Newport oil fields...On the northwest, the zone terminates abruptly against the Malibu

Coast fault system in the vicinity of the Cheviot Hills oil field, but the extension of the zone to the southeast beyond the West Newport field is a matter of controversy". Ziony and Yerkes (1985) discuss the southeastern extension as follows: "Faults having similar trends and projections occur offshore of San Clemente and in San Diego (the Rose Canyon and La Nacion faults). Altogether, these various faults constitute a system more than 240 km long".

The oil producing anticlines described above, and the physiographic features described in the last section, are underlain by a deep seated fault zone. At depth, the NIFZ is a nearly vertical right-lateral strike-slip fault, with the Pacific Ocean side moving northwestward relative to Los Angeles (Harding, 1973). At the surface, the individual fault segments comprising the NIFZ are discontinuous. For example, the Inglewood fault segment is 4 miles (6 km) long. The sense of offset between surface fault segments is left stepping, which indicates a through-going right-lateral strike-slip fault at depth.

Hauksson (1987) analyzed 70 small earthquakes (M 2.5 to M 3.8) that occurred in and bordering the NIFZ from 1973 to 1985. He observed earthquake epicenters along the NIFZ from Dominguez Hill to Cheviot Hills. Adjacent to Long Beach however, the earthquake epicenters are offset 2 to 3 miles (3 to 5 km) to the east of the NIFZ, along the trend of the subsurface Los Alamitos fault. Most of the earthquakes occurred at depths of 4 to 7 miles (6 to 11 km), which is normal for southern California.

THE ALQUIST-PRIOLO SPECIAL STUDIES ZONES

The Alquist-Priolo Special Studies Zones Act was enacted in 1972 in order to mitigate the hazard of surface fault rupture along active faults in California. The purpose of this Act is to avoid locating structures for human occupancy across traces of active faults. Responsibilities for carrying out the provisions of the law are shared by State and local government. Specifically, the State Geologist (California Department of Conservation's Division of Mines and Geology) is required to establish regulatory zones--known as Special Studies Zones (SSZ's)--for those faults considered to be "sufficiently active and well-defined as to constitute a potential hazard to structures from surface faulting or fault creep." Cities and counties must regulate most building projects within the SSZ's by requiring geologic investigations prior to issuing development permits.

SSZ maps were first issued for the NIFZ in 1976. The SSZ's for the NIFZ were subsequently revised in 1986 as part of DMG's long-range Fault Evaluation and Zoning Program (Hart, 1985; Hart and others, 1986). The active fault traces from the SSZ maps are reproduced on Map 5-S. They are discontinuous segments, that are generally offset in a left-stepping pattern, as in Long Beach. Some of these traces show evidence of active movement during Holocene time or the last 11,000 years (Bryant, 1988).

Reduced-size copies of the SSZ maps for the NIFZ are appended to this report. Active traces are not well located for some segments of the fault. In general, the SSZ maps distinguish those traces of the fault that are well defined from those that are not. The effectiveness of the Alquist-Priolo Act varies from place to place, depending largely on how well the Newport-Inglewood fault is defined. Even so, the law only applies to new real estate development and structures for human occupancy. Many older structures (including some important ones) sit astride active traces of the fault. The extent of damage produced by this scenario event will depend on the amount of displacement that occurs locally on the fault and on the measures taken to mitigate the hazard.

Photograph 3. Buildings damaged during 1920 Inglewood earthquake on western side of Commercial Street (now Brea Avenue) in Inglewood. Photo reproduced from Plate 8 of Taber (1920).

EARTHQUAKE HISTORY

Earthquakes have been reported in the Los Angeles area since 1769, when the Portola expedition felt more than two dozen earthquakes during one week, while they traveled between the Santa Ana and Los Angeles rivers.

PRE-1933 EARTHQUAKES

The following information on the earthquakes of 8 and 21 December 1812 was interpreted by Toppozada and others (1981) from documents written by the Franciscan missionaries in December 1812 and January 1813.

8 December 1812

An earthquake on this day destroyed the bell tower at Mission San Juan Capistrano (intensity VII), causing the roof of the church to cave in, and killing 40 Indians who were at Mass. At Mission San Gabriel, statues at the church were broken, the bell tower had many cracks, and other Mission buildings were extensively damaged (VII). At Mission San Fernando, the walls of the church were damaged (VII), and 30 beams were required to support them.

The M 6.3 Long Beach earthquake of 1933 generated intensity V to VI effects in Capistrano, San Gabriel, and San Fernando. The earthquake postulated in this scenario (M about 7 on the NIFZ) generates intensity in the low VIII range at Capistrano, San Gabriel, and San Fernando.

Toppozada and others (1981) compared the 1812 and 1933 earthquakes, and suggested that the 1812 epicenter was located near the 1933 epicenter on the NIFZ or on other neighboring faults. Evernden and Thomson (1985) independently determined that the 1812 intensity effects are consistent with an origin on the NIFZ.

The 1812 intensity effects are not sufficient to define the source fault. Jacoby and others (1987) found evidence from tree-rings for an 1812 earthquake on the San Andreas fault 30 miles northeast of San Gabriel, and hypothesized that it was the 8 December event.

21 December 1812

This major southern California earthquake was not centered in Los Angeles or Orange counties. It is discussed here to avoid the confusion that is sometimes made between the two major events of December 1812.

On 21 December 1812, an earthquake strongly damaged the Missions at San Buenaventura, Santa Barbara, Santa Ynez, and Purisima Concepcion. The 21 December 1812 earthquake also had a magnitude of about 7 and was apparently located in the Santa Barbara Channel (Toppozada and others, 1981). The intensity effects of this earthquake were also interpreted by Evernden and Thomson (1985) to indicate an origin in the Santa Barbara Channel.

Confusion of the two southern California earthquakes of December 1812 has sometimes led to the mistaken impression that a single earthquake was destructive from Orange County to Santa Barbara County. In fact, there were two separate events, each damaging a different area. The 8 December event was damaging in Orange and Los Angeles counties, and the 21 December event was damaging in Santa Barbara and Ventura counties.

10 July 1855

The bells of Mission San Gabriel were thrown down, and 26 buildings in Los Angeles were damaged. The earthquake was felt from San Bernardino to Santa Barbara. It was probably located on one of the surface faults bordering the Los Angeles basin, such as Hollywood-Raymond, Whittier, or

NIFZ. It could also have been located on a concealed fault, as was the case for the 1987 Whittier Narrows earthquake.

21 June 1920

This earthquake of magnitude 4.9 (Richter, 1970) was destructive only at Inglewood. Because of this, Taber (1920) assumed a shallow epicenter at or west of Inglewood. According to Taber (1920), "The damage to buildings was due to poor construction rather than to the intensity of the vibrations. Thin brick walls built as fronts to wooden buildings and not tied in properly, toppled outward into the street. Poorly-built brick cornices and fire walls along the fronts of buildings were shaken off."

THE LONG BEACH EARTHQUAKE OF 10 MARCH 1933

The hypocenter of this M 6.3 earthquake was just off the coast of Newport Beach at a depth of about 10 km (6 miles). Aftershocks (of magnitude up to 5.5) occurred along the NIFZ from Newport Beach to Long Beach, a distance of 25 km (15 miles). This indicates that the earthquake was generated by about 25 km of subsurface faulting that initiated near Newport Beach and propagated northwestward along the NIFZ toward Long Beach. Fault rupture was not identified at the surface, and no seismic sea waves were observed. The isoseismal map (Figure 2) shows that the area damaged at intensity VII to IX extended from Laguna Beach to Marina Del Rey and inland to Whittier.

According to Richter (1958), "Loss of life is commonly stated as 120, and property damage at 50 million dollars." The 1933 earthquake stimulated passage of the Field Act by the California legislature, under which the construction of public schools is regulated, and the Riley Act which regulates buildings larger than two-family dwellings.

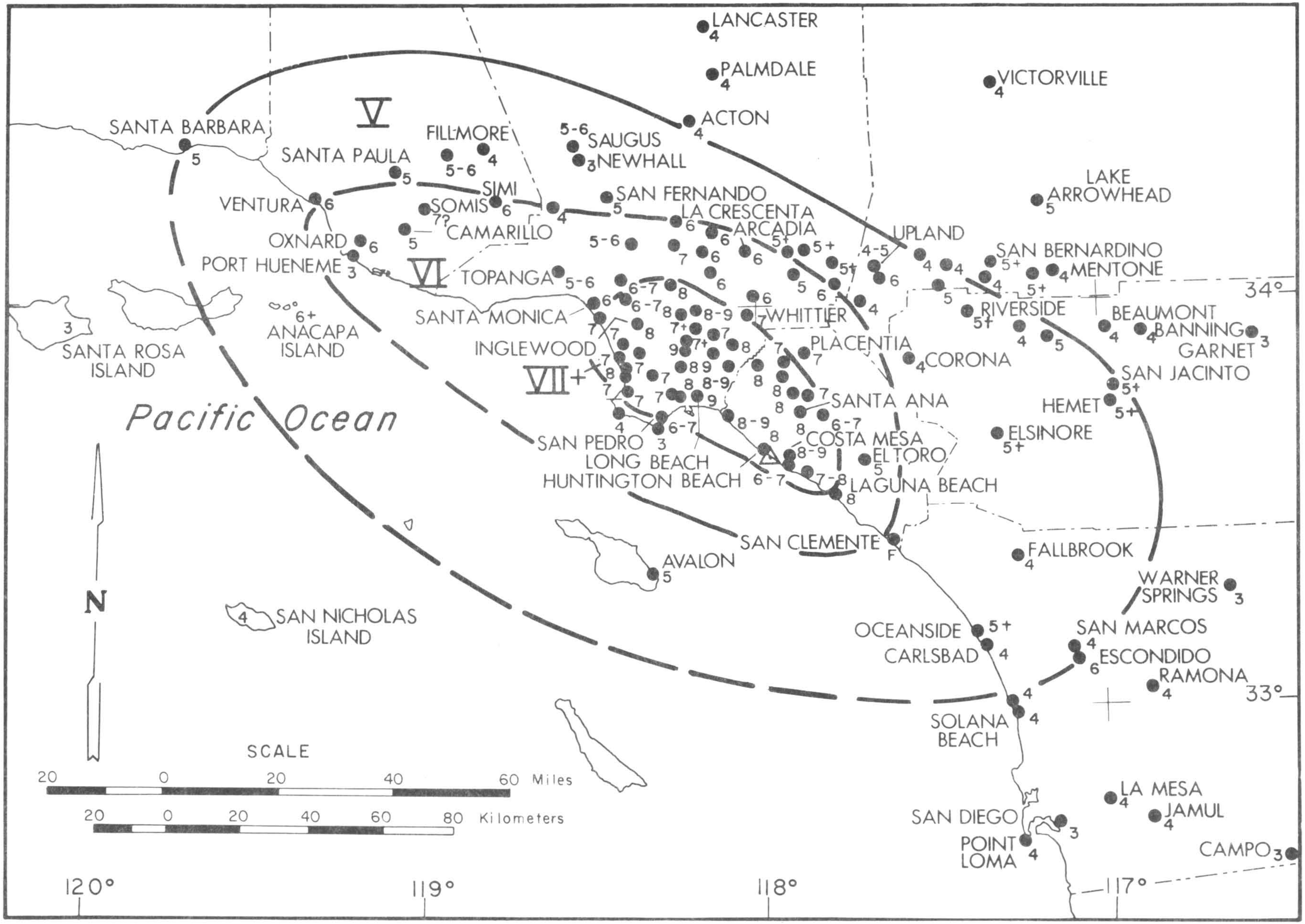


Figure 2. Isoseismal map of the 1933 Long Beach earthquake. Arabic numeral indicate Modified Mercalli intensities. From Toppozada and Parke (1982).

The following excerpts from Wood (1933) describe the effects of the 1933 event:

> General damage of significant degree--the upper range of grade VII of the modified Mercalli scale of 1931, and higher--was caused in an area bounded by a rudely elliptical curve drawn approximately through Manhattan Beach, Inglewood, Hyde Park, Vernon, Downey, Norwalk, Fullerton, Santa Ana, and Laguna Beach. The longer, northwest-southeast axis of this area may be as much as 70 kilometers (say 45 miles) in length; its shorter northeastward semi-axis is at most 15 to 20 kilometers (say 9 to 12 miles) long. The land area seriously affected may amount to 1,200 square kilometers (say 450 square miles).
>
> In the aggregate, considerable damage was done outside this area, in isolated districts sporadically distributed. Much of it was of minor nature.
>
> Inside the area mentioned there are many places where significant damage was not conspicuous--on hilly ground or where underground conditions were not unfavorable and construction not too bad or unsuitable. This was noticeably the case on the compact sedimentary rock of the San Pedro Hills west of Long Beach. In fact, a considerable part of the area appeared to be characterized by intensity lower than grade VII of the 1931 scale. Even in the most vigorously shaken areas excellent construction on well-chosen or well-prepared foundations suffered relatively little, even at Compton where the proportion of damaged structures was greatest and the scene of destruction the most spectacular. Many chimneys remained standing in districts where general damage was conspicuous; but in a hurried survey there was not time to ascertain whether these were wholly undamaged.

There are a few sparsely distributed cracks in the ground in the wet, alluviated bottom land of the Los Angeles plain, 1 or 2 of which exceed a kilometer (0.6 mile) in length. These are diverse in direction and appear to be, without doubt, simply secondary cracks in magnitude. Their development is less marked than frequently happens with shocks of comparable intensity and size. To guard against misunderstanding, however, it should be stated that some of these cracks follow directions approximately parallel to the Inglewood fault zone, and other recognized faults, but it is clear that they do not mark, or follow, the surface outcrop of known or suspected faults.

Along the shore between Long Beach and Newport Beach, and in a few localities nearby a short distance inland, road fills across marshy land, and similar earth construction resting on wet sand or mud, settled, shook apart, or moved laterally, causing considerable damage to the concrete highway surfaces, and to the approaches to highway bridges, which, being better founded, were less affected. Analogous phenomena were observed where piers and landings adjoin the shore. In a few places elsewhere the roadway was buckled.

The following extracts are reproduced from "United States Earthquakes, 1933" (U.S. Department of Commerce). The material was originally compiled and published in a report of the National Board of Fire Underwriters entitled, "Report of the Southern California Earthquake of March 10, 1933".

Loss of life.--The number of deaths is placed at 120, which does not include those who died of heart disease or from exposure or over-exertion subsequent to the earthquake. Few persons were killed inside buildings. Probably two-thirds of the loss of life was occasioned by persons being struck by falling cornices, parapets, and ornaments as they tried to escape from shaking buildings. There is abundant evidence to show the futility of trying to escape while such a barrage is in progress. That the loss of life was so small is partly due to the fortunate hour at which the earthquake occurred [5:54 p.m.]; had it come 3 hours earlier when the schools were in session, the dead would have been numbered by thousands. Fortunate, too, for the comfort of the thousands of persons obliged to live in the open for several days was the mildness of the weather.

Property loss.--Total property loss in the shaken area was of the order of $40,000,000 including cost of repairs.

A conflagration in Long Beach was prevented by the following: the fire department received notification of fires by telephone, messenger, or direct discovery, although more or less delayed, in time to extinguish them before they could reach serious proportions; dangerous fires occurred in districts where the water supply was not seriously weakened; no fires occurred in the principal mercantile, beach, or industrial districts; and there was little or no wind.

Structural features.--The cities of Compton, Long Beach, and Huntington Park, and the smaller towns between them suffered more severely than other communities. These cities are located near the present course of the Los Angeles River, largely on soft material approaching swampy character in some locations. Compton and vicinity are on soft alluvial fill, probably well saturated; a large part of Long Beach proper is on firmer ground sloping toward the ocean from Signal Hill, but the fault line supposedly causing the disturbance passes directly through the city.

Ordinary masonry.--There was total collapse of some ordinary masonry buildings with wooden floors and serious damage to others due partly to faulty design and inferior grade of workmanship. Few in the shaken area have basements, and foundations are not carried down to any great depth. The greatest damage was to fronts and parapet walls. Ordinary brick buildings in the Compton area suffered severe damage.

School buildings throughout the shaken area suffered more than any other class of buildings. Passageways and exits were often piled high with debris due to toppling of architectural ornaments, towers, copings, etc. Many of these buildings were of brick-and-tile construction. Buildings with pronounced architectural effects were damaged much more severely than those of plainer design and more regular shape.

The report stresses that mortar used was frequently of low grade and in some cases of wretched quality. Not only that, but the actual laying of brick was sometimes of indifferent standard, with vertical joints especially slighted. In some walls that collapsed the brick fell out practically clean.

Steel-frame fireproof.--The majority of such buildings had brick or panel walls and often tile partitions. Owing to distortion of the unbraced flexible frames, panel walls were quite generally loosened and the bond between framing and walls broken, but walls were not shaken out except in a few instances. Distortion of frames was in general not sufficient to cause the diagonal cracking of panels which is characteristic in a severe shock. Damage to partitions or enclosure walls around stairways and elevator shafts of steel-frame buildings was very noticeable.

Reinforced-concrete frame.--Response of this type of building was analogous to those with steel frames. Panel walls of brick and tile were cracked and loosened, the latter occurring even in the downtown areas of Los Angeles, where the shock was not severe. Fracture of first-story concrete columns at top and bottom was quite marked. Failures of reinforced concrete were frequently at construction joints or cold joints where a day's pouring of concrete stopped and surfaces had not been cleaned.

More structural failures occurred in columns supporting heavy concentrated loads such as water tanks than in building columns. Reinforced concrete buildings with filler walls of the same material survived the shock with less damage.

General.--Well-built frame buildings on good foundations withstood the shock very well, even in the badly shaken areas. Some instances occurred where houses were moved bodily off their foundations, but there is every reason to believe that bolting of mudsills to foundations would have eliminated this difficulty. Nothing like a wholesale wrecking occurred in residential buildings in any locality. A common source of structural damage to frame buildings was the buckling of underpinning which was not sufficiently braced, dropping the building so that the first floor rested on the ground. A striking commentary is the good behavior of frame stucco dwellings and apartment houses near the Long Beach Polytechnic High School.

Thousands of brick chimneys were thrown down, fractures generally occurring at the roof line but numerous examples exist of chimneys of apparently unstable dimensions still standing, perhaps by reason of a superior grade of masonry. Tile roofs suffered little damage, indicating that the ordinary methods of fastening roof tiles are sufficient.

Oil properties.--Modern methods of storing and handling petroleum products were subjected to a severe test by the earthquake. In the Los Angeles Basin is the largest concentration of oil storage in the world, about 75,000,000 barrels being now in storage, and 60 percent of this lies within the area which was severely shaken. The tank farms and refineries at Watson Station are very close to the line of the Inglewood fault, and in addition are on soft swampy ground on which a maximum of damage would normally be expected. In spite of these unfavorable conditions, the loss to oil properties was a very slight percentage of the total investment in this industry.

The chief damage to the oil industry resulted from breakage of piping and pipe connections, especially where rigid connections are made to tanks. Tanks themselves, when well constructed, suffer very little. Much of the trouble could be avoided by providing a reasonable degree of flexibility in piping connections.

The experience of the oil industry in this earthquake was far different from that which past history would lead us to expect. In the Tokyo quake of 1923, practically all oil tankage was destroyed, tank connections were broken, the oil ignited and spread over a large area in the adjacent harbor.

Water supply.--The water systems supplying Santa Monica, Glendale, Pasadena, Alhambra, Pomona, and the major part of Los Angeles were unharmed. Systems supplying Huntington Park and Santa Ana received only slight damage. Long Beach and the harbor district of Los Angeles were kept in water with great difficulty.

At Long Beach the most serious trouble was caused by leakage from numerous breaks in distributing mains ranging in size from 4 to 12 inches. The three pumping stations which supply the distribution system were placed out of service by the first shock, leaving only elevated storage to supply the demand.

The Alamitos reservoir was replaced in 1931 with 6 steel tanks designed to withstand strong earthquake shocks and having a total capacity slightly in excess of 20,000,000 gallons. At the time of the earthquake they were about two-thirds full. They were undamaged, although the ground on which they rested was badly shaken and cracked.

The water department reports 127 breaks in distributing mains, not counting places at which pipes were pulled apart. In addition there were numerous breaks in Seal Beach, a small community to the southeast which is supplied by the Long Beach system, and it was out of water several days. Breaks were dependent on the character of soil, all occurring in sand, silt or filled ground, and none being reported in firm adobe. The widening of the sandy spit between Alamitos Bay and the ocean caused pipes to pull apart at many places so that in making repairs it was frequently necessary to install an extra 4 feet of pipe.

The 12-inch main under the channel was pulled apart 3 1/2 inches on Mormon Island and 4 inches on Terminal Island; there were also 21 leaks in the under water portion of the main, as determined by air pumped into it. The 16-inch main under the channel was found to be intact.

Steel tanks at ground level.--The Western Avenue tank of the Los Angeles Water Department is the most striking example of complete destruction suffered by any water-supply structure. It was built in 1917 on a slight knoll in a sparsely settled district 7 1/2 miles southwest of the congested value district. It survived the Inglewood earthquake of 1920 with only nominal damage, although it was only three-fourths of a mile from the fault line.

There was considerable distortion under wind action, and as the location was exposed to frequent and prolonged high winds, the weaving of the metal through 16 years may have induced fatigue.

At the time of the earthquake there were between 5,000,000 and 6,000,000 gallons of water in the tank. So violent were the forces wrecking the tank, that it appears almost as if an explosion had taken place. Portions of the shell were transported as much as 200 feet from their original positions, generally in a southwest direction. Undoubtedly wave action played an important part, the wave period probably synchronizing with the earthquake period and gradually building up an enormous force.

The Long Beach tanks, which were undamaged, were of smaller size, and had less than half the capacity. They had no concrete base, but rested directly on oiled sand, particular pains having been taken to make the foundation homogeneous by removing the adobe top layer.

At least six smaller water tanks at various locations had trouble with the anchor bolts securing them to concrete foundations. These bolts were either bent, broken or pulled out of the base or had the plates holding them buckled or ruptured. Several of these tanks were only moderately shaken.

Elevated tanks.--Twenty-five elevated steel tanks on steel legs were used for municipal water supply in the area affected. Two collapsed and two others were placed out of service because of broken risers. Practically all steel towers had tie rods stretched or snapped, the destruction being most general in the top panel. A number of large steel tanks for automatic sprinkler supply behaved in the same manner.

So far as known, the only elevated steel tank actually designed for earthquake resistance is a 75,000-gallon tank for sprinkler supply near the waterfront in Long Beach. It survived the earthquake in perfect condition, not even the tie rods needing adjustment, and fully justified the slight additional cost of the safe construction.

Gas service.--Broken gas services and devices caused 7 of the 19 fires reported in Long Beach during the night of March 10. Prompt closing of valves, together with a major break in a high-pressure main, undoubtedly prevented fires in numerous locations in the business district. Preparedness for seismic disturbance is of very great importance in connection with gas service.

Light and power service.--The earthquake has shown power companies the necessity for improved station construction and installation of generators and connected equipment, and has called attention to the vital importance of maintaining power to water supply pumps and the desirability of street illumination.

Telephone service.--Automatic operation of telephones with its selective handling of emergency calls has proven to be a more successful method of transmitting fire alarms, first aid, and police calls, in the event of disaster than the manual method. In addition to the obvious need of properly constructed buildings, design of equipment should be ample to transmit the full capacity of connected lines and trunks without danger to apparatus.

> The failure of telephone toll lines connecting Long Beach with other cities indicates the necessity of listing for use all private communicating systems, such as those of power and gas corporation, telephone systems, etc., so that aid may be summoned from other cities with a minimum of delay.

POST-1933 SEISMICITY

The 1933 earthquake was followed by a M 5.4 earthquake centered near Signal Hill on 2 October 1933.

In 1941 two earthquakes of M 4.9 and M 5.4 caused damage in Torrance and Gardena. The first occurred on 21 October in the West Dominguez oil field and damaged wells at depths of 5000 feet to 6000 feet (Barrows, 1974). The second occurred on 14 November to the west of the NIFZ and was destructive in Torrance to structures imperfectly repaired after the 1933 earthquake (Richter, 1958, p. 499).

In 1944 on June 18, two earthquakes of M 4.5 and M 4.4 occurred in the Dominguez Hills and damaged oil wells in the Rosecrans oil field at depths of 3000 feet to 6000 feet (Barrows, 1974).

Ziony and Yerkes (1985, p. 419) discuss the 1941 (October) and 1944 offsets in the casings of oil wells: "...several centimeters of slip occurred at depths as shallow as 1 km along minor south-dipping reverse faults along the western side of the NIFZ during each event."

In 1947, on December 14, an apparent earthquake of M 2.7 sheared oil well casings on Terminal Island at a depth of 1550 feet (Richter, 1958, p. 155; Hileman and others, 1973).

In 1949, on November 17, an apparent earthquake of M 3.7 occurred and was felt in Long Beach. Richter (1958, p. 155) states: "Nearly 200 oil wells went off production, many of them permanently; damage was at least 9 million dollars. There were similar occurrences on August 15, 1951, and on January 25, 1955; less damage was done on these dates, partly because of a shift in the center of the disturbance (from Terminal Island)." Richter (1958, p. 155) attributes the 1947, 1949, 1951, and 1955 events to "slumping on an enormous scale, incidental to subsidence" due to the compaction of the substrata from oil withdrawal.

In 1961, on October 20, an earthquake of M 4.3 occurred on the NIFZ near Huntington Beach; it cracked some plaster, damaged stock in a number of stores, and broke some windows in Orange County.

In 1969, on October 27, an earthquake of M 4.5 occurred on the NIFZ near Laguna Beach. This is the southernmost earthquake of M 4 or greater on the NIFZ, and coincides with the southern end of faulting assumed in this planning scenario.

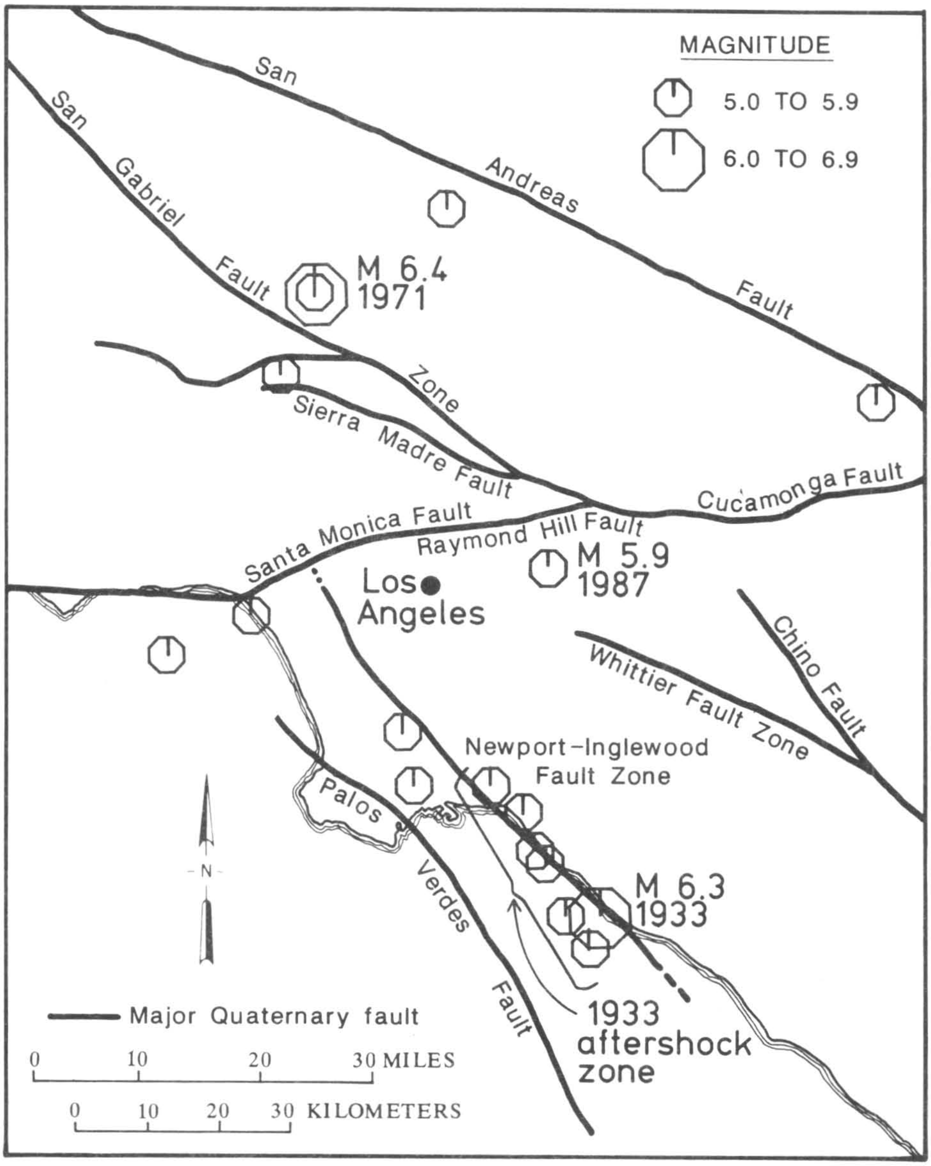


Figure 3. Map of Los Angeles Metropolitan area and surroundings, showing major Quaternary faults and epicenters of earthquakes of M 5 or greater since 1927.

THE SCENARIO EARTHQUAKE

Rationale for Selecting the Earthquake

Figure 3 shows the major Quaternary faults that surround Los Angeles, and the epicenters of earthquakes of magnitude 5 or greater since 1927. The epicenter of the 1933 earthquake of M 6.3 on the NIFZ is represented by the large symbol near Newport Beach. The six smaller symbols located within 25 km of the epicenter represent aftershocks of M 5.0 to M 5.9 of that earthquake.

The rationale for the selection of the scenario earthquake on the Newport-Inglewood fault zone (NIFZ) is as follows:

1. The NIFZ is part of a fault system that is more than 145 miles (240 km) long that extends to Baja California (Ziony and Yerkes, 1985, p. 45).
2. The NIFZ lies within the highly urbanized Los Angeles metropolitan area, and is a threatening source of a major (M about 7) earthquake with consequences potentially greater than those of a larger magnitude event on the more distant southern San Andreas fault.
3. Faults within the NIFZ have been active during the Holocene epoch, which is the last 11,000 years (Bryant, 1988).
4. The displacement rate on the NIFZ during the last million years is 0.6 mm/yr (vertical component, Clark and others, 1984). Ziony and Yerkes (1985, p. 76) assign the NIFZ a provisional slip rate of about 1 mm/yr based on probable continuity with the Rose Canyon fault near San Diego, that has a slip rate of 1.2 to 1.4 mm/yr. Woodward-Clyde Consultants (1970) estimate a slip rate of 0.5 mm/yr based on right-lateral displacement of geologic markers 3 to 5 million years old. The geomorphic character is consistent with a

displacement rate of 1 mm/yr or a meter per thousand years (W. Bryant, 1987, verbal communication).

5. On 8 December 1812 an earthquake severely damaged the Missions at San Juan Capistrano, San Gabriel, and San Fernando, suggesting a magnitude of about 7 and an epicenter within 50 miles of these Missions.
6. The destructive Long Beach earthquake of 1933 (M 6.3) occurred on the NIFZ.
7. Small earthquakes continue to occur on the NIFZ in the Los Angeles metropolitan area; for example, see the seismicity map for 1975 through 1983 from Hutton and others, 1985.

Characteristics of the Scenario Earthquake

Subsurface faulting extending 75 kilometers or 45 miles on the NIFZ is postulated. The northern end is near Beverly Hills at the intersection of the NIFZ with the Santa Monica fault. The southern end is offshore from Laguna Beach (Map 5-S). This zone of faulting overlaps and extends beyond the locations of the 1933 Long Beach earthquake and its aftershocks. Surface faulting will be discontinuous, and occur mainly on the Holocene active traces shown on Map 5-S and in Appendix B.

The 75 kilometer extent of faulting on the NIFZ corresponds to M 7.4 using the relation of Bonilla and others (1984), to M 7.1 using the relation of Slemmons (1982), and to M 7.0 using the relation of Wyss (1979). For planning purposes, a maximum surface displacement of 6 feet or 2 meters is assumed. The more prevalent average displacement is usually half the maximum value (Slemmons, 1987, verbal communication), or about 3 feet or 1 meter. The displacement is assumed to be dominantly right-lateral strike slip, and occurs on the Holocene active (Alquist-Priolo) fault traces shown on Map 5-S. Minor dip slip or vertical components of faulting will occur locally. Where there are no known active faults in the NIFZ, displacement occurs possibly on other unidentified faults within the approximately 2 km wide zone of deformation. Warping and uplift of about 1 meter will also occur in the zone.

Potentially damaging ground shaking continues for about 25 seconds within 25 miles (40 km) of the fault. Potentially damaging aftershocks occur for about a month following the main shock, with a few earthquakes in the magnitude 5.5 to 6.5 range.

The southernmost 12 km segment of the postulated subsurface faulting is offshore between Newport Beach and Laguna Beach. Because only minor vertical displacements are expected, the potential is small for generating a seismic sea wave or tsunami from this 12 km offshore segment, and is not considered in this scenario. Oscillatory waves in enclosed water bodies (seiches) occur in the local harbors.

The scenario earthquake is consistent with Ziony and Yerkes' judgement (1985, p. 91) "...that earthquakes of M 6.5 to 7, accompanied by as much as 2 m of surface displacement, are appropriate design earthquakes for ordinary planning purposes (for most faults in the Los Angeles region)".

PREDICTED SEISMIC INTENSITY DISTRIBUTION

Introduction

To develop an earthquake planning scenario, it is necessary to estimate the regional patterns of ground shaking and permanent ground deformation. This procedure is aided by assuming that the effects of the scenario earthquake can be deduced from previous earthquakes about which there is some knowledge. In this instance the scenario earthquake has been assumed to be similar to, but considerably larger than the M 6.3 earthquake of March 10, 1933. The effects of that earthquake were addressed in the preceding section.

Seismic <u>intensity</u> is the felt effect of an earthquake at a particular place. A numerical value conveys the various effects of earthquake shaking at a given place on buildings, furnishings, etc. The determination of seismic intensity is therefore subjective. Many intensity scales have appeared during the last century (Barosh, 1969, p.6). The Modified Mercalli intensity scale, used in this scenario, is reproduced and related to the Rossi-Forel scale in Appendix A.

Earthquake <u>magnitude</u> is an instrumental measure of earthquake size, regardless of location or of intensity effects. Earthquakes of similar magnitudes, occurring at different locations, can have different intensities. The M 6.3 earthquake of 1933 generated intensity IX in Long Beach. An earthquake of similar magnitude in 1908 had a maximum reported intensity of less than VII, because it occurred in an unpopulated area (Death Valley). The instrumental magnitudes of the 1908 and 1933 earthquakes were similar, even though their felt intensity effects were very different.

Regional Seismic Intensity Investigations

The degree of ground shaking resulting from the scenario earthquake will depend on several factors. Among the most important is the distance from the causative fault. Generally, the amplitude of vibratory motion diminishes away from the source of excitation. The vibrations associated with earthquakes are complex. Characterizing their anticipated effects at specific locations is further complicated by variations in the geologic materials through which they pass. Consolidated bedrock transmits most seismic frequencies while unconsolidated sand and gravel or water-saturated mud preferentially transmit low frequencies.

The development of seismic intensity maps also requires consideration of the consequences of ground breakage. In contrast to vibratory shaking, ground breakage is a permanent displacement of earth materials resulting from fault rupture, liquefaction, differential settlement, or slope failure. Lifeline damage due to fault rupture will be confined to a narrow zone within about 100 meters (330 feet) of the fault (Bonilla, 1967). The potential for liquefaction (Borchardt and Kennedy, 1979) is governed by the presence of susceptible substrate materials such as water-saturated mud or sand. Differential settlement is primarily a site-specific engineering problem occurring where structures are built on materials of varying density and degree of consolidation. Seismically induced landslides occur primarily on slopes greater than 3 in 10 (or 30% grade) in hills containing unstable geologic materials.

Development of the Seismic Intensity Distribution Map

In preparing a regional intensity map for assessing lifeline damage, Reichle and Kahle (1986) developed an algorithm based on the Evernden model (Evernden and others, 1973, 1981; Evernden, 1975; and Evernden and Thomson, 1985). This computer model calculates the ground shaking acceleration on a grid of reference points throughout a region employing equations that account for the influence of distance from the fault source, attenuation, and the surface geology. The intensities are calculated by using an empirical relationship between acceleration and the intensity scale.

Reichle and Kahle's model is used in this scenario, and differs from that of Evernden and others (1981) in that it assumes that shaking intensity does not depend on depth to water table. Also, it predicts intensities for bedrock sites within 5 km of the fault and at distances greater than 40 km on unsaturated alluvium that are approximately one unit higher than Evernden's. The model was guided by the areal extent of Intensity VII and VIII shaking for earthquakes of magnitude about 7 on other California faults, notably the 1868 Hayward and the 1952 Kern County earthquakes.

The methodology of the Evernden model does not predict ground failure. In order to add this dimension to the intensity maps, areas of potential ground failure (liquefaction and landslides) were defined from the information on local geology. These areas are identified on the Seismic Intensity Distribution map (Map 5-S).

The U.S. Geological Survey (1981) has published a series of intensity maps for specific earthquakes using Evernden's method, including a M 7.5 event on the NIFZ. The geologic information used in the U.S. Geological Survey analysis was based primarily on 1:250,000-scale maps from the DMG "Geologic Atlas of California." The intensity map in this scenario differs from the U.S. Geological Survey's 1981 map, because the model differs from Evernden's, and because newer geologic and hydrologic information (Ziony, 1985) was used.

Development of the seismic intensity distribution map begins with attenuation versus distance calculations plotted as concentric ellipses centered on the NIFZ. With distance from the fault, each successive ellipse is an intensity unit less than the previous one. On well consolidated bedrock within a distance of 8 km of the fault the ellipses denote Modified Mercalli intensities of VII; within 35 km they are VI or greater; within 80 km they are V or greater. In areas of less-consolidated ground, seismic intensities due to shaking can be up to 2 units higher. Therefore, within 8 km of the fault, the softest ground, Quaternary sedimentary deposits, would have predicted intensities of IX. In the same area, bedrock of intermediate consolidation would have predicted intensities of VIII. Table 1 lists the geologic units in the Los Angeles area and the relative intensity factors

Table 1. Geologic Units and Shaking Intensity Factors

Geologic Map Units (Los Angeles, Long Beach, and Santa Ana sheets)	Intensity Factor
Plutonic and Metamorphic Rocks	0
Ti, Mz, grMz, grPz, grCz, gb, Mzv, gr-m, mv, m, pEc, pE, sch, J, gr	
Volcanic Rocks	
Qv, Qrv, Tv, P_v	0.3
Pre-Cretaceous Sedimentary Rocks	
Pm, C,	0.4
Upper Cretaceous, Paleocene, and Eocene Marine Sediments	
Ep, E, Ku	1.2
Tertiary Nonmarine Sediments	
Tc	1.3
Oligocene and Miocene Sedimentary Rocks	
Mc, M, Oc	1.5
Plio-Pleistocene and Pleistocene Sedimentary Rocks	
Pml, Pu, Qc, Qm, Qt, QP	1.8
Holocene Deposits	
Qs, Qal	2.0

assigned to each. The seismic intensity for consolidated bedrock is increased by this factor to include the effect of geology. Table 1 is similar to those of Evernden and others, (1981, Tables 1 and 2), but the factors are positive instead of negative because the algorithm gives intensity for consolidated bedrock instead of for alluvium. Evernden and others (1981) have a range of 3 for the intensity factor. Table 1 has a range of only 2 for the intensity factor, because we consider that shaking intensity on saturated Holocene deposits is only 2 units higher than on consolidated bedrock. Also, there are slightly different classifications for some geologic units. For instance, we consider "Plio-Pleistocene" sedimentary deposits (+1.8) to be slightly more consolidated than Quaternary sedimentary deposits (+2.0). This is supported by the shear wave velocity being higher in Plio-Pleistocene deposits than in Holocene deposits (Fumal and Tinsley, 1985).

Intensities higher than IX are not shown because intensities X through XII are generally attributed to the secondary effects of ground breakage. Intensities X through XII may occur in the areas of potential ground breakage (faulting, liquefaction, landslides) identified on Map 5-S.

Characteristics of the Seismic Intensity Distribution Map

The intensities are generally highest at the fault and decrease with distance from the fault. The concentric pattern is modified by the areal distribution of geologic materials that respond differently to shaking. This difference accounts for the intensity being VIII nearest the fault in the uplifted area of consolidated rock, and for intensity IX occurring 5 km away from the fault in unconsolidated alluvium.

After applying the geological intensity factors listed in Table 1, the corrected intensities were rounded to integer values. Half integers are shown only for the intensity VIII range: 8- indicates 8.0 to 8.4, and 8+

indicates 8.5 to 8.9. The half integers help to differentiate between Miocene deposits having a geological factor of 1.5 and Quaternary deposits having geological factors of 1.8 (Plio-Pleistocene) to 2.0 (Holocene). Intensities could be greater on Quaternary deposits than on Miocene deposits by <u>more</u> than the half a unit indicated on the map, because of the high liquefaction potential of some Quaternary deposits. For example, the intensity indicated on the map is VIII- in Palos Verdes and VIII+ in Los Angeles Harbor, but the liquefaction potential is high in the harbor, and if liquefaction occurs, the intensity would be higher (IX or greater).

The map is confined to the area within 40 km of the fault, and includes all the areas affected by intensity VIII or greater. Intensity VIII or greater shaking effects extend throughout the alluvial sections of the Los Angeles basin, to the vicinity of Monrovia and West Covina, including the San Fernando Valley and virtually all of the populated alluvial areas of coastal Orange County south to San Juan Capistrano.

Intensity VII and lesser intensities occur in the consolidated rocks in the hilly areas, including the Santa Monica Mountains, Verdugo Mountains, Puente Hills, and the mountainous areas of Orange County.

Within the planning area, there are local zones where ground breakage could produce intensities greater than IX. These include: (a) the areas within the NIFZ where surface rupture could occur; (b) areas where ground conditions favor liquefaction; e.g., the Los Angeles and Long Beach harbors, Marina Del Rey, Newport Bay and Balboa, and significant areas of urban Orange County; (c) areas of potential landsliding, such as, the Palos Verdes Hills, Santa Monica bluffs, and some potentially unstable slopes in eastern Orange County.

The NIFZ is indicated by a zone of deformation about 2 km wide, that includes the folds and faults that are the surface expressions of the inferred deep seated fault zone. Known Holocene (last 11,000 years) active fault traces in the zone of deformation are shown, as mapped in the Alquist-Priolo Special Studies Zones.

The liquefaction potential in Holocene sediments is indicated on the map, from Tinsley and others (1985, p. 276). The liquefaction potential is high when the depth to the water table is less than 10 feet (3 m). The liquefaction potential is medium when the depth to the water table is between 10 and 30 feet. Areas where the ground water table is deeper than 30 feet (10 m) have low liquefaction potential, and are not identified on the map. The intensity in areas of potential liquefaction could be higher than the intensities shown on the map.

Areas subject to seismically induced landsliding are outlined on the map. This information is modified from Morton and Miller (1981), Yerkes and Campbell (1980), and Wentworth, Ziony, and Buchanan (1970). Intensities in areas of potential landslides could be higher than the intensities shown on the map.

Comparison to M 8 Earthquake on the San Andreas Fault

The NIFZ is located within the Los Angeles Metropolitan area, whereas the San Andreas fault (SAF) is more than 30 miles distant. Consequently, in the Los Angeles metropolitan area, the impact of an earthquake of M 7 on the NIFZ is stronger than the impact of a M 8 earthquake on the SAF.

In 1857 an earthquake of magnitude about 8 occurred on the San Andreas segment nearest Los Angeles. That earthquake resulted from a nearly 200 mile rupture of the San Andreas fault, from Cholame Valley in central California to Cajon Pass near San Bernardino; maximum displacement was 9 meters or 27 feet. A scenario of the impact of such an earthquake on presently existing lifelines was published by Davis and others (1982b). The earthquake postulated in the present scenario is of magnitude about 7, resulting from rupture of 45 miles of the NIFZ, and the maximum displacement is 2 meters or 6 feet. An earthquake of magnitude about 7 occurred in 1812 in the Los Angeles Orange county area, but the source fault is not known with certainty. The destructive 1933 Long Beach earthquake of M 6.3 occurred on the NIFZ.

The M 8 earthquake on the SAF damages a larger area, including parts of San Bernardino, Kern, and Ventura counties, than does the M 7 event on the NIFZ. Within the Los Angeles metropolitan area, the impact of the M 7 event on the NIFZ is greater than that of the M 8 event on the SAF. In the Los Angeles - Long Beach area the shaking intensity is mostly VII from the M 8 earthquake on the SAF (Davis and others, 1982b), and is VIII to IX from the M 7 event on the NIFZ. This is a significant difference in the intensity of shaking (Appendix A), and occurs in the heart of the Los Angeles metropolitan area. Also, faulting and ground deformation from the NIFZ event directly impact many more lifelines, critical structures, and industrial facilities, than do faulting and ground deformation from the SAF event. Lifelines in the Los Angeles metropolitan area, such as highways, petroleum, and waste water, will be more severely damaged by the NIFZ event than by the SAF event.

Photograph 4. Collapsed single story business building of unreinforced masonry, in the 1933 earthquake. Photo by Olaf P. Jenkins.

Section 2.

BUILDINGS

General Seismic Considerations

Introduction

Scenarios describing damage patterns are not precise predictions of what will occur. A statement that a building will survive, or will collapse, can be given only in probabilistic terms; in a parallel situation, one cannot predict that a person who is driving under the influence of alcohol will certainly have an accident, but one can state that the probabilities are significantly higher. Knowing building construction types and past earthquake performances of structures with given characteristics, realistic scenarios on probable damage can be developed for use in disaster response planning.

The numerical values associated with each response planning topic, such as damage to hospitals or other critical facilities represent reasonable maximum expected conditions. In other words, these values are credible; they have experience data or experienced judgment behind them. The quality of the numbers vary depending on the degree of extrapolation from experience data, the reliability of the assumptions supporting the calculations, and the quality of the judgment behind the decisions.

In addition to the possible variations in seismological parameters, the response of buildings and structures to earthquake ground motions is not well understood. Surprises have occurred and lessons have been learned in every destructive American earthquake, including the recent earthquakes of Whittier Narrows 1987, Coalinga 1983, Imperial Valley 1979, and San Fernando 1971. As noted, the expected seismic performance of any particular facility can be stated only in a probabilistic sense. As a result, this report generally states its findings on a class of building construction, by a geographic grouping, or on some other compatible basis.

Ground Motions and Building Damage

In a destructive earthquake, the seismic motions at their source are generally of rapid and irregular oscillatory types having large amplitudes. Earthquake waves change in character as they travel from their energy source in regions of faulting. Human observations as well as seismographic records show that the very rapid and violent ground oscillations (short period motion) in the epicentral region are quickly damped and dispersed, leaving principally the gentle swaying (long period motion) at large distances away from the earthquake. The greater the distance, the slower the observed predominant oscillations. The predominant oscillations at large distances from the epicenter can be so gentle that they may not be felt by all persons, and yet be strong enough to cause water in reservoirs and in harbors to oscillate with sometimes destructive effects.

Buildings respond differently to different kinds of ground motion. Each building has it own specific vibrational characteristics based on its stiffness, and will respond to a particular ground motion in a specific manner. One of these vibrational characteristics is termed the structure's natural period of vibration. In general, the taller the building, the longer is its natural period of vibration. If the building's natural period of vibration roughly coincides with a few cycles of the principal motions of an earthquake, a case of quasi-resonance will occur. As a result the vibratory motions of the building may dramatically increase, along with damage. Damage from quasi-resonance is generally observed in taller buildings shaken by distant earthquakes (such as at Mexico City in 1985).

The changes in ground motions as a function of distance, may reverse the relative damage of tall and short buildings as distance increases. Near the epicenter, damage to low rigid (short period) buildings may exceed damage to high rise (long period) buildings. At distances over 100 miles, damage to high rise building damage may predominate over that of even poorly built one story structures.

Short Period Motion Effects

The historical damage patterns that cover thousands of years and thousands of earthquakes are associated with the short-period ground motions (i.e., rapid back-and-forth motions). Isoseismal maps, including the seismic intensity distribution map (5-S) in this report are based on short period effects.

In general, light mass structures perform much better than do the heavier mass structures. This is because the ground moves away from the structure during an earthquake, and the structure must follow these movements. The heavier the mass of the structure, the greater will be its resistance to follow the ground movement. Therefore, a "heavy substantial" building which is not designed to be earthquake resistive is more likely to fail than is a "flimsy" wood frame structure. Countless evidences of this exist throughout the historic record.

Long Period Motion Effects

Long period motion principally affects high rise buildings. Long period effects of the 1952 Kern County, California, earthquake resulted in numerous instances of non-structural damage to multistory steel or concrete-frame buildings in Los Angeles and Long Beach, but essentially, no damage to one and two story buildings of any kind in the same area. These cities are located about 70 and 90 miles from the epicenter, respectively. Generally, the affected buildings were 10 to 12 stories high and had a measured natural period of vibration of 1 to 2 seconds. Buildings as low as 6 stories were also damaged. (There were no buildings over 20 stories at that time.)

The 1964 Alaskan earthquake caused more damage to multistory than to single story buildings in Anchorage, which was 75 miles from the epicenter.

Earthquake Resistive Design

Codes and Damage Control

After the 1906 San Francisco earthquake, new buildings in San Francisco were designed to resist heavy wind forces since earthquake resistive design methods were unknown; in time, these standards were reduced since "San Francisco has no heavy winds."

In the years following the 1925 Santa Barbara, California earthquake, a few moderate size communities in California adopted building codes that required earthquake bracing. After the 1933 Long Beach earthquake, a number of southern California communities adopted these codes, with their usage generally spreading to northern California by 1950. Concurrently, improvement in research and design practices also led to substantially improved earthquake resistive construction. Recent earthquakes have clearly shown that earthquake resistive design methods are highly effective, and many case histories exist in the literature showing that most major structures can and do perform well.

The intent of the earthquake resistive design as required by building codes, such as the Uniform Building Code, is to protect life, and is only partially directed toward damage control. There are certain exceptions, such as code provisions for new hospitals in California since 1972 which are discussed in the next section.

The basic philosophy behind the seismic provisions of the Structural Engineers Association of California Building Code is to "Resist major earthquakes of the intensity or severity of the strongest experienced in

California, without collapse, but with some structural as well as nonstructural damage." In most structures, it is expected that structural damage, even in a major earthquake, could be limited to repairable damage. By using certain types of flexible, but "safe", construction systems in certain occupancies, such as hotels, it is quite possible for a structure to suffer 50 percent property loss without serious structural damage.

In most cases, the earthquake provisions of the building code are interpreted by the design engineer to determine the seismic damage characteristics of a particular structure. Expert advice may be obtained from engineering geologists, seismologists, geotechnical engineers, and others. The design engineer must evaluate all reports and synthesize them into a good architectural design. The design is too often influenced by the minimum standards of the building code; to do otherwise might invite a lawsuit for "wasting the owner's money." Unfortunately, barely meeting the minimum earthquake standards of building codes places a building on the verge of being legally unsafe.

A majority of computer installations have inadequate earthquake bracing. In many cases the bracing of false floors, air conditioning (vital for continued operation), back-up power, and other equipment, is deficient. Unless the response planner has specific information to the contrary, computer systems should be considered damaged after a major earthquake.

Special California Earthquake Legislation

The Field Act, adopted after the 1933 Long Beach earthquake, assigned to a State agency regulatory powers over public school design and construction. The improved public school construction proved to be very successful in resisting damage in the 1952 Kern County and 1983 Coalinga earthquakes. The original Field Act applied only to new schools. In time, it became evident the older remaining schools continued to exist as major threats. In 1969, the Garrison Act was passed by the California Legislature to deal with the difficult task of hazard abatement. The legislation was subsequently amended and non-Field Act schools are now essentially gone.

California's Hospital Act of 1972, adopted after the 1971 San Fernando earthquake, assigned damage control to State regulation. It followed the precepts of the Field Act for public schools with the addition of the following significant statement:

> **Section 2.** It is the intent of the Legislature that hospitals, which house patients having less than the capacity of normally healthy persons to protect themselves, and which must be completely functional to perform all necessary services to the public after a disaster, shall be designed and constructed to resist, insofar as practicable, the forces generated by earthquakes, gravity and winds.

The intent of the legislation does not state that the hospital must remain "undamaged", but it must remain "functional" in order to perform all necessary services.

Planning Considerations

Damage will probably be greatest in pre-1934 masonry buildings. A total of 8,380 such buildings were identified in the City of Los Angeles (Pre-Earthquake Planning for Post-Earthquake Rebuilding, 1987, p. 40).

Most of the larger governmental agencies and private corporations have disaster response plans that include priority arrangements for the use of temporarily leased equipment such as bulldozers. In each case, the agency or corporation has stated that it expects the contractor will supply required equipment upon demand after an earthquake. Response planners may wish to examine this carefully to verify that suppliers do not have similar contracts with several different agencies, which in effect, over-commits their equipment. Alternate planning may be made through the Association of General Contractors.

HOSPITAL FACILITIES

General

The principal concerns addressed in this planning scenario relate to the earthquake vulnerability of the major transportation and utility lifelines. However, emergency response planners, when engaged in allocating priorities, must give highest attention to saving lives. Hospital facilities are absolutely vital in this regard. Staff, medical resources, blood banks, and ambulance services must be available.

The principal analysis of potential earthquake effects on these medical resources is "A Study of Earthquake Losses in the Los Angeles, California Area", by the National Oceanic and Atmospheric Administration (NOAA, 1973); this was updated by Steinbrugge and others in 1981. In general, the findings in those reports are applicable today. In the period from 1973 to 1986 there have been increases of about 20% in the population densities (both residential and commercial) in the areas that would be impacted by a major event on the NIFZ. There have been comparable increases in the number and size of hospital facilities of all categories. Tables 2 and 3 summarize current 1986 data on acute care hospital facilities in the planning area.

A general acute care hospital is defined as a facility having a patient capacity of 99-beds or more. While there are more than 200 general hospitals located in the five southern California counties, this study is limited to the 155 major facilities (including two VA hospitals) with a total bed count of 43,000 beds located in Los Angeles and Orange counties. Although smaller hospitals with less than 99-bed capacity were not considered, the problems faced by them are similar to those of larger facilities. For a complete inventory of all types of medical facilities located throughout California, refer to "Health Facilities, Directory, July

1985", by the California Department of Health Services, Licensing and Certification Division.

Locations of general acute care hospitals within 5 miles (8 km) of the NIFZ are shown on Map 5-H. A summary listing of general, acute care hospitals (99 beds or more) within 5 miles of the NIFZ is given in Table 2.

Seismic Considerations

California's Hospital Act of 1972, a consequence of the 1971 San Fernando earthquake, has significant implications in that attempts at damage control became mandatory when the State pre-empted new hospital construction from local control. The intent of the legislation does not state that the hospital must remain "undamaged", but that it must remain "functional" in order to perform all necessary services.

There are about 155 acute care hospitals located within the zone of potentially damaging ground shaking, within about 25 miles of the fault zone. There are approximately 55 acute-care hospitals within 5 miles of the fault zone and 4 acute care hospitals within the 2-kilometer-wide fault zone. Table 3 summarizes the number, bed capacities and estimated bed losses of acute care hospitals located within these various areas.

There are three hospitals located within or very near the Alquist-Priolo Special Studies Zone, one in Inglewood and two in the Long Beach area.

Losses in the San Fernando earthquake of 1971, in which four major hospital buildings were severely damaged and mostly evacuated, suggests that many hospital facilities constructed prior to the passage of the Hospital Act will be subject to severe damage during a major earthquake on the NIFZ.

A major hospital may become an added burden rather than an asset in the post earthquake period.

Another important consideration in the vulnerability assessment of hospitals is access. Even though a facility may survive, it will be of limited value if access is cut off or restricted due to ground failure, a collapsed freeway structure, or building debris on nearby streets.

Hospitals are also dependent on off-site public utilities for long-term continuous operations. Though hospitals maintain emergency electric generators, these systems can only meet limited demands for a limited period of time. Routine scheduled maintenance and testing of all emergency equipment is essential to ensure that the equipment will be operational when needed.

Modern hospitals contain a variety of complex electronic monitoring and test equipment and laboratory supplies. These items commonly rest on tables or racks and are highly vulnerable to damage by strong shaking. Consequently, even though hospital buildings may escape structural damage, effectiveness of the facility can be greatly reduced by damage to equipment and supplies.

Planning Considerations

For the purposes of this scenario we assume that the hospital facilities located within the 2-km-wide zone of deformation will be inoperable mainly as a result of loss of vital utility services.

There exists ample experience to show that some structures can survive quite well even when located adjacent to a surface fault rupture. Mitigating the hazards at a particular hospital site should include methods of maintaining utility services and consideration of alternative access routes.

Another effective way of examining the potential loss of facilities is to estimate the loss of hospital beds rather than to consider only potential building damage. A slightly damaged building evacuated for psychological or liability reasons results in a critical loss of hospital beds just as effectively as severe structural damage or loss of utility services.

Planners should review operational capabilities of hospital facilities from at least these viewpoints:

1. Loss of life and injuries to staff personnel and patients.
2. Physical building damage.
3. Loss of medical supplies and equipment.
4. Loss of hospital function due to disrupted utility services or access problems.
5. Evacuation of hospitals adjacent to major surface faulting due to loss of confidence by staff or the public for whatever reasons.

Planning Scenario

As a result of the Hospital Act of 1972, most hospital facilities and additions built since that date should remain functional. For planning purposes, exceptions will be located in those areas where loss of water and natural gas can be expected (see sections on "Water Supply" and "Natural Gas").

For planning purposes, it is estimated that 34% or 14,439 beds will be lost out of a total of 43,000 beds, in the 155 major acute care hospitals in Los Angeles and Orange Counties (See Table 3).

All 1,877 beds in the four hospitals within the fault zone can be expected to be lost, principally due to functional impairments.

In the area outside of the fault zone to a distance of 5 miles it should be assumed, for planning purposes, that the losses will be 50% or 5,562 of the 11,123 beds in the 51 hospitals involved.

In the 88 hospitals located in areas of strong shaking from 5 miles to 25 miles from the fault, losses are estimated at 25% or 7,000 beds of a total of 28,000 beds.

TABLE 2.

ACUTE CARE HOSPITALS WITHIN 5 MILES OF NIFZ

	LOS ANGELES COUNTY	NO. OF BEDS
Artesia	Pioneer Hospital 17831 S. Pioneer Artesia, CA 90701	99
Bellflower	Bellflower Doctors Hospital 9542 East Artesia Bellflower, CA 90706	163
	Bellwood General Hospital 10250 E. Artesia Bellflower, CA 90706	85
	Kaiser Foundation Hospital-Bellflower 9400 E. Rosecrans Avenue Bellflower, CA 90706	438
Compton	Dominguez Valley Hospital 3100 South Susana Road Compton, CA 90221	250
Culver City	Brotman Medical Center 3828 Delmas Terrace Culver City, CA 90230	566
	Washington Medical Center 12101 West Washington Blvd. Culver City, CA 90230	99
Gardena	Community Hospital of Gardena 1246 West 155th Street Gardena, CA 90247	55
	Memorial Hospital of Gardena 1145 W. Redondo Beach Gardena, CA 90247	200

TABLE 2. (cont)

	LOS ANGELES COUNTY	NO. OF BEDS
Harbor City	Bay Harbor Hospital 1437 W. Lomita Blvd. Harbor City, CA 90710	150
	Kaiser Foundation Hospital 25825 South Vermont Avenue Harbor City, CA 90710	280
Hawaiian Gardens	Charter Community Hospital 21530 South Pioneer Blvd. Hawaiian Gardens, CA 90716	150
Hawthorne	Memorial Hospital of Hawthorne 13300 South Hawthorne Blvd. Hawthorne, CA 90250	73
	Robert F. Kennedy Medical Center 4500 116th Street Hawthorne, CA 90250	274
Inglewood	Centinela Hospital Medical Center 555 E. Hardy Street Inglewood, CA 90307	403
	Daniel Freeman Memorial Hospital 333 North Prairie Avenue Box 1 Inglewood, CA 90307	430
	Kaiser Foundation Hospital Inglewood 3425 W. Manchester Blvd. Inglewood, CA 90305	149
Lakewood	Doctors Hospital of Lakewood 3700 South Street Lakewood, CA 90712	252

TABLE 2. (cont)

	LOS ANGELES COUNTY	NO. OF BEDS
Long Beach	Long Beach Community Hospital 1720 Termino Avenue Long Beach, CA 90804	300
	Los Altos Hospital 3340 Los Coyotes Diagonal Long Beach, CA 90808	97
	Memorial Medical Center of Long Beach 2801 Atlantic Avenue Long Beach, CA 90806	998
	Pacific Hospital of Long Beach 2776 Pacific Avenue Long Beach, CA 90806	208
	St. Mary Medical Center 1050 Linden Avenue Box 887 Long Beach, CA 90801	540
	Veterans Administration Hospital Long Beach, CA 90804	1200
	Woodruff Community Hospital 3800 Woodruff Avenue Long Beach, CA 90808	99
Los Angeles	Beverly Hills Medical Center 1177 South Beverly Drive Los Angeles, CA 90035	241
	Careunit Hospital of Los Angeles 5035 Coliseum Street Los Angeles, CA 90016	104
	Cedars-Sinai Medical Center 8700 Beverly Blvd. Los Angeles, CA 90048	1201

TABLE 2. (cont)

	LOS ANGELES COUNTY	NO. OF BEDS
Los Angeles (cont)	Century City Hospital 2070 Century Park East Los Angeles, CA 90067	195
	Century Community Hospital 9500 S. Broadway Los Angeles, CA 90003	56
	Kaiser Foundation Hospital-West LA 6041 Cadillac Avenue Los Angeles, CA 90034	185
	Los Angeles Co. Martin Luther King, Jr. Drew Medical Center 12021 Wilmington Avenue Los Angeles, CA 90059	480
	Los Angeles Doctors Hospital 2231 South Western Avenue Los Angeles, CA 90018	196
	Midway Hospital Medical Center 5925 San Vicente Blvd. Los Angeles, CA 90019	230
	Orthopedic Hospital 2400 S. Flower Street Los Angeles, CA 90007	162
	UCLA Medical Center 10833 Le Conte Avenue Los Angeles, CA 90025	711
	Veterans Administration Hospital West Los Angeles, CA	1600
Marina Del Rey	Daniel Freeman Marina Hospital 4650 Lincoln Blvd. Marina del Ray, CA 90291	203

TABLE 2. (cont)

	LOS ANGELES COUNTY	NO. OF BEDS
Paramount	Charter Suburban Hospital 16453 South Colorado Avenue Paramount, CA 90723	184
Redondo Beach	South Bay Hospital 514 N. Prospect Ave. Redondo Beach, CA 90277	203
San Pedro	San Pedro & Peninsula Hospital 1300 West Seventh Street San Pedro, CA 90732	348
Santa Monica	Santa Monica Hospital Medical Center 1225 15th Street Santa Monica, CA 90404	399
	St. John's Hospital and Health Center 1328 22nd Street Santa Monica, CA 90404	551
Torrance	Charter Pacific Hospital 4025 West 226th Street Torrance, CA 90505	96
	Little Company of Mary Hospital 4101 Torrance Blvd. Torrance, CA 90503	327
	Los Angeles Co. Harbor-UCLA Medical Center 1000 West Lomita Blvd. Torrance, CA 90505	716
	Torrance Memorial Hospital Medical Center 3330 West Lomita Blvd. Torrance, CA 90505	325

TABLE 2. (cont)

	ORANGE COUNTY	NO. OF BEDS
Costa Mesa	Costa Mesa Medical Center 301 Victoria Street Costa Mesa, CA 92627	99
Fountain Valley	Fountain Valley Community Hospital 17100 Euclid Fountain Valley, CA 92708	287
Huntington Beach	Humana Hospital Huntington Beach 17772 Beach Blvd. Huntington Beach, CA 92647	141
	Pacifica Community Hospital 18792 Delaware Street Huntington Beach, CA 92648	109
La Palma	La Palma Intercommunity Hospital 7901 Walker Street La Palma, CA 90623	136
Laguna Hills	Saddleback Community Hospital 24451 Via Estrada Laguna Hills, CA 92653	155
Los Alamitos	Los Alamitos Medical Center 3751 Katella Avenue Los Alamitos, CA 90720	173
Newport Beach	Hoag Memorial Hospital Presbyterian 301 Newport Blvd. Newport Beach, CA 92663	471
San Clemente	San Clemente General Hospital 654 Camino de los Mares San Clemente, CA 92672	116

TABLE 2. (cont)

	ORANGE COUNTY	NO. OF BEDS
Santa Ana	Mercy General Hospital Inc. 2701 Bristol Street Santa Ana, CA 92704	215
South Laguna	South Coast Medical Center 1872 Coast Highway South Laguna, CA 92677	268
Westminster	Humana Hospital Westminster 200 Hospital Circle Westminster, CA 92683	182

TABLE 3

SUMMARY OF BED LOSSES IN
LOS ANGELES AND ORANGE COUNTIES

	No. of Hospitals	Total Beds	Estimated Bed Loss	Percent Loss
Within Fault Zone	4	1,877	1,877	100%
From Fault Zone to 5 mi.	51	11,123	5,562	50%
5 mi. to 25 mi.	88	28,000	7,000	25%
25 mi. to edge of counties	12	2,000	0	0%
Total LA & Orange Counties	155	43,000	14,439	34% (average)

Photograph 5. Los Angeles Harbor looking north. Bridges connecting Terminal Island to the mainland are Vincent Thomas to the west (center), Schuyler Heim to the north (right), and Gerald Desmond to the east (off the photo to the right). Photograph courtesy of Port of Los Angeles.

Section 3.

TRANSPORTATION LIFELINES

HIGHWAYS

This chapter is based largely on contributions from James Gates of CALTRANS.

General Characteristics

The California Department of Transportation (CALTRANS) is a relatively young department, having been created by legislation in 1972. However, it represents a transportation legacy for California which spans over 100 years.

With headquarters in Sacramento, CALTRANS operates out of eleven district offices and over 300 maintenance stations throughout the state. The Los Angeles area is served by the CALTRANS District 7 office in downtown Los Angeles which has responsibility for Los Angeles, Ventura, and Orange counties.

There are approximately 3,150 state bridges in District 7, located on about 1,645 miles of state highways. This includes about 760 miles of freeways.

In California, about 37 percent of the 175,000 miles of maintained highways are located in urban areas and only about 9 percent of these are state highways. In the Los Angeles area, the state highway system includes most of the heavy-duty traffic arteries that carry over 60 percent of the traffic volume.

The major corridors for highway traffic in the region close to the Newport-Inglewood fault zone are as follows:

- Five major north-south routes:
  Route 1, Route 405, Route 110, Route 710, and Route 605
- Four major east-west routes:
  Route 10, Route 42, Route 91, and Route 22

Routes 1 and 405 lead into the planning area from both the north and south, and about 30 miles of each route is exposed to intensity IX shaking. The other three north-south routes traverse the area diagonally and each has about 8 miles exposed to intensity IX (MM) shaking.

The major east-west routes traverse the area diagonally and each has about 8 miles exposed to intensity IX (MM) shaking.

Route 5 provides an alternative north-south corridor east of the zone of high intensity shaking.

There are numerous alternative surface streets which can be used to bypass damaged portions of freeways.

Seismic Considerations

Over 130 miles of state highways and over 350 state bridges in the Los Angeles area will be shaken at intensity IX (MM) or greater resulting from the scenario event on the Newport-Inglewood fault.

A recent federal highway study (Vulnerability of Transportation Systems to Earthquakes - U.S., FHWA/RD-81/128, October, 1982) considers intensity VIII-IX (MM) to be the threshold of critical damage to highways.

After the 1971 San Fernando earthquake, the California Department of Transportation implemented design criteria and details for bridges which improved seismic resistance. Bridges built before 1971 have considerably less seismic resistance than later bridges, and most of the damage due to shaking will be in some of these old bridges.

A major statewide program to strengthen and retrofit bridges, involving over $50 million, is now essentially complete. Many of the retrofit bridges are located in the high intensity areas postulated in this scenario.

It is estimated that the structures in this area, including the retrofit bridges, will have a damage threshold of intensity IX (MM). The retrofit of a bridge does not guarantee against damage or collapse. However, it is expected that the damage to retrofit bridges will be more readily repairable. Depending on the nature of damage, some damaged bridges may be usable after the earthquake.

The amount of movements and settlements due to liquefaction and soil failures are difficult to predict. In previous events, much of the damage took the form of settlement of high fill embankments, and soils near bodies of water. Many lengthy sections along the southern portions of Route 405 and Route 1 along the coast will be subject to damage from ground failure due to liquefaction. Much of the road system in the Long Beach area is also located in areas of potential liquefaction.

Planning Considerations

Emergency planners need to identify major emergency corridors that can be most readily opened immediately following the earthquake. Segments of the freeway system are above or below grade and have structures subject to damage. Alternate emergency routes should be selected that are at grade, and not likely to be significantly affected by fallen power lines or other obstructions. Routes should preferably avoid locations close to buildings that may be heavily damaged. Selection of emergency corridors is especially important along Route 405 north and south of Long Beach and Route 710 leading into the Long Beach area where significant damage can be expected. Wherever possible, alternate corridors into and bypassing the Long Beach area and Route 405 south of Long Beach should be established for flexibility. Route 110 appears to be subjected to less shaking and provides a reasonable alternate route into the Long Beach area.

The utilities, and local government agencies should identify installations and facilities that they will need to rapidly inspect, repair, operate, or otherwise have access to in an emergency.

Emergency planners need to examine available routes to critical facilities, assess the potential for damage, and identify the most probable access routes. Critical facilities include communication centers, hospitals, airports, heliports, staging areas, fuel storage sites, and other locations essential to emergency response operations.

Access to Los Angeles International Airport may be partially restricted to autos carrying outbound passengers due to approach fill settlements at some bridges. Otherwise, little damage to the roadway system is expected in the immediate vicinity of the airport.

Highway emergency response plans should be coordinated with those developed for air, rail, and marine transport in order to optimize plans for integrated transportation capability. Access to and travel within the stricken area will be difficult and should be limited to the highest emergency priorities.

Planning Scenario

In the Marina Del Rey area along Routes 1 and 90, and along Route 405 south of Long Beach, liquefaction has caused considerable settlement and distortion of pavements. Gigantic traffic jams are present on all routes in the vicinity of Marina Del Rey and Long Beach. The Vincent Thomas suspension bridge in Long Beach is undamaged but large approach fill settlements prohibit access. Routes are blocked by damaged bridges and pavement breakage. Hundreds of vehicles are trapped and abandoned along Route 405, especially in the Westminster and Fountain Valley area.

Route 1 along the coast south of Long Beach is blocked by severe pavement breakage and liquefaction failures.

Several surface streets in the Long Beach area are blocked by fires and rubble. All nonessential traffic bound to the Long Beach and Marina Del Rey areas is being held at checkpoints and redirected around these areas.

This scenario is presented for planning purposes only and is generally pessimistic in its overall effect.

Damage Assessments

Damage assessments have been postulated for certain highway facilities as set forth below. **The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations.** Locations of facilities are shown on Map No. 5-HA. Routes not discussed may be assumed to be open with delays due to heavy traffic and obstructions.

Route 1

At Santa Monica, collapse of a large segment of the bluffs at Palisades Park has closed all but one lane of Route 1.

This route is closed for at least 72 hours through the Marina Del Rey area due to extensive settlements and liquefaction failures of roadways and pavements. Limited one lane emergency traffic may be restored in about 24 hours.

Access to the Los Angeles International Airport (LAX) is restricted to outbound traffic due to approach fill settlements on the upper level bridge structures. Full access is currently being provided on the lower level, but traffic is heavy. Damage to the Century Boulevard/Sepulveda Boulevard interchange limits access to LAX.

The interchange with Route 110 is damaged, and is closed for 48 hours for temporary repairs.

Route 1 through Long Beach is closed (open to local emergency traffic only) from the Los Angeles River (Route 710) east to Route 22 (7th St.).

Route 1 south of Route 22 (7th St.) to Corona Del Mar is closed due to many pavement breaks and settlements. Short portions are open, but no significant through traffic is able to use the route. Reopening the entire route in less than 72 hours is not expected. However, short portions may be accessible to emergency traffic in less than 24 hours.

Route 10 (Santa Monica Freeway)

Route 10 is generally open to traffic, with some movement restrictions at the Route 10/405 interchange. Westbound Route 10 to southbound Route 405 and eastbound Route 10 to northbound Route 405 are closed and a detour is being used for these two movement directions. Traffic is heavy with close to "grid-lock" conditions on Route 10, especially in the area of the Route 10/405 interchange.

Route 19 (Lakewood Boulevard)

Damage to Route 19 is limited to the interchange with Route 91. Minor damage at the Route 19/91 interchange has reduced traffic flow on Route 19 to one lane. Improvement of this situation in less than 72 hours is not expected.

Route 22 (Garden Grove Freeway)

Route 22 will be damaged at the interchanges, with Route 405, and Route 39.

Moderate damage at the Route 22/405 interchange combined with fill settlements has blocked traffic flow on Route 22 for 36 hours.

Moderate damage at the Route 22/39 interchange combined with major liquefaction failures has blocked traffic flow on Route 22 for more than 72 hours.

Light damage at the Route 22/Harbor Boulevard interchange near Garden Grove, combined with major liquefaction failures and fill settlements has blocked traffic flow on Route 22. Improvement of this situation in less than 48 hours is not expected.

Route 39 (Beach Boulevard)

Damage to Route 39 occurs at the interchanges with Routes 405, and 22.

Moderate damage at the Route 39/405 interchange combined with minor liquefaction damage has limited traffic flow on Route 39 to one lane for more than 72 hours.

Moderate damage at the Route 39/22 interchange combined with major liquefaction failures has limited traffic flow on Route 39 to one lane for more than 72 hours.

Surface deformation in the fault zone severely restricts traffic in Huntington Beach.

Route 42 (Manchester Boulevard)

Route 42 is open but there is very heavy traffic at the Route 42/110 interchange due to a Route 110 detour on surface streets in the area.

Surface faulting has disrupted the pavement and several utility pipelines necessitating a lengthy detour between Crenshaw Boulevard and Prairie Avenue.

Route 47 (Terminal Island Freeway)

Severe liquefaction failures on Terminal Island has caused approach failures on both the Vincent Thomas Bridge and Commodore Schuyler F. Heim Bridge. The approaches of the Gerald Desmond Bridge are damaged, and access to the Island is limited to light emergency vehicles across this bridge, via Ocean Boulevard. Reopening either of the main Route 47 bridges within 72 hours is not expected. However, an all-out effort could possibly open the Vincent Thomas Bridge in about 36 hours.

Extensive liquefaction damage on Route 47 north of the Commodore Schuyler F. Heim Bridge has made access from the north virtually impossible for 72 hours.

Route 55 (Newport Boulevard and Costa Mesa Freeway)

Severe damage at the Route 1/55 interchange combined with heavy liquefaction damage will not permit any traffic to move through this interchange area for at least 72 hours. Route 55 east of the Route 1 interchange to Route 405 is partly open.

Heavy liquefaction damage, combined with fill settlements at several bridges and interchanges from Route 405 to Route 5 have completely closed this section of freeway. Reopening this portion of Route 55 is less than 72 hours is not expected.

Route 73

Route 73 is closed for more than 72 hours at San Diego Creek due to moderate fill settlements and liquefaction failures.

Damage at the Route 73/55 interchange is minor and Route 73 is open to restricted traffic through the interchange. Access to Route 55 is blocked due to damage to Route 55 both north and south of Route 73. Route 73 can be opened to near normal traffic through the Route 55 interchange in less than 24 hours.

Route 90 (Marina Freeway)

Route 90 into the Marina Del Rey area is closed for more than 72 hours at Ballona Creek due to extensive liquefaction and settlement failure at the bridge.

Route 91 (Artesia Freeway)

Route 91 is generally open to traffic with a detour around the Route 91/710 interchange and some lane restrictions in the Route 91/19 interchange. Improvement of this situation in less than 72 hours is not expected.

Surface rupture has damaged the roadway at the fault crossing between Central Avenue and Avalon Boulevard necessitating a detour around this segment for 36-48 hours.

Route 101 (Hollywood Freeway)

Damage at the Sunset Boulevard and Hollywood Boulevard over-crossings has blocked all lanes of Route 101 requiring detour of all traffic over city streets for 72 hours.

Route 110 (Harbor Freeway)

North of Route 405, Route 110 has several detours around bridges with approach settlements. Traffic is moving very slowly, at times approaching "grid-lock" conditions. Improved traffic capacity can be expected in less than 36 hours.

Surface rupture in the immediate vicinity of the Route 110/El Segundo Boulevard interchange has caused damage to both roadways and utility pipelines, necessitating a lengthy detour around the interchange area.

The interchange with Route 1 is damaged, and is closed for 48 hours for temporary repairs.

The settlements at the east end (island end) of the Vincent Thomas Bridge precludes access to Terminal Island (see Route 47).

Route 405 (San Diego Freeway)

In Sepulveda Canyon between Mulholland Drive and Sunset Boulevard, a major slope failure has blocked the southbound lanes of Route 405, severely restricting use of this facility for several weeks.

At the Route 405/10 interchange, damage in the interchange area is restricting turn movements from Route 10 only and Route 405 traffic is narrowed to one lane in each direction through the interchange area. Traffic in the area of the interchange is near "grid-lock" conditions. Improvement in the one-lane condition through the interchange in less than 72 hours is not expected.

Route 405 from Route 110 to Route 605 is closed due to damage to several bridges, pavement damage, and approach fill settlements. Limited emergency traffic with some detours may be restored in about 24 to 36 hours. Limited access to the area west of Route 710 may be obtained in about 8 hours. However, movement through the area between Route 710 and Route 605, including access to the Long Beach Airport, cannot be opened to more than very light traffic in less than 72 hours.

Route 405 from Route 605 to Route 22-East is open to restricted traffic with detours at several locations due to approach fill settlements. This section will be open to near normal traffic in less than 36 hours.

Route 405 is closed from Route 22-East to San Diego Creek. This route in the Westminster and Fountain Valley area has suffered considerable pavement and liquefaction damage. Liquefaction in the vicinity of the San Diego Creek Bridge and at the Santa Ana River crossing has closed Route 405 in the Irvine-Costa Mesa area. Route 405 is not expected to be reopened to through traffic in less than 72 hours. However, short segments of freeway north of the Santa Ana River may be opened to restricted traffic in 36 hours. The roadway between the Santa Ana River and San Diego Creek is closed indefinitely.

<u>Route 605 (San Gabriel Freeway)</u>

Route 605 is only partially open at the South Street interchange south of Route 91 due to liquefaction failure in the South Street interchange. Traffic is limited to one lane in each direction. Restoring normal traffic through this interchange in less than 48 hours is not expected.

At the Route 605/405 interchange, minor bridge damage in the interchange area has restricted traffic to a single lane. However, Route 605 traffic is moving through the interchange to Route 22.

In the M 5.9 Whittier Narrows earthquake of 1987, cracks in the 605/5 interchange caused 24 hour closure for temporary repairs. This interchange is being retrofitted to prevent damage in future earthquakes.

<u>Route 710 (Long Beach Freeway)</u>

Route 710 is closed between Routes 91 and 405 due to pavement and bridge damage from surface faulting at the Southern Pacific and Union Pacific Railroad crossings (about a mile north of the Route 405/710 interchange) and damage at both the Route 710/91 and 710/405 interchanges.

Route 710 is closed south of Anaheim Street in Long Beach due to extensive liquefaction settlements in the 9th/7th Street interchange.

Access to the southeast basin area is limited to light emergency vehicles via the Queensway Bridge. Improved traffic capacity to the southeast basin area cannot be expected for at least 48 hours.

At the 710/405 interchange, traffic is restricted to a single lane due to damage and settlements in the interchange area. Traffic through the interchange may be improved in about 36 hours.

At the 710/91 interchange, through traffic is blocked at the interchange. However, a detour is available to carry traffic around the interchange area. Improvement of this situation in less than 72 hours is not expected.

AIRPORTS

General Characteristics

The major commercial airports in the Los Angeles basin and their approximate air passenger volumes are as follows:

Airports	Annual Passenger Traffic (1985)
Los Angeles International	40 Million
Burbank (Glendale, Pasadena)	6 Million
Ontario International	4 Million
John Wayne (Orange County)	4 Million
Long Beach International	4 Million

Los Angeles International has the third largest passenger volume of any airport in the United States (after Chicago and Atlanta). Two hundred and fifty thousand people, including airport personnel, are on site each day.

Major military airports are located at the following bases:

Armed Forces Reserve Center - Los Alamitos
Norton Air Force Base - San Bernardino
Marine Corps Air Station - El Toro
March Air Force Base - Riverside

The Ontario, Norton, and March facilities are located outside the planning area, more than 25 miles from the NIFZ and should not experience severe ground shaking. Los Angeles International and Orange County airports are about 4 miles from the fault zone. Long Beach International Airport is located adjacent to the fault zone, Los Alamitos about 3 miles distant, and the Van Nuys, Burbank and El Toro airports are 10 to 12 miles from the fault zone.

In Los Angeles and Orange Counties, there are numerous smaller secondary airports that service local communities throughout the greater metropolitan area. Some of these small commercial and municipal airports, such as Torrance and Van Nuys, could play important roles in post-earthquake response and recovery operations, but additional personnel and equipment would have to be available to make them effective.

Seismic Considerations

Airport operations can be seriously impacted by a severe earthquake in several ways:

1. Damage to structures, control towers and equipment, off-site control centers, including other non-runway facilities, etc.
2. Ground access and egress problems due to damage to freeway and highway structures leading to the airport.
3. Damage to on-site utility lines and equipment serving the airport, particularly electric power, jet fuel, gas, emergency power facilities, communication equipment, etc.
4. Damage to runways and taxiways.

Damage to Structures

Ample experience shows that airports can remain functional even if control towers are inoperable, or equipment within them becomes non-functional provided the runways remain intact. Even if the control tower is earthquake resistive and the equipment remains functional, broken windows may let adverse weather in.

Control towers inspected for this study are earthquake resistive and are expected to remain safe despite glass breakage. Some essential equipment is not anchored and will probably be displaced and become inoperable. Earthquake braced emergency power equipment is available and is expected to remain functional. Runway lights will be able to perform wherever the runways remain intact. Even if the control towers and other buildings become nonfunctional, it is possible for aircraft to continue to land and take off under handicapped conditions by use of stand-by emergency power and communications systems.

The 1964 Alaska earthquake provides an excellent example of the ability of airports to continue operations even after a M 8.4 event (NOAA, 1973, p. 239). A total of 13 airports were found to have had runway or taxiway damage out of the 64 airports which were inspected after the Alaskan shock. Virtually all airports were operational within hours after the shock despite runway damage and building damage. Some resourcefulness was required to accomplish this. For example, the collapse of the control tower at Anchorage International Airport required the use of radios in a grounded plane for air traffic control.

The 1971 San Fernando earthquake did not prevent the operation of nearby airports, none of which were in areas subject to ground failure. The 1987 Whittier Narrows earthquake (M 5.9) closed the Burbank airport for a few hours due mostly to glass breakage in the control tower.

Access to the Airports

Even if an airport remains completely functional after an earthquake, it would be virtually useless as a resource if it was not accessible by surface transport. Most major airport facilities are located adjacent to major freeways. Ground transportation access and egress from the facility normally involves freeway overpasses, underpasses, and interchanges, and other bridge structures. Damage to, or collapse of, these structures would seriously impair airport accessibility.

Damage to Utility Lines

The utility lines and jet fuel lines make up the "lifeline" system necessary for continued airport operation. The performance of these lifelines, especially electrical power and fuel lines, is critical. This applies not only to the lines at the airport but also to the service lines leading to the airport. In the scenario earthquake, many utility and fuel lines in the vicinity of Los Angeles International, Long Beach, and Los Alamitos airports will be vulnerable to damage by fault rupture or ground failures.

Runway Damage

Runway damage can render an airport inoperable for large commercial aircraft for substantial periods of time. However, runways can be quickly repaired for use of military-type cargo planes such as the C-130 and C-141. Runway damage due to an earthquake is a direct function of the strength characteristics of the underlying soils. Most of the airport runways under consideration are built upon firmly compacted soils, but in this scenario earthquake all will be subjected to severe ground shaking for a period of 25 seconds or more. Only two airport runways, those at Los Alamitos and John Wayne, are located on a site with known liquefaction potential. Major differential settlements are possible that could result in inoperable runways.

Planning Considerations

Airborne transport will play a vital role in the transport of people and material to and from the stricken areas and in search and rescue, damage assessment, and many other emergency response efforts. Pre-selection of one or more air cargo delivery facilities will influence related planning for distribution of material by helicopter, highway, and rail transport.

Airports available for major logistics need to be evaluated in terms of auxiliary electrical power supply, integrity of airport buildings, and vulnerability of access routes in order to establish transportation plans. The vulnerability of runways to liquefaction at Los Alamitos and John Wayne should be further assessed.

Although some damage to structures and facilities is to be expected, for planning purposes all major airports are expected to remain functional for some types of aircraft. Depending on the time of day the event occurred, the task of clearing the normal commercial air traffic and ground passengers will be the first challenge to overcome. As an example, LAX normally has over 250,000 passengers, visitors and operating personnel during each 24-hour period.

Planning Scenario

Numerous major airports in the planning area are capable of providing the 5,000 feet of undamaged runway necessary for landing of C-130 and C-141 aircraft that will provide massive logistics to the response effort. Some damage could occur to runways at Los Alamitos Armed Forces Reserve Center and John Wayne Airport, but this may not be great enough to disrupt emergency operations. The other major airports are located in areas where predicted shaking will produce minimal damage to runways. In general, then, virtually all of the numerous major airports are capable of handling emergency response operations. Performance of the lifeline systems necessary for airport operations will be critical. The success of air operations will be more dependent on electrical power, fuel handling, and survival of critical buildings than on the direct effects of the earthquake.

Secondary airports for distribution of supplies and equipment have not been evaluated in terms of auxiliary electrical power supply, integrity of airport buildings, and vulnerability of access routes, but should be examined if they are found to be vital to response planning.

Damage Assessments

Damage assessments have been postulated for certain airport facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map No. 5-HA.

No. AIRPORT

A1 **Los Angeles International Airport (LAX)**
Closed for up to six hours
No liquefaction potential.
Predicted Shaking Intensity, VIII+ (MM).

For planning purposes, and due to the extent of facilities (approximately 4 square miles) of the Los Angeles International Airport, it is reasonable to expect that damage to some critical facilities will occur and that specific functions will be disrupted. As an example, an FAA regulation indicates that any 3 inch, or larger, holes or "pop-outs" in the runway is cause for the shutdown of normal operations of an airport.

Airport buildings (including the control tower) were constructed between 1962 and 1984 to seismic code requirements. The control tower is not critical since operations can be carried on from other locations. There is one older (1929) unreinforced masonry building on the property, but its use is not critical to airport operations. There are seven public parking structures built during the 1962-1984 period which are precast concrete systems. In general, past seismic performance of precast concrete structures indicates that this type of building system is potentially hazardous and clearly subject to damage. One of the older parking structures will have major damage and will be closed down, causing impairment to traffic circulation along World Way North and South.

Three of the four runways are of reinforced concrete. The fourth was asphaltic concrete, which was replaced with concrete in the spring of 1988. Runways are 15" to 16" thick concrete on a 6" to 10" crushed aggregate base over a 12" to 30" sub-base (about 4 feet total). There is no liquefaction potential because the ground water table is about 100 feet deep. The long tunnel on Sepulveda Boulevard under the south runways was reinforced in 1979 with a new 34" thick concrete slab designed to carry Boeing 747 jet loads.

Principal access to the Los Angeles International Airport is by Sepulveda Boulevard from the north and south or by Century Boulevard from the east. To gain access to the airport, traffic from both boulevards must pass through a major arterial interchange of underpasses and bridges located at their intersection. Damage to the complex arterial interchange at the intersection of Century Boulevard and Sepulveda Boulevard, which is the principal entrance to the airport, will disrupt critical access and egress. Sepulveda Boulevard leads under the southern runway system of the airport, via the 1900-foot long Sepulveda Tunnel. Traffic will have to be rerouted around Sepulveda Boulevard. Damage to I-405 will also affect access, but alternate surface routes are available (Map 5-HA). Traffic circulation inside the airport is on two levels: the upper level for departures (completed in 1984 for the Summer Olympics), and the lower level for arrivals. Seven large, multistory, precast concrete public parking structures are located in the center of the airport between the terminals fed by the major circulation road, World Way. Despite damage to the San Diego Freeway structures or other overpasses on some main arteries, access to the airport is available by surface streets from all four directions. However, with the damage to the main access routes, the functional capacity of LAX will be reduced to 30 percent for 2 days after the earthquake. Within a week, the capacity will reach 75 percent of normal.

Los Angeles International Airport has several major fuel depots. Pipelines from refineries to the south supply fuel to bulk storage tanks from which fuel is then distributed to day-storage tanks on the north side of the airport. Pumping of fuel depends on electrical power. Fuel also can be transported via tanker trucks that have their own pumping systems which are independent of commercial electrical power. Emergency diesel electrical power generators with one day's fuel supply are distributed around the airport in various locations and are used for buildings, lights, communication systems, roadways, and designated use by the FAA.

Each terminal building, the control tower, and operations headquarters has its own separate emergency power system, well maintained and checked periodically. Redundancy has been designed into power and communications systems. Operation of the airport can continue even if the control tower becomes inoperable. Operations personnel are on duty 24 hours per day and are trained to respond to emergencies of all kinds. An elaborate emergency response plan has been developed in conjunction with the emergency management department of the City of Los Angeles. Periodic emergency response exercises are carried out by all airport operations personnel.

Jones (1983, p. 157; Holms and others, 1986, p. 23) indicate that a M 7.5 earthquake on the NIFZ would damage runways at LAX. We think this is unlikely because there is no liquefaction potential at LAX; the water table is about 100 feet deep. Ground failure is not expected and the runways should remain functional.

A2 **Burbank-Glendale-Pasadena Airport**
Closed for up to six hours
Low liquefaction potential.
Predicted Shaking Intensity, VIII-(MM).

The runways remain functional, but glass breakage in the control tower requires several hours to clear.

According to NOAA (1973, p. 239), after the M 6.4 1971 San Fernando event (Intensity VII (MM) at this locality, Scott, 1971) the "runways remained functional... However, there was glass breakage in the control tower... The most critical problem was the loss of commercial electric power, resulting in blackouts of the terminal buildings and... preventing the pumping of aircraft fuel stored underground."

The 1987 Whittier Narrows earthquake (M 5.9) produced intensity less than VII at Burbank, but it closed the airport for several hours due to glass breakage in the control tower.

Jones (1983) indicates runway damage at this airport, from a M 7.5 earthquake on the NIFZ. We think this is unlikely because the liquefaction potential at this airport is low. Ground failure is not expected, and the runways should remain functional.

A3 Van Nuys Airport
Closed for up to six hours
Low liquefaction potential.
Predicted Shaking Intensity, VIII-(MM).

Glass breaks in the control tower, but the runways remain functional.

According to NOAA (1973, p. 239), after the M 6.4 1971 San Fernando event (Intensity VII (MM) at this locality, Scott, 1971) the "runways remained functional... However, there was glass breakage in the control tower. The most critical problem was the loss of commercial electric power, resulting in blackouts of the terminal buildings and... preventing the pumping of aircraft fuel stored underground."

A4 Los Alamitos Armed Forces Reserve Center
Closed for 24 hours
Possible high water table and liquefaction hazard present (Gulliver and Sonnenfeld, 1980; Tinsley and others, 1986).
Predicted Shaking Intensity, IX (MM).

Runways will be damaged by ground failure due to liquefaction.

The reinforced concrete control tower appears to be reasonably well constructed. Runways are mainly of asphalt. Damage can be readily repaired for landings of C-130 cargo transport. A new emergency power system is being installed. Fuel is delivered by truck and stored in a 650,000 gallon underground tank. Fresh water is obtained from local wells. This field will serve as the emergency communication and administrative center for the California Office of Emergency Services (OES). It has communication vans and some emergency hospital facilities on site. The southern California headquarters of the

National Guard is also located there. There appear to be no critical problems in regard to vehicular access to this facility.

Holms and others (1986) state that Los Alamitos is "likely to sustain runway damage sufficient to keep them temporarily out of service. Also, damage to control towers, fuel tanks, and other structures is expected. Loss of electrical power will affect tower operations and fuel service pumping (p. 23)."

These assessments may be valid in view of the recent report by the U.S. Army Environmental Health Agency (USAEHA, 1985). This report supersedes earlier subsurface information which was used for assessments of liquefaction at this facility in the past (Davis and others, 1982). This new data and the new map of Tinsley and others (1986) indicates that the AFRC is in an area of moderate potential for liquefaction during an earthquake.

A review of USAEHA (1985) shows that eight borings southwest of the aircraft parking area and west of the runways encountered ground water at depths between 10.1 and 13.9 feet below ground level. The water table is currently well within the range for potential liquefaction.

Materials sampled at depths between 15 and 31.5 feet were analyzed for particle size. Only one sample was definitely not liquefiable. It had 15 percent clay. The rest of the samples were marginal, with the most likely candidates for liquefaction having fine sand with less than 4 percent clay.

Shallow lakes occur to the northwest and to the southeast of the runway. A sanitary landfill in the area of the borings is routinely excavated to a depth of 5 m.

A detailed geotechnical study needs to be performed to assess the liquefaction potential near the runways and critical facilities. If the outcome of the study is favorable, this base could confidently be used as a staging area for recovery operations after major earthquakes.

A5 **El Toro Air Station (U.S.M.C.)**
Closed for up to six hours
Low liquefaction potential.
Predicted Shaking Intensity, VIII+ (MM).

Jones (1983, p. 157) indicates runway damage at this airport from an earthquake of M 7.5 on the NIFZ. We think this is unlikely because the liquefaction potential at El Toro is low. Ground failure is not expected, and the runways should remain functional.

A6 **Long Beach International Airport**
Closed for up to six hours
Low liquefaction potential.
Predicted Shaking Intensity, VIII+ (MM).

Although Long Beach International is only a kilometer from ground rupture along the fault, we predict that the shaking intensity will be no greater than at El Toro, which is 17 km from the NIFZ. Some of the earlier pessimistic assessments of Long Beach airport (NOAA, 1973; Jones, 1983; Holms and others, 1986) apparently were based on the possibility of liquefaction under the site. As recent studies (Tinsley and others, 1986) show, this is unlikely. While there will be significant damage to the control tower and other facilities, the runways will remain functional.

Freeway bridge damage (I-405) will impair access to Long Beach International from the south; from the north access will be limited to Lakewood Boulevard.

A7 **John Wayne Airport - Orange**
Closed for 24 hours
Liquefaction potential is moderate at the northeastern end of the single runway at this airport.
Predicted Shaking Intensity, VIII+ (MM).

Jones (1983, p. 157) states that John Wayne is "likely to sustain runway damage sufficient to keep them out of service for a considerable period." Holms and others (1986) states that John Wayne is "likely to sustain runway damage sufficient to keep them temporarily out of service. Also, damage to control towers, fuel tanks, and other structures is expected. Loss of electrical power will affect tower operations and fuel service pumping (p. 23)." These assessments appear to be valid in view of the moderate potential for liquefaction on the northeastern half of the only runway at this airport. The closure here may be for only 24 hours - long enough to inspect the runway and to fill possible areas of minor settlement.

Freeway bridge damage will interrupt normal surface access to the John Wayne Airport because of damage to Routes 55 and 73 and I-405. Alternate surface routes will have to be determined to allow emergency traffic to reach South and North Airport Way.

RAILROADS

General Characteristics

The southern California metropolitan area is served by rail lines from the north, south, and east. From the north, Southern Pacific's two main lines enter the planning area through the San Fernando Valley, its central valley line via San Fernando and the coastal route through Chatsworth. From the south, the Santa Fe Railroad follows the coast north from San Diego to Capistrano before turning inland through Orange County. The mainlines of the three principal railroads, the Santa Fe, Southern Pacific, and the Union Pacific enter the planning area from the east via San Bernardino-Riverside. In the Los Angeles - Long Beach harbor areas, these three railroads jointly operate an extensive service network called the Harbor Belt Line.

Rail lines cross the NIFZ in eight locations. Numerous railroad bridges and overpass structures are located within or close to the fault zone and others are located in areas of high liquefaction potential and ground shaking (MM VIII to IX).

Locations of rail lines are shown on Map 5-RM.

Seismic Considerations

For planning purposes, severe damage can be expected to both roadbeds and bridge structures located within the 2-km-wide fault zone where surface displacements averaging 1 m are postulated. Damage to bridge supports, approach fills and roadbeds can also be anticipated in areas of potential ground failure. Bridge damage generally involves a lengthy repair time. Significant settlement of bridge approach fills require repair before bridge structures can be used. Concrete bridge piers supported on old timber piling are considered most vulnerable to damage. Rail facilities are also highly vulnerable to closure by collapse or major damage to the many freeway over-crossings and other grade separation structures. The standard response procedures of the Southern Pacific railroad are to inspect all bridge supports after an earthquake of M 3.5 or larger and to stop all trains in an area experiencing a M 6.0 or larger earthquake.

According to NOAA (1973), railway bridges generally do not suffer serious damage except in areas subject to ground failure or by surface fault rupture. Railroad tunnels experience severe damage in areas affected by permanent ground movements due to landslides or surface rupture, but rarely suffer internal damage from ground shaking.

Planning Considerations

Railroad companies possess substantial in-house repair capabilities that they can supplement by outside contractors. Major washouts, landslides, and derailments are not uncommon. It is reasonable to assume that the railroads will be able to solve many, but not all of their reconstruction problems without undue attention from those concerned with disaster response. However, complete restoration of rail service throughout the area will take time and this, in turn, will impact others dependent on rail service. Failures that involve both the railroad and other transportation facilities or utilities may result in problems of jurisdiction and work priorities.

Many rail lines in the planning area are located in areas with very high potential for ground failure. Rail lines extend to major port facilities, industrial plants, and military installations that are also in areas of poor ground. Priorities given to rail repairs in these areas should be considered in the context of the ability of the trucking industry to replace the loss of rail service.

Two recent studies considered the potential impact of a major earthquake on rail facilities. Holms and others (1986, p. 25) expect "several areas to be subject to landslide and that many rail bridges are susceptible to damage because of age, design, and construction." To date, Jones (1983, p. 147-155) produced the most detailed analysis of the response of the rail system to a major event on the NIFZ. In general, this scenario predicts that rail traffic to Los Angeles will be stopped at San Fernando on the north, El Monte and Placentia on the east, and San Clemente on the south.

Planning Scenario

The three major railroads that serve the Los Angeles-Long Beach harbor complex, together with their mutually operated Harbor Belt Line, traverse an extensive area of high liquefaction potential. Given the high intensity of projected earth shaking (MM-IX) in this area, extensive damage due to soil settlements is probable.

Rail lines and bridges in the fault zone will suffer extensive damage with resulting interruption of service for extended periods to the coastal communities, industries, refineries, and harbor facilities.

Rail service into the planning area will sustain only minimal damage, with all main line facilities functional within 5 days.

Extensive damage to freeway overpass structures will block many rail lines, especially in the areas within and adjacent to the fault zone. As freeway overpasses are under the jurisdiction of CALTRANS, repair is a shared responsibility.

For planning purposes, 20 percent of the lines in the ground-disturbed zone around the NIFZ should be considered closed for at least 30 days and 10 percent for 60 days.

Those wishing to review what ground shaking can do to rail facilities in areas with a high water table should examine the many photos in the classic work by McCulloch and Bonilla (1970).

The most extensive damage to railroads in the planning area will occur in the NIFZ, and in other areas of poor ground where the roadbed is seriously disrupted by ground movement. In addition, failure of other structures, notably, highway over-crossings and many other secondary spans, will seriously impair the railroad's ability to function.

Damage Assessments

Damage Assessments have been postulated for certain rail facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 5-RM.

R1 **San Fernando Valley (SP)**
Closed for more than 72 hours.

Southern Pacific tracks in the southern and western San Fernando Valley are disrupted locally by roadbed failure caused by severe shaking in areas of high ground water.

R2 **South Coast Harbor Areas (ALL)**
Closed for more than 72 hours.

The rail system in the Wilmington, Long Beach, Seal Beach harbor areas is considerably damaged due to localized occurrences of ground failure, particularly in areas of filled ground near the port facilities.

NOAA (1973) notes that the railroad bridge from the mainland to Terminal Island has been closed frequently due to subsidence induced ground movements and conclude that this structure would not function after a major earthquake.

Bridge damage on the El Segundo to Long Beach segment effectively closes this route (Jones, 1983, p. 149).

R3 **Santa Ana Canyon (AT&SF)**
Open East of Placentia within 24 hours.

The AT&SF railroad from Placentia to the Riverside County line which follows the Santa Ana River through Santa Ana Canyon, is damaged by localized ground failures causing temporary disruption of rail traffic via this route.

According to Jones (1983, p. 152), this segment will survive the earthquake. He agrees, however, that liquefaction damage will disrupt travel west of Placentia.

R4 **Pomona to Montebello (UP)**
Open within 24 hours.

Union Pacific and Southern Pacific lines along San Jose Creek south and west from Diamond Bar to Pico Rivera are damaged as a result of localized ground failures due to intense shaking in areas with a high ground-water table.

According to Jones (1983, p. 152), this segment survives the quake. He agrees, however, that liquefaction damage will disrupt travel west of Pomona.

R5 **Los Angeles to Santa Monica (SP)**
Closed For more than 72 hours.

The northern end of the NIFZ crosses tracks here, causing minor ground displacement and disruption of tracks. The railroad bridge over Ballona Creek is damaged by surface rupture, closing this line at this location.

R6 **Los Angeles to El Segundo (AT&SF)**
Closed for more than 72 hours.

Fault displacement in the NIFZ causes major disruption of tracks. The bridges on this segment are damaged by the shaking (Jones, 1983, p. 149).

R7 **Watts to El Segundo (SP)**
Closed for more than 72 hours.

The NIFZ crosses tracks here, causing major disruption. The bridges on this segment survive the shaking (Jones, 1983, p. 149). The alternate route to Torrance does not cross a known Holocene fault trace, and sustains only minor grade level changes. The bridges on this segment survive the shaking (Jones, 1983, p. 149).

R8 **Compton to East Long Beach (SP)**
Closed for more than 72 hours.

NIFZ parallels tracks here, causing major disruption of tracks for a distance of more than 1 km. The bridges on this segment are damaged (Jones, 1983, p. 149). There is major damage to bridge structures at the crossing of the Union Pacific Railroad and Route 710 just west of the Los Angeles River.

R9 **Seal Beach/Naval Weapons Station**

<u>Closed for more than 72 hours</u>.

The NIFZ crosses tracks here. Fault displacement and liquefaction causes major disruption of tracks within the Naval Weapons Station.

R10 **Saugus to Burbank (SP)**

<u>Closed for more than 72 hours</u>.

The tracks are disrupted locally due to liquefaction. The bridges along this segment are damaged by the shaking (Jones, 1983, p. 149). The Interstate 5 overhead collapsed onto the tracks at this locality during the 1971 San Fernando M 6.5 event (see Penzien and Clough, 1975, photos 2 through 6). The freeway overhead has been replaced with one of resistant design (Meehan, 1971). The tracks were disrupted just west of the Los Angeles County Juvenile Hall Facilities (Meehan, 1971, Figure 7).

R11 **San Diego to Orange (AT&SF)**

<u>Closed for more than 72 hours</u>.

The tracks are disrupted due to liquefaction failures. The bridges on this segment will survive the shaking (Jones, 1983, p. 150). Holms and others (1986, p. 24) expect the route to be "closed by ground failure near San Clemente."

R12 **Los Angeles to Long Beach (UP)**

These two lines sustain only minor grade level changes -- but the bridges are damaged (Jones, 1983, p. 149). The bridge structure at the crossing of the SP railroad and Route 710 just west of the Los Angeles River is heavily damaged.

MARINE FACILITIES (PORTS)

General Characteristics

The two major commercial port facilities in this planning area are the Port of Los Angeles (WORLDPORT LA) and the Port of Long Beach which are contiguous in the Los Angeles-Long Beach harbor area. Although they are commercially competitive, they have many areas of cooperation. As a combined harbor complex, the two ports handle more tonnage than any other port complex in the nation. The combined harbors have developed the largest international intermodal rail yard complex in the nation, and are the leading import auto port in the U.S.

A large percentage of port facilities for both harbors are located on Terminal Island which is roughly 3.5 miles long by 1 mile wide. Extensive dock facilities, oil storage facilities, the Long Beach Naval Station, Naval shipyards, and some of the container facilities are located on this island. Vehicular access to the island from the mainland is by the Vincent Thomas Bridge (suspension) at the west, the Gerald Desmond Bridge (tied arch) at the east, and the Commodore Schuyler F. Heim Bridge (vertical - lift bridge) from the north. These are all of modern construction. Railway access from the north is provided by the old Henry Ford (bascule) bridge which has suffered some damage in previous earthquakes.

A former subsidence area, roughly elliptical in shape, is centered near the northeast corner of Terminal Island. In 1963, maximum cumulative subsidence at the center of this area had reached 28 feet and affected many square miles. This subsidence, attributed to the withdrawal of petroleum, has been successfully halted by a program of water injection initiated in 1958.

Three major railroads serve the harbor area - the Southern Pacific, Santa Fe and the Union Pacific. They jointly operate the Harbor Belt Line in the Port of Los Angeles with a network of rails to the various terminals, docks and intermodal facilities. The Southern Pacific does the switching for the rail system in the Port of Long Beach.

Seismic Considerations

The harbor areas and port facilities are located from 3 to 6 miles from the NIFZ. They are in areas of high liquefaction potential and predicted ground shaking intensities of IX (MM). The severe ground shaking and probable liquefaction will affect many structures, roadways, bridges, cranes, docks, naval facilities, quay walls, utilities, etc.

No seismic sea wave (tsunami) is assumed in this scenario. However, oscillatory waves in enclosed bodies of water (seiches) can be anticipated. This would damage boats and moorings at harbors at Newport Beach, Long Beach, Los Angeles, and Marina Del Rey.

Most of the major terminal and dock facilities are supported on piling which has performed well in previous earthquakes. Quay wall facilities, which are large gravity-type structures (concrete quay), tied-back steel sheet pile, or dike and fill, are subject to potential settlement and damage due to liquefaction of the retained sandy soils. All of the old unreinforced masonry structures have been removed so that a large percentage of buildings are of modern engineered construction supported on piling 70 to 90 feet below grade. Warehouse #1 in the Port of Los Angeles is a large old concrete building dating back to about 1910. This building is currently being studied for remodeling and rehabilitation.

An earthquake loss assessment of Worldport LA facilities (URS Corp., 1986) includes the following assessment of buildings and waterfront construction:

Building Structures

For building structures, soil liquefaction is the primary geotechnical hazard of concern. Past experience has shown that buildings supported on pile foundations are relatively unaffected by soil liquefaction while buildings on spread footings may be subject to extensive damage due to poor soil. At WORLDPORT LA, most if not all of the important and valuable building structures have pile foundations. In fact, non-pile supported buildings account for only approximately 2 percent of the port's assets.

Wharves, Bulkheads, and Rock Dikes

Typical waterfront construction at this site is characterized by pile supported wharves, rock or soil dikes, and relatively low bulkheads behind which hydraulic fill material has been placed. This type of construction is considered to be fairly resistant to damage due to geotechnical hazards. Liquefaction of the hydraulic fill is expected to cause little or no damage to the pile supported wharves. However, the tied bulkheads are subject to damage or failure depending upon the intensity of the earthquake shaking. In addition, the rock retention dikes may be subject to localized slope failures caused by excessive pressure due to liquefaction of the hydraulic fill. Although only relatively minor damage is expected, damage to the rock dikes may be largely undetected and unrepairable without removal of the wharf.

The bridges connecting the mainland to Terminal Island can probably survive the postulated earthquake without major damage though approach failures could severely restrict access. The Commodore Schuyler Heim lift bridge could be nonfunctional due to mechanical failure. The railroad drawbridge could become nonfunctional.

Many of the hundreds of rail-mounted gantry cranes could be dislodged from their rails and become inoperable due to settlements resulting from earth shaking and consequent liquefaction. Serious damage to underground oil lines and utility lines can also be expected from the same effects.

Planning Considerations

Although the operation of the combined Los Angeles - Long Beach facilities will be seriously impacted by the scenario earthquake, the continuing function at diminished or restricted capacity should not be critical to the post-earthquake emergency response effort. Only a small percentage of vital food supplies or other emergency supplies enter the area through the harbor. Loss of rail transportation can be replaced by truck transport.

Planning Scenario

Damage Assessments

Damage assessments have been postulated for certain marine facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Location of facilities are shown on Map-5 RM.

Los Angeles-Long Beach Harbor

Severe liquefaction failures on Terminal Island has caused approach failures on both the Vincent Thomas and Commodore Schuyler F. Heim bridges. The approaches of the Gerald Desmond Bridge are damaged, and access to the island is limited to light emergency vehicles across this bridge, via Ocean Boulevard. Reopening either of the main Route 47 bridges within 72 hours is not expected. However, with an all-out effort it may be possible to open the Vincent Thomas Bridge in about 36 hours.

Extensive liquefaction damage on Route 47 north of the Commodore Schuyler F. Heim Bridge (which has mechanical failure) has made access from the north virtually impossible. Reopening this portion of Route 47 in less than 72 hours is not expected.

Route 710 is closed south of Anaheim Street in Long Beach due to extensive liquefaction settlements at the 9th/7th Street interchange. Access to the southeast basin area is limited to light emergency vehicles via the Queensway Bridge, whose approaches are also damaged. Improved traffic capacity to the southwest basin area cannot be expected for at least 48 hours.

Damage to the roadway system leading to and within the harbor area will restrict truck access to 75 percent of normal for a period of two weeks.

Rail access to the area and within the area is severely restricted due principally to damage caused by ground settlements and liquefaction. Rail access to Terminal Island via the old Henry Ford Bridge (bascule) is suspended. Numerous railroad cars are overturned as a result of ground failure adjoining the southeast basin. Rail services should be restored to 75 percent of normal within three weeks.

Many rail-mounted gantry cranes are dislodged from their rails or otherwise damaged; restoration to service will require a month or more. The heavy equipment required for restoration will be employed in higher priority tasks such as life saving.

Intense shaking and ground failures have damaged electrical power transmission towers at the crossing of Cerritos Channel north of the Long Beach Power Plant. This is damage assessment E 13 in the electrical power chapter and on Map 5-E.

The most serious problems are the result of extensive damage to underground utility lines, oil pipelines, and waste water lines. Loss of vital utilities and contamination of harbor waters will reduce the operation of harbor facilities to 25 percent for one week, 50 percent for 3 weeks, and 80 percent for an undetermined period (depending on priorities).

Ground failures along the west side of the Los Angeles River Channel south of the Shoemaker (7th St.) Bridge has damaged pipelines traversing this corridor to the Long Beach Harbor area.

Ground failures on Mormon Island (Port of Los Angeles berths 161-181) have ruptured oil storage facilities. There is a fire on Mormon Island and discharge of fuel into the channel, posing the threat of an extensive fire.

A large diameter oil pipeline is ruptured as a result of ground failures on the Terminal Island side of the channel crossing, resulting in discharge of oil into the main channel.

Pile-supported docks, terminals, and other structures have performed well with minimal damage. Ground failures have caused the partial collapse of a major warehouse at the west end of Terminal Island, and another near the Southern Pacific Freight Station. (On Eighth Street in Long Beach)

Harbor waters are being increasingly contaminated with raw sewage as a result of ruptured mains and overflow from non-operational waste water treatment plants.

Electrical power is unavailable except from emergency power sources and restoration of power throughout the harbor area will require several days.

Several small fires have started throughout the harbor area. Available fire fighting capabilities are limited by restricted access and an absence of water pressure, and by the focussing of efforts to save lives. A major fire is in progress at one of the restaurants at the Ports 'O Call Village.

Oscillatory waves in enclosed bodies of water (seiches) have damaged yachts, boats, and moorings in Los Angeles - Long Beach Harbor, Marina Del Rey Harbor, Huntington-Seal Beach Harbor, and Newport Harbor.

Section 4.

UTILITY LIFELINES

COMMUNICATIONS

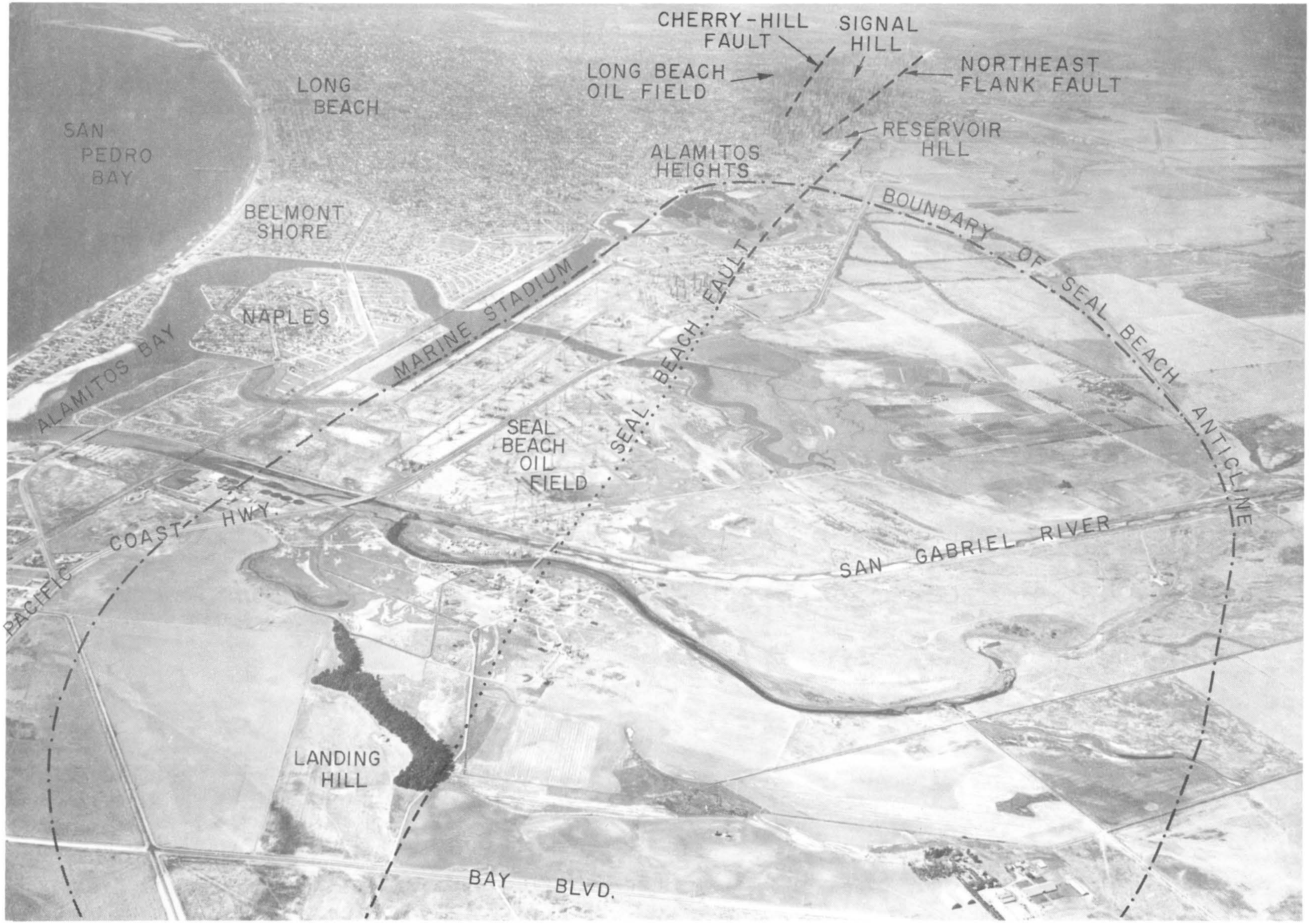
Introduction

The following discussion of communications systems was prepared in collaboration with representatives from telephone companies, the Governor's Earthquake Task Force on Telecommunications, and the Department of General Services (DGS), Division of Telecommunications. Damage assessments were not possible with available resources, and no scenario or map is given.

Telephone communications will be severely overloaded by post-earthquake calls. This situation will be further complicated by damage to some of the equipment. The loss of service due to commercial electrical power failure will be minimal because backup power is available.

The systems in the greater Los Angeles region can process emergency calls automatically on a previously established priority basis. A Telephone Industry Communications Disaster Plan ensures that key agencies and personnel have access to needed communications after the scenario earthquake. This plan anticipates the needs of essential services. The telephone system, however, should not be relied upon as the sole source of communications and alternate systems should be in place. Public reliance on the telephone system should be kept at a minimum. Communications to the general public will use surviving commercial radio and television stations.

Telecommunications systems are composed of many subsystems, each interconnected and interdependent. A radio network, for example, may use a combination of telephone lines, microwave circuits, satellite interfaces, underground and overhead cables, and secondary radio paths. The failure of one link in this electronic "chain" can effectively disable a large portion of the system. The earthquake will reduce the effectiveness of systems rather than completely destroy them. Criteria such as geographical coverage, the number of system elements, and functional integration are



Photograph 6. Northwestward view along the NIFZ. The San Gabriel River flows from the right into Alamitos Bay on the left. Photo from Spence Collection, University of California at Los Angeles taken in 1941.

important in estimating the post-earthquake effectiveness of a particular system. "Effectiveness" is defined as the ability of a system to perform to its design limits and provide the intended service.

The communications network is described in subsections treating the telephone systems, public safety radio, and other communications systems.

Telephone Systems

Telephone systems are a vast complex of interconnecting networks. Prior to January 1, 1984, any trouble was reported to "the telephone company" and the responsibility for restoring the service was theirs.

As a result of divestiture of the telephone industry, the traditional concept of end-to-end service must be altered. Services are classified as intra-exchange, access, and inter-exchange carriers. The Bell System portion of the network is divided to reflect this segmentation of responsibility. In accordance with the divestiture rulings, the Bell Operating Companies (BOC) have divided the territory they serve into areas known as Local Access and Transport Areas (LATA). The State of California is divided geographically into 10 LATA's. Calls originating and terminating in the same LATA (i.e., intra-LATA) are typically handled, as in the past, by "the telephone company" that serves that LATA. However, calls that originate and terminate in different LATA's (i.e., inter-LATA) are transported between LATA's by a carrier referred to as an inter-exchange carrier (IEC).

Terminal equipment (telephone instruments, telephone switches, and cable) can be purchased by the customer and maintained by a third party.

Under the new structure, the former Bell System telephone network may be viewed as three separate parts: intra-LATA, inter-LATA and customer owned equipment. Therefore, the customer must participate to a greater extent than previously in restoring telephone communications.

The regulated telephone companies have installation standards designed to minimize earthquake damage. They also have emergency mobilization plans and have exercised these plans effectively. Nonetheless, there has not been a disaster in modern times of the magnitude being addressed. It is, therefore, quite difficult to forecast the detailed effects of a major earthquake on the telephone system. There are, however, a number of outcomes that can be anticipated: hardware damage, underground cable failure in areas of liquefaction, damage to surface cable carriers, system call saturation during post-earthquake recovery, and repair-access problems.

Evaluation of system performance takes into account the likelihood of any or all of these events occurring and subjectively applies this. We attempt to quantify the ability of public safety agencies to conduct recovery efforts by using the telephone system. Our estimate is not directly applicable to the general performance of the system nor to the public's ability to use the system.

Our evaluation is based on past telephone performance in disaster situations, casualty projections, population density and demography, post-earthquake transportation evaluations, the probable performance of commercial power facilities, and any known site-specific technical considerations. No attempt has been made to separately evaluate each of several hundred telephone facilities.

Some basic assumptions have been made: (1) the shaking intensities are as projected in Map 5-S; (2) areas suffering a shaking intensity of Modified Mercalli VIII or higher will have significant hardware damage, although such damage would be fairly localized and not on a large regional scale; (3) some underground cables will be damaged by ground failure, but not in sufficient number to preclude switching alternatives; (4) most predesignated public safety circuits will receive priority restoration; (5) most telephone company backup-power provisions will be functional; (6) the long distance network, although difficult to access, will remain generically stable; (7) inter-exchange facilities will be difficult to access, but would remain intact; (8) shortly after the event, numerous relatively simple failures will occur, coupled with intense call saturation, that will materially impair the telephone networks in the affected areas for at least 12 hours.

Effectiveness of Essential Services Lines

Emergency response agencies have a portion of their telephone lines, sometimes as little as 10%, predesignated as essential services lines. For planning purposes, we postulate that after the scenario earthquake, these essential services telephone lines will be 25% usable in the first day, 50% usable in the second day, and 75% usable at the end of the third day. This assessment is for most of the area within 40 km (25 mi) of the fault. The availability of telephone communications for the general public will be significantly lower than for emergency response agencies.

Specific Vulnerabilities

The most vulnerable aspects of telephone systems are the computers used to switch message traffic. All are sensitive to changes in cooling and may be mounted on false floors. Call saturation is the most obvious system access problem. Most exchanges, however, have the capability through the switching computers, to control system load by limiting access to only predesignated circuits. The telephone systems work primarily on battery power, with backup generators. If emergency power fails, system performance on batteries will degrade at a significant rate.

Assuming the earthquake occurs outside normal business hours, a number of staffing dimensions must be considered. The first concern of telephone company employees will be their families and friends. A small percentage of staff will leave their jobs to ameliorate the effects of the disaster in their personal lives. Some employees will suffer casualties or will be confronted with blocked streets and highways. Most repair vehicles will be inaccessible to staff for several hours and, in some cases, will probably be immobilized by facility failure.

Prior to divestiture, a single call to the local operating telephone company would start the complete installation or repair of network and equipment; i.e., lines, instruments, Public Branch Exchange, etc. Now, two or more calls could be required. Maintenance contracts for customer owned equipment should include repair or replacement of equipment in the event of a disaster.

Public Safety Radio Systems

Radio systems will operate at 75% effectiveness for the first 12 hours after the earthquake. A slow decline will occur after this due to equipment failures, battery life, and operations overload. As spare equipment and support personnel are moved into the area, the effectiveness of the radio system will increase. Portable command centers will be established by the Governor's Office of Emergency Services to set priorities and coordinate the use of various law enforcement and fire prevention agencies.

Radio systems are less susceptible to damage due to their relatively small size and minor dependence on wire cable. These systems are made up of various components, such as, radio control consoles, base stations, micro-wave radio, repeaters, mobile relays, mobile radios, hand held radios, and portable radios. The failure of any particular component will not adversely affect the system because alternate operations are part of the public radio system design.

In addition to public safety radio systems, the following communication systems can aid in providing emergency communications.

Amateur Radio

The amateur radio system is designed for an entirely different application than the public safety radio. However, it has helped in disaster recovery operations. Radio Amateur Civil Emergency Service (RACES) has been organized to provide emergency communications during disasters. The Office of Emergency Services command center has integrated this radio system within their operating procedures.

Aircraft and Marine Radio Communications

This radio service will be at least 90% effective. Some public safety systems, such as those of California Department of Forestry, California Highway Patrol, and the U.S. Forest Service have aircraft communication.

Cellular Radio Systems

This radio system will have the same operational problems as the telephone network, because it is an extension of that network. However, since it is not dependent on cable for connection, it will be more reliable than basic telephone service. In addition, the priority features of this system will allow selective use for the emergency.

Satellite Communications

This is the most reliable method of point-to-point communications. The use of satellite for emergency communications is limited by the vulnerability of the earth station and by the time required to connect to it.

Commercial Broadcasters

Commercial radio and television stations have the capability of disseminating information to the public better than any other means. Because their stations cover a wide area, their service will be very valuable in the disaster recovery efforts.

The emergency broadcast system can be activated very rapidly and is a reliable method of communication to the public, if commercial stations are on the air.

Data Communications

Communications systems used to support computers will be 80% effective. They are subject to telephone failure but less vulnerable to the voice problems because they usually have dedicated-line facilities and redundant communications links. However, dial-up data will be subject to the same problems as the telephone system.

Other Radio Systems

Small public and private radio systems can be used on a very limited basis where the application will assist a specific operation. Some of the systems are as follows:

- Paging Systems
- Medical Radio Systems
- Trucking Systems
- Taxicab Systems

Planning Considerations

When a disaster occurs, the most reliable method of communication will be the Public Safety Radio System. Portable command centers will fill most communication needs after the earthquake. Trained personnel will operate radio systems such as those of the Office of Emergency Services, California Highway Patrol, and California Department of Forestry. Telephones will be available only to a few essential services.

The Governor's Task Force on Earthquake Preparedness has just completed a comprehensive plan to restore communications. A cooperative effort involving all telephone companies serving California has developed a plan that will provide mutual assistance as needed.

The remaining section is from the Communications Annex of the (CALIFORNIA EARTHQUAKE RESPONSE PLAN) (Office of Emergency Services, 1983).

CONSEQUENCES FOR COMMUNICATIONS

The following procedures are based on the normal direction and control (D&C) structures utilized in major area-wide emergencies. This usually involves each jurisdiction providing for its own continuity and internal response. When the problem exceeds their capabilities, they will invoke mutual aid and/or request assistance from the next higher level of government, i.e., local to county to state to federal. While at times this concept may not be implemented, it must be the concept upon which communications planning takes place.

Generally, communication planning is based on day-to-day operational requirements which dictate a high level of reliability. This is especially true in the public safety services where standby and emergency equipment is available. Government normally does not provide for communication support to private enterprise nor do they have the license or funding to do so in preparation for earthquake response.

In the absence of specific direction and in direct response to the potential earthquake problem, this annex is based on the hypothesis that state direction and control will take place from the Disaster Support Area located at Los Alamitos, California.

CONCEPT OF OPERATION

Anticipated sequence of events after notification of a major earthquake.

First hour:

1) Request the California National Guard to set up the OES mobile communications complex located in Los Alamitos, at the Disaster Support Area (DSA).

2) Request the California National Guard set up a four-channel high frequency radio link between OES, Sacramento and the DSA, and establish microwave telephone lines to the nearest telephone entry point out of the disaster area.

3) Contact RACES operators to work in OES Headquarters.

4) Activate the radio equipment at OES Headquarters to receive messages from southern California.

5) Request telephone company to install phone service at DSA.

Second Hour:

1) Request Communications Division, Department of General Services, survey and repair as necessary radio/microwave equipment.

2) RACES operators arrive OES Headquarters. Each radio will have an operator and stenographer.

Fourth Hour:

1) Dispatch OES Telecommunications Division personnel to DSA to ensure van complex is operational and to coordinate repairs and requests for additional lines of communication.

2) Request Communications Division dispatch Los Angeles area supervisor to DSA.

Eighth through twenty-fourth hour:

1) OES Telecommunications personnel check out van complex and other radio communications links. Repair/replace as necessary with assistance of DGS area supervisor.

2) Request other communications as situation dictates.

Local communication personnel carry out emergency assignments in accordance with local operating plans. State agency personnel respond in accordance with their agencies' plans or directions. Communications Division has published a Standard Operating Procedure for alerting and assigning their personnel.

Communication personnel remain in their individual command structures and respond to their own leadership.

There are few uncommitted communication resources. Existing day-to- day requirements are what will be available in an emergency. Emergency reserve equipment is for increased operating requirements of the owner and cannot be readily diverted to other agencies. Generally, this would be impractical for technical reasons such as frequency or antenna mismatch, even if made available.

ORGANIZATION

All communication is by coordinating rather than rigorous organizational structure.

1) **Department of General Services (DGS) - Communications Division:**

Primary objective is to ensure that state agencies are provided necessary communication services meeting their operational requirement at a minimum expenditure. This division operates its service and maintenance shops. It also manages a very extensive microwave system reaching into all areas of the state and the state's Automatic Telecommunications Switching System (ATSS). The latter is a statewide telephone system for use of state agencies.

2) **Office of Emergency Services (OES) - Telecommunications Division:**

This office coordinates emergency communications. It operates three major statewide communication systems (emergency services, fire, and law nets). It coordinates mutual aid radio systems, five state emergency operations centers, and provides coordination and planning guidance to local emergency services. It also manages a number of mobile communication centers equipped for state agency communication support.

3) **California Highway Patrol (CHP) - Telecommunications Section:**

This section manages the CHP communications system which serves the operational requirements of the agency. All radio nets are local nets with long-distance operations served by a microwave telephone system. It has extensive mobile capability.

4) **California Department of Forestry (CDF) - Communications Management Section:**

This section coordinates the department's communication systems which serve the various regions. All nets are local area nets with long-distance operations served by microwave intercom and telephone systems. It has extensive mobile capability.

5) **Department of Fish and Game (DFG) - Telecommunications Branch:**

This branch coordinates the operation units. It has no state-wide long-distance capability. It has extensive mobile capability.

6) **Department of Water Resources (DWR) - Telecommunications Office:**

This office coordinates the department's communications resources serving the operational units. It provides for water monitoring radio operating. It has no long-distance capability.

7) **Department of Transportation (DOT) - Telecommunication Branch:**

This branch coordinates the department's communication resources serving the operational units. It has some long-distance capability from its Sacramento headquarters to districts. Most operation is via local nets. It has extensive mobile capability.

8) **Department of Justice (DOJ) - Telecommunications Branch:**

This branch has some local radio nets servicing its operating personnel. One section manages the statewide California Law Enforcement Telecommunications System (CLETS) serving state and local law agencies.

9) **Department of Parks and Recreation (DPR) - Telecommunications Unit:**

This unit coordinates the agency's communications resources serving the department's operational requirements. Most operation is local net. It has some mobile capability.

10) **California National Guard (CNG) - Communications:**

This office coordinates the communications resources of the State Military Department. It has various assortment of communication capability. It has limited day-to-day in-place systems. Most communications serve their own operating forces. It has some reserve equipment.

Federal Agency Communications Functions

1) **Federal Communications Commission (FCC):**

The FCC is charged with oversight of communications in the United States. As such, it regulates the telephone companies, broadcast industry, and other licensed radio users. The Interagency Radio Advisory Committee (IRAC) controls radio users for the federal agencies. The FCC has certain authorities under emergency conditions to suspend operations. It does not have authority to control or reassign equipment.

2) **National Communication Systems (NCS):**

The NCS is a confederation in which certain federal agencies participate with their assets to provide necessary communications for the federal government under all conditions including national emergencies. One of the functions performed in support of the NCS mission is to develop plans and procedures for the management of federal telecommunications during Presidentially declared disasters and emergencies. The Regional NCS Manager for California also serves as the Emergency Communication Coordinator and works out of the federal General Services Administration in San Francisco.

3) **Emergency Broadcast System (EBS):**

The EBS is devised to provide the President and federal government with a means of emergency communication with the general public through nongovernment broadcast stations during and following an Emergency Action Condition (EAC). The system may be used on a voluntary basis during day-to-day situations posing a threat to safety of life and property. The Federal Communications Commission has oversight of this program.

Priority for use is:

- Presidential messages
- Local area programming
- State programming
- National programming and news

Common Program Control Stations (CPCS) for EBS input are:

- o KFI, Los Angeles
- o KEZY, Orange County

Personal Communication Responses:

The FCC licenses individuals in the radio amateur and citizen services. The radio amateur operates under authority of FCC Rules and Regulations, Part 97; the citizens services under Part 95. Both have provision for operations in emergencies. Persons with such licenses participate in numerous volunteer organizations providing communication support to local government and relief organizations. Generally, these organizations work at the local level in accordance with plans developed by them and approved by the supported agency. It is expected these organizations will be a major source of supplementary communications in the event of a major wide-area disaster.

RESOURCES

The State of California Office of Emergency Services has two mobile command complexes consisting of a communications van, an operations van, a command van, and a generator to provide power. One complex is stored at Los Alamitos. Its primary purpose is to provide initial communications from the disaster area to OES Headquarters, Sacramento, and to act as a collection point for damage assessment until more sophisticated communications are established and/or restored. This complex is equipped for operation on each of the major state radio communications systems, the satellite systems, various mutual aid radio systems and the Radio Amateur Civil Emergency Service (RACES). Radio operators must be provided by the responsible agency.

UPDATE

In December 1986, the Office of Emergency Services (1986) generated "Southern California Earthquake Response Plan", which is an update of "California Earthquake Response Plan" referred to in the last section. The communications annex of the most recent report is an additional source of information.

ELECTRIC POWER FACILITIES

General Characteristics

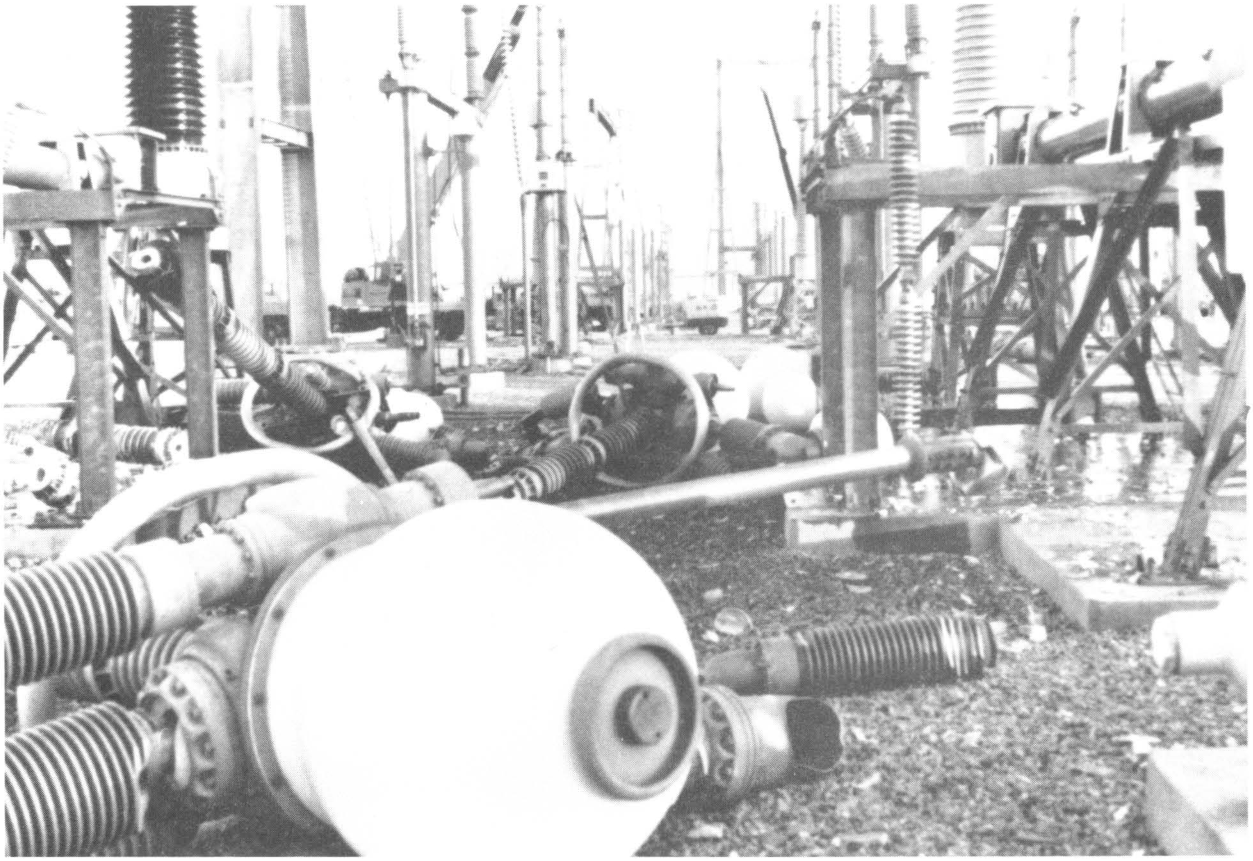
The Los Angeles Department of Water and Power (LADWP) supplies electrical power to the City of Los Angeles. Southern California Edison Company (SCE) serves the remainder of the area, except for the cities of Glendale, Burbank, and Pasadena which have their own power generating facilities augmented with purchased power. The City of Anaheim Electric System purchases power from SCE which it distributes throughout the city.

Most of the electrical power demand is supplied by plants located outside the planning area. About one-third of the total demand is imported from hydroelectric nuclear and coal fired plants to the north and east. In an emergency, these lines can tap ample reserves from other outside sources including the hydro-electric power plants in Owens Valley, and on the Colorado and the Columbia rivers. The locations of electrical facilities and the extensive network of major substations and interconnecting transmission lines within the planning area are shown on Map 5-E.

Seismic Considerations

There are many critical elements within the electrical power system, including:

1. Power generating facilities
2. Transmission and distribution substations
3. Transmission lines, both overhead and underground high-voltage lines
4. Local substations and distribution lines
5. High-voltage transformers, circuit breakers, and ceramic insulators
6. Water services to generating stations and substations
7. Gas and oil fuel lines to generating stations
8. Emergency power generating facilities



Photograph 7. Devers substation, showing insulators destroyed within 1 mile of the epicenter of the 8 July 1986 North Palm Springs earthquake of M 5.6. (from Borchardt and Manson, 1986).

For planning purposes, it should be assumed that earth shaking and ground failures resulting from the scenario earthquake will seriously impact each of the critical components of the electric power system.

Power Plants

According to NOAA (1973, p. 274), "Experience indicates that well designed electrical generating plants should suffer minimum (less than 5%) damage in intensity VIII (MM) zones and only slight (less than 10%) damage in intensity IX (MM) zones." They note that damage at the Valley Steam Plant during the 1971 San Fernando earthquake (M 6.4) was negligible though estimated ground motion at this plant was intensity VIII (MM). Power plants, auxiliary switchyards, and other ancillary facilities located in areas of high ground water or poor soil conditions (such as areas of potential liquefaction), however, are susceptible to significant damage as a result of ground failure.

All of the 12 thermal electric power plants in the planning area (see Map 4-E) are located in areas of predicted heavy ground shaking, intensity VIII and IX. Six of these plants, located near the coast from Long Beach to Huntington Beach, are also within areas of high liquefaction potential.

Three power plants are located within or very near the fault zone:

Alamitos Power Plant (SCE), Seal Beach	2071 MW
Haynes Generating Station (LADWP), Seal Beach	1589 MW
Huntington Beach Power Plant (SCE), Huntington Beach	981 MW

Most of the power companies used earthquake design criteria that were double those required by local building codes at the time of construction (NOAA, 1973). The major structures are generally supported on pile foundations which have performed well in past earthquakes. However, in view of the severe ground shaking and ground displacements predicted in this scenario earthquake significant damage to major structures and their associated equipment, switching facilities, piping, fuel and water lines can be expected.

The fuel supply (oil or gas), cooling water, and fresh water are critical to the operation of a power plant. These services are all subject to interruption by the effects of earth movements and shaking. Emergency power facilities and storage facilities for fuel and fresh water are vital.

Damage to power plants and their ancillary facilities within the study area will result in a reduction in generating capacity of as much as 33 percent. The impact of this reduction in local output will be lessened, however, by the availability of power from sources outside the planning area and by an anticipated reduction in consumer demand following the earthquake. The primary restoration problems will involve repair or replacement of equipment at major substations, restoring damaged and collapsed transmission line towers, reactivating equipment at local substations, and replacing fallen poles, burned transformers, etc.

Substations

Transmission substations are the most vulnerable element in the electrical power delivery system. Major substations contain banks of switches, circuit breakers, massive transformers, control equipment, and tall high-voltage porcelain insulators that are particularly vulnerable to earthquake shaking. In the areas of intensity VIII and IX shaking during the 1971 San Fernando earthquake (M 6.4), the distribution substations generally fared much worse than the power generating stations (Moran and Duke, 1975). More recently, on July 9, 1986, the North Palm Springs earthquake produced $3.5 million in damage to SCE's Devers bulk power substation even though it was only a M 5.9 event (Borchardt and Manson, 1986). A strong motion accelerograph at the substation recorded horizontal accelerations up to 0.97g for 14 seconds (Ostrom, 1986). The higher voltage equipment installed in 1982 and designed to withstand up to 0.5 g failed while the low voltage equipment installed in 1967 did not. This is because the high voltage equipment included large porcelain insulators that were heavily damaged by earthquake shaking. The damage was repaired in nine days by borrowing parts from other substations. For the scenario earthquake, this recovery option may be limited because so many substations will be affected at the same time.

In addition to the major transmission substations through which high voltage (≥ 230 KV) is routed, damage may occur at many of the smaller local substations that provide additional vital links in the electrical power distribution network.

About 35 major substations are located within the area of intensity VII to IX shaking. Some of these stations are also located within or adjacent to the zone of fault rupture as follows:

LADWP Substation	West Los Angeles
SCE Substation	Culver City
SCE Substation	Windsor Hills
LADWP Substation	Morningside
SCE Substation	North Long Beach
SCE Substation	Costa Mesa

For planning purposes, it should be assumed that serious damage and power outages will occur to these substations and their associated switching and other equipment. The damage will be sufficient to curtail their performance for at least 3 days. The seismic performance of facilities such as these is the subject of ongoing research by the utility industry. A comprehensive assessment of the expected effects of the earthquake requires a geotechnical study of each of the numerous substation sites. Lacking this, substations in the intensity VIII and VII areas were considered to be incapacitated for at least 24 hours.

In coping with such circumstances, it should be noted that an electrical power utility has considerable flexibility to reroute power. Temporary repairs could permit transmission of some power within 24 hours provided transmission lines are intact. Completion of repairs to these substations could involve an extended period.

Transmission Lines

Overhead Lines

LADWP and SCE import power to the planning area along numerous routes from generating sources to the north and east. These transmission facilities combined with power transmitted from the many power plants located within the planning area, comprise an extensive high-voltage transmission network involving hundreds of miles of overhead transmission lines. LADWP and SCE power enters from both the north and from the east into areas with projected high ground shaking intensities. All of the transmission lines originating from the twelve generating plants located in the planning area traverse areas of projected ground shaking with intensities of VII to IX. Many cross areas of medium to high liquefaction potential. This high degree of exposure suggests that some major transmission facilities will be out of service due to collapsed or heavily damaged towers.

Even though transmission towers are designed to resist significant lateral forces due to wind loading and broken conductors, it is prudent to plan for a few structural failures and consequent loss of power caused by ground shaking. In addition, towers are susceptible to structural damage caused by ground failure produced by fault rupture, landslides, and liquefaction. According to NOAA (1973, p. 275) "twenty-five percent of the transmission lines entering the 2 county study area will likely be out of service due to damage resulting from rock slides in the mountainous areas and damage to switching terminals." We now consider this to be overly pessimistic. Damage to major transmission lines during earthquakes has seldom resulted in lengthy power outages. For instance, while $3.5 million of damage was sustained at the Devers substation during the 1986 North Palm Springs earthquake, the 500 KV transmission lines serving it escaped unscathed (Borchardt and Manson, 1987). Furthermore, a single fallen transmission tower can be bypassed within a few hours (Luis Escalante, LADWP, personal communication). In order for the impact of power line damage to rival that of substation damage, a large number of towers must fail sequentially.

Buried Cable

Extensive runs of buried transmission cable are located in the West Hollywood-Culver City-LA International Airport-Inglewood area and in the Wilmington-LA Harbor area. These cable are laid in conduit that allows for at least 2 to 3 feet of play (Luis Escalante, LADWP, personal communication). For planning purposes, it should be assumed that local fault displacements of about 3 feet will damage some of these cables.

Planning Considerations

The scenario earthquake is expected to have a significant impact on many of the major facilities that comprise the complex electrical power network serving this major urban area (See Map 5-E). Damage to power plants and their ancillary facilities within the planning area and in adjacent areas affected by the earthquake may be expected to reduce combined generating capacity by two-thirds. The impact of this loss will be lessened by the availability of power from other sources outside the planning area and by the significant reduction in consumer demand that will occur following the earthquake. Primary restoration problems will involve repairs to route power through the major substations, restoration of damaged transmission line towers, reactivation of equipment at local substations, and replacement of fallen poles, burned transformers, broken insulators, circuit breakers, etc.

Planning Scenario

The following scenario is for planning purposes only and is not based on site-specific investigations. It is based on the conservative assessment of the performance of these facilities during quakes. Discussions were held with representatives of the engineering and operations divisions of the Los Angeles Department of Water and Power and the Southern California Edison Company. Field observations were also made.

A major earthquake on the NIFZ is expected to damage a considerable portion of the electrical power system in the Los Angeles-Orange County metropolitan area. Due to the location of the fault within a heavily populated area, the number of transformers damaged will be four times the number that a great earthquake on the San Andreas fault would produce (NOAA, 1973, p. 277). The 1971 San Fernando earthquake interrupted 1,000 circuits and a major event on the San Andreas fault is expected to interrupt 16,000 circuits. The scenario event could interrupt 64,000 circuits.

For this scenario earthquake on the NIFZ, it is reasonable to make the following assumptions regarding the damage to the electrical power system and consequent power outages to users in the study area:

1. Thermal Generating Plants - functional impairment of about 25 percent with a restoration of full capacity within 5 days.

2. Major Substations within 10 miles of the fault zone - extensive damage. Large circuit breakers and ceramic insulators will be damaged. Emergency rerouting of power should be possible in 80 percent of the cases.
3. Major Transmission Lines - light damage, with problems generally confined to areas suffering ground failure affecting consecutive towers. Some buried transmission cables crossing the fault rupture zone will be damaged.
4. Distribution Lines - light to moderate damage. Unanchored pole mounted transformers will be heavily damaged.
5. Service Connections. About 25 percent of the service connections in the planning area are expected to be without power for the first 24 hours. For those services within 5 miles of the fault zone, the percentage of power loss could be as high as 50 percent for the first 24 hours. Restoration of power could vary from 1 to 14 days.

Some areas, particularly between Culver City and Compton and segments of coastal Orange County, are expected to be without power for more than a week. Emergency planning for all power-dependent systems such as communications, water supply, fire fighting, and waste treatment should consider the possibility of an extended power outage.

According to NOAA (1973, p. 275), 25 percent of the transmission lines entering Los Angeles and Orange Counties will be out of service due to rock slides and landslides where the lines traverse mountainous terrain. This is now regarded as overly pessimistic, and the numerous alternate routes that exist into the area will be able to supply the reduced demand.

Serious impairment is expected to occur at those generating plants located close to the postulated fault break and those on poor soils. For planning purposes, the Harbor, Long Beach, Haynes, Alamitos, and Huntington Beach plants should be considered at 50 percent capacity for 30 to 60 days (shut downs, inspections, and repairs), amounting to 26 percent of the total generating capacity in the Los Angeles basin (NOAA 1973, p. 275).

Damage Assessments

Damage assessments have been postulated for certain electrical power facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 5-E.

NO. FACILITY

E1 **Sylmar Converter Station**
Shut down for 48 hours.

This major station converts 800 KV direct current from the Pacific Northwest to 230 KV alternating current for use in the Los Angeles area (Moran, 1971). The facility contains equipment that is especially vulnerable to earthquake shaking. In the 1971 San Fernando event part of this facility (it has since been enlarged) suffered $22 million in damage--40 percent of its value (Moran and Duke, 1975). The ground beneath the station liquefied and shifted as much as 5 feet toward the free face in Upper Van Norman Reservoir (Smith and Fallgren, 1975; Youd, 1971). In general, however, "the damage to electrical equipment was caused by ground vibration rather than permanent soil movements" (Moran and Duke, 1975).

For this scenario earthquake the predicted shaking intensity at this site is VII, (MM) whereas during the San Fernando event it was IX (MM). Damage due to shaking at the converter station is only a fraction of that produced in 1971. Nonetheless, the station is only 33 km from the

NIFZ--well within the radius of potential liquefaction effects (Tinsley and others, 1986, p. 307). The water table in the area is still high, the free face at Upper Van Norman Reservoir still exists, and fine sands still underlie the site. The ground liquefies much less than it did in 1971; only minor damage occurs.

E2 **Burbank Olive/Magnolia Power Plants**
Shut down for 48 hours.

According to NOAA (1973, p. 277) a M 7.5 event on the NIFZ (this scenario event is M about 7) would produce a functional impairment of 10 percent (slight damage) at this plant.

E3 **La Puente Area Substations**
Shut down for 48 hours

Two major substations located along the San Jose Creek drainage sustain minor damage resulting from intensity VIII-(MM) shaking.

E4 **Long Beach-Huntington Beach Area Power Plants**
(Harbor, Long Beach, Alamitos, Haynes, Huntington Beach)
All of these plants are shut down for more than 72 hours.

Designed to lower than current standards and situated on poor ground, these plants respond as did the reinforced concrete hydroelectric generating plant that suffered ground failure during the 1971 San Fernando earthquake: "Structural damage was severe (Moran and Duke, 1975, p. 419)." According to NOAA and others (1973, p. 275), "serious functional impairment is expected to the older thermal generating plants, to those located close to the postulated fault break, and to those on poor soil. For planning purposes, the Harbor, Long Beach, Haynes, Alamitos, and Huntington Beach plants should be considered at

50 percent of capacities for 30 to 60 days (shut downs, inspections, and repairs), amounting to a loss of 26 percent of the total generating capacity in the Los Angeles Basin." NOAA (1973, p. 277) estimated that a M 7.5 event on the NIFZ would produce a functional impairment of 20-25 percent (moderate damage) at each of these plants.

E5 **Segundo-Redondo Beach Area Power Plants**
(Scattergood, El Segundo, Redondo Beach)
Shut down for 48 hours.

Although these three plants are near the beach, they are founded on terrace deposits that are not subject to liquefaction. Shaking intensities will be VIII+. According to NOAA (1973, p. 277) a M 7.5 event on the NIFZ would produce a functional impairment of 10 percent (slight damage) at each of these plants.

E6 **Valley Steam Plant**
Shut down for 48 hours.

The behavior of this plant in the 1971 San Fernando earthquake was "remarkably good, the only damage being one broken lightning arrester. Maximum ground acceleration in this area is estimated at 30 to 40 percent of gravity (Moran and Duke, 1975, p. 419)." "Damage was negligible although the estimated ground motion at this plant was intensity VIII" (NOAA, 1973, p. 274). A M 7.5 event on the NIFZ would produce a functional impairment of 10 percent (slight damage) at this plant (NOAA, 1973, p. 277).

E7 **Grayson (Glendale) Power Plant**
Shut down for 48 hours.

According to NOAA (1973, p. 277) a M 7.5 event on the NIFZ would produce a functional impairment of 10 percent (slight damage) at this plant.

E8 **Glenarm/Broadway Power Plant**
No functional impairment.

According to NOAA (1973, p. 277), a M 7.5 event on the NIFZ would not produce any functional impairment at this power plant.

E9 **San Onofre Nuclear Power Plant**
No functional impairment.

Shaking at San Onofre will be intensity VII, which should not damage the power plant. A routine post-earthquake inspection will be conducted. Dennis Ostrom (Southern Cal. Edison) indicated that the operating basis earthquake shaking is an acceleration of 1/3 gravity, or intensity VIII, and should not damage the plant; [damage would occur at an acceleration of 2/3 gravity, or intensity IX+, but the plant could safely shut down].

E10 **Substations - Culver City/Compton Area**
Out of service for more than 72 hours.

The Culver City and Compton areas are served by five major substations, four of which lie within the NIFZ and another which lies in an area of moderate liquefaction potential. All will receive shaking intensities of VIII+ (MM) or greater. We postulate that significant damage to all five substations will make it extremely difficult to reroute power into the area. The survival of even one of these substations could reduce the duration of the power outage from 14 to 3 days.

E11 **Substations - Anaheim/Huntington Beach Area**
Out of service for more than 72 hours.

Coastal Orange County is served by three major substations located in areas of moderate to high liquefaction potential. All are subject to shaking intensities of VIII+ (MM) or greater. We postulate that significant damage occurs at all three substations making it extremely difficult to reroute power into the area. The survival of the Anaheim substation could reduce the duration of the power outage from 14 to 3 days.

E12 **Transmission Lines - Compton**
Line nonfunctional.

Two transmission line towers are heavily damaged and a third has collapsed as a result of ground movement near the fault crossing at Alondra Boulevard in Compton. High voltage lines are down across Alondra Boulevard.

E13 **Transmission Lines - Cerritos Channel**
Operating on limited capacity.

Intense shaking and ground failures have damaged transmission towers at the crossing of the Cerritos Channel north of the Long Beach Power Plant.

E14 Transmission Lines - Baldwin Hills
Operating on limited capacity.

Several towers are heavily damaged by fault rupture and related ground movements in the Baldwin Hills.

WATER SUPPLY

General Characteristics

The water supply for the extensive area affected by the scenario earthquake is derived from the following sources:

1. The Los Angeles aqueduct from the eastern slopes of the Sierra Nevada provides the major portion of water used by the City of Los Angeles. The system is operated by the Department of Water and Power of the City of Los Angeles (LADWP).
2. A large percentage of the water used by the remaining portions of Los Angeles and Orange counties is imported from the Colorado River through facilities of the Metropolitan Water District (MWD) and from northern California via the California Aqueduct operated by the State Department of Water Resources.
3. Ground water wells and rain water storage provide approximately one-third of the total water used in the planning area.

Sources of supply and annual water usage (excluding agricultural use) for the South Coast Basin are approximately as follows:

<u>Sources</u>

Natural supply from local sources	1,000,000	Acre Feet
Los Angeles Aqueduct	500,000	Acre Feet
Colorado River Aqueduct	850,000	Acre Feet
California Aqueduct	850,000	Acre Feet

Water supplies are stored in a number of major reservoirs and numerous small local reservoirs and storage tanks. Numerous municipal water departments and publicly owned water companies deliver water to industrial, commercial and residential users.

Map 5-W shows the major aqueducts, storage reservoirs, primary transmission pipe lines, and water treatment plants in the planning area.

Seismic Considerations

The following elements of the water supply systems are susceptible to damage as a result of ground failures or ground shaking caused by the scenario earthquake:

Aqueducts

The major aqueducts that deliver imported water to the planning area from outside do not traverse areas of significant earth shaking resulting from a major earthquake on the NIFZ. These systems, therefore, should not be damaged.

Reservoirs

The major terminal reservoirs of the three aqueduct systems are located beyond the area of potential damage and are unaffected by an earthquake on the NIFZ.

A number of intermediate size reservoirs (10,000 acre-feet to 35,000 acre-feet) and numerous small reservoirs are located within or near the perimeter of the area of intensity VIII-IX (MM) shaking. A statewide program of seismic investigation and modification of dams and reservoirs which was precipitated by the 1971 San Fernando earthquake is intended to insure that no catastrophic damage occurs to these structures. For planning purposes, however, some damage to certain of these storage facilities should be anticipated.

Wells and Tanks

Numerous water wells and water tanks are located throughout the area of heavy ground shaking (Intensity $\geq$ VIII). Considerable damage to these facilities should be expected, including damage to the connecting piping systems and, particularly, to th)se installations near the fault zone.

Water Treatment Plants

Six water treatment plants are located in the area, of which five are located on Map 5-W:

Long Beach Water Dept - Long Beach - within 1 mile of NIFZ
Peters Canyon Plant - Irvine - 15 miles from NIFZ
Robert B. Diemer Plant - MWD - Yorba Linda - 18 miles from NIFZ
Los Angeles Aqueduct Plant (started operation in 1987)
- LADWP - Sylmar - 18 miles from NIFZ
Joseph Jensen Plant - MWD - Sylmar - 18 miles from NIFZ
The Weymouth Memorial Plant - MWD - is in San Dimas (off the map) about 30 miles from the NIFZ.

All of these, except the Long Beach plant, will be subjected to earth shaking intensities of VII-VIII (MM). For planning purposes, it is reasonable to assume that these plants will not sustain major damage and will remain functional. The Long Beach plant borders the fault zone and has projected shaking intensities of VIII-IX (MM). For planning purposed this facility is assumed to sustain major damage.

Primary Transmission Water Lines

Numerous primary transmission pipe lines of MWD and LADWP traverse the planning area within the areas of severe ground shaking. These primary pipe lines traverse the fault zone to serve the various coastal communities (Map 5-W). There will be major damage to lines crossing the fault zone and to pumping stations within the zone.

Secondary Distribution Lines

There is an extensive network of distribution lines and associated pumping facilities that are susceptible to damage from high shaking intensities and fault rupture.

Planning Considerations

Water supply to the planning area is provided by several systems. The vulnerability of each of these systems should be appraised. It is essential that all water agencies examine their transmission and distribution system in detail to identify areas and facilities most likely to be impaired. Programs should be established and maintained to progressively upgrade facilities of questionable seismic resistance in areas of high vulnerability.

While there should be ample water storage in the numerous water reservoirs to satisfy all water demands during the emergency, damage to treatment plants and distribution systems may prevent deliveries to some service areas. In the short term, the loss of electrical power will prevent pumping water to many areas at higher elevations, and only undamaged gravity systems will be able to provide a continuous water supply.

Distribution of water using trucks or temporary pipes needs to be planned in areas identified as having a significant possibility of water system damage.

As has been noted, a number of public utilities provide water to the various communities in the planning area. Many systems are largely independent of the others. The equivalent of mutual aid does not exist for short term practical situations. One problem is that utility system pipes are generally smallest near district boundaries. It is perhaps appropriate for federal and state planners to examine the possibilities of funding adequate size interconnections between adjacent water supply utilities.

Planning Scenario

For planning purposes, within 25 miles from the fault, damage to treatment facilities, pumping stations, transmission and distribution pipelines, etc., will result in loss of service of 20 percent to the planning area for up to 3 days. The Long Beach Water Treatment Plant, which borders the fault zone, will be out of service for 48 hours, after which it will have 50 percent capacity.

For planning purposes, the postulated surface displacements along the NIFZ will damage many transmission lines and distribution lines located within the fault zone. Damage will also occur to treatment plants and storage facilities that are in or near the fault zone. The flow of water in primary transmission lines crossing or within the fault zone will be reduced by half for the first 24 hours, with 90 percent restoration within a week. For a period of time (1 day minimum, 1 week maximum), some segments of the population will be asked to use emergency supplies, boil their water, or take other safety measures against contamination.

Negligible damage to the major aqueducts is expected. Disruption of major transmission lines and elements of the distribution system that cross the fault is anticipated. This could effectively isolate the urban areas southwest of the fault zone such as, Huntington Beach, Long Beach, Torrance, Gardena, Lawndale, Hawthorne, and Inglewood, and force reliance on local storage facilities or tank trucks.

Substantial outages in distribution systems are expected. Within the fault zone, the distribution system will be 95 percent out of service.

Due to the public's crucial need for water, highest priorities need to be given to the restoration of electric power supplying water facilities. It is, therefore, expected that electric power will be provided by some means to all major pumping stations.

Restoration of water service to some areas west of the fault in the coastal communities will be delayed and, when available, is expected to be on a restricted basis. Many lines in and near the NIFZ may be in the form of temporary hose or above ground pipe similar to that provided to many residences after the 1971 San Fernando earthquake.

To prevent contamination, waste water lines must be repaired before fresh water lines are restored.

Damage Assessments

Damage assessments have been postulated for certain water supply facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 5-W.

W 1 **Sepulveda Feeder (MWD)**

MWD's Sepulveda Feeder is damaged by surface rupture where it crosses the fault zone at two locations in the City of Inglewood.

W 2 **Palos Verdes Feeder (MWD)**

This major transmission pipeline is damaged at several locations by fault related displacements along Avalon Boulevard in Compton.

W 3 **Middle Feeder (MWD)**

Fault rupture and secondary ground failures in the Dominguez Hills have caused numerous breaks in this major transmission pipeline.

W 4 **West Coast Feeder**

This major water supply pipeline is seriously damaged by fault rupture across El Segundo Boulevard near Vermont Avenue.

W 5 **Culver City Feeder**

This major pipeline is damaged by fault rupture where it crosses the zone on Slauson Boulevard near La Brea Avenue.

W 6 **Transmission Pipeline (LADWP) vic. Hollywood Park**

LADWP's primary water transmission pipeline from the San Fernando Valley to the Harbor sustains major breaks from surface rupture near Crenshaw and Century boulevards.

W 7 Transmission Pipeline (LADWP) vicinity of Baldwin Hills

Surface rupture and related ground failures in the Baldwin Hills have caused numerous breaks in this major transmission line.

W 8 Second Lower Feeder (MWD)

This major pipeline is heavily damaged by the effects of fault rupture where it crosses the zone at the Los Angeles River near the route I-405/710 interchange.

W 9 Water Treatment (Filtration) Plant - Long Beach

Intense shaking has caused major damage at this facility putting it totally out of service for 48 hours and limiting its capacity to 50% for an extended period thereafter.

W 10 West Orange County Feeder (MWD) near Buena Park

This major pipeline sustains several breaks as a result of ground failures near the crossing of Fullerton Creek in Buena Park.

W 11 Palos Verdes Reservoir

This facility has sustained damage to its outlet works which will limit its operational capability for several days.

Photograph 8 Settling cracks along Pacific Coast Highway 1.4 miles southeast of Huntington Beach Pier, in the 1933 earthquake.
Photo from Long Beach Public Library history collection.

WASTE WATER

General Characteristics

The waste water disposal system impacted by the scenario earthquake consists of many interrelated elements, as follows:

1. The major collection and treatment plants with outfall lines and pumping facilities discharging effluent into the ocean.
2. Primary interceptor conduits which carry waste water to the treatment plants.
3. Secondary transmission lines in streets or other rights of way.
4. Service lines from customers to secondary transmission lines.
5. Vital utility services such as electric power and fresh water.

Three principal agencies provide waste water collection, treatment, re-use, and disposal services for the 8 to 9 million residents and the many commercial and industrial facilities in the area. These agencies are:

1. The City of Los Angeles Bureau of Sanitation which serves over 3 million residents of the city.
2. The County Sanitation Districts of Los Angeles County which serve about 3.5 million residents and many industries in southern and eastern Los Angeles County.
3. The County Sanitation Districts of Orange County which provides services to 2 million residents in the northern portion of Orange County.

Also, the Los Angeles County Department of Public Works and about 100 smaller municipal waste water agencies operate collection systems that feed waste water to the interceptors of the agencies listed above.

The waste water treatment plants (Map 5-W) of the three agencies are described below:

The main primary and partial secondary treatment and disposal plant of the Bureau of Sanitation of the City of Los Angeles is the Hyperion Treatment Plant located in El Segundo. This plant is one of the largest in the world with a capacity of approximately 420 million gallons per day (MGD). It discharges effluent through a 12-foot diameter outfall sewer that extends 5 miles into Santa Monica Bay. Smaller reclamation plants are located in the Sepulveda Basin (Tillman Water Reclamation Plant - 40 MGD, to be enlarged to 80 MGD), in Glendale (20 MGD), and in San Pedro (Terminal Island Treatment Plant - 30 MGD).

The main treatment and disposal plant operated by the Los Angeles County Sanitation Districts is the Joint Water Pollution Control Plant (JWPCP) located in the City of Carson. It provides advanced primary and partial secondary treatment for 350 million gallons of waste water per day. Effluent from this plant is pumped through 2 six-mile long tunnels, 8 feet and 12 feet in diameter, under the Palos Verdes Hills to an outfall system at Whites Point. The outfall system consists of 4 outfall lines varying from 5 to 10 feet in diameter that extend from 1 to 2 miles offshore into 200 feet of water. Five upstream tertiary treatment plants that provide for water re-use are located in Cerritos (Los Coyotes), Long Beach, Whittier Narrows (2) and Pomona (of Map 5-W).

The County Sanitation Districts of Orange County operates two waste water treatment plants, Plant No. 1 in Fountain Valley (65 MGD) and Plant No. 2 in Huntington Beach (185 MGD). This system pumps its effluent into the ocean through a five-mile long 10-foot diameter outfall into 200 feet of water.

Many of the treatment plants in the planning area use digester gas (methane) as fuel for engines or turbines which power plant operation.

A network of thousands of miles of primary and secondary transmission lines and customer service lines covers the planning area. The pipes range from 6 to 144 inches in diameter.

Seismic Considerations

All three of the principal treatment plants are located in low lying areas on or near the coastline.

The Hyperion plant of the Los Angeles City Bureau of Sanitation is supported on spread or flat slab footings founded in sand roughly 35 feet above sea level. This plant is approximately 5 miles from the NIFZ and will be subjected to shaking intensities of VIII to IX (MM). The main vulnerability of this plant is loss of electrical power. The main 12-foot diameter outfall line that extends 5 miles offshore has a back-up emergency by-pass line of 12 foot diameter that extends 1 mile offshore.

The Joint Water Pollution Control Plant of the Los Angeles County Sanitation Districts is located about five miles from the ocean and four miles from the fault zone in a low lying area at elevation +40 feet. This is an area having a predicted shaking intensity of IX (MM). Facilities at this plant have been built and expanded since the 1930's. As with the Hyperion Plant, the structures and facilities at this plant will be vulnerable mainly to liquefaction, loss of electrical power and interruption of water supply.

The main plant of the County Sanitation Districts of Orange County is located within the fault zone and in an area of high liquefaction potential. This plant will be seriously impacted by ground displacements and settlements resulting from the scenario earthquake. For planning purposes it should be considered nonfunctional for an extended period of time after the event.

Main waste water interceptor lines traverse the fault zone in several locations (Map 5-W). The largest lines are 10 to 12 feet in diameter. Lines serving the Hyperion plant are of unreinforced concrete and are 50 years old. Lines into the Los Angeles and Orange County Sanitation Districts treatment plants are of reinforced concrete. For planning purposes, extensive damage to these lines is to be expected as a result of the scenario earthquake. The same can be said of the many secondary transmission lines located within the fault zone.

Underground waste water pipelines can be expected to perform reasonably well in areas of moderate ground shaking. However, in the liquefaction areas where ground shaking intensities of IX (MM) together with ground settlements are predicted, significant damage should be anticipated. Potential failure locations are at connections between service lines and transmission lines.

In addition to the loss of sanitary sewer service to hundreds of thousands of people, the most serious impact of the projected damage to the waste water system will be the contamination problems resulting from the discharge of untreated or poorly treated sewage into the soils in low lying areas, into flood control channels, streets and other routes which lead to the ocean or harbor waters.

Planning Scenario

Damage to the waste water system will result in the loss of sanitary facilities, and widespread contamination of soils, ground water supplies and the coastline.

Collection System. Main transmission lines crossing the fault zone are expected to be severely damaged reducing total capacity and flow into the treatment plants by 50%. Similar damage can be expected to the secondary lines in the fault zone. Damage to main lines and secondary lines outside of the fault zone in areas of liquefaction and heavy earth shaking will reduce capacities by 25%. Waste water leaking from damaged piping systems will flow into flood control channels, streets, open trenches, and low lying areas, eventually reaching ground water levels or the ocean.

Treatment Plants. The two main treatment plants in Los Angeles County will be damaged by oscillation of liquids in tanks, and will shut down because of loss of electrical power. Power requirements will diminish as the quantity of arriving waste water diminishes, but almost concurrently the production of methane gas used for power generation will be reduced. The main Orange County plant will be severely damaged because of its location within the fault zone and will be inoperable for a period of months.

Restoration of power for treatment and for pumping will be a function of priorities. Preference will probably be given to direct life support operations such as water systems, hospitals, housing, transportation, and others. Consequently, emergency treated raw sewage will be discharged through storm channels to the ocean for up to two months.

Restoration of water lines and service connections will have to be phased with restoration of waste water lines to protect against contamination.

Damage Assessments

Damage assessments have been postulated for certain waste water facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluation. Location of facilities are shown on Map 5-W.

WW 1 Hyperion Treatment Plant

Differential settlements resulting from high intensity shaking have caused considerable damage to various plant facilities. Storage facilities are damaged from oscillations of liquids and numerous interconnecting pipes and other conduits are damaged. This situation and loss of power closes the secondary treatment portion of the plant for several weeks. Inflow to the plant is reduced as a result of unreinforced waste water mains that are heavily damaged by ground failures in the Culver City-Marina Del Rey area. Initially, all inflow to the plant is being bypassed and discharged into the ocean with resulting contamination of adjacent beaches.

WW 2 Joint Water Pollution Control Plant

Ground failures and intensity IX shaking have caused some structural damage to several sedimentation basins, digesters, and interconnecting conduits. This, and loss of electrical power and fresh water closes the facility for several days and limits its capacity for an extended period thereafter. The loss of power and damage to pumping equipment precludes pumping effluent across Palos Verdes Hills to the Whites Point outfall, with resulting diversion of sewage to the Harbor.

WW 3 Orange County Plants #1 and #2

Both plants sustain major damage to various facilities as a result of intensity IX shaking and differential settlements. There is serious damage to several digesters and sedimentation basins and inter-connecting tunnels at each plant. The line connecting Plant No. 1 to Plant No. 2 is severed. There is no bypass for effluent from Plant No. 1 to the Santa Ana River. Consequently sewage inundates residential areas. At Plant No. 2, damage to facilities and the absence of power results in inflow being bypassed to the Santa Ana River Channel, contaminating nearby beaches. This condition will prevail for several weeks.

WW 4 Long Beach Interceptor

The primary interceptor between the Long Beach Water Reclamation Plant and the JWPCP is heavily damaged by surface rupture where it crosses the fault zone just west of Pacific Coast Highway near Recreation Park.

WW 5 Primary Interceptors to JWPCP

The primary interceptors to JWPCP are heavily damaged by surface rupture where they cross the fault zone near Del Amo Blvd. and the Long Beach Freeway.

WW 6 Terminal Island Treatment Plant

Strong shaking and ground failures induced by liquefaction have strongly damaged this plant. These effects and the loss of electrical power result in untreated effluent discharging into Los Angeles Harbor for several weeks.

NATURAL GAS FACILITIES

General Characteristics

Natural gas supplies for southern California are imported from sources outside the area through major pressurized pipelines. Transmission pipelines from the San Joaquin Valley, Ventura County, and one major import line from the east enter the metropolitan area via Newhall and the western San Fernando Valley. The other major import lines, from eastern sources, are routed through Cajon and San Gorgonio Passes.

These transmission lines traverse extensive areas subject to severe ground shaking caused by the projected scenario earthquake. Some are located in areas of potential liquefaction. Several major supply lines cross or enter the fault zone where earth movements averaging 3 feet are postulated.

Other elements of the natural gas supply system consist of pumping stations (compressor), underground storage fields, distribution trunk lines, and service pipe lines to users. Pumping stations and associated underground storage fields are at four locations in the planning area - Aliso Canyon, Montebello, East Whittier and Playa del Rey.

The Southern California Gas Company (SoCal Gas) serves about 98% of the natural gas customers used in the planning area. The remaining customers are served by the City of Long Beach, which is supplied by SoCal Gas.

Routes of the major gas transmission pipelines, compressor stations and underground storage fields are shown on Map 5-G. Distribution trunk lines within the area of projected intensity IX shaking (within about 8 km from the fault) are also shown.

Seismic Considerations

The primary impact on natural gas facilities in the area will be the widespread damage to transmission and distribution system pipelines resulting from surface rupture along the fault zone. Displacements averaging 3 feet across the fault zone will cause thousands of breaks in mains, valves, and service connections. Secondary ground failures resulting from high intensity shaking will result in many additional breaks in the system in the proximity of the fault zone. Fires can be expected due to broken gas mains and service connections.

The gas supply to the area west of the fault zone may be interrupted where the large diameter transmission pipelines are damaged by fault offsets. In addition to major damage at the fault crossings, the gas transmission and distribution system is vulnerable to damage from landslides and liquefaction.

Major gas transmission lines (diameter $\geq$ 24 inches) cross the fault zone at five locations (starting from the NW):

1) Slauson Avenue in the Baldwin Hills
2) 104th Street, southeast of Hollywood Park
3) Central Avenue
4) Del Amo Boulevard southwest Dominguez Hills; and
5) Along the Los Angeles River about 1/2 mile north of the I-405/710 interchange.

In addition to possible damage to these large diameter transmission lines by surface rupture, many breaks and leaks can be expected on the distribution system lines throughout the planning area, particularly in the zone of fault rupture and in areas of high liquefaction potential. These areas of potential liquefaction are generally in low lying areas three to four miles east and west of the fault zone.

According to SoCal Gas, vulnerability to damage from ground shaking has been reduced in the distribution pipe line systems since the 1971 San Fernando earthquake. This improvement is largely due to replacement of steel pipe (and, in some instances, cast iron pipe) with medium density polyethylene plastic pipe having ductile properties that should result in better resistance to damage from earth movements. About 90% of all pipe replacement of 4" diameter and less are made with plastic pipe. Large diameter modern arc welded steel transmission pipe lines are fabricated with .375" to .500" wall thickness and have performed very well in past earthquakes. Probably the greatest vulnerability to damage is in the distribution system, at the service to mains connections.

Underground storage reservoirs and related compressor stations are not considered highly vulnerable to this scenario earthquake.

Segments of the major gas transmission lines that serve all eight of the regions' coastal thermal power generating plants are vulnerable to damage resulting from ground movements within the NIFZ. These plants are:

Facility	Location	Utility
Scattergood Station	El Segundo	So. Calif. Edison
El Segundo Power Plant	El Segundo	So. Calif. Edison
Redondo Beach Power Plant	Redondo Beach	So. Calif. Edison
Harbor Generating Station	Wilmington	LADWP
Long Beach Power Plant	Long Beach	So. Calif. Edison
Alamitos Power Plant	Seal Beach	So. Calif. Edison
Haynes Generating Station	Seal Beach	LADWP
Huntington Beach Power Plant	Huntington Beach	So. Calif. Edison

All of these plants use oil as an alternate fuel, and could operate without gas supplies.

Planning Considerations

The major area of concern relating to transmission and distribution line damage is along the fault zone and within the area three to four miles on either side of the fault. Damaged pipelines resulting from fault ruptures across the multitude of residential streets and major traffic arteries will pose a formidable challenge. The gas service company considers their residential customers and places of assembly such as schools to be first in order of importance in their emergency response program. Hospitals and other critical users normally have alternate sources of fuel, but these users will also be impacted.

The San Fernando earthquake of 1971 resulted in disruption of service to over 17,000 customers. For planning purposes, it is reasonable to assume that the number of customer service disruptions resulting from the scenario earthquake could be in the tens of thousands. These impairments will be concentrated in the disturbed ground areas in the NIFZ and in adjacent areas where poor ground conditions exist.

Repairs to main transmission facilities can be accomplished more rapidly than repairs to distribution systems, and would be completed first. Restoration within the distribution system is a gradual process as described in the following:

> "Unlike electricity, which can usually be turned off, and on at will, the restoration of gas service is an expensive and time consuming task. If a pipeline is broken, or part of a distribution network loses all pressure, every customer being supplied from that network must individually be shut down before repressuring can begin. To prevent explosions, the entire system of mains, feeders, and service lines in the affected area must be purged before pilot

lights can be relighted and service restored. In addition, extensive gas leak detection surveys may be needed, using flame ionization equipment throughout the affected area" (LNG Task Force, 1980).

For planning purposes, 30% of the areas relying on gas supplied by lines that cross the NIFZ will be without gas. Repair time will depend on priorities that cannot be estimated at this time.

Planning Scenario

Damage Assessments

Damage assessments have been postulated for certain natural gas facilities as set forth below. Although SoCal Gas consider that transmission lines that are not oxy-acetylene welded are not likely to be damaged, prudent planning should consider some disruption. The gas system has loops and feeds that allow breaks to be isolated rather than to shut down all of the affected area. The statements regarding the performance of specific facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 5-G.

Map No.

G 1 Distribution System

All along and adjacent to the zone of surface rupture there are thousands of damaged and leaking mains, valves and service connections. There are numerous fires in streets at broken gas lines. Throughout the heavily shaken area, structural fires result from damaged house line connections, overturned water heaters, etc.

Map No.

G 2 **Transmission Pipeline - Santa Monica Mountains**

A major landslide in Sepulveda Canyon has destroyed several hundred feet of one of the major supply lines from the San Fernando Valley.

G 3 **Transmission Pipeline - Slauson Avenue**

Surface rupture has caused multiple breaks in a major transmission pipeline near the intersection of Slauson Avenue and La Brea Avenue.

G 4 **Transmission Pipeline - 104th Street**

Surface rupture has caused multiple breaks in a 30-inch diameter transmission pipeline on 104th Street near Crenshaw Boulevard.

G 5 **Transmission Pipeline - Jefferson Boulevard**

Liquefaction ground failure has caused a break in the major transmission pipeline on Jefferson Boulevard at the intersection with Lincoln Boulevard.

G 6 **Transmission Pipeline - Los Angeles River**

Surface rupture and related ground movements have caused multiple breaks in the 26-inch diameter transmission pipeline along the Los Angeles River from Del Amo Boulevard south to near the Route 405-Long Beach Freeway Interchange.

<u>Map No</u>.

G 7 Distribution Trunk Line - Avalon Boulevard

A break in the trunk line at Avalon Boulevard near the crossing of the Dominguez Channel and Route 405 necessitates temporary closure of Avalon Boulevard north of Route 405.

G 8 Distribution Trunk Line - Long Beach Harbor

In the Long Beach Harbor ground failures adjacent to the Cerritos Channel have caused rupture of the 8-inch diameter trunk line crossing the channel at the Heim Bridge.

G 9 Distribution Trunk Line - Compton/Redondo Beach Boulevard

Surface faulting has ruptured a 8-inch diameter trunk line near the intersection of Compton Boulevard and Redondo Beach Boulevard.

G 10 Distribution Trunk Line - Bolsa Chica

The 34-inch diameter high-pressure gas line to the Huntington Beach Power Plant sustains multiple breaks where it crosses the marshlands east of Bolsa Chica Beach State Park.

PETROLEUM REFINERIES, CRUDE OIL AND PRODUCT PIPELINES

General Characteristics

There are sixteen operating refineries in the area which vary in capacity from 5,000 to 405,000 barrels per day (bpd). Crude oil is transported to the refineries by pipeline principally from local fields and from fields in the San Joaquin Valley and Oxnard Plain. About 20% is imported by ocean tankers. There is a resulting network of crude oil and petroleum product pipelines throughout the planning area, many of which cross over or are within the fault zone. Nine major pipeline companies control about 90% of the crude and product lines. The Southern Pacific Pipeline Co., now owned by the Santa Fe Railway, is also a major mover of petroleum products.

The largest of all refineries in the area is Chevron in El Segundo, approximately 5 miles from the NIFZ. Much of Chevron's crude oil supply arrives on tankers that are unloaded off-shore through a flexible underwater pipeline to a marine terminal facility located along the beach front, an area susceptible to soil failures. The refinery itself is on firm ground at a higher elevation.

The major companies have large internal capabilities: financial, manpower, fire fighting, and equipment. Restoration of functions vital to local public needs requires some resources beyond those of the companies. For example, electric power and water are vital for day to day refinery operations.

See Map 5-P for locations of principal refineries and major pipelines in the planning area.

Seismic Considerations

Long established refineries, such as those found in southern California, have some facilities that are decades old; earthquake standards have changed considerably since the first refinery construction. Older construction will have significantly poorer seismic performance than newer facilities. Retrofitting is often expensive and not cost-effective. Earthquake damage to old equipment is expected and experience around the world confirms this. Refineries are extremely complex facilities and only an overview of their behavior during a major earthquake is within the scope of this study.

Earthquake damage to petroleum related facilities may be placed into one of three categories. First, damage may occur to the incoming crude oil transportation facilities such as pipelines from the oil fields or marine terminals. Second, the refinery may (a) suffer direct damage such as broken piping, buckled storage tanks, damage to processing towers, etc., (b) suffer consequential damage from fire following the earthquake, or (c) become nonfunctional due to loss of outside water supplies or electric power. Third, the distribution system may become nonfunctional due to damaged storage facilities or pipelines.

The major refineries are located at distances varying from 1/2 mile to 10 miles from the fault zone, in areas of predicted ground shaking intensities of VIII or IX MM, as summarized below:

Table 4. Major Petroleum Refineries within 10 miles of NIFZ

Refinery	Capacity bpd.	Distance from Fault Zone (miles)	Predicted Shaking Intensity (MM)	Location
Chevron	405,000	5	VIII+	El Segundo
Mobil Oil	124,000	4	VIII+	Torrance
ARCO	210,000	2	IX	Carson
Shell	108,000	3	VIII+	Wilmington
Union	108,000	6	IX	Wilmington
Texaco	75,000	2	VIII-IX	Wilmington
Edgington	42,000	1/4	VIII+	Long Beach
Gulf	42,000	10	VIII-	La Mirada
Paramount (Douglas)	47,000	5	VIII+	Paramount
Powerine	46,000	10	VIII-	Santa Fe Springs

Site-specific studies are required to evaluate the vulnerability of each facility.

Earthquake performance of refineries and other petroleum product plants has been excellent from the standpoint of direct damage, but several significant instances of damage have occurred as a result of fire following an earthquake. In the 1952 Kern County earthquake, the Paloma Cycling Plant survived the earthquake quite well until two large butane spheres collapsed releasing highly volatile material. The gaseous material spread out over the area and was ignited within minutes. The 1964 Niigata, Japan, earthquake resulted in fire at the Showa Oil Company refinery which burned continuously for two weeks. Fire occurred at failed storage tanks following the 1964 Alaska earthquake.

The use and storage of different types of hazardous materials at refineries are more of a hazard to the public than fire, because of the potential release of toxic fumes.

The low earthen embankments used as retention dikes around fuel and oil storage tanks are subject to failure from earthquake shaking. The locations of these types of structures, their vulnerability, and the consequences of failure need to be examined as part of any company's emergency planning program.

Damage to storage tanks is commonly due to the sloshing of liquids which damages or destroys the fixed or floating tank tops. Tank piping often breaks when it does not possess sufficient flexibility. While the spillage of oil may be spectacular, it has not been serious when contained within its dikes and kept free of ignition sources.

During the 1971 San Fernando earthquake (M 6.4), damage to refineries in that area was limited to internal piping and some storage tanks. Production was curtailed at one refinery located 11 miles from the epicenter as a result of utility failures.

Pipelines designed to carry products under high pressure have performed well in past earthquakes. A large diameter, interstate, natural gas line was not damaged where it crossed the White Wolf fault during the 1952 Kern County earthquake (M 7.2). Fuel lines were undamaged during the 1979 Imperial Valley (M 6.4) earthquake. Pipeline damage was minimal during the Coalinga earthquake (M 6.4) of 1983. Natural gas transmission lines crossing Turnagain Arm of Cook Inlet at Anchorage experienced no damage in the 1964 Alaska earthquake (M 8.4) despite extensive ground failure. The major water line (Hetch Hetchy) to San Francisco performed without damage in the 1906 earthquake, even on Bay mud. On the other hand, major natural gas distribution lines in the fault zone at San Fernando failed during the 1971 earthquake (M 6.4). Experience shows that damage occurs in areas of ground breakage, but not necessarily to every line.

Numerous major petroleum crude and product pipelines cross or are very near to the fault zone and are vulnerable to surface rupture or other ground failures. Pipe connections at storage facilities are especially vulnerable to the differing response between buried pipe and rigid structures.

If pipe rupture occurs during the dry season, fire could be a serious problem. This threat is also present during the rainy season if fluids are ignited as storm waters wash them into sewers.

Valves installed on many of these pipelines will automatically shut off when the line pressure drops below a particular threshold, such as would occur in the case of a pipe rupture. Some of these valves are dependent on electrical power, and would not perform in the event of a large-scale power loss.

Planning Considerations

Emergency planning should provide for distribution of fuel to those locations designated for emergency response operation. Adequate emergency power and pumping capability should be available at fuel storage locations for refueling of aircraft and other emergency vehicles. Locations for temporary storage of emergency fuel supplies, including those for aviation fuels, should be predetermined and emergency procedures established to ensure that these supplies will be available when needed.

Planning Scenario

Direct damage to the refineries that experience strong shaking will be in the form of broken and cracked piping, piping shifted off its supports, broken brick linings in boilers, buckled tanks, buckled steel stacks, stretched anchor bolts, and extensive elongation of cross-bracing. Older horizontal vessels that are not anchored to their concrete saddles will shift and break piping. The overall direct damage should be minimal.

For planning purposes, refinery fires should be anticipated following the earthquake. These fires will generally be controlled within hours by plant personnel with their normal suppression systems. For planning purposes, a major fire at one facility is postulated to burn for several days.

Affected refineries will be shut down for inspection and repairs. Refinery personnel will make necessary repairs (except for fire damage) to restore functions on a limited basis within a week, subject to the availability of electric power and water. For planning purposes, the restoration of water service should be regarded as the more time consuming of the two. Major water transmission pipelines will be damaged and restoration priorities to customers will favor human rather than industrial needs.

Petroleum products available at local refineries are, for planning purposes, adequate for about 5 days of normal demand. Other factors may lengthen this 5-day post-earthquake supply. It should be remembered that gas stations will not be able to pump gasoline without electrical power. Also, truck transport of fuel supplies throughout the area will be slowed due to the damaged highway network.

All refineries will be shut down for 48 hours for inspections and repairs, returning to 75% of normal operations within a week. Refineries east of the NIFZ will be less severely impacted by loss of utility services.

For planning purposes and depending on the time of day, access to the Chevron refinery in El Segundo could be a problem due to the development which has taken place in the immediate area over recent years. For example, one recently completed high-tech commercial development in the area added a work force of over 10,000 employees.

New medium-rise buildings have also become common in this area which only recently was low in population density and related traffic. During peak hours, surface traffic along Sepulveda Boulevard, Rosecrans Avenue, and I-405 (San Diego Freeway) is now heavily congested.

Damage Assessments

Damage assessments have been postulated for certain petroleum related facilities as set forth below. The statements regarding the performance of facilities are hypothetical and are intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map 5-P.

P 1 **Fuel line break - Overhill Drive**

Surface faulting on Overhill Drive about 1/2 mile north of Slauson Avenue in the Baldwin Hills has ruptured fuel lines.

P 2 **Fuel line break - Florence Avenue**

Surface faulting near Florence Avenue and Prairie Avenue has ruptured a fuel line.

P 3 Fuel line breaks - Rosecrans Boulevard

Surface faulting across Rosecrans Boulevard has caused multiple breaks with fuel spillage.

P 4 Fuel line break - vicinity Harbor Freeway and Sepulveda Boulevard

Ground failure adjacent to the Santa Fe Railroad and the Joint Water Pollution Control Plant between the Harbor Freeway and Figueroa St. has ruptured this fuel line.

P 5 Refinery Fire

A major fire is burning at one of the refineries in the Carson-Wilmington area. This fire will rage for several days.

P 6 Los Angeles Harbor - Mormon Island

Ground failures on Mormon Island have ruptured oil storage facilities. There is a fire on the island and discharge of fuel into the channel, posing the threat of a greater fire.

P 7 Pipeline Crossing - L.A. Harbor

A large diameter oil pipeline is ruptured as a result of ground failures on the Terminal Island side of the channel crossing resulting in discharge of oil into the main channel.

P 8 Long Beach Harbor area

Ground failures along the west side of the Los Angeles River Channel south of the Shoemaker (7th St.) Bridge has damaged pipelines traversing this corridor to the Long Beach Harbor area.

P 9 So. California Edison Co. fuel line

Edison's fuel line is damaged and leaking as a result of surface rupture at the fault crossing near 31st Street and Pasadena Avenue in Long Beach.

P 10 Oil lines vicinity of Signal Hill

Along the fault zone between Pacific Coast Highway and the Los Angeles River most city streets contain buried oil lines. Surface faulting and secondary ground failures produce numerous breaks in these lines. Repairs to these and other oil production facilities will curtail operations in this area.

P 11 LADWP Fuel line - East Long Beach

The fuel line to LADWP's Power Plant is damaged by fault rupture near Colorado St. and Manila Avenue in East Long Beach.

P 12 Seal Beach area

Ground failures in the Seal Beach area have damaged storage facilities and related piping with consequent fuel spillage into Alamitos Bay.

P 13 Oil lines - Huntington Beach

There are numerous breaks in oil lines located in the streets along the fault zone between Edwards St. and Newland Avenue in Huntington Beach.

P 14 So. California Edison Co. fuel line - Huntington Beach

The fuel line to Edison's Huntington Beach Power Plant is damaged by surface faulting on Newland St. near Indianapolis Avenue in Huntington Beach.

P 15 San Diego fuel line

Ground failure at the Peters Canyon Channel at the southeast corner of the Marine Corps Air Station has damaged fuel pipelines with resulting discharge of fuel into the Channel.

GLOSSARY

(Definitions adapted from Glossary of Geology, American Geological Institute, 1981, and American Heritage Dictionary, 1981)

ALLUVIUM Surficial sediments consisting of poorly consolidated gravels, sands, silts, and clays deposited by flowing water.

BEDROCK A general term for coherent, usually solid rock, that underlies soil or other unconsolidated surficial material.

DEFORMATION A general term for the processes of folding, faulting, shearing, compression, or extension of rocks.

EARTHQUAKE Vibratory motion propagating within the earth or along its surface caused by the abrupt release of strain from elastically deformed rock by displacement along a fault.

FAULT A fracture (rupture) or a zone of fractures along which there has been displacement of adjacent earth material.

FAULT LINE A scarp that has been produced by differential erosion along an old fault line.

GROUND FAILURE Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.

GROUND RUPTURE Displacement of the earth's surface as a result of fault movement associated with an earthquake.

ISOSEISMAL AREA An area composed of points of equal earthquake intensity on the earth's surface.

INTENSITY A measure of the effects of an earthquake at a particular place. Intensity depends on the earthquake magnitude, distance from epicenter, and on the local geology.

GLOSSARY

LIFELINES	Facilities such as highways, bridges, tunnels, major airports, electrical power lines, fuel pipelines, communication lines, water supply lines, marine terminals and railroads.
LIQUEFACTION	The transitory transformation of sandy water saturated alluvium with properties of a solid into a state possessing properties of a liquid as a result of earthquake shaking.
MAGNITUDE	A measure of the size of an earthquake, as determined by measurements from seismographic records.
MODIFIED MERCALLI INTENSITY SCALE	See Appendix A.
REINFORCED MASONRY	Masonry construction with steel reinforcement.
ROSSI-FOREL INTENSITY SCALE	See Appendix A.
WATER TABLE	The upper surface of ground water saturation of pores and fractures in rock or surficial earth materials.

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Appendix A

Modified Mercalli and Rossi-Forel Intensity Scales

APPENDIX A

Modified Mercalli Intensity Scale of Wood and Neumann, and its Relation to the Rossi–Forel Scale

The numbers in parentheses in the left margin and the initials R.F. refer to the Rossi–Forel intensity scale.

I [I R.F.]

Not felt — or, except rarely under especially favorable circumstances.
Under certain conditions, at and outside the boundary of the area in which a great shock is felt:
sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced;
sometimes trees, structures, liquids, bodies of water, may sway—doors may swing, very slowly.

II [I to II R.F.]

Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons.
Also, as in grade 1, but often more noticeably:
sometimes hanging objects may swing, especially when delicately suspended;
sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly;
sometimes birds, animals, reported uneasy or disturbed;
sometimes dizziness or nausea experienced.

III [III R.F.]

Felt indoors by several, motion usually rapid vibration.
Sometimes not recognized to be an earthquake at first.
Duration estimated in some cases.
Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away.
Hanging objects may swing slightly.
Movements may be appreciable on upper levels of tall structures.
Rocked standing motor cars slightly.

IV [IV to V R.F.]

Felt indoors by many, outdoors by few.
Awakened few, especially light sleepers.
Frightened no one, unless apprehensive from previous experience.
Vibration like that due to passing of heavy, or heavily loaded trucks.
Sensation like heavy body striking building, or falling of heavy objects inside.
Rattling of dishes, windows, doors; glassware and crockery clink and clash.
Creaking of walls, frame, especially in the upper range of this grade.
Hanging objects swung, in numerous instances.
Disturbed liquids in open vessels slightly.
Rocked standing motor cars noticeably.

V [V to VI R.F.]

Felt indoors by practically all, outdoors by many or most: outdoors direction estimated.
Awakened many, or most.
Frightened few—slight excitement, a few ran outdoors.
Buildings trembled throughout.
Broke dishes, glassware, to some extent.
Cracked windows—in some cases, but not generally.
Overturned vases, small or unstable objects, in many instances, with occasional fall.
Hanging objects, doors, swing generally or considerably.
Knocked pictures against walls, or swung them out of place.
Opened, or closed, doors, shutters, abruptly.
Pendulum clocks stopped, started, or ran fast, or slow.
Moved small objects, furnishings, the latter to slight extent.
Spilled liquids in small amounts from well-filled open containers.
Trees, bushes, shaken slightly.

VI [VI to VII R.F.]

Felt by all, indoors and outdoors.
Frightened many, excitement general, some alarm, many ran outdoors.
Awakened all.
Persons made to move unsteadily.
Trees, bushes, shaken slightly, moderately.
Liquid set in strong motion.
Small bells rang—church, chapel, school, etc.

Damage slight in poorly built buildings.
Fall of plaster in small amount.
Cracked plaster somewhat, especially fine cracks; chimneys in some instances.
Broke dishes, glassware, in considerable quantity, also some windows.
Fall of knick-knacks, books, pictures.
Overturned furniture in many instances.
Moved furnishings of moderately heavy kind.

VII Frightened all—general alarm, all ran outdoors.
Some, or many, found it difficult to stand.
[VIII – R.F.] Noticed by persons driving motor cars.
Trees and bushes shaken moderately to strongly.
Waves on ponds, lakes, and running water.
Water turbid from mud stirred up.
Incaving to some extent of sand or gravel stream banks.
Rang large church bells, etc.
Suspended objects made to quiver.

Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc.
Cracked chimneys to considerable extent, walls to some extent.
Fall of plaster in considerable to large amount, also some stucco.
Broke numerous windows, furniture to some extent.
Shook down loosened brickwork and tiles.
Broke weak chimneys at the roof-line (sometimes damaging roofs).
Fall of cornices from towers and high buildings.
Dislodged bricks and stones.
Overturned heavy furniture, with damage from breaking.
Damage considerable to concrete irrigation ditches.

VIII Fright general—alarm approaches panic.
Disturbed persons driving motor cars.
[VIII+ to IX – R.F.] Trees shaken strongly—branches, trunks, broken off, especially palm trees.
Ejected sand and mud in small amounts.
Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
Damage slight in structures (brick) built especially to withstand earthquakes.
Considerable in ordinary substantial buildings, partial collapse, racked, tumbled down, wooden houses in some cases; threw off panel walls in frame structures, broke off decayed piling.
Fall of walls.
Cracked, broke, solid stone walls seriously.
Wet ground to some extent, also ground on steep slopes.
Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers.
Moved conspicuously, overturned, very heavy furniture.

IX Panic general.
Cracked ground conspicuously.
[IX+ R.F.] Damage considerable in (masonry) structures built especially to withstand earthquakes:
threw out of plumb some wood-frame houses built especially to withstand earthquakes;
great in substantial (masonry) buildings, some collapse in large part;
or wholly shifted frame buildings off foundations, racked frames;
serious to reservoirs; underground pipes sometimes broken.

X Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks.
[X R.F.] Landslides considerable from river banks and steep coasts.
Shifted sand and mud horizontally on beaches and flat land.
Changed level of water in wells.
Threw water on banks of canals, lakes, rivers, etc.

Appendix A (continued)

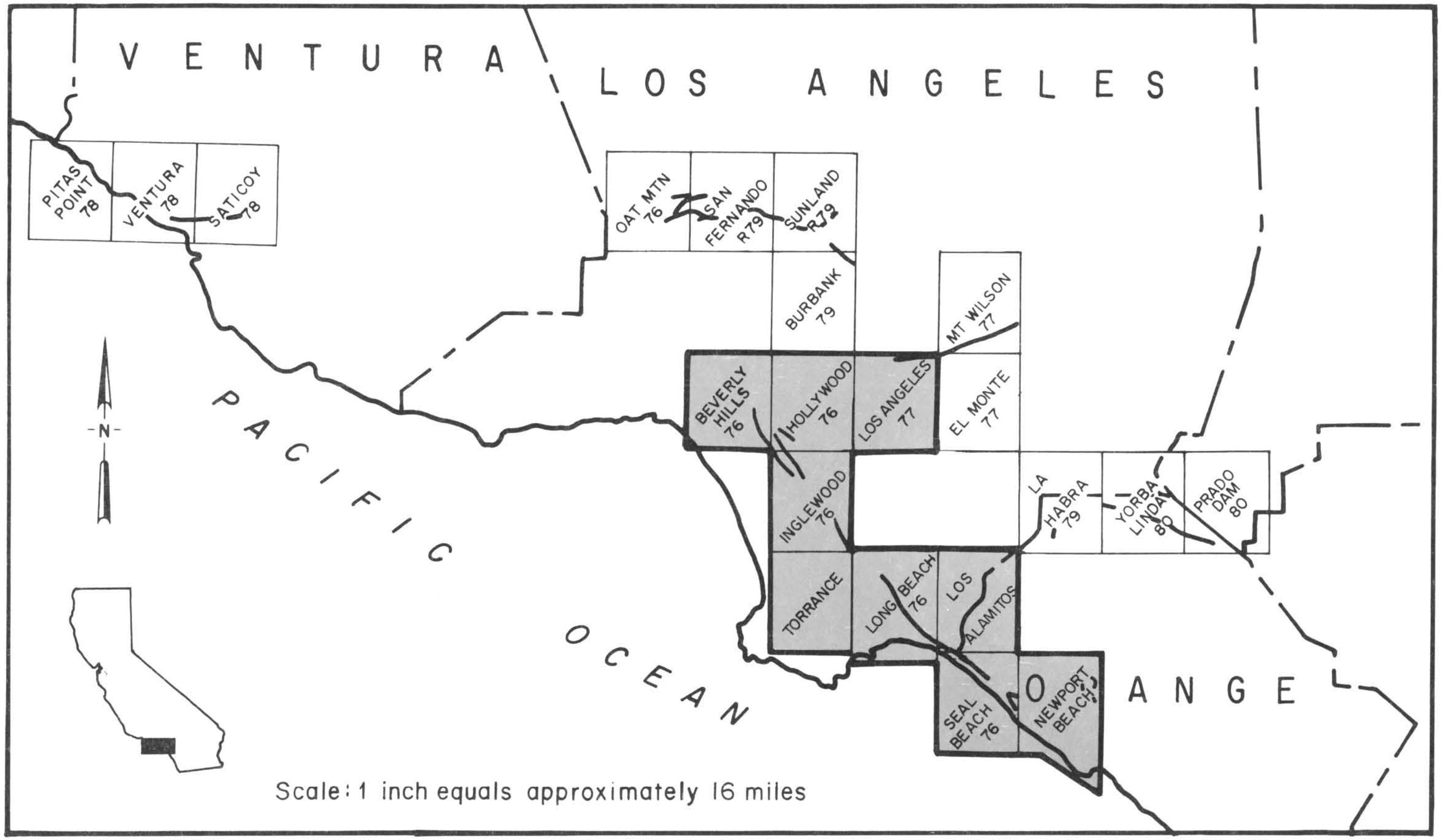
Damage serious to dams, dikes, embankments.
Severe to well-built wooden structures and bridges, some destroyed.
Developed dangerous cracks in excellent brick walls.
Destroyed most masonry and frame structures, also their foundations.
Bent railroad rails slightly.
Tore apart, or crushed endwise, pipe lines buried in earth.
Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI Disturbances in ground many and widespread, varying with ground material.
Broad fissures, earth slumps, and land slips in soft, wet ground.
Ejected water in large amount charged with sand and mud.
Caused sea-waves ("tidal" waves) of significant magnitude.
Damage severe to wood-frame structures, especially near shock centers.
Great to dams, dikes, embankments, often for long distances.
Few, if any, (masonry) structures remained standing.
Destroyed large well-built bridges by the wrecking of supporting piers, or pillars.
Affected yielding wooden bridges less.
Bent railroad rails greatly, and thrust them endwise.
Put pipe lines buried in earth completely out of service.

XII Damage total—practically all works of construction damaged greatly or destroyed.
Disturbances in ground great and varied, numerous shearing cracks.
Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive.
Wrenched loose, tore off, large rock masses.
Fault slips in firm rock, with notable horizontal and vertical offset displacements.
Water channels, surface and underground, disturbed and modified greatly.
Dammed lakes, produced waterfalls, deflected rivers, etc.
Waves seen on ground surfaces (actually seen, probably, in some cases).
Distorted lines of sight and level.
Threw objects upward into the air.

Appendix B

Alquist-Priolo Special Studies Zone Maps (9) for the Newport-Inglewood Fault Zone



Index to Appendix B - Alquist-Priolo Special Studies Zone Maps.

Appendix C

Earthquake Planning Scenario Maps

INDEX TO APPENDIX C

EARTHQUAKE PLANNING SCENARIO

PLANNING AREA 5 - NEWPORT-INGLEWOOD FAULT ZONE