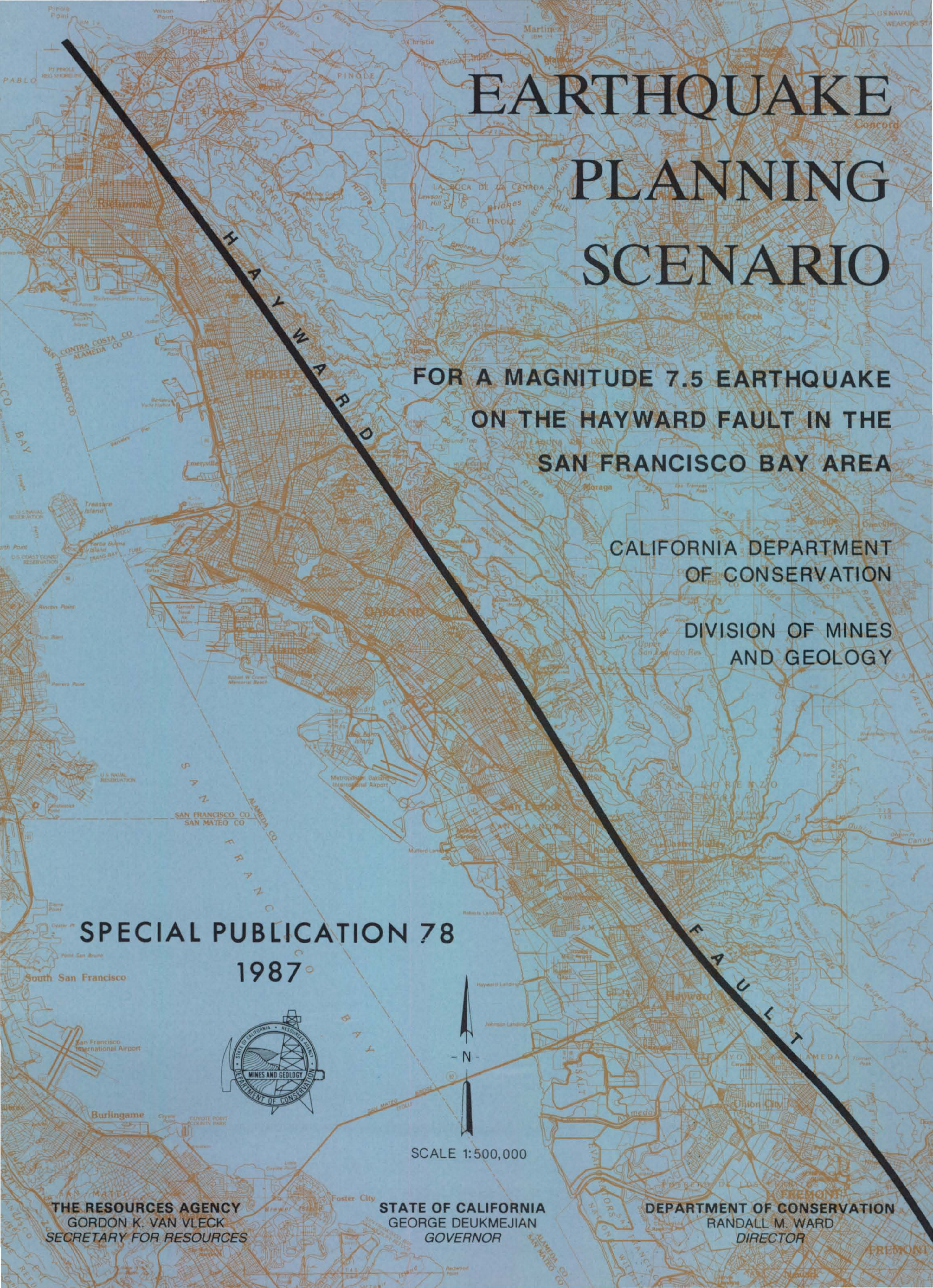

EARTHQUAKE PLANNING SCENARIO

FOR A MAGNITUDE 7.5 EARTHQUAKE ON THE HAYWARD FAULT IN THE SAN FRANCISCO BAY AREA

CALIFORNIA DEPARTMENT OF CONSERVATION

DIVISION OF MINES AND GEOLOGY

SPECIAL PUBLICATION 78

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EARTHQUAKE PLANNING SCENARIO FOR A MAGNITUDE 7.5 EARTHQUAKE ON THE HAYWARD FAULT IN THE SAN FRANCISCO BAY AREA

By

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1987

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Courthouse at San Leandro after the Hayward earthquake of October 21, 1868.

FOREWORD

- During the past 130 years, California has been struck by five major earthquakes--in northern California, the 1868 Hayward and 1906 San Francisco earthquakes; in southern California, the 1857 Ft. 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 have occurred in California or near its borders since 1900. These earthquakes have been responsible for the deaths of thousands of people and $2 billion in property damage.

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

- The Hayward fault was the source of the destructive 1868 earthquake (magnitude ~ 7) and the probable source of an equivalent event in 1836. Earthquakes of comparable and possibly larger magnitudes are certain to recur on the Hayward fault and could do so at any time.

- A major earthquake on the Hayward fault within the highly urban San Francisco Bay area poses one of the greatest hazards to lives and property in the nation.

- This earthquake planning scenario portrays many of the credible consequences of such an earthquake. Hopefully, increased awareness of the threat will provide impetus for coordinated regional planning programs to cope with this eventuality.

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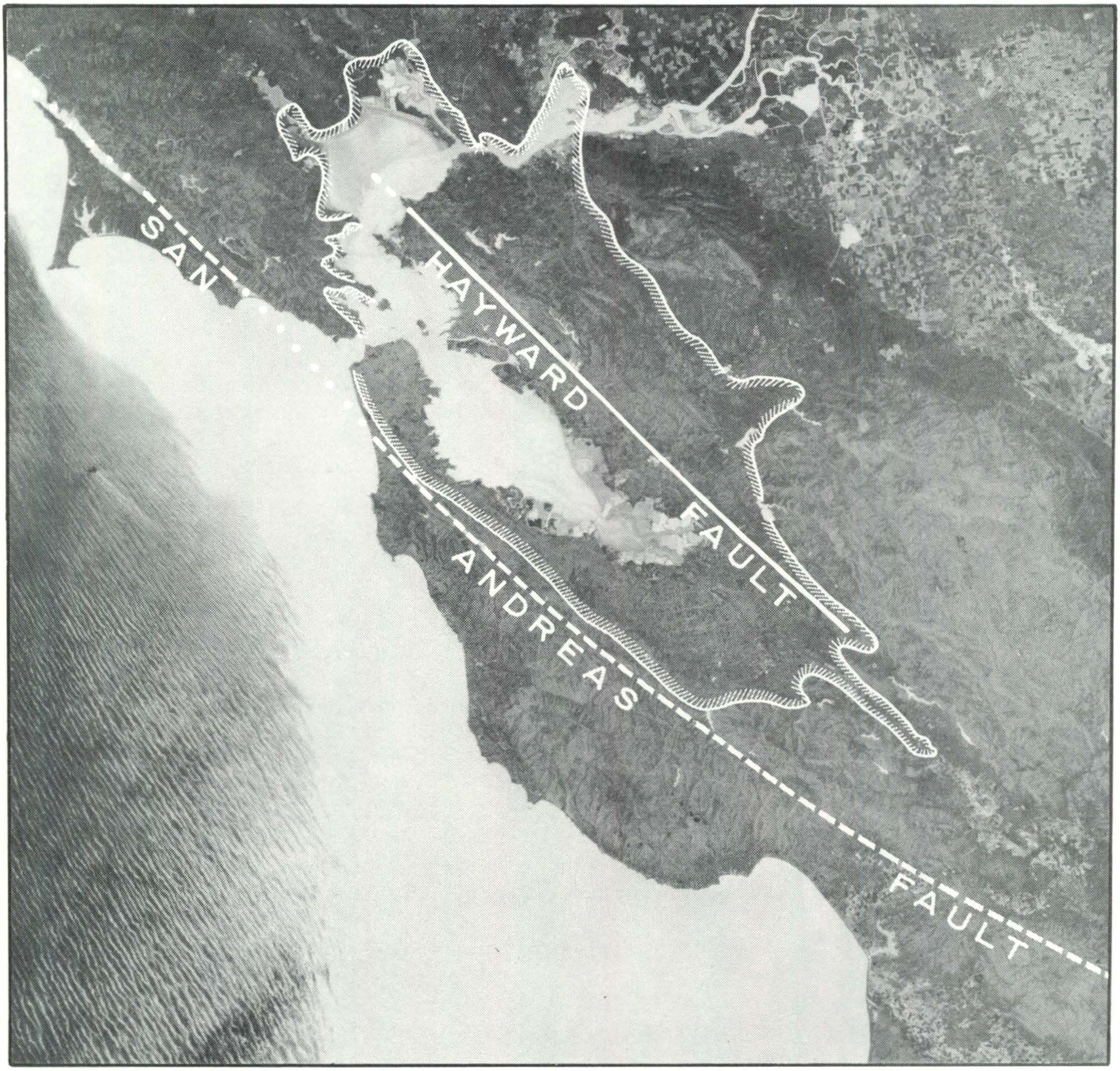

Figure 1. Landsat image of the San Francisco Bay area. The magnitude 7.5 scenario earthquake is the result of rupture of the entire 100-kilometer (62-mile) length of the Hayward fault. Prolonged strong shaking sufficient to cause significant structural damage (Modified Mercalli intensity VIII and greater) would occur throughout the area outlined. Note that downtown San Francisco is about equidistant from the Hayward and San Andreas faults and, therefore, vulnerable to a major earthquake originating on either fault.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

THE EARTHQUAKE THREAT

The Hayward fault is a seismically active major element of the San Andreas fault system. The Hayward earthquake of October 21, 1868 of Richter Magnitude about 7 (M7) is one of the largest earthquakes to occur in California, causing widespread damage throughout the then sparsely populated Bay area. In 1868 the fault ruptured from Oakland to Fremont (50 kilometers), and the maximum reported displacement was 3 feet. An event of similar destructive magnitude in 1836 also occurred on the Hayward fault. Future earthquakes of comparable magnitude are a reasonable expectation and could occur at any time.

A large earthquake on either the Hayward or the San Andreas fault poses a major threat to the entire Bay area. While the effects of these earthquakes may differ from place to place, a major earthquake on the Hayward fault is not an exclusive East Bay concern and a San Andreas event is not an exclusive San Francisco concern. The threat to San Francisco from the Hayward fault was recognized by Lawson (1908, p. 447): "The foot of Market Street, San Francisco, is about midway between the San Andreas Rift and the fault scarp upon which movement occurred in 1868. The city has, therefore, to reckon with the latter as well as the former in its future career, and, consequently, should be doubly prudent in the location and structure of its important buildings".

THE SCENARIO EARTHQUAKE

Description

This planning scenario is based on the maximum credible earthquake that could occur on the Hayward fault. The assumed characteristics of this earthquake are: a Richter magnitude of 7.5 (M7.5) that results from rupture of the entire 100 kilometer (62 mile) length of the fault from San Pablo Bay to east of San Jose; surface faulting that produces horizontal offsets averaging 5 feet (maximum 10 feet); potentially damaging shaking that continues for 25-35 seconds within 20-25 miles of the fault; frequent aftershocks that continue for many weeks, including events of M6 or larger. The likelihood of occurrence of the M7.5 scenario earthquake is much lower than that of a M about 7 event such as occurred in 1868.

While this planning scenario is based upon a maximum credible event for the Hayward fault, damage patterns would in many respects be similar for an event of smaller magnitude. A magnitude about 7 event (similar to the 1868 earthquake), for example, would result from rupture along only one half the length of the fault (50 kilometers) and would produce about 3 feet of surface offset. The resulting damage to lifelines, critical facilities, local utility distribution systems, etc., while not as severe, would affect most of the same facilities along the ruptured segment of the fault. Shaking near the rupture zone would be as severe, but presumably, not as prolonged. Ground failures would occur in the same general areas.

Predicted Effects

Fault Rupture

Horizontal fault offset averaging 5 feet along the 62 mile length of the fault would cause major damage to structures located on active fault traces. Throughout most of its length the fault traverses residential and commercial areas, posing the threat of widespread damage to buildings, utility lifelines and distribution systems, and transportation routes.

Shaking Intensity

The area subject to shaking of Modified Mercalli intensity VIII (strong enough to cause considerable damage in ordinary substantial buildings; great damage in poorly built structures) extends from near Petaluma and Napa in the north Bay to south of San Jose. The area encompasses most of the populated areas of eastern Contra Costa County and Livermore Valley on the east, most of the heavily populated greater San Jose area, the communities north along the Peninsula to and including much of San Francisco, and the low-lying urban areas of bayside Marin County.

Predicted shaking of Modified Mercalli intensity IX (strong enough to cause considerable damage in specially designed structures; great damage in substantial buildings with partial collapse; buildings shifted off foundations) encompasses an area of some 5 miles in width lying generally west of the Hayward fault, an area that includes virtually all the developed urban area of the East Bay from San Pablo southeast to and including the eastern half of San Jose.

Intensities greater than IX will most commonly occur along the zone of surface rupture and in those areas having a high potential for ground failure, notably around the Bay margins.

Ground Failures

Secondary ground failures, notably differential settlements and shifting of the land surface due to liquefaction will be common, particularly on filled ground around the Bay margins. These movements will damage various major structures and lifeline facilities, notably highways, railroads, airport runways, port facilities, and some utility pipelines. Seismically induced landslides pose an additional threat, particularly in the East Bay hills, with the probability of failure being highest in the rainy season.

THE EARTHQUAKE IMPACT

Deaths and Injuries

Deaths resulting from this scenario earthquake are estimated to range from 1,500-4,500 depending upon the time and day of occurrence. Hospitalized casualties are estimated to be 3 times the number of deaths; significant non-hospitalized casualties are estimated at 30 times the number of deaths.

Hospitals near the Fault

Eight of the 26 general acute care hospitals (99 beds or more) in Alameda and Contra Costa Counties are located within one mile of the Hayward fault. This represents a bed capacity of 2,300 of a total of 6,200 available in these major facilities (about 35 percent). Almost all buildings at these 8 sites were constructed prior to adoption of more stringent hospital building requirements in 1972. Direct damage, restricted access, prolonged loss of public utility services and reduced public confidence in structures near the fault, will necessitate closure of some of these facilities. Thus, one or more hospitals could become an added post-earthquake burden.

Public Schools

Earthquake resistant public school buildings are generally well distributed throughout populated areas and are normally in a safe condition following earthquakes. These structures provide a major resource for mass shelter and feeding. Some substantial damage to several schools can be anticipated, however, because of close proximity to the fault. Also, schools located in the hills east of the fault will be functionally impaired due to disrupted utility services. The Hayward fault traverses the University of California campus where about 20 percent of the floor space is in buildings classified as seismically poor or very poor, some of which can be expected to partially or totally collapse.

Transportation Lifelines

Trans-Bay Bridges

The trans-Bay bridges will be temporarily closed due to ground and structural failures at the bridge approaches. Roadway clearance, emergency repairs, detours, and bridge inspections will preclude or severely restrict use of these structures during the initial post-earthquake hours. The Oakland Bay Bridge will be effectively closed due to major damage at the east approach interchange and northward along Interstate 80/Route 17; the Richmond-San Rafael, San Mateo, and Dumbarton crossings should be available to limited emergency traffic in less than 36 hours. The Golden Gate Bridge will remain open, but traffic will be severely limited by damage at the southerly bridge approaches.

Major Freeway Routes

All of the major freeway routes to the East Bay from the east and south either cross the fault or are otherwise vulnerable to damage by strong shaking and ground failures. Major routes subject to surface fault offset average 5 feet) include Interstate 80 at San Pablo, Interstate 580 in East Oakland, Interstate 680 at Fremont and south to Milpitas, Route 24 west of the Caldecott Tunnel and most of Route 13 (Warren Freeway). Ground failures due to liquefaction and strong ground shaking cause major damage along Route 17 from Richmond to San Jose.

Virtually all older freeway bridges in the area have been retrofited to increase their resistance to shaking. Nevertheless, damage to and collapse of some of these structures is to be expected. Access to and travel within the East Bay will be difficult and limited to emergency traffic. Most principal routes on the San Francisco and Marin Peninsulas and western portion of the greater San Jose area will be open subject to major delays and detours.

Airports

Runways at the major Bay area airports are generally constructed of fill placed over Bay mud of varying depths. Their performance when subjected to prolonged shaking is questionable, and liquefaction and differential settlement may render all or portions of many runways unusable by larger aircraft. For planning purposes, San Jose Municipal Airport is assumed to be available for larger transport aircraft. San Francisco and Oakland International, Hayward Municipal, and other secondary Bay area airports should be available for limited use by small aircraft and helicopters. Alameda Naval Air Station will be closed.

BART

BART will be shut down due to the lack of electrical power and need to assess and repair damage. Principal damage will be to the Berkeley Hills tunnels which will be closed indefinitely as a result of fault rupture. Damage to a few elevated spans is postulated in the East Bay. The trans-Bay tube and the subway systems survive with no major damage.

Railroads

Rail service to the Bay area from the east and south will be curtailed due to fault rupture, ground failures at various locations around the Bay perimeter, and structural damage to numerous bridges. Rail service via the coast route from southern California to San Francisco will be restored rapidly but all other lines to and from the Bay area will be blocked for at least the initial 72-hour post-earthquake period.

Port Facilities

Most of the docks in the Bay area are pile supported and are not expected to be greatly affected. Port facilities at San Francisco are, therefore, expected to generally remain functional, though initially the loss of power and impaired access to the area will curtail operations.

In the East Bay, the major Port of Oakland and other smaller commercial port facilities at Richmond and in the Carquinez Straits will generally be nonfunctional as a result of prolonged power loss and damage to truck and rail access routes. Within the port areas filled land will settle disrupting both rails and streets. Damage to oil pipeline and storage facilities at the Richmond and Carquinez facilities poses a threat of contamination and fire.

Utility Lifelines

Communications

Telephone communications will be overloaded by post-earthquake calls within the area and from the outside. This situation will be further complicated by physical damage to equipment due to ground shaking and loss of electrical power. Moreover, not all of the systems in the region are set up to process emergency calls automatically on previously established priority bases. Thus, overloading of equipment still in service could be very significant.

The East Bay and San Jose areas have a substantial number of telephone facilities located in areas subject to severe shaking and high probability of ground failure. Access for repairs will be a major problem.

The lack of emergency power has been the primary cause of radio and microwave communications failure in past disasters. Poor installation practices and inadequate preventative maintenance of backup power equipment contribute to a high failure rate.

Electrical Power

During some portion of the first 72-hour period following the earthquake, all portions of the planning area will experience some loss of power. It is reasonable to consider about one-third of the service connections in the area to be without power for 24 hours. In the urban sections of Oakland and other East Bay cities, the power outage should be considered at 100% for the first 24 hours and 75% for an additional 24 hours. This means that 75% of customers have no power and not that all customers are limited to 25% of demand. The power outage for San Francisco should be considered at 50% for the initial 24 hours and at 25% for an additional 24 hours.

Electrical power facilities in the East Bay are particularly vulnerable to damage from the scenario earthquake, and the time required to restore full power will be prolonged. While the resources may be available to rapidly deal with repairs to the system, the general confusion and damage to other lifelines such as communications and highways will complicate restoration efforts. Realistically, power is unlikely to be restored to many areas for several days or longer. Those concerned with emergency planning for power-dependent systems such as communications, water supply, fire fighting, and waste treatment should be cognizant of this likelihood.

Water Supply

Water supply systems in the East Bay will be severely crippled in this scenario earthquake. Displacement along the Hayward fault will heavily damage all major tunnels, aqueducts and the many distribution systems that cross the fault. The flow of water crossing the fault will be reduced to 10-30% for the first 24 hours. The public will need to conserve available supplies (e.g., water in hot water heaters) and to take safety measures against contamination.

Restoration of water service to all areas east of the fault in the East Bay hills will be greatly delayed. Where water systems are heavily damaged along the fault zone, temporary pipe similar to that provided to many residences after the 1971 San Fernando earthquake may be used. Restoration of full service could take months.

Within the past 10 years, the East Bay Municipal Utility District (EBMUD) has rebuilt the older, weaker dams in their system to improved seismic standards. Consequently, a major dam failure is not considered a credible element in this scenario.

Waste Water

Waste water pipelines from the hillside areas that cross the Hayward fault will be sheared and unable to carry sewage. Open trenches may be necessary to carry sewage for short distances. Alternatively, planners will have to provide for emergency housing or temporary sanitary facilities.

Treatment plants will shut down due to lack of power. EBMUD's electric power system which uses methane gas from its treatment plant will be unable to support full plant function. It may be necessary for emergency treated raw sewage to be discharged into the Bay for up to one month.

Natural Gas

Horizontal displacement averaging about 5 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. Some fires will occur in streets due to broken gas mains; structural fires will occur as a result of broken service connections.

Fault rupture will also cause damage to the larger diameter transmission pipelines where they cross the fault at San Pablo and Fremont. As a result of damage to these transmission facilities, natural gas will be unavailable to all of the East Bay from San Pablo on the north to Milpitas on the south.

While gas supplies to most areas of the East Bay will be restored rapidly, some areas in the hills immediately east of the fault could be without gas for several weeks.

Damage to facilities serving the south Bay and San Francisco Peninsula should be minimal. Where poor ground conditions result in substantial damage to distribution systems, restoration of service will be prolonged. Throughout the north Bay, only minimal damage to isolated segments of the distribution system is anticipated.

Petroleum Refineries and Products

The six major Bay area refineries are located along or near the margins of San Pablo and Suisun Bays, all are subject to damage by shaking, and all have facilities that are subject to damage by ground failure. Refineries may also suffer damage by fire and operations will be curtailed by loss of utility services. Pipelines and storage facilities located on poor ground along the Bay margin are vulnerable to damage, particularly those at marine terminals. All major pipelines transporting petroleum fuels to the Bay area cross the Hayward fault either at San Pablo or Fremont and all are vulnerable to damage by surface fault rupture.

Lifeline Corridors

The major transportation corridors that serve the East Bay area, such as at San Pablo and Fremont, are commonly shared by various other lifeline facilities, all of which are vulnerable to major damage where they cross the fault. Simultaneous failure of several major lifelines within these restricted corridors could vastly complicate emergency response efforts. These corridors warrant special attention by emergency planners.

INTRODUCTION

ACKNOWLEDGEMENTS

INTRODUCTION

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 of that analysis was that although there is a general capability to respond to moderate-size earthquakes, it is unlikely that the collective emergency response capabilities of all levels of government and the private sector would be adequate to cope with the consequences of a major destructive earthquake near 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 _et al._, 1982 _a_ and _b_). These scenarios were based upon a repeat of the 1906 San Francisco earthquake ($M \sim 8$) on the northern San Andreas fault and a repeat of the 1857 Ft. Tejon earthquake ($M \sim 8$) on the southern San Andreas fault. These analyses extended 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 great earthquakes on the northern and southern San Andreas fault are basic for emergency planning efforts, it was apparent that similar analyses were needed for other faults in metropolitan areas that are capable of producing earthquakes of equivalent or even greater destruction. Paramount among these were consideration of a M7.0 earthquake on the Newport-Inglewood fault in southern California and a M7.5 earthquake on the Hayward fault.

Funded in part by the Earthquake Hazards Reduction Program of the U.S. Geological Survey, the Division of Mines and Geology, in collaboration with structural engineer Karl V. Steinbrugge and others, undertook development of this planning scenario for the Hayward fault. A similar scenario for a M7.0 earthquake on the Newport-Inglewood fault is in progress.

While no scenario will prove accurate in detail, a general effort such as this provides planners with a regional pattern of the magnitude and types of problems that will confront emergency response personnel. As more detailed engineering and geologic data become available, these scenarios can be periodically updated. Other scenarios could be developed for earthquakes on other faults, or for different earthquakes on the same fault. As these scenarios are developed, a more complete understanding of earthquake hazards and our ability to cope with them will evolve.

It is intended, and it is our hope, that this planning scenario will contribute to the efforts of the following users:

- Local, State, and federal officials with emergency planning responsibilities.

- Elected officials who must be able to visualize the threat in order to commit themselves to the leadership roles needed to cope with the earthquake.

- Private-sector managers and planners who must understand the hazard in order to prepare for it.

- Educators, journalists, and other public opinion makers who must appreciate the threat and communicate its character in order to motivate citizen commitment to preparedness.

- The citizens of northern California who must support public mitigation efforts and develop personal strategies for themselves and their families in order to minimize the effects of the earthquake on their lives.

ACKNOWLEDGEMENTS

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Section 1.

THE EARTHQUAKE PLANNING SCENARIO

THE EARTHQUAKE PLANNING SCENARIO

The Planning Area

The planning area for this study is centered on the Hayward fault and extends some 112 miles from Santa Rosa on the north to Morgan Hill on the south. The area is approximately 32 miles wide and is bounded by the San Andreas fault on the west and by the cities of Livermore, Concord, and Napa on the east. The area encompasses the vast majority of the 5.5 million people who populate the nine counties that constitute the greater San Francisco metropolitan area. 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 3". Planning Areas 1 and 2 designated the areas encompassed in previous scenarios based upon M8.3 earthquakes on the San Andreas fault in northern and southern California (Division of Mines and Geology Special Publications 61 and 60, respectively).

Earthquake Planning Scenario Maps

Twelve EARTHQUAKE PLANNING SCENARIO maps are included in this report. These maps show the locations of one or more major types of facilities discussed in the text, i.e., the major transportation and utility lifelines and principal medical care and educational (potential mass care) facilities. One map (Map 3-S) summarizes the regional geologic and seismological input that constitutes the basis for development of the damage assessments. This basic geotechnical information includes the location of the Hayward fault (surface rupture), the predicted seismic intensity distribution (earthquake shaking), the areas with high potential for ground failure (notably settlement and liquefaction), and areas subject to seismically induced landslides. The information presented separately on Map 3-S is also included on each of the EARTHQUAKE PLANNING SCENARIO maps, enabling 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 reflect the fact that earthquake damage will not be uniform. Damage will be related to the design of specific structures, the geologic ground conditions upon which they are built, their distance from the fault, and the character of the earthquake generated wave forms to which they are subjected.

Except for areas of fault rupture, the ground surface in areas of competent bedrock is not likely to suffer permanent deformation (ground failure). Consequently, structural damage will be less. On the other hand, structures on compressible deposits, particularly 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. Structural damage in these areas will be greater. In general, these effects diminish with distance from the causative fault. 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 failure as shown on the EARTHQUAKE PLANNING SCENARIO maps. These assessments derive from evaluations of the earthquake engineering literature, comments by various engineers and other public agency officials, and judgments by the authors. It is important that all users of these data recognize that the statements concerning the performance of individual facilities are hypothetical and that these assessments are not the result of site-specific evaluations. They are intended to portray, for planning purposes, some of the types of earthquake effects that are likely to occur, thereby providing emergency planners and other users with a reasonable perspective on the impact of this scenario earthquake.

Use of the Earthquake Planning Scenario Maps and Damage Assessments

The approach in formulating damage assessments was, first, to evaluate the regional pattern of ground shaking and ground failure and, second, to interpret the resulting performance of various major facilities. In this way, conclusions were reached which constitute the regional post-earthquake damage pattern for each of the lifelines. It is totally impractical to determine the effects of the scenario earthquake on each individual bridge, power plant, or other lifeline structure. It is, therefore, improper to use the earthquake scenario conclusions to forecast the effects of the scenario earthquake for any other purpose than emergency response and preparedness planning. For example, decisions on whether or not to replace or retrofit certain lifeline components should definitely be based upon intensive and rigorous investigations of those components and their geologic setting. This scenario can, however, help identify particular high-risk areas where such detailed evaluations should be given priority.

Some damage predictions, such as those resulting from surface rupture, have a relatively high likelihood of occurring (given this scenario earthquake). Others are much more speculative. The damage assessments also vary in completeness. The information developed for the few major airports, for example, is substantial and all major airports were considered. Gathering information for an equivalent assessment of all major water or electrical power facilities, on the other hand, would be a formidable task beyond the scope of this type of report.

The damage assessments for specific transportation and utility lifeline facilities (except Highways and Communications) include a "Map No.". This number refers to that facility shown on the appropriate EARTHQUAKE PLANNING SCENARIO map. Recognizing that many users of this report may have occasion to refer to Special Publication 61 (SP 61), "Earthquake Planning Scenario for a Magnitude 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area", the map numbers assigned to specific facilities are identical in these two reports; e.g., in each report the damage assessment for Oakland International Airport is identified by "Map No." A-2. In some instances, a damage assessment for a facility that was included in SP 61 is not included in this scenario. In these instances, the particular "Map No." was not used in this report. Similiarly, additional numbers have been assigned to facilities that were considered in this report but not in SP 61.

Limitations

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., a M7.5 earthquake resulting from rupture of the entire 62-mile length of the Hayward fault. 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 upon which the damage assessments are highly dependent 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 concerning ground conditions associated with 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 2.

THE HAYWARD FAULT

GEOLOGIC SETTING

The Hayward fault is the southern segment of an extensive fracture zone consisting of the Hayward, Rodgers Creek, Healdsburg, and Maacama fault segments. The zone extends northwest to Mendocino County (Slemmons and Chung, 1982), a total distance of 280 km (175 miles). The 100 km long Hayward segment extends from San Pablo Bay to an obscure convergence with the Calaveras fault near Mt. Misery east of San Jose (Figure 2).

The Hayward fault is one of several northwest-trending strike-slip faults associated with right-lateral tectonic movement (facing the fault, the side of the fault opposite the observer is displaced to his right) between the North American and the Pacific plates. Basement rocks underlying the area are those of the Franciscan Assemblage (50 to 200 million years old) and the Great Valley Sequence (65 to 150 million years old) overlain mostly by rocks of Miocene age deposited at the continental margin during the past 15 million years. Most of the rocks in the Bay area were folded and faulted as a result of the early convergence of the North American and the Pacific plates (Graham et al., 1984). A vivid display of the resulting compressional forces can be seen in the deformed rocks at the east portal of the Caldecott Tunnel. Here, formerly flatlying marine and nonmarine sediments of Miocene age stand almost vertical in the roadcut along Route 24.

About 10 million years ago, the tectonic regime in the San Francisco Bay area changed from convergent to transform, that is, instead of colliding, the North American and the Pacific plates began to slip past each other. In the Bay area, this relative movement is about 32 mm/yr, being distributed among the various faults of the San Andreas system (Page, 1982). Over geologic time, the San Andreas fault accommodates about 12 mm/yr of this movement, while the Hayward fault accommodates about 5 mm/yr at Fremont (Prowell, 1974).

In general, the Hayward fault is the boundary between two distinctly different geologic and physiographic provinces. The hills on the east side of the fault may be 10 million years old, but the flatlands on the west side are barely 10,000 years old. San Francisco Bay lies in a structural trough that was formed through subsidence during the Quaternary (last 2 million years) (Atwater et al., 1977). During the last major glaciation more than 15,000 years ago, sea level was 100 meters (330 feet) lower than it is today. The Bay contained no standing water, and the streams draining the hills emptied directly into the Sacramento-San Joaquin River which entered the Pacific Ocean near the Farallon Islands. As the ice from the great continental glaciers began to melt, sea level began to rise. The sea entered the Bay about 10,000 years ago, reaching its present level about 6,000 years ago.

Sediments formerly carried far into the Pacific Ocean were then deposited in and around the margins of the Bay. These flat-lying deposits have provided convenient building sites for most of the development in the East Bay. Being geologically very young, however, these alluvial sediments are not as well

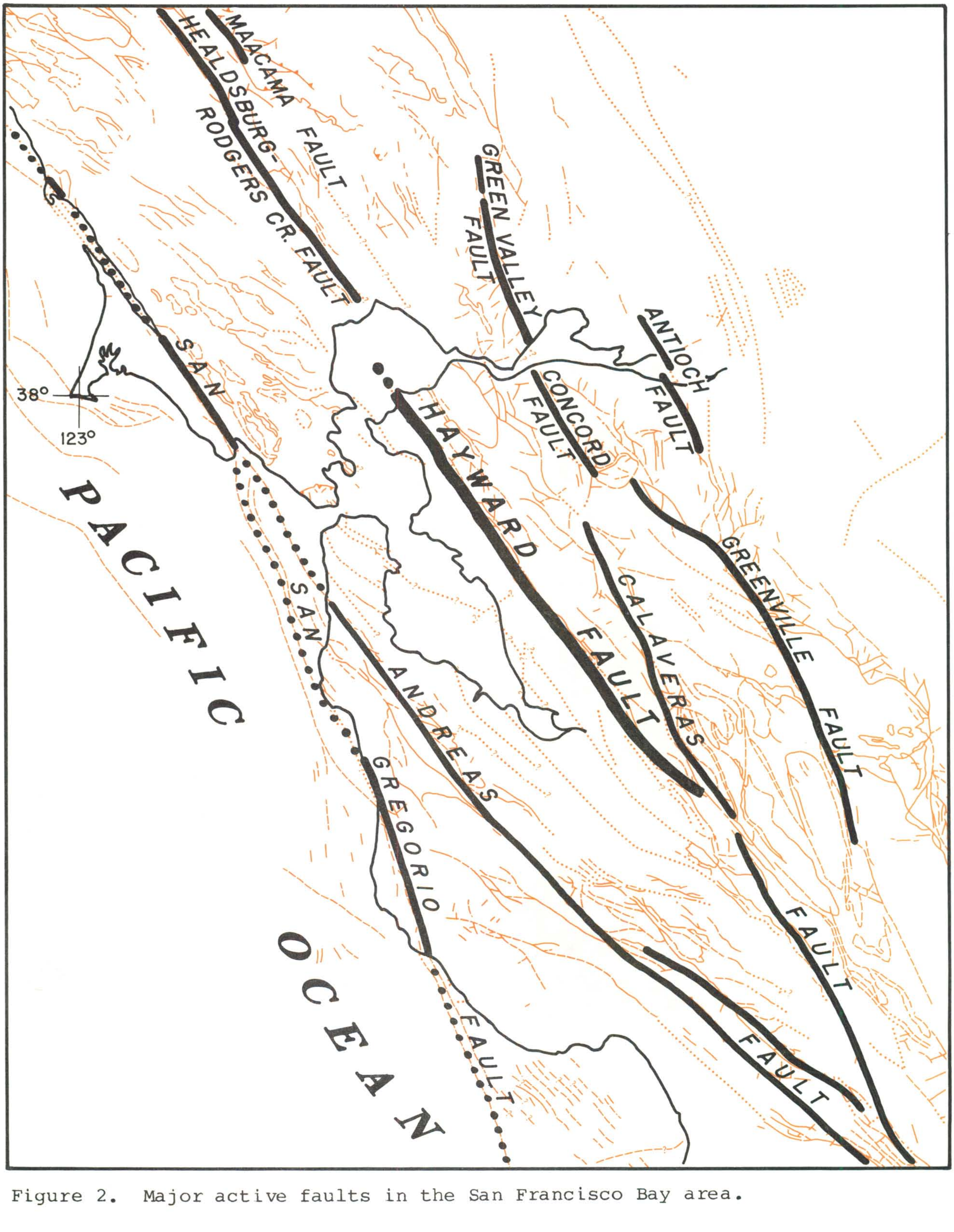
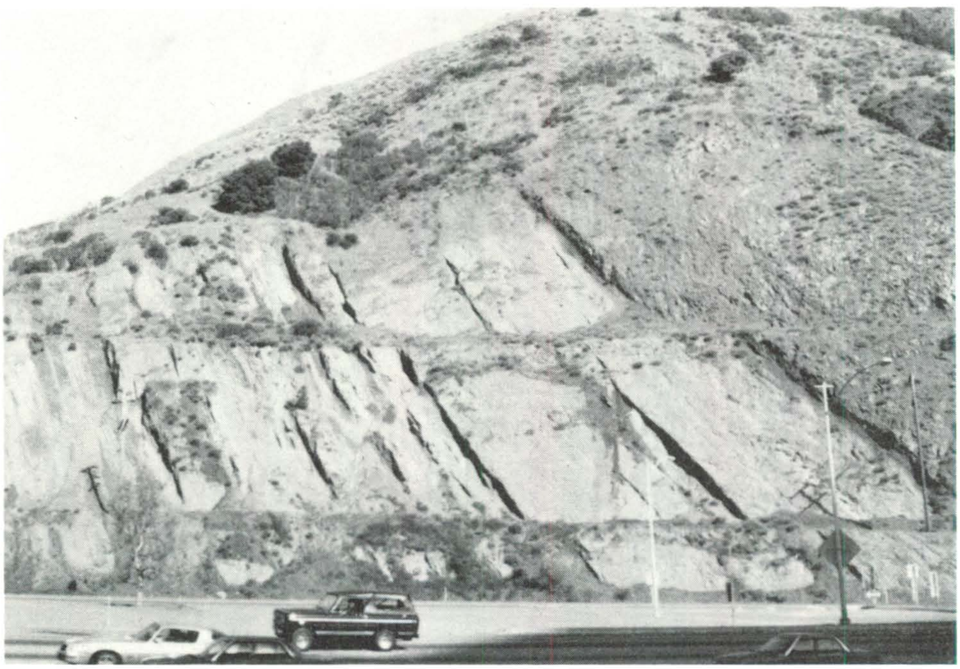


Figure 2. Major active faults in the San Francisco Bay area.

consolidated as the rocks in the hilly areas. During earthquake shaking, bay mud deposits may settle and fine-sand layers in the water-saturated sediments along the margins of the Bay may liquefy and move laterally. Shaking intensities in the flatlands are generally much greater than in the hills.



Former flatlying sediments stand almost vertical in this roadcut along Route 24 east of the Caldecott Tunnel. This deformation evidences the compressive forces that once prevailed along the boundary between the North American and Pacific plates.

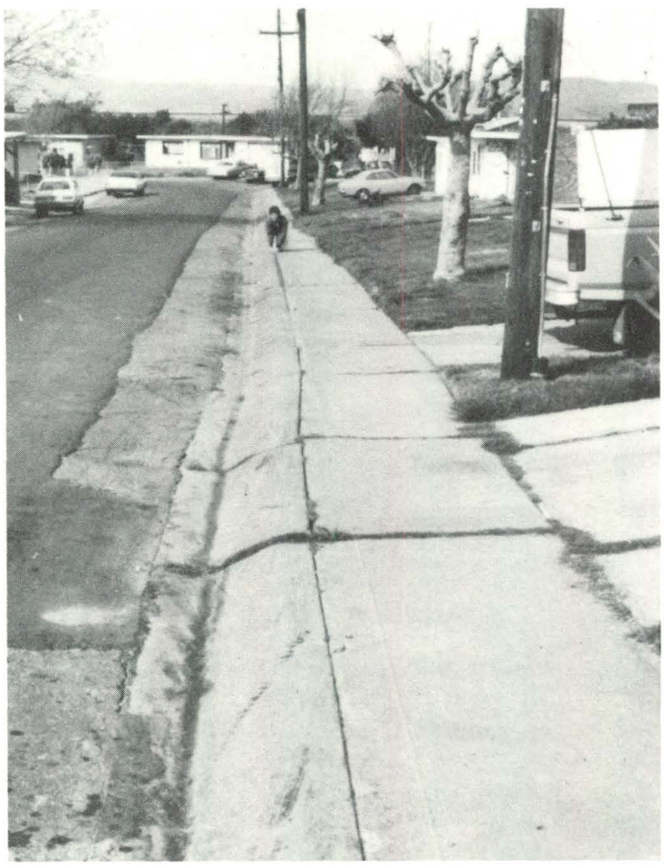
FAULT CHARACTERISTICS

Several segments of the Hayward fault are presently undergoing fault creep, a very gradual horizontal displacement that occurs both episodically and continuously. While fault creep has been documented along many segments of the Hayward fault between San Pablo and Fremont, it has not been observed along all segments throughout the fault's length. Creep rates vary considerably from place to place and with time. The long-term slip rate since the 1920's is 8 to 11 mm/yr at Fremont and 5 to 6 mm/yr at Hayward (Galehouse and Brown, 1982; Harsh and Burford, 1982; Burford and Sharp, 1982). Since 1968, a slip rate of 5 mm/yr has been measured at San Pablo (Harsh and Burford, 1982) and 6 to 8 mm/yr at the BART tunnel in Berkeley (Brekke and Brown, 1982). Most other creep localities show less than 6 mm/yr.

The width of the zone of surface fault rupture is generally less than a few meters wide along individual fault traces. Related horizontal and vertical deformation, however, is known to occur over much wider zones.

Because the Hayward fault has had repeated and systematic displacements in the recent geologic past, it is possible to characterize future displacements in several ways. The sense of displacement is almost purely right-lateral although small segments have a vertical component of displacement. Seismic rupture is known to have occurred in 1868 from east Oakland to Fremont (Warm Springs), with a maximum reported displacement of about 3 feet. However, the fault rupture was not carefully mapped nor measured, so the amount of displacement for most locations along the fault is uncertain. Evidence of afterslip (a form of rapid creep that follows seismic rupture) also was reported in Hayward, amounting to "several inches" within a "couple of weeks" after the 1868 earthquake (Lawson, 1908). This phenomenon is common on other strike-slip faults after earthquakes.

In several areas the surface traces of the Hayward fault are extensively obscured by massive landslides. The largest landslide complexes are in the Berkeley-Kensington and northeast San Jose areas. Because of the thickness of these large landslides, fault movement may not appear as discrete surface rupture during a major earthquake. However, significant reactivation of the landslides accompanied by ground failure may occur.



Fault creep totaling about 0.5 feet has occurred at this location on the Hayward fault in San Pablo since the sidewalk was constructed. Right-lateral movement is exemplified with the opposite side of the fault moving to the observer's right.

THE ALQUIST-PRIOLO SPECIAL STUDIES ZONE

The Alquist-Priolo Special Studies Zones Act was enacted in 1972 in order to mitigate the hazard of surface fault rupture along the Hayward and other 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 Hayward and other faults of the San Andreas fault system in 1974. The SSZ's for the Hayward fault were subsequently revised in 1982 as part of DMG's long-range Fault Evaluation and Zoning Program (Hart, 1985; Hart et al., 1981). A representative segment of the SSZ map for the Hayward fault is shown in Figure 3. Reduced size copies of the SSZ maps for the entire Hayward fault are included in Appendix C.

Although the Hayward fault is one of the most studied and best known faults in the world, active traces are not well located for some segments of the fault. In general, the 1982 SSZ maps distinguish those traces of the fault that are well defined from those that are not. Traces identified by well defined, youthful, fault-produced topography (e.g., linear scarps and

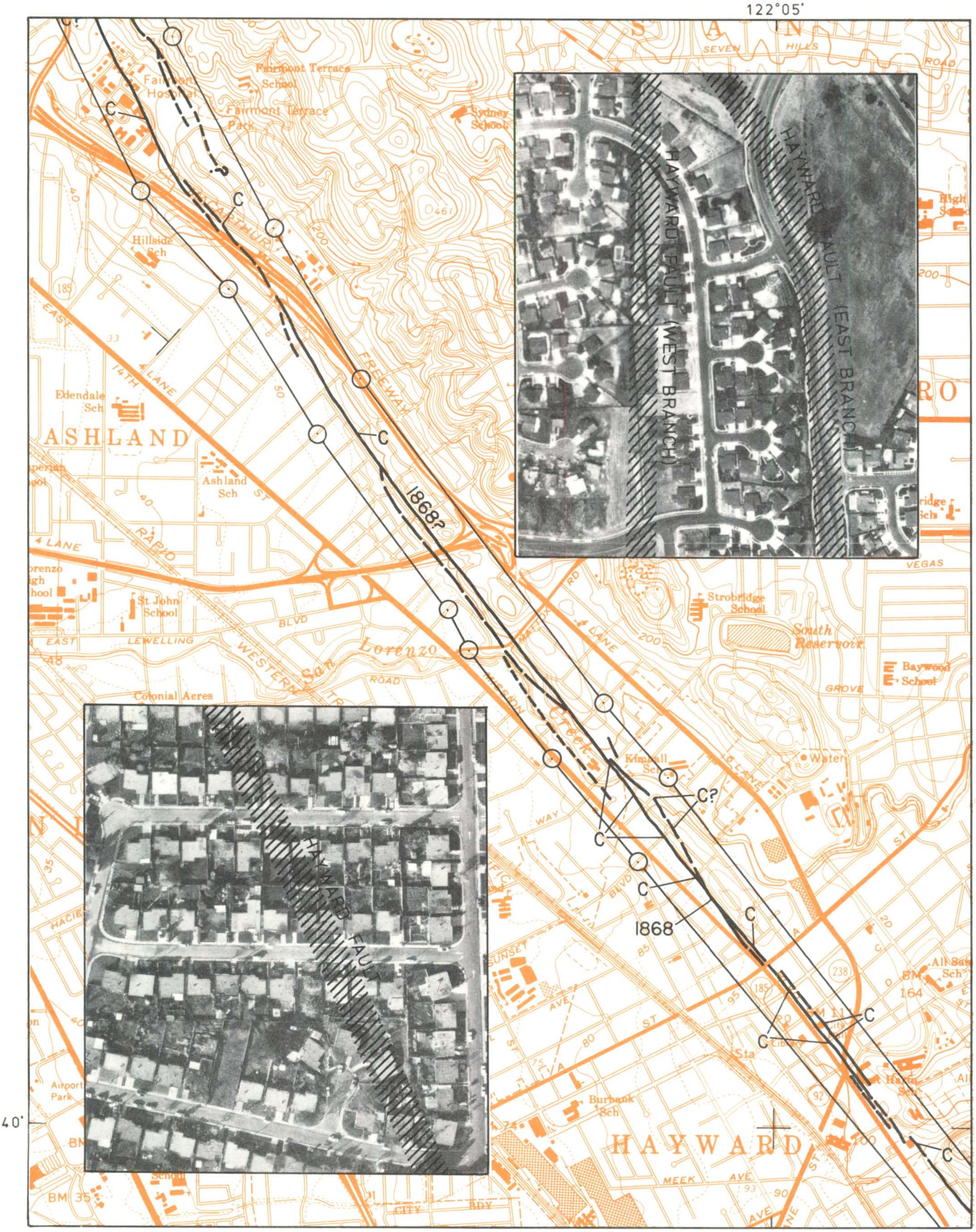


Figure 3. A typical section of an Alquist-Priolo (A-P) Special Studies Zone Map (scale 1:24,000). The photo in the lower left typifies the lack of consideration for fault hazards that existed prior to enactment of A-P legislation in 1972. Photo in upper right is an example of post A-P development with structures set back from recognized active fault traces.

benches, offset drainage, sag ponds) or historic fault creep are shown on the maps as solid lines. Traces that are approximately located, based on more obscure topographic or other evidence, are shown by long dashed lines. Inferred traces are indicated by short dashed lines and by queries. Localities where fault creep has been documented are identified by the letter "C" on the maps.

The effectiveness of the Alquist-Priolo Act varies from place to place, depending largely on how well the Hayward 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. Many of these structures are being progressively damaged or weakened by fault creep; others will be damaged by future seismic rupture. The extent of damage produced by this scenario event will be partly dependent on the amount of displacement that occurs locally on the fault and on the measures taken to mitigate the hazard.

CONTEMPORARY SEISMICITY

Earthquakes in the San Francisco Bay area during the past 15 years are concentrated near the juncture of the San Andreas and Calaveras faults, and in the East Bay (Figure 4). Seismicity along the San Andreas fault on the San Francisco Peninsula is relatively low compared to the Calaveras-Hayward-Rodgers Creek fault zone. The April 1984 Morgan Hill earthquake occurred on the Calaveras fault near the southern end of the Hayward fault. This is the largest epicenter shown in Figure 4, and also appears in Figure 5. Other seismic trends east of San Francisco Bay are along the Concord fault and the Greenville fault. The latter is the easternmost trend shown in Figure 4 and was active in the January 1980 earthquakes that caused damage in Livermore Valley.

On the Hayward fault, small earthquakes are common throughout most of the fault length from San Pablo southeast to Fremont. South of Fremont, the Hayward fault is seismically quiet. The seismicity, however, continues along a zone trending more southeasterly, denoting an active connection with the Calaveras fault near Calaveras Reservoir. On the Calaveras fault north of this juncture there is no obvious correlation between seismicity and the mapped trace of the Calaveras fault. Thus, the high level of seismic activity present along the Calaveras fault south of Calaveras Reservoir transfers to the Hayward fault near Fremont. Ellsworth _et al_. (1982) pointed out that the seismic activity along this trend generally coincides with the Mission fault, though geologic evidence of recent movement on the Mission fault is lacking (Herd, 1982 and Hart, E.W., personal communication).

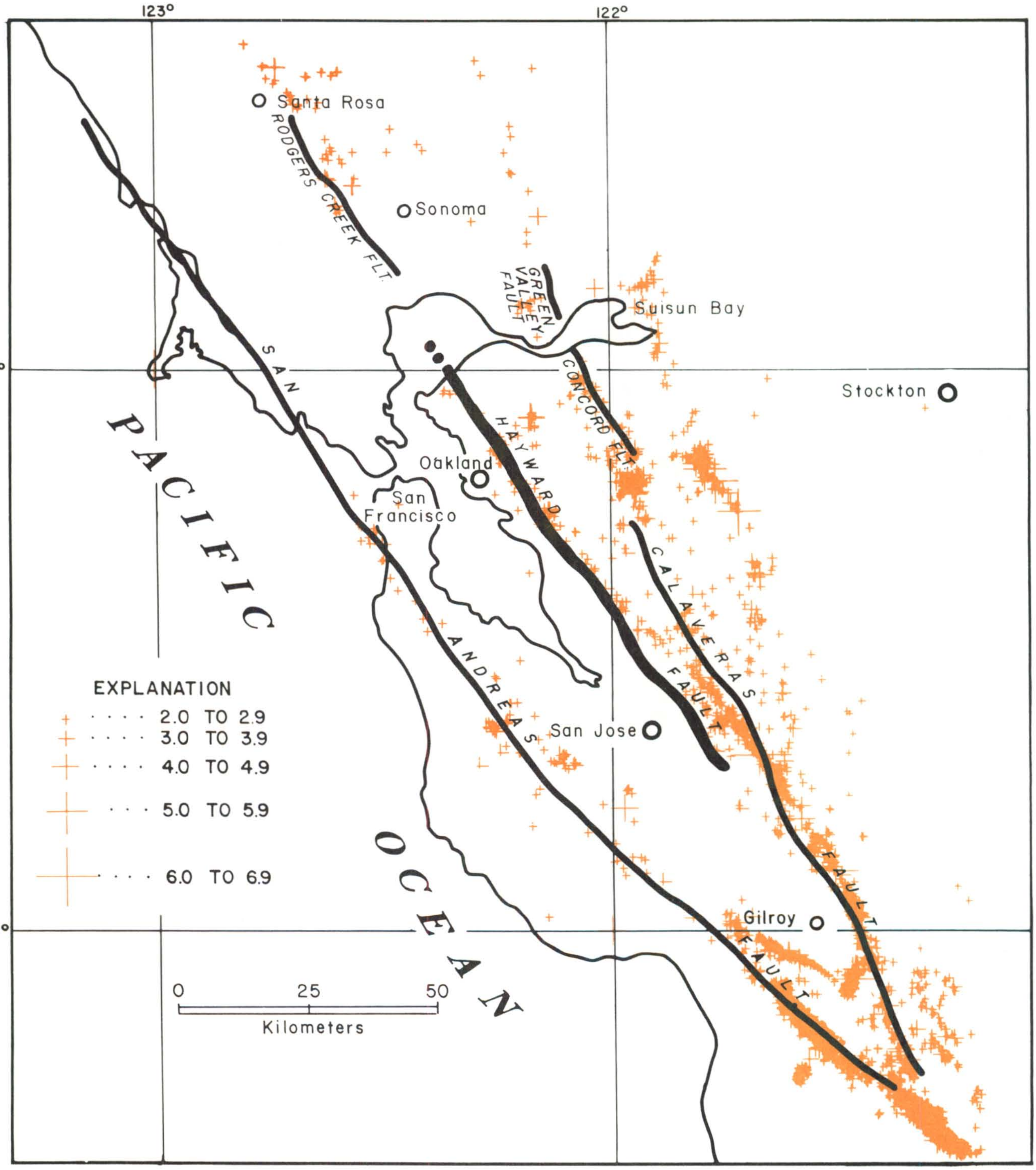


Figure 4. Epicenters of earthquakes of magnitude 2 and greater in the San Francisco Bay area from 1969 to 1984. Data from the U.S. Geological Survey central California seismograph network. Solid lines are the principal active faults.

Recent studies by Ellsworth *et al.* (1982) indicate that shallow earthquakes are distinctly absent along the Hayward fault northwest of San Leandro, with most events occurring at depths of 5-10 kilometers. Southeast of San Leandro, earthquakes occur throughout the fault plane from the surface to 10-kilometer depths. This contrasting seismicity pattern reflects a distinct difference in fault behavior north and south of San Leandro, that may be related to San Leandro being near the northern end of the 1868 surface rupture.

EARTHQUAKE HISTORY

Earthquakes of magnitude greater than 6 have occurred within 30 kilometers of the Hayward fault in 1836, 1838, 1858, 1864, 1865, 1868, 1898, 1906, 1911, and 1984. Only the 1868 event, and possibly the 1836 event, are related to surface rupture of the Hayward fault. Figure 5 shows the approximate epicenters of these events. This figure indicates that historically, more earthquakes greater than M6 have occurred on the Calaveras-Hayward-Rodgers Creek zone than on the adjacent segment of the San Andreas fault zone.

A brief description of the pre-1900 earthquakes follows (from Toppozada *et al.*, 1981). Roman numerals are shaking intensities on the Modified Mercalli (MM) or Rossi-Forel (RF) scales. These descriptive intensity scales are included in Appendix A. Magnitudes of these historic events were estimated from the areal extent of reported damage (Toppozada, 1975).

10 June 1836 M6.8

This earthquake appears to be comparable to the 1868 earthquake and, consequently, the same magnitude was assumed. *The Oakland Daily News* (10 November 1868) carried the following: "An Earthquake Reminiscence.--We are informed that in June 1836, there was an earthquake in what is now the Oakland Valley, the effects of which were felt along the foothills from San Pablo to Mission San Jose. There were large fissures in the earth, and the shocks must have been much heavier than those we have lately experienced. After the first and most violent shock, there were innumerable lesser ones, and for a month afterward, there were continuous tremors of the earth, uniformly decreasing in violence. Since the earthquake of the 21st ult. (Oct. 1868), there have been numerous shocks, diminishing in violence, and the phenomena appear to have been a repetition of those observed in 1836, and noted by persons then residing in the valley." Louderback (1947) interprets the 1836 effects from San Pablo to Mission San Jose as indicating an origin on the Hayward fault, and that the fissures probably included "fault-trace phenomena." Louderback was able to document that the 1836 earthquake caused "...havoc in Monterey and Santa Clara, and arousing great fear among the people. Intensity was apparently at least VII(RF) at Monterey and Mission Carmel." These effects are similar to those of the 1868 earthquake which damaged brick walls and chimneys in Santa Clara and was described as very heavy and of long duration in Monterey.

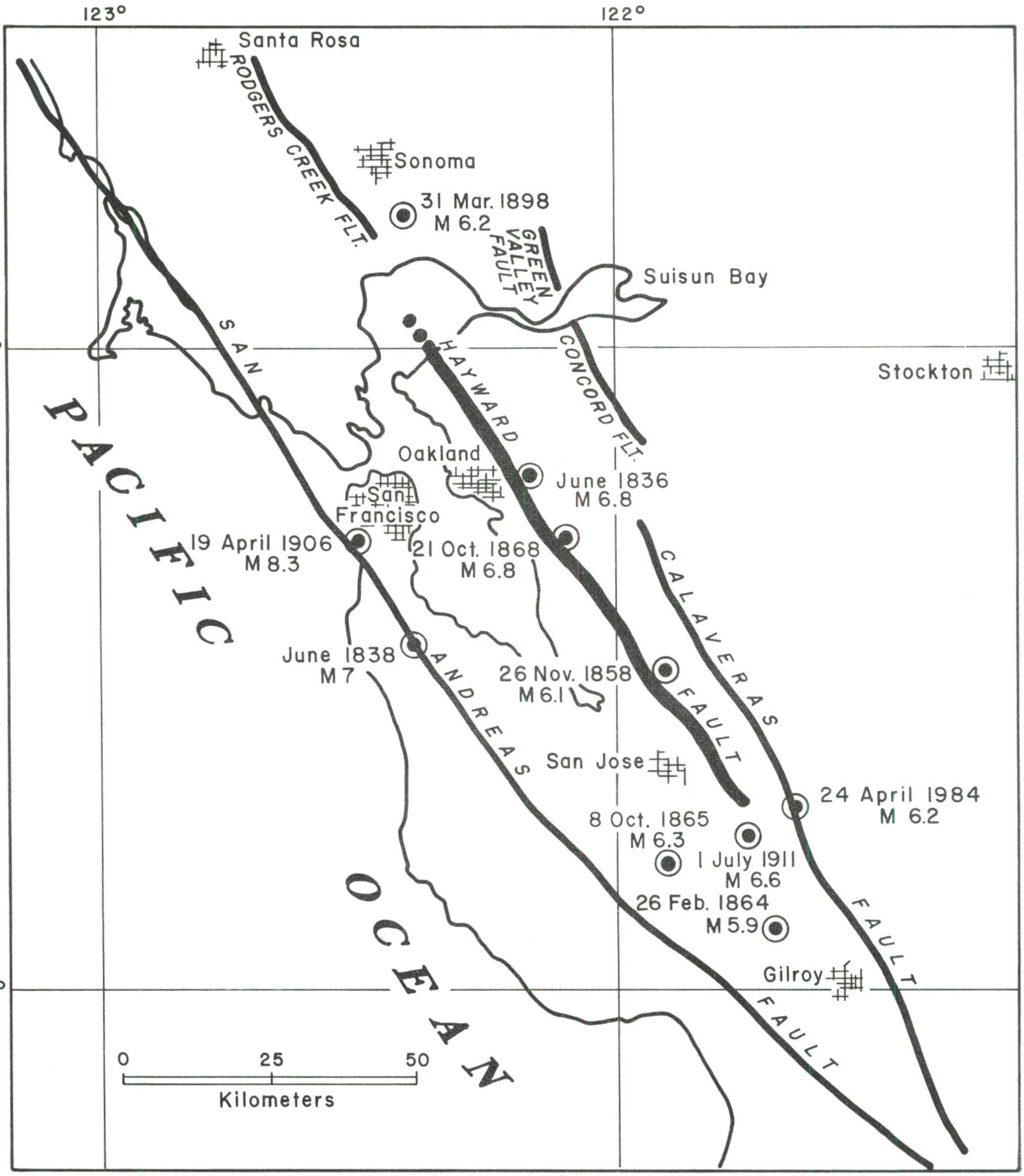


Figure 5. Epicenters of earthquakes of magnitude approximately 6 and greater within 30 kilometers (18 miles) of the Hayward fault from 1836 through 1984. Pre-1900 epicenters and magnitudes are estimated from intensity data by Toppozada et al. (1981).

June 1838 M7.0

Probable rupture on the San Andreas fault was reported from near Santa Clara to San Francisco, about 60 km. This suggests a magnitude of about 7, which is a minimum estimate because no reports were available north of San Francisco or south of Santa Clara, except at Monterey. Walls were cracked at Mission Dolores (San Francisco) in the 1838 earthquake, which is comparable to the effects of the 1906 earthquake. In Monterey, crockery and glassware were broken and some adobe walls were reportedly cracked in 1838, compared to 1906 when the only damage reported was of some glassware and some furniture moved. Louderback (1947) states that "The fault rupture may have occurred throughout all or most of the line active in 1906, but north and south beyond the limits indicated...it lay under water or in wild country uninhabited by whites (except at Fort Ross, from which we have no report). The evidence of greater intensity at Monterey than in 1906 may mean that the fault rupture extended farther south in 1938 than in 1906."

26 November 1858 M6.1

At San Jose, an adobe building and the corner of a new building were thrown down (VIII MM). A cornice was thrown down in San Francisco and part of a chimney was thrown down in Mountain View (VII MM). The earthquake was felt to Downieville on the north, Mariposa on the east, and Monterey on the south. No reports of aftershocks have been found.

26 February 1864 M5.9

Adobe walls were cracked (VI MM) in Monterey and the earthquake was felt as far as Napa to the north and San Luis Obispo to the south. In Watsonville, small articles and light furniture were tipped over and moved around.

8 October 1865 M6.3

Several houses were thrown down (IX MM) at New Almaden. In Santa Cruz, brick walls were cracked and many chimneys were thrown down (VII-VIII MM). Brick walls were thrown down in San Jose (VIII MM). The earthquake was damaging from San Juan Bautista on the south to Napa on the north. Ground cracking was reported at Mountain Charlie's near the San Andreas fault; this cracking might be fault rupture or secondary failure due to shaking.

21 October 1868 M6.8*

This was one of the most destructive earthquakes in California because of its location in a populated area. Much of the second floor of the Court House at San Leandro collapsed (IX MM). Extensive damage was done to other towns in the San Francisco Bay area. This quake was accompanied by slip on the Hayward fault in the East Bay area (Lawson, 1908). The area shaken at intensity VIII MM or greater was about 2300 km^2.

31 March 1898 M6.2

Several buildings partially or totally collapsed at Mare Island Naval Yard and at Tubbs Island. Houses were knocked from their foundations at Schellville, on the Greenwood Estate, and along Petaluma Creek, Sonoma County. Extensive ground cracks were reported at Mare Island Naval Yard, Schellville, and Greenwood Estate. The area shaken at intensity VIII MM or greater was 530 km^2.

18 April 1906 M8.3

The great 1906 San Francisco earthquake, described in detail by Lawson (1908).

1 July 1911 M6.6 and 24 April 1984 M6.2

The 1911 and 1984 earthquakes were described and compared by Toppozada (1984). The 1984 earthquake occurred on the Calaveras fault, 5 km east of the Hayward fault. The 1911 earthquake, which was shown in the above reference to have been more damaging in Santa Clara and San Jose than the 1984 earthquake, could have been either on the Hayward or Calaveras faults.

* Though of somewhat smaller magnitude than the earthquake postulated in this planning scenario, historic accounts of this earlier major earthquake provide a perspective on some of the effects to be anticipated in a future event on the Hayward fault. Accordingly, the 1868 earthquake is the subject of more detailed discussion in the following section.

Speculation on the Cause of the 1868 Hayward Earthquake

(from an article in the *Santa Clara Argus*, October 31, 1868)

...."In all probability, there is a vast mineral vein underlying San Francisco and stretching to the Sierras, which serves as a prime conductor for the negative currents of this region. By reason of the recent dry weather, and by reason of other causes for renewed electrical energy in the earth, this great prime conductor had become overcharged with negative fluid, and when the recent moist fogs floated into the dry, vaporless atmosphere, a means of conduction and equalization was formed between the negative currents of the earth and the positive current above the insulating atmosphere, producing the local disturbance which lately occurred."

House at Hayward after the earthquake of 21 October 1868. Photo courtesy of the Bancroft Library, University of California, Berkeley.

THE HAYWARD EARTHQUAKE OF OCTOBER 21, 1868

The effects of the 1868 Hayward earthquake were described in newspaper accounts and in the subsequent investigation by the California Earthquake Commission (Lawson, 1908). Reported effects at various locations throughout the Bay area are shown on Figure 8. Descriptions of the earthquake effects near Hayward and in San Francisco are relatively detailed and are included in the text below.

It is important to recognize that the magnitude of the 1868 earthquake was approximately 7, while the scenario earthquake is based upon a postulated magnitude of 7.5. The areal extent and duration of shaking resulting from the scenario event would be significantly greater. Faulting in the scenario earthquake extends for 62 miles (100 km) with a maximum offset of up to 10 feet, (average 5 feet). In 1868 the faulting extended only some 30 miles and the maximum reported offset was 3 feet.

The following descriptions of the subject earthquake and its effects are reproduced from the Report of the California Earthquake Commission, (Lawson, 1908):

> The earthquake of October 21, 1868, was most severely felt in the region about San Francisco Bay, particularly on the east side in the vicinity of Haywards. The time of its occurrence is variously stated from 7^h 47^m to 7^h 54^m A.M. It gave rise to disasters in the city of San Francisco, and some people recalling the event vividly are of the opinion that the shock was as severe as that of April 18, 1906. Early in the investigation of the latter earthquake, it became apparent that the relationship of the two earthquakes would be an essential part of the inquiry. Shortly after the earthquake of 1868 a committee of scientific men undertook the collection of data concerning the effects of the shock, but their report was never published nor can any trace of it be found, altho some of the mem-

bers of the committee are still living. It is stated that the report was supprest by the authorities, thru the fear that its publication would damage the reputation of the city. Our knowledge of that earthquake is therefore not very full, and is contained chiefly in the newspaper reports of that day......

With the object of supplementing the facts regarding the earthquake of 1868......an inquiry was started and intrusted to Mr. A.A. Bullock. This gentleman has reviewed the periodicals of the time, and has interviewed many people who experienced the shock. He has also examined the region of maximum intensity, and has had, on several of his trips, the guidance of old residents. In response to a request by the Commission, several people have written an account of their experiences at the time of the earthquake of 1868. In this way a considerable body of valuable information has been gotten together, which supplements to an important degree the extant accounts of that earthquake.

THE FAULT-TRACE

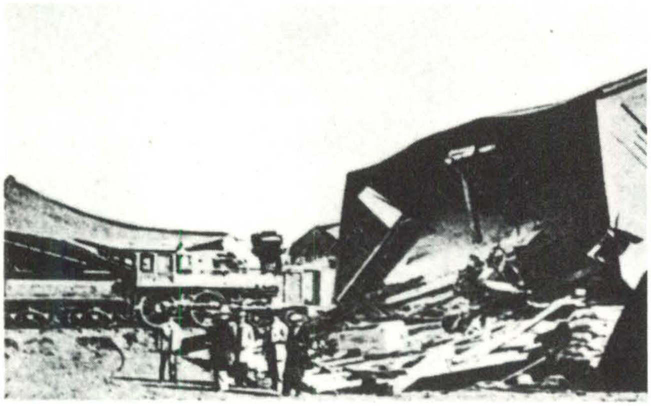
It appears from Mr. Bullock's inquiries that the earthquake of 1868 was due to an earth-movement along the base of the hills which overlook San Francisco Bay on the east, and which are often referred to, particularly farther north, as the Berkeley Hills. These hills present a remarkably even, straight front, and without doubt represent a degraded fault-scarp. Along the base of this scarp a crack opened on the morning of October 21, 1868. This crack is regarded as the trace of the fault which caused the earthquake. Its position has been determined at intervals along a nearly straight line from the vicinity of Mills College, east of Oakland, to the vicinity of Warm Springs near the Santa Clara County line; but the evidence of its existence to the northward of San Leandro is not very satisfactory. The county was then unsettled, and the information consisted of reports of cow-boys riding the range. From San Leandro southeastward, however, the evidence is full and conclusive. The general trend of the fault is northwest-southeast; or, to be more exact, N. 37^{o} W., a bearing almost the same as that of the fault-trace of 1906 along the San Andreas Rift.... While in general it lies along the base of the old degraded scarp, it is still, for the most part, within the hill-slopes and not in the alluvium which extends from the base of the hills. In some places where it crost the lower ground, the crack showed faulting or displacement of 8 or 10 inches, but from the accounts given it is not clear in what direction the faulting took place. The statements indicate a slight downthrow on the southwest side. In other places a displacement of 3 feet is said to have been observed. In places the crack along the fault-trace opened to a very considerable depth with a width of 10 or 12 inches, and remained open until filled with falling earth. On the higher ground of the hillslopes no open crack was observed; there was merely the trace of the rupture in the sod. This fault-trace could be followed at intervals for 20 miles southeast from San Leandro, and it had a straight course without regard to the contour of the hills. In some places it was quite at the bottom of a hillside, while at other places it was high on the slope; and on at least one low hill it past near the top thru a saddle-like depression. Springs are common along the base of the hills, and the fault-trace was above the springs. According to the testimony of old residents the flow was not affected by the earth-movement. In the hills to the northeast of the fault-trace, however, new springs were started and old ones revived, altho some few ceased flowing.

That the crack extended down into the bedrock is testified to by many who observed closely. Three men reported that they tried to sound the bottom of the crack, but were unable to do so. In the vicinity of Haywards it is reported that there were two branch cracks from the main one, trending off into the hills. Water and sand were ejected from the crack in one place.

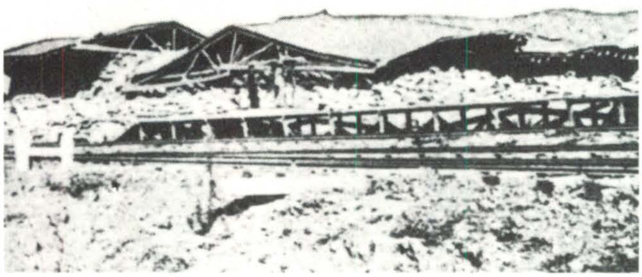
Between Decoto and Niles the crack left the base of the hill front, and deviating slightly from its general trend thus far, crost the plain of the alluvial fan of Alameda Creek at the mouth of Niles Canyon to the foot-hills at the town of Irvington. For the greater part of this distance, it appeared as an open crack. It past thru a lagoon about 0.5 mile in length, following closely the longer axis of the depression, and the water of the lagoon was drained out, apparently into the crack. At Irvington the crack became coincident with the very straight and even ancient fault-scarp of the foot-hills southeast of that town. This ancient scarp has a strike of N. 38°W. Beyond this, it was not observed farther than Aqua Caliente Creek.

The greatest intensity of the earthquake was along the crack and in its vicinity. On the projection of this line southward into Santa Clara County, the intensity diminisht steadily as far as Morgan Hill, where it again rose. At Gilroy, Hollister, and San Juan, according to reports, the intensity was sufficient to throw down a few chimneys and to crack some brick and adobe buildings.

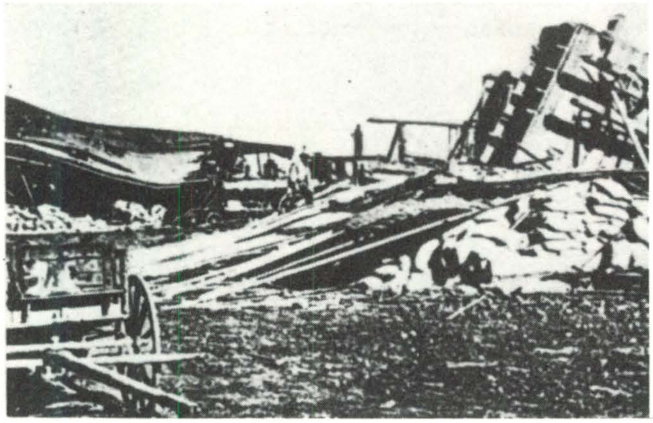
The greatest damage was done at Haywards, where nearly every house was thrown off its foundations; while at San Leandro the shock was less severe. A house near old Blair Park, in the present Piedmont district of Oakland, was badly damaged. The only other town of that date in close proximity to the fault-trace was Mission San Jose, which lies in the hills a few hundred yards west of it. In this town were several adobe buildings, one of which, a church, was wrecked. Many chimneys were thrown, but the general effect was much less severe than at Haywards.



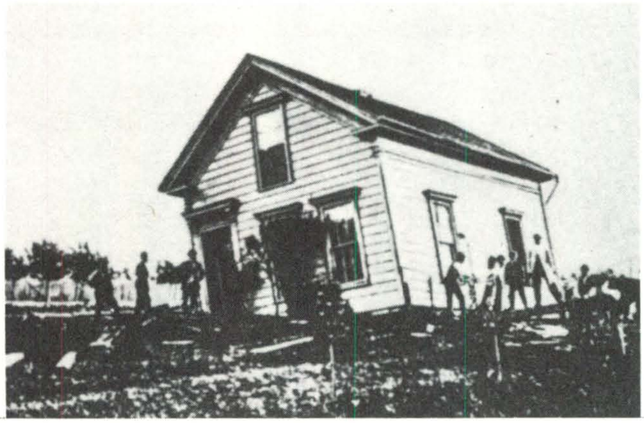
A. Flour mill, Haywards. Wrecked by earthquake of 1868.



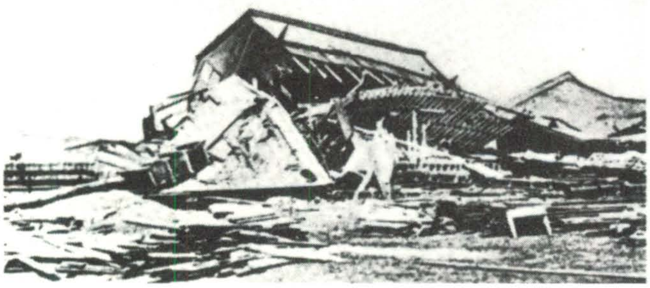
B. Edmonson's warehouse, Haywards. Wrecked by earthquake of 1868.



C. Flour mill and warehouse, Haywards. Wrecked by earthquake of 1868.



D. Pierce's house, Haywards. Earthquake of 1868.

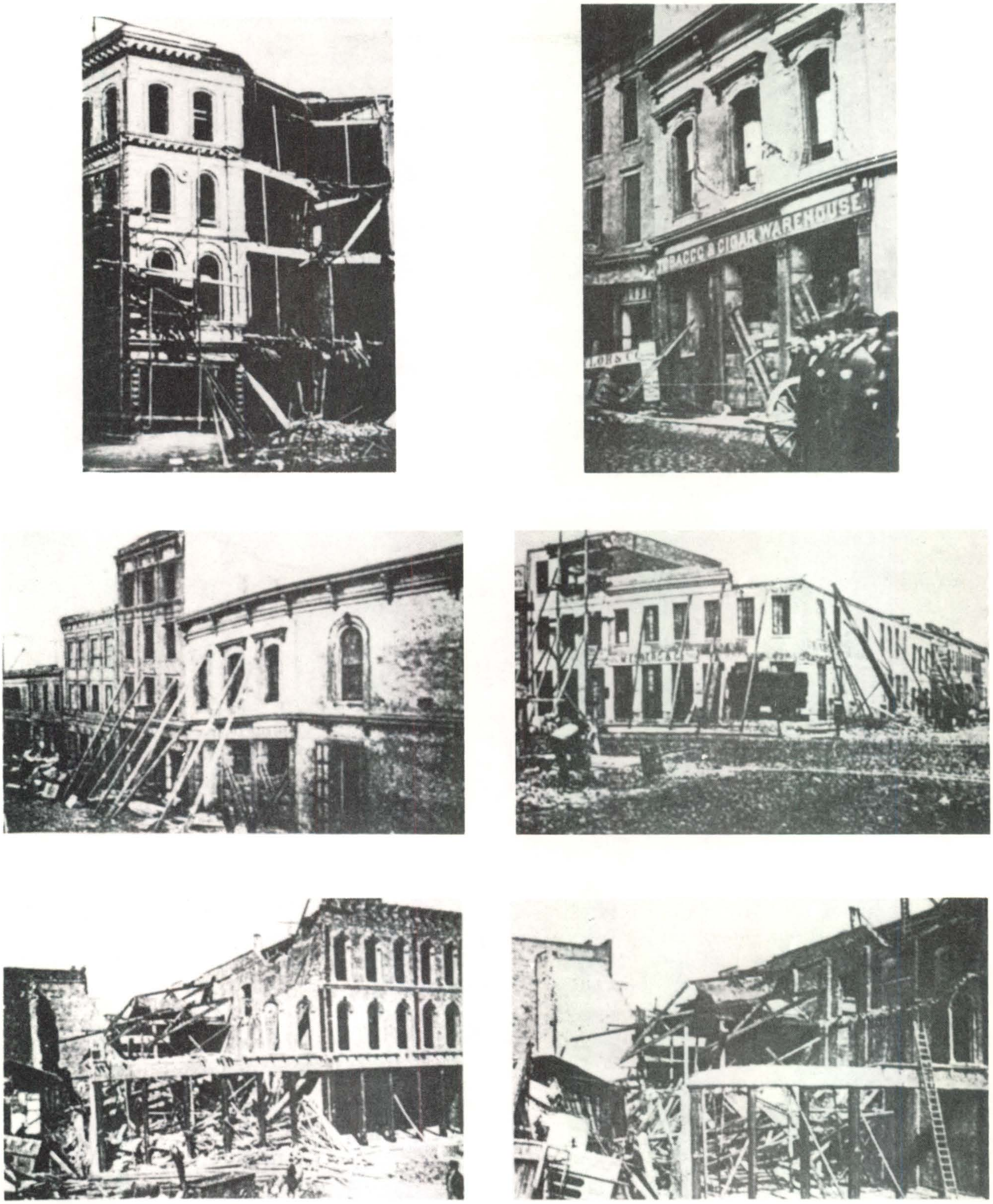


E. Haywards. Wreck of buildings by earthquake of 1868.

F. Court-house, San Leandro. Wrecked by earthquake of 1868.

From photographs preserved by Mr. H. Bendel.

Figure 6. Earthquake damage near Hayward resulting from the 1868 Hayward Earthquake. (Reproduction of Plate 144 from Lawson, 1908).



Effects of the earthquake of 1868 in San Francisco. From photographs preserved by Mr. H. Bendel.

Figure 7. Earthquake damage in San Francisco resulting from the 1868 Hayward earthquake (Reproduction of Plate 145 from Lawson, 1908).

In general, the direction of throw of objects was north or south. From several tanks the water slopt north and south. Nearly all the chimneys reported were thrown either north or south. Several frame houses were thrown south. One of these, 0.5 mile south of the line of the fault, was thrown 4 feet and another on the line was violently thrown 6 feet.

Several people report that rumblings preceded the shock, coming apparently from the south or southwest. Others saw a wave-like motion set up in the surface of the ground approaching from the south or southwest.

EFFECTS OF THE EARTHQUAKE NEAR HAYWARDS

The crack past out diagonally up the Haywards Hill and crost 3 feet from the south corner of the old hotel; past just east of the Odd Fellows' Building, through the Castro lot, tearing off a corner of the adobe house which stood where the jail now is, on through Walpert's Hill toward Decoto. By the hotel the crack first opened 18 to 20 inches, but soon closed to 5 or 6. It was of unknown depth; several balls of twine, tied together, with an iron sinker, failed to find bottom. There was no water in the fissure, for the iron came up dry. From the corner of B and First Streets another crack past nearly eastward toward the hills, and faded out by the sulfur spring about 1.5 miles distant. In a general way, the crack from Haywards to beyond Decoto past from 100 to 300 feet above the base of the hills. Practically not a house was left on its foundations in Haywards. At one place south of town the fault showed a throw of some 3 feet. (W.H. Weilbye)

"On going down the county road toward Oakland, we came to Mr. A.L. Rockwood's house, which had been thrown from its foundation and one end thrown into the cellar. The house was badly wrecked. In the south part of the town there was a flour mill on a foundation about 4 feet high. This building was thrown to the ground and wrecked. On the ground which is now the plaza stood a new brick warehouse filled with grain from the season's crop. the building was completely torn to pieces; grain was spilt from the sacks, and everything was in a mess. The building was 300 feet long by about 60 feet wide. A wooden warehouse about the same size shared the same fate as the brick. On B Street the ground opened about 2 inches, and water and sand were forced from the opening. Some springs were closed, while others were opened or made to flow more freely. Many wells were affected in the same manner. Mr. Charles Herman, who was in the baking business, was driving back to Haywards after delivering bread. Looking up the road, he saw the ground coming toward him in waves, and when the motion struck his horse, she went down on her knees. Mr. Herman thought the world had come to an end. As he neared the San Lorenzo Creek, he noticed that the water had been thrown out of the bed of the creek on to the road.

"At San Leandro the earthquake destroyed the brick court house, which was then located there. A Mr. Joslyn was killed in attempting to escape from the building. Many buildings were much damaged in that town as well as in Haywards. The earthquake was the direct cause of the death of 2 persons in Haywards." (George A. Goodell)

The crack past thru a gravel quarry practically on the summit of the first range of hills. (O. Hill)

The crack below Haywards Hotel was 12 inches wide. It ejected water and white sand. A fence which traversed a hill from north to south was crost by the crack, and had the ends of the boards loosened from the posts. Gradually these boards lapt over one another, until within a couple of weeks they overlapt several inches, the progress of the overlapping being noted from time to time by a pencil mark. The 'cap' board of the fence was also archt up in consequence of this movement. Large waves were set up in the soil. The house was moved southward, while a neighbor's was tipt northward. (D.S. Malley)

The shock was from southwest to northeast. The ground opened from 6 inches to 2 feet, and water with sand was ejected to a height of from 1 to 3 feet. North of the village a ridge of ground 3 feet wide was raised 2 feet. By the time the shock was over, nearly the whole place was in ruins. Near Hayward's Hotel the hill shifted a good deal, and a crack opened for several hundred feet. On the hills there were several new springs. In the first 12 hours after the main shock there were 36 aftershocks. Between Haywards and Mission San Jose there were numerous cracks, so that it was difficult to drive a stage between the two towns. (Alta California, Oct. 22-25, 1868.)

THE EFFECTS OF THE EARTHQUAKE IN SAN FRANCISCO

At San Francisco and nearby points the earthquake lasted for about 42 seconds. It was in general north and south. A second shock followed the first at 9^h 23^m A.M., and lasted for 5 seconds, with the same direction as the first. Until about 12^h 15^m P.M., light shocks continued to be felt about every 30 minutes; and inside of the 24 hours immediately following the initial shock, 12 minor shocks were felt. The first indication of the approach of the earthquake was a slight rumbling sound, coming apparently from the direction of the ocean. The sound was heard very distinctly in the lower part of the city, but the residents on the hills do not appear to have heard it. (San Francisco Times, Oct. 21.) The shock commenced in the form of slow, horizontal movements. The oscillations continued from 10 to 15 seconds growing more rapid and more violent for 6 to 7 seconds, then partially ceasing for 3 or 4 seconds, then increasing in force and rapidity for 4 or 5 seconds, then suddenly ceasing. (Alta California, Oct. 22, 1868.)......

The portion of the city which suffered most was that part of the business district, embracing about 200 acres, built on "made ground"; that is, the ground made by filling in the cove of Yerba Buena. The bottom of this cove was a soft mud varying from 10 to 80 feet in depth, and the material used to fill it was largely "dump" refuse, much of which is organic and hence perishable. Many of the buildings of that period were built flat on this filled mud, without piling, and before the land had had time to become firm. On this made land there was a very evident belt of maximum damage several hundred feet wide and running about northwest and southeast, commencing near the custom-house and ending at the Folsom Street wharf. One account of this belt goes so far as to trace 8 or 10 distinct lines of maximum disturbance, practically every building on these lines being more or less damaged, while none outside of these lines was seriously injured.

In many places the made land settled. At the junction of Market and Front Streets, the ground sank for a foot or two, and there was evidence that the tide had risen in the adjoining lot at the same time, for a pond of water collected and remained until low tide. On Pine Street, near Battery, the cobbles on the south side of the street sank away from the curbstones to the depth of 1 foot in some places; and the asphalt sidewalk on the north side was twisted and torn out of all shape, and its connection with the curb-stone severed. (Alta California, Oct. 22, 1868.)

At the corner of First and Market Streets, the ground opened in a fissure several inches wide. At other places the ground opened and water was forced above the surface. (San Francisco Bulletin, Oct. 21, 1868.) At Fremont and Mission Streets the ground opened in many places. (Alta California, Oct. 22, 1868.) The general course of damage in the city was along the irregular line of the "made land," or low alluvial soil, where it met the hard or rocky base beneath it. Along the line of the old shore of Yerba Buena Cove, we found the damage to brick buildings much the largest. The custom-house, at the corner of Sansome and Clay Streets, was hurled south, by what seemed to be an undulating motion, and plaster fell...

A 3-story brick structure on the corner of Market and Battery Streets, in an unfinished condition, was completely thrown down. Several different reports state, however, that it was very poorly constructed. In the Union Foundry, on First Street at the corner of Market Street, most of the machinery was displaced. (San Francisco Bulletin, Oct. 22, 1868.)
The floor of the Pacific foundry was raised about 2 feet in places. The center of Mission Street (opposite Fremont Street) exposed an opening from 8 to 10 inches wide; and openings of the ground were also plainly to be seen on Fremont Street, in the same vicinity. (San Francisco Bulletin, Oct. 21, 1868.)

Outside of the immediate district described above, damage to the rest of the city was very meager......the region of greatest agitation was confined to the low portions of the city, or the vicinity of some old creek bed or swamp.....

From the meagerness of reports it is certain that no great loss was occasioned by the parting of water mains. The Bulletin for October 21 reports that the water at the Mission was shut off by the pipe being disconnected. In several parts of the city the water pipes broke underground and caused some loss of water, but the water company soon had all repairs made. No fires are reported in the upper Mission district during the 24 hours following the earthquake. At Laguna Honda (a natural reservoir and the chief source of water supply, 2.5 miles west of Valencia and Market Streets) the water was violently agitated and the waves met in the center, throwing up a large jet several feet into the air. (Alta California, Oct. 22, 1868.).....

There was no tidal wave accompanying the earthquake. The passengers on a ferry steamer (off Angel Island) felt the shock and supposed for the time that they were aground. Many other boats reported the same experience. Two boatmen in a Whitehall boat off Fort Point report a heavy rumbling sound coming from the water. Their boat was shaken and whirled rapidly around (before the rollers reached them) and shortly they met 3 heavy rollers coming from the northwest on a calm sea. (Alta California, Oct. 22, 2868.) The shock of the earthquake was distinctly felt at sea near San Francisco. Captain Tobey, of the ship Pactolus, reported being at anchor in deep water about 15 miles west of the Heads when the shock took place. At first it seemed as if the vessel were passing over a coral shoal and striking quite heavily. The noise and motion made it seem as if the ship were dragging, with her chains also slipping out. (San Francisco Bulletin, Oct. 22, 1868.) The ship Cesarewitz felt the shock nearly out at the Farallones; the brig Orient, bound in, 8 miles out, experienced the shock heavily. Pilot Murphy, on a transport bound out, reported that the bark seemed to have struck bottom, her progress being impeded, and the ship, especially the yards and masts, trembled violently. (San Francisco Times, Oct. 22, 1868.)

The total list of casualties due directly to the earthquake numbered 5, and about 25 more occurred from secondary causes. The total loss of property was variously stated from $300,000 to $5,000,000. However, a careful estimate of damages made a day or two after the disaster, placed it at about $350,000. (San Francisco Bulletin, Oct. 23, 1868.)

Apparently, the effects in the hills were minor, as stated in the Daily Evening Bulletin (San Francisco) Oct. 21, 1868, p. 3, which is not quoted in Lawson:

> Upon Russian and Telegraph Hills the shock does not appear to have been so severely felt as in other parts of the city. In some houses ornaments were not displaced from the mantel-piece, and the inmates did not come to the door. In others, books and ornaments fell down, and marble mantels were started from their places. The oscillations on Russian Hill were more sensibly felt. There was a pretty general stopping of clocks, some cracking of plastering and throwing down of light articles. Houses upon the flat between Howard street and Mission Bay were more severely shaken, but the damage save to chimneys and plastering is slight.

Section 3.

THE SCENARIO EARTHQUAKE

CHARACTERISTICS OF THE SCENARIO EARTHQUAKE

The scenario earthquake, Richter magnitude 7.5, is based upon the postulated rupture of the entire 100 kilometer length (about 62 miles) of the Hayward fault, extending from San Pablo Bay to near Mount Misery east of San Jose.

Potentially damaging shaking continues for 25-35 seconds in the area within 20-25 miles of the fault. Surface rupture occurs throughout the fault length with the zone of faulting varying in width from a few meters to 100 meters (330 feet). Total right-lateral horizontal offset reaches a maximum of 3.5 meters or about 10 feet. The average displacement over most of the fault length is about half the maximum displacement. This offset is generally distributed over more than one shear plane, in a fault zone 10 to 20 feet wide. Vertical movements are minor and of limited extent.

The earthquake occurs during the Spring when saturated ground conditions increase the propensity for ground failures, notably seismically induced landslides.

Frequent aftershocks continue during the weeks following the main shock, with several events reaching magnitude 6.0 or larger.

LIKELIHOOD OF THE EVENT

While a planning scenario provides information on the regional impact of a catastrophic earthquake for emergency response and preparedness planning purposes, it provides no insight to the likelihood of such an event. A complete description of an earthquake threat requires knowledge of both impact and imminence. Imminence, usually expressed in terms of probability, is important because it provides a means of selecting appropriate levels of mitigation.

Recent findings from worldwide studies of major plate boundaries have been applied to the assessment of hazards along the San Andreas fault system. This permits estimating the long-term probability of major earthquakes along the Hayward fault, an important element of the San Andreas system. This section summarizes the results of these assessments and their implications on the likelihood of the hypothetical event upon which this scenario is based.

Studies of major fault zones have shown that the behavior of a fault can vary markedly along its extent. Slip occurs along some fault segments with little resistance or associated seismicity while the rocks along other segments strongly resist movement, allowing strain to accumulate. As a consequence, size and repeat times of large earthquakes can vary greatly from one fault segment to another. Within a particular segment, however, the frequency and size of large earthquakes appears relatively constant. Use of these concepts to estimate the probability of future earthquakes requires 1) the ability to divide a fault into segments based on available seismic and geologic information, 2) knowledge of the time required to accumulate enough strain to cause failure of a segment, and 3) knowledge of the current status of the segment in relation to the cycle of strain accumulation.

Using this approach, Coppersmith (1982) estimated the probability of major earthquakes along the Hayward fault. A probability of 14% and 26% was computed for a M7 event to occur within the next 50 years, assuming strain accumulation (slip) rates of 3 mm/yr and 6 mm/yr. Similarly, Lindh (1983) calculated a probability of 20% for a M6.5 to M7.0 earthquake to occur in the next 30 years. These calculations are based on the 114-year interval dating from the 1868 earthquake to 1982.

Recent observations of geodetic strain and fault creep indicate that the current rate of strain accumulation along the Hayward fault is probably less than 4 mm/yr (Prescott and Lisowski, 1982). Whether this rate is representative of the entire fault zone for the entire 114-year interval and of future fault behavior is unknown.

The probability of occurrence of the M7.5 scenario earthquake will be smaller than these probabilities because the earthquake is larger. Nevertheless, this scenario is a credible worst case situation for emergency planning purposes.

PREDICTED SEISMIC INTENSITY DISTRIBUTION

Introduction

To develop an earthquake planning scenario, it is necessary first to estimate the regional patterns of ground shaking and ground failure. 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 about 7 earthquake of October 21, 1868. The effects of that earthquake were peripherally addressed by the classic "Report of the State Earthquake Commission" (Lawson, 1908), pertinent portions of which were reproduced in the preceding section. The effects observed in 1868 provide a means of checking the general validity of the regional seismic intensity map developed for this scenario earthquake.

"Seismic intensity" is the effect of an earthquake at a particular place. A single numerical value attempts to convey the various effects of earthquake shaking on humans and their cultural paraphernalia at a given place. The measurement of seismic intensity, therefore, is unavoidably subjective. Over 44 different intensity scales have appeared during the last century (Barosh, 1969, p.6). The Modified Mercalli and Rossi-Forel intensity scales are in Appendix A.

Regional Seismic Intensity Investigations, in General

The degree of ground shaking at a specified location resulting from the scenario earthquake will be dependent 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. Well consolidated bedrock, for example, transmits most 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; Legg _et al_., 1982, p. 2-5). 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%) in areas containing landslide deposits. Both liquefaction and seismically induced landslides have been observed as far as 500 km from an earthquake source (Keefer, 1984, p. 411).

Development of the Seismic Intensity Distribution Map

Shaking Intensity

In preparing a regional intensity map to be employed in the assessment of lifeline damage, we developed an algorithm based on the Evernden model (Evernden *et al.*, 1973, 1981; Evernden, 1975). 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 fault source, attenuation, and the geology of the substratum. The intensities are calculated by using an empirical relationship between acceleration and the intensity scale. The Modified Mercalli (MM) intensity scale (see Appendix A), which was developed in 1931, is extensively used today and provides a classification of earthquake effects related to types of construction.

Development of the seismic intensity distribution map begins with attenuation versus distance calculations plotted as concentric ellipses centered on the Hayward fault. With distance from the fault, each successive ellipse becomes 0.1 intensity unit less than the previous one. Thus, on well-consolidated bedrock within a distance of 8 km of the fault the ellipses denote Modified Mercalli intensities of VII or greater; 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 are expected to 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. Following Evernden, Kohler, and Clow (1981, p. 9), we prepared a table of the geologic units common to the Bay area and assigned relative intensity values to each (Table 1). Thus, for any particular location in the Bay area, the predicted seismic intensity is increased by this factor to include the effect of ground condition. Our table is similar to Evernden, Kohler, and Clow (1981, tables 1 and 2), with the following differences: because our algorithm gives intensity for bedrock instead of for alluvium, geologic factors are positive instead of negative. We simply added +3 to the relative intensity values in their table 2. Also, we have slightly different classifications for some geologic units. For instance, we consider "Plio-Pleistocene" sedimentary (+1.8) to be slightly more consolidated than Quaternary sedimentary deposits (+2.0). This is supported by the shear wave velocity measurements of Fumal and Tinsley (1985), that show Plio-Pleistocene deposits to have higher values than Holocene deposits.

Each geologic map unit was placed into one of the ground-condition categories. The intensity values for the various ground conditions were added to the computer-generated intensity values for well-consolidated bedrock. These values were rounded to the nearest whole unit and the boundaries of the resulting "geo-seismo units" were drawn. The resulting map was then superposed with the areas having potential for liquefaction and the areas having potential for seismically induced landslides.

We predict no intensities higher than IX, because intensities X through XII are attributed to the secondary effects of ground breakage. The potential for ground breakage is estimated independently.

TABLE 1

Geologic Units and Relative Intensity Factors

Geologic Map Units	Relative Intensity Addition Factor
Classification for the San Francisco (Jennings and Burnett, 1961) and San Jose (Rogers, 1966) Sheets	
Plutonic and metamorphic rocks (Ti, Kjfv, gr, bi, ub)	0
Volcanic rocks (Pv, Mv, Tv)	0.3
Jurassic and Cretaceous sedimentary rocks (Jk, Kjf)	0.8
Cretaceous through Eocene sedimentary rocks (E, Ep, K, Ku, Kl, [Kjf El Cerrito area])	1.2
Oligocene through middle Pliocene sedimentary rocks (Pmlc, Pml, Mu, Mm, Ml, Ø)	1.5
Plio-Pleistocene sedimentary rocks (Qc, QP, Pc, Pu)	1.8
Quaternary sedimentary deposits (Qs, Qal, Qf, Qb, Qt, Qm)	2.0
Classification for the Santa Rosa Sheet (Wagner and Bortugno, 1982)	
Plutonic and metamorphic rocks (Kgr, PzMz[ls])	0
Volcanic rocks (Psv, Mpt, Mbm, Mpp)	0.3
Jurassic and Cretaceous rocks (KJf, um)	0.8
Jurassic through Eocene sedimentary and mafic rocks (Emk, En, Ed, Ec, Pmz, Tkf, Ku, Kfo, Kg, Kf, Ks, Ky, Kv, Kl, KJu)	1.2
Tertiary sedimentary rocks (Pwg, Pp, Mo, Mdb, Msp, Mmy, Ml)	1.5
Plio-Pleistocene sedimentary rocks (Qmi, QT, Pt, Ppt)	1.8
Quaternary sedimentary deposits (Q, Qa, Qls, Qs, Qi, Qo, Qt)	2.0

Our model differs from that of Evernden _et al._ (1981) in the following ways: 1) we predict 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 theirs; 2) we predict no difference in seismic intensity as a result of depth to water table. Our model was guided by the areal extent of Intensity VII and VIII shaking for the Hayward earthquake of 1868 and by earthquakes of similar size on other California faults. The methodology of the Evernden model does not predict ground failure. In order to add this dimension to the intensity maps, we evaluated information on local geology in order to identify areas of potential ground failure. These areas are identified on the Seismic Intensity Distribution map (Map 3-S).

The U.S. Geological Survey (1981) has published a series of intensity maps for specific earthquakes using Evernden's method, including a M 7.4 event on the Hayward fault. The geologic information used in the USGS analysis was based primarily on 1:250,000 scale maps from the DMG "Geologic Atlas of California." Our model differs from Evernden's, and for the area north of 38 degrees latitude, we utilized the newer Santa Rosa geologic quadrangle map of Wagner and Bortugno (1982).

Ground Breakage

Three types of ground breakage will occur as a result of the scenario event on the Hayward fault:

1) fault rupture,

2) liquefaction,

3) landslides.

1) Fault Rupture

In this scenario we postulate that the entire 100 km length of the Hayward fault extending southward from San Pablo ruptures in a single event. About half of this 100-km fault segment ruptured in the 1868 earthquake (Lawson, 1908; Bonilla, 1967). In the 1836 earthquake also, there were reports of "large fissures" in this fault segment.

The most recent data (Bonilla *et al.*, 1984; Slemmons, 1982) are used to derive the earthquake magnitude and the fault displacement from the postulated 100-km rupture length.

We derive the earthquake magnitude using the relation for strike-slip faults (Bonilla *et al.*, 1984),

$$M_s = 6.24 + 0.619 \log L$$

substituting L = 100km gives

$$M_s = 7.48.$$

The same rupture length gives a lower magnitude using the relation of Slemmons (1982),

$$M_s = 1.404 + 1.169 \log (100{,}000 \text{ meters})$$

$$M_s = 7.25$$

For planning purposes, the maximum value M 7.5 is assumed.

We derive the maximum fault displacement using the relation for strike-slip faults (Bonilla *et al.*, 1984),

$$\log d = -1.28 + .914 \log L$$

substituting L = 100 km gives a *maximum* displacement

$$d = 3.5 \text{ meters (about 10 feet).}$$

The *maximum* displacement can occur at one or more locations in the surface rupture. The *average* displacement is about half the maximum, or about *5 feet*, and will be more prevalent throughout the rupture length. In the 1868 event 3 feet of ground displacement was observed (Lawson, 1908). Total displacement can be distributed across more than one fault trace. This scenario predicts that ground breakage will occur along the active traces delineated on the Alquist-Priolo Special Studies Zone maps. These maps are included in Appendix C. About 60 km (37 miles) of faulting occurs in Alameda County, 25 km (16 miles) in Santa Clara County, and 15 km (9 miles) in Contra Costa County.

2) Liquefaction

The area designated as having high potential for ground failure includes all Bay mud deposits (Nichols and Wright, 1971), all areas considered of high liquefaction potential by numerous authors, and most areas in which ground failure was noted in the 1906 earthquake (Youd and Hoose, 1978; Nason, 1980a, 1980b, 1982). These data were checked against detailed work in the literature and modified as indicated below for the nine Bay area counties:

Alameda County

The data of Helley *et al.*, (1972) was the prime reference. Younger fluvial deposits (Qyfo) north of Newark had historic liquefaction in the 1906 earthquake (Youd and Hoose, 1978). These deposits are considered subject to potential failure along with the underlying deposits (Qb) in the area extending east of Coyote Hills and south to the county line. Some parts of the older Bay mud (Qom) are included because there is historical evidence for failure near Alameda Creek (Youd and Hoose, 1978). Interfluvial basin deposits (unit Qb) are considered unlikely to fail in the region near the Oakland Coliseum. Units 1a and 1b of Legg *et al.* (1982) are considered subject to liquefaction during the scenario event. Although the water table in unit 2a of Legg *et al.*, (1982) is within 3m of the surface, we considered this unit not subject to liquefaction. This unit, for example, comprises the central portion of Alameda Island, an area in which there was little evidence for liquefaction in the San Francisco earthquake of 1906 (Youd and Hoose, 1978).

Contra Costa County

The Richmond area is generalized, with zones I, II, and IV of Bishop et al., (1973) considered susceptible to ground failure. To the east of Richmond we used unit III of the Contra Costa County Planning Department (1974), as modified north of Rodeo by using the data of Helley et al., (1979).

Marin County

Rice (1973; 1975), Rice et al., (1976), and Blake et al., (1974) were used to delineate the areas of Bay mud likely to sustain ground failure.

Napa County

Sims et al., (1973) was used to delineate the areas of Bay mud.

San Francisco County

We used the data of Jacobs (1974), but excluded some dune sand at higher elevations southwest of Lake Merced.

San Mateo County

In addition to the areas delineated "moderate to locally high" in liquefaction potential by Woolfe et al., (1975), the younger basin (Qb) and beach deposits (Qs) of Lajoie et al., (1974) were included. The alluvial fan deposits (Qy and Qyo) in the northeast corner of the County and in east Palo Alto are considered unlikely to fail (Lajoie et al., 1974) and were removed from consideration.

Santa Clara County

The historical data of Youd and Hoose (1978) was used to outline the area susceptible to liquefaction along Coyote Creek. In 1906, liquefaction was reported to the east of the Guadalupe River, but not to the west. Thus, the Guadalupe River was chosen as the western boundary of the area influenced by liquefiable sands deposited by the Coyote Creek drainage. The potential for liquefaction is considered minimal in the rest of the county (James Berkland and Ben Patterson, geologists, Santa Clara County, oral communication, 1981).

Solano County

The data of Sedway/Cooke (1977) was used to define areas of potential ground failure due to liquefaction.

Sonoma County

Blake *et al*., (1974) was used to outline the areas of Bay mud.

3) Seismically Induced Landslides

According to Keefer (1984, p. 410, p. 414), a magnitude 7.5 earthquake can produce landslides as well as liquefaction over an area of 3,000 to 25,000 square kilometers. In this scenario, most of these effects would be confined to an area within 25 km of the Hayward fault. Landslides will occur mainly on unstable hillsides in areas experiencing shaking intensities of at least V (MM) and having slopes of 15 degrees or greater. Unstable hillsides having slopes less than 15 degrees are unlikely to fail in earthquakes (Keefer, 1984).

Little detailed information exists on the areas susceptible to seismically induced landslides in the Bay area. The areas so designated on the Seismic Intensity Distribution map were determined as follows: First, an overlay of areas with slopes greater than 30% (17 degrees) was prepared from the 1:125,000 scale slope map of the San Francisco Bay region (U.S. Geological Survey, 1972). This was enlarged to 1:100,000 scale and superimposed on the 1:100,000 base map. Next, various maps showing landslide deposits and areas of high potential for landsliding were reduced or enlarged to fit the 1:100,000 scale base map. These were superimposed on the base, and a mylar overlay was drawn showing the landslide-prone areas with slopes of 30% (3 in

10) or more. Most of the landslide data were obtained from Wright and Nilsen's (1974) "Isopleth map of landslide deposits, southern San Francisco Bay region, California." Information for the area north of 37° 52' 30" was compiled from the sources indicated below:

Alameda County

Wright and Nilsen (1974) was the only reference.

Contra Costa County

Nilsen and Turner (1975) was the only reference.

Marin County

Wright and Nilsen (1974) was used for the area south of 37° 52' 30". For the Novato area, we used stability areas 3 and 4 of Rice _et al_ (1976). The landslide areas for the remainder of Marin County were delineated from Wentworth and Frizzell (1975).

Napa County

Frizzell _et al_., (1974) was used for the southern part of the County and the data of Dwyer _et al_., (1976) were consulted for the remainder.

San Francisco County

Wright and Nilsen (1974) was the only reference.

San Mateo County

Wright and Nilsen (1974) was the only reference.

Santa Clara County

Wright and Nilsen (1974) was the only reference.

Solano County

Frizzell _et al_., (1974) was used for the southern part of the County and the data of Dwyer _et al_., (1976) were consulted for the remainder.

Sonoma County

The data of Huffman and Armstrong (1980) were used. In the southeastern part of the County these data were combined with the data of Frizzell et al., (1974) to produce the most conservative map.

Except for oceanside cliffs undergoing coastal erosion and excavations along transportation routes, it is highly unlikely that seismically induced landslides will occur outside the areas so designated. As recently initiated detailed landslide studies are completed, some of the areas we have designated as susceptible to seismically induced slope failure may be shown to be stable.

Characteristics of the Seismic Intensity Distribution Map

The area encompassed in this earthquake planning scenario, within some 30 km of the Hayward fault, includes most of the heavily populated areas of the San Francisco Bay region. This scenario earthquake would also cause some damage in communities beyond the limits of the planning area that are within 50 kilometers or so of the surface rupture.

Predicted intensities resulting from this earthquake are shown on Map 3-S. The areas of predicted intensity IX (MM) include virtually all of the developed lowlands within 8 km (5 miles) of the fault in the East Bay. This area of intense shaking (strong enough to shake unbolted woodframe houses off their foundations and to cause some collapse of unreinforced masonry buildings) extends through the cities of Pinole, San Pablo, Richmond, El Cerrito, Albany, Berkeley, Emeryville, Alameda, Oakland, San Leandro, Castro Valley, San Lorenzo, Hayward, Union City, Newark, Fremont, Milpitas, and the eastern portion of San Jose.

Intensity VIII (MM) shaking (strong enough to destroy most of the unreinforced brick chimneys in the area and to cause some walls to fall) will occur predominantly on soft sediments within about 30 km (18 miles) of the fault. This includes much of San Francisco and the other cities south along the Peninsula, the low-lying areas around San Pablo Bay, as well as the Concord, Walnut Creek, and Livermore areas.

Intensity VII (MM) shaking (strong enough to destroy a few unreinforced brick chimneys and to crack walls) will occur as far away as Santa Rosa and Hollister.

Throughout the entire planning area, low-lying ground with high potential for liquefaction will be subject to failure. Unstable hilly areas having slopes greater than 30% or 3 in 10 will have numerous scattered landslides and rockfalls, especially in roadcuts and other over-steepened excavations east of the fault.

These regional patterns associated with the scenario event, and the average fault displacement of 5 feet, are the basis for the evaluation of general effects on lifelines and certain critical structures in the greater San Francisco Bay area. The discussions and maps included in subsequent sections highlight these anticipated regional effects.

Comparison with a Repeat of the 1906 San Francisco Earthquake

Earthquake Characteristics

Before comparing the scenario earthquake (M7.5) with a $M\sim8$ event on the northern San Andreas fault, one needs to bear in mind that the scenario event is the maximum credible earthquake that is likely to occur on the Hayward fault. Historically, no earthquake of this magnitude has occurred on this fault. We know, however, that even during this State's brief history, earthquakes of destructive magnitude have originated on the Hayward fault, as evidenced by the 1868 earthquake ($M\sim7$) and a presumably comparable event in 1836. There is little doubt, therefore, that destructive earthquakes of at least $M\sim7$ will recur and that a larger magnitude event is plausible. The 1906 experience is testimony to the fact that future great earthquakes ($M\sim8$) on the northern San Andreas fault are a totally credible expectation.

The 1906 San Francisco earthquake resulted from rupture of approximately 400 kilometers (240 miles) of the San Andreas fault from near San Juan Bautista to near Cape Mendocino and produced surface fault displacements of up to 20 feet. The Hayward scenario earthquake is based on the assumed rupture of the entire length of the Hayward fault, approximately 100 kilometers (62 miles) from San Pablo Bay to east of San Jose. A rupture length of this extent is, from observation of other earthquakes, likely to produce an event of about M7.5 and surface fault offsets of 5 to 10 feet. The duration of strong shaking could be somewhat greater for the larger event, but in both cases probably in the range of 25-35 seconds.

Areal Extent of Damage

The area of potential structural damage (I $\geq$ VIII) resulting from a San Andreas event would extend up to about 30 to 40 miles from the fault throughout the rupture length, causing damage from Salinas to Eureka and east to the western margin of the Great Valley. Damage (I $\geq$ VIII) resulting from a M7.5 Hayward event would be generally confined to the greater San Francisco Bay area within approximately 20 to 25 miles of the fault. While the total area impacted by a San Andreas event is much greater, it is important to note that, in both cases, the vast majority of the affected population is located within the urban Bay area where both events have great impact. Of primary significance is the fact that virtually the entire 62-mile surface rupture associated with a M7.5 Hayward event occurs within the highly developed and heavily populated communities of the East Bay, whereas the San Andreas rupture occurs in generally rural areas and offshore.

Effect on Lifelines

Many of the major transportation and utility lifelines that serve the Bay area, including San Francisco and the Peninsula, cross the Hayward fault and are vulnerable to major damage resulting from surface faulting. These lifelines include the major freeway routes, water supply aqueducts, electrical power lines, natural gas and petroleum product pipelines, and railroads. In addition, innumerable elements of the local utility distribution systems are also vulnerable. Therefore, planning for the necessary emergency response and subsequent repair efforts to return these facilities to operation is especially important along the Hayward fault. Surface rupture on the San Andreas fault, on the other hand, poses a relatively minimal direct threat to lifelines since the fault is generally in remote areas or offshore. Lifeline damage due to shaking will be significant in both events with facilities located on potentially unstable ground around the Bay margin being particularly vulnerable.

Earthquake Shaking in Downtown San Francisco

Downtown San Francisco is situated about 10 miles east of the San Andreas fault and 10 miles west of the Hayward fault (Figure 1). Consequently, ground shaking in the downtown area resulting from a M7.5 event on the Hayward fault would be essentially the same as the shaking from a $M \sim 8$ event on the San Andreas fault. This is because most of the strong ground motion at any given location is contributed by the 100-km length (approximately) of the causative fault that is nearest to that location (in this case, downtown San Francisco). In a $M \sim 8$ San Andreas earthquake, faulting that occurs along the coast of Sonoma and Mendocino Counties north of the Bay area would generate destructive strong ground motion at Santa Rosa and Ukiah, but its contribution at San Francisco would be only to the long-period shaking affecting structures higher than about 10 stories. Communities further south on the San Francisco Peninsula are closer to the San Andreas fault and would, therefore, be more strongly affected by a large earthquake originating on that fault than by one originating on the Hayward fault.

Casualties

Estimation of the relative number of casualties is extremely difficult, involving many variables, notably time of day and day of the week. Steinbrugge et al. (1981) estimated the number of deaths from a M8.3 San Andreas event in the range of 3-12,000. The lower figure is an estimate for 2:30 a.m., while the greater number relates to an event occurring on a weekday afternoon. Deaths resulting from the Hayward scenario event are estimated at roughly one-third to one-half of those for a San Andreas event, i.e., 1500-4400 (See Table 2). Hospitalized injuries are estimated at three times the number of deaths.

Summary

According to a Federal Emergency Management Agency report (1980), the impacts of either of these events "would surpass those of any natural disaster thus far experienced by the Nation." A repeat of the $M\sim8$ 1906 earthquake on the San Andreas fault would be damaging from Humboldt County in the north to San Benito County in the south. Throughout much of the highly populated San Francisco Bay area, the damage from shaking caused by a San Andreas event would be generally comparable to that produced by a M7.5 earthquake on the Hayward fault. Fault rupture produced on the Hayward fault, because of its location within the urban East Bay area, would have a more direct impact on a much greater population than fault rupture on the San Andreas fault. Moreover, many more lifelines that are vital to the entire Bay area, including San Francisco, cross the Hayward fault. Consequently, the disruption of lifelines serving the Bay Area would be significantly greater in a M7.5 Hayward event than in a larger San Andreas event.

Section 4.

DEATHS AND INJURIES

CASUALTY ESTIMATES

Parameters

Estimating the number of potential casualties in a major earthquake is difficult because of the many variables and uncertainties involved. The estimates are greatly influenced by the location of the populace at the time of the earthquake, such as being at home, at the workplace, shopping, on the highways, at school, and the like. These estimates are also greatly influenced by the time of day that the earthquake occurs. At 2:30 in the morning most of the population will be in wood frame dwellings--the safest kind of structures. During the workday many of these same people will be in much more hazardous buildings such as unreinforced brick masonry and poorly designed "tilt-up" buildings. During the school year most children will be in relatively safe structures. Shopping areas may be busier on Saturdays than on Monday through Friday, but office buildings will be mostly empty.

The collapse of a single high-rise structure during business hours could cause 1,000 deaths with relatively few persons escaping with injuries. In contrast, the more common partial collapse of unit masonry buildings will result in many more injuries than deaths.

The failure of a dam can have catastrophic downstream results. The near failure of Lower San Fernando Dam in 1971 is a vivid example of the potential problem. However, in recent years, all major dams vulnerable to damage resulting from a major earthquake on the Hayward fault have been strengthened including, notably, those of the East Bay Municipal Utility District. For the purposes of this scenario, none of the principal dams affecting Bay area cities is expected to fail.

Injuries requiring hospitalization are more difficult to estimate than deaths. Many people who, under normal circumstances, would have gone to hospitals may receive emergency treatment and return to their homes. Hospitals may not welcome additional patients in view of their potentially crowded conditions as well as their own difficulties in remaining functional. Keeping these limitations in mind, hospitalized casualties are often estimated to be 3 or 4 times the number of deaths, while non-hospitalized casualties may be 30 times the number of deaths. The difference between hospitalized and non-hospitalized injuries has not been adequately defined.

Methods

Calculations necessary to estimate casualties require data on the population at risk by class of building construction, by building location, and by local seismic intensity. In wood-frame buildings such as houses, 2 to 4 deaths per 10,000 occupants is typical in the highest intensity areas, and, of course, fewer elsewhere. On the other hand, unreinforced brick or masonry structures, which are not earthquake resistive, may have a ratio as high as 4,000 deaths per 10,000 occupants in the same high intensity areas. Development of current inventories of population at risk by building construction class, seismic intensity, time of day, and day of year is a major undertaking beyond the scope of this study. For the purposes of this scenario, casualty estimates have been extrapolated from:

National Oceanic and Atmospheric Administration (NOAA), 1972. "A study of earthquake losses in the San Francisco Bay area." A report prepared for the Office of Emergency Preparedness. See, particularly, pages 108 through 125.

Federal Emergency Management Agency (FEMA), 1980, An assessment of the consequences and preparations for a catastrophic California earthquake: findings and actions taken: Report prepared by FEMA from analysis carried out by the National Security Council, Ad hoc Committee on Assessment of Consequences and Preparation for a Major California Earthquake.

Steinbrugge, K.V., Algermissen, S.T. and Lagorio, H.J., 1984, Determining monetary losses and casualties for use in earthquake mitigation and disaster response planning: in Proceedings, Eighth World Conference on Earthquake Engineering, vol. 7, pp. 615-622.

The casualty estimates summarized in Table 2 were based on changes in population and their geographic distribution as obtained from updated census figures, with consideration of construction practices throughout the area. The geographic distribution of the population at risk is that of a normal weekday, not during the Holiday season. The computational method developed conservative (i.e., high-side) estimates of casualties which are not likely to be exceeded. The times of day used in this scenario are 2:30 a.m. (when most of the population is in safe wood-frame buildings), 2:00 p.m. (middle of the work and shopping day), and 4:30 p.m. (start of the evening commute period).

Current population estimates for each of the nine Bay area counties including those of all incorporated cities are included in Appendix B. These estimates include data concerning population distribution among various categories of housing units in each city and county.

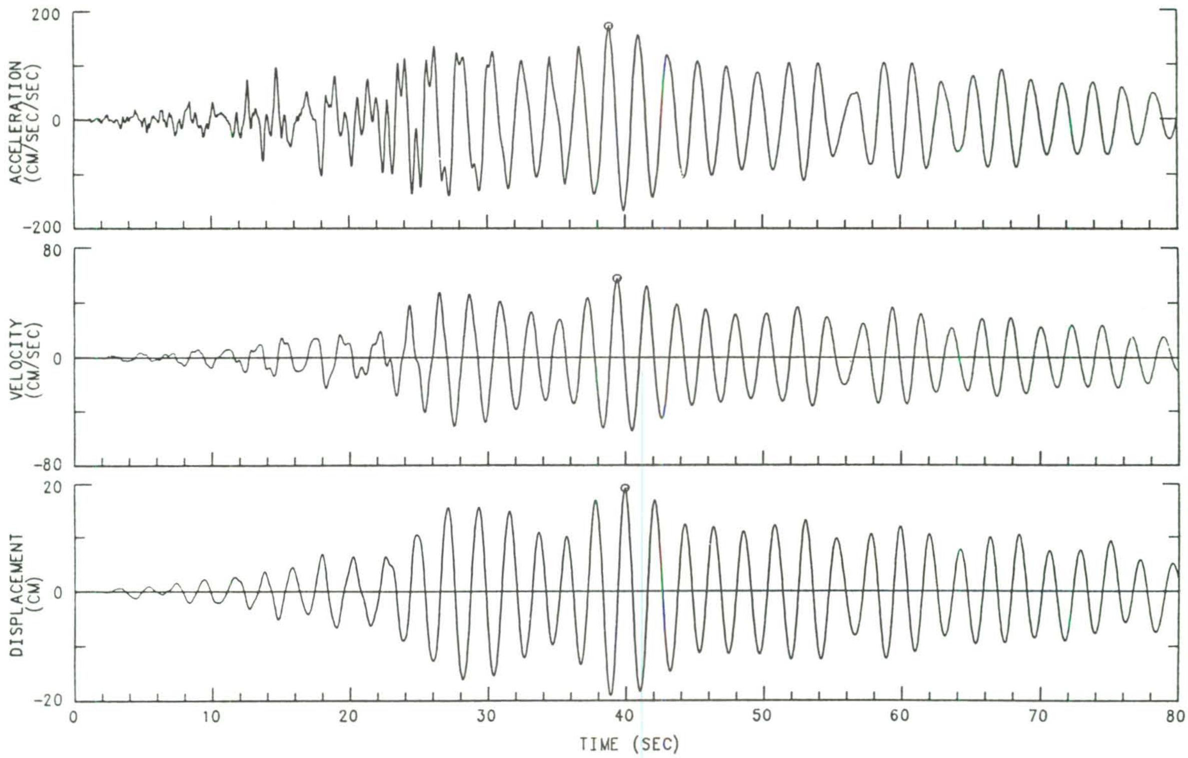
TABLE 2

ESTIMATED CASUALTIES IN THE NINE BAY AREA COUNTIES

	2:30 a.m.	2:30 p.m.	4:30 p.m.
DEATHS	1,500	4,400	3,200
HOSPITALIZED INJURED (Estimated at 3 times the number of deaths)	4,500	13,200	9,600
SIGNIFICANT NON-HOSPITALIZED INJURED (Estimated at 30 times the number of deaths)	45,000	132,000	96,000

Section 5.

BUILDINGS



Strong motion accelerographs installed in various types of buildings, lifeline structures and on different geologic formations are providing structural engineers and seismologists with valuable new data concerning ground and structural response to earthquake shaking. The processed record shown indicates the characteristics of motion recorded on the roof of the Santa Clara County Administration Building during the 1984 Morgan Hill earthquake (M6.2).
(Record and photo by California Strong Motion Instrumentation Program)

GENERAL SEISMIC CONSIDERATIONS

Introduction

Scenarios describing damage and damage patterns are not precise predictions of what will occur. A statement that a building will survive or 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 than if he were not. Knowing building construction types and past earthquake performance of structures with given characteristics, realistic scenarios of probable damage can be developed for use in disaster response planning.

The numerical values associated with each response planning topic represent reasonable maximum expected conditions. In other words, these values are credible; they have past data or experienced judgment behind them. The quality of the numbers vary depending upon the extrapolation of past 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 and lessons learned have resulted from every damaging American earthquake, and these are included in reports of such recent earthquakes as 1983 Coalinga, 1979 Imperial Valley, and 1971 San Fernando.

Summing the loss totals for various situations must be done with understanding and judgment. For example, maximum building damage from landslides occurs in the wet season while the maximum fire hazard exists during the summer season. For a second example, the population density shifts to dwellings and apartment houses during the night hours while a different distribution exists during the working and shopping day; therefore, the failure of a dam causing maximum casualties in dwellings (night hours) should not be added to the maximum casualties in shopping areas (day hours).

Ground Motions and Building Damage

The seismic motions at the source of destructive earthquakes are generally rapid and irregular oscillatory motions having large amplitudes. Of considerable significance is the fact that earthquake waves change in character as they travel away from their energy source. 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 slower long-period motion at greater distances from the earthquake source. The greater the distance, the slower the observed predominant oscillations. The predominant oscillations at large distances from the earthquake can be so gentle that they may not be felt by all persons, and yet be strong enough to cause water in reservoirs to oscillate with sometimes destructive effects.

Buildings respond differently to different kinds of ground motion. Each building has its own specific vibrational characteristics based on its stiffness. Each building will therefore respond to the particular ground motion at the site 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, quasi-resonance or a condition similar to near-resonance will occur. As a result of this quasi-resonance, the vibratory motions of the building may dramatically increase, along with damage. Damage from quasi-resonance is generally observed in taller buildings from distant earthquakes.

Based on the changes in ground motions as a function of increasing distance, observed damage patterns tend to reverse with distance. Damage to low, rigid (short-period) buildings predominates over high-rise (long-period) damage in the epicentral and energy-source regions nearer the fault. At distances over 100 miles, for example, high-rise building damage may predominate over that of even poorly built one-story structures. This was dramatically evidenced in Mexico City during the September 1985 earthquake.

Short-Period Motion Effects

The historical damage patterns are associated with short-period motions (i.e., rapid back-and-forth motions). Isoseismal maps are based on short-period effects.

In general, light mass structures perform much better than do heavier mass structures. Conceptually, this is due to the fact that 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 the inertial (resisting motion) force on the structure. Therefore, a "heavy substantial" building which is not designed to be earthquake resistant is more likely to fail than a "flimsy" wood-frame structure. Countless examples of this exist throughout the historic record.

Long-Period Motion Effects

Long-period motion principally affects high-rise buildings. An excellent example of long-period effects is demonstrated by the 1952 Kern County, California, earthquake. This earthquake resulted in numerous instances of non-structural damage to multi-story 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 70 to 90 miles from the epicenter. Generally, the affected buildings were 10 to 12 stories high and had a measured natural period of vibration of 1 to 2 seconds, but buildings as low as 6 stories were also damaged. (The many modern high-rise structures of over 20 stories did not exist then.)

In Anchorage, which was 75 miles from the epicenter, the 1964 Alaskan earthquake caused extensive damage to multi-story buildings; low rigid buildings did not suffer comparable damage; even a snowman survived!

Occurrence of the scenario earthquake could cause damage to tall buildings in Sacramento, with little effect on one-story structures.

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 (30 pounds per square-foot) since earthquake resistive design methods were unknown. In time, those standards were reduced since "San Francisco has no heavy winds".

In the years following the 1925 Santa Barbara earthquake, a few moderate-size communities in California adopted codes which required buildings to have earthquake bracing. After the 1933 Long Beach earthquake, a number of southern California communities adopted these codes, with their usage spreading generally 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 earthquake resistive design required by building codes is to protect life, and is only partially directed toward damage control. There are certain exceptions, such as the code provisions adopted in 1972 for new hospitals in California, that are discussed later in this section.

The basic philosophy behind the seismic provisions of most American building codes states that the code intends buildings 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." It goes on to state, "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. Design for damage control usually includes life safety, but design for life safety, i.e., minimum code standards, does not necessarily include damage control.

In most cases, the earthquake provisions of a building code plus the design engineer's judgment determine the seismic damage characteristics of any particular building or structure. Expert advice may be obtained from engineering geologists, seismologists, soils engineers, and others, but the design engineer must evaluate all reports and synthesize them into a judgment decision in the context of a good architectural design. The design is too often influenced by the minimum earthquake standards of the building code. Unfortunately, barely meeting the minimum standards of a building code places a building on the verge of being legally unsafe.

Exceptions to earthquake bracing are common in major computer installations in all occupancies. In far too many cases, the bracing of false floors, the air-conditioning vital for continued operation, backup power, and other equipment is deficient. Unless the response planner has specific information to the contrary, the system should be held suspect.

Special California Earthquake Legislation

The Field Act, adopted shortly after the 1933 Long Beach earthquake, assigned to a state agency regulatory powers over public school design and construction. The resulting high standards, particularly noticeable in substantially improved construction standards, proved to be very successful as evidenced by the 1952 Kern County and 1983 Coalinga earthquakes. The original Field Act applied only to new public schools; the remaining older public schools and private 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 abating the hazard posed by the older public schools. The legislation was subsequently amended, and non-Field Act public schools are now essentially gone. Some private schools continue to exist as major threats.

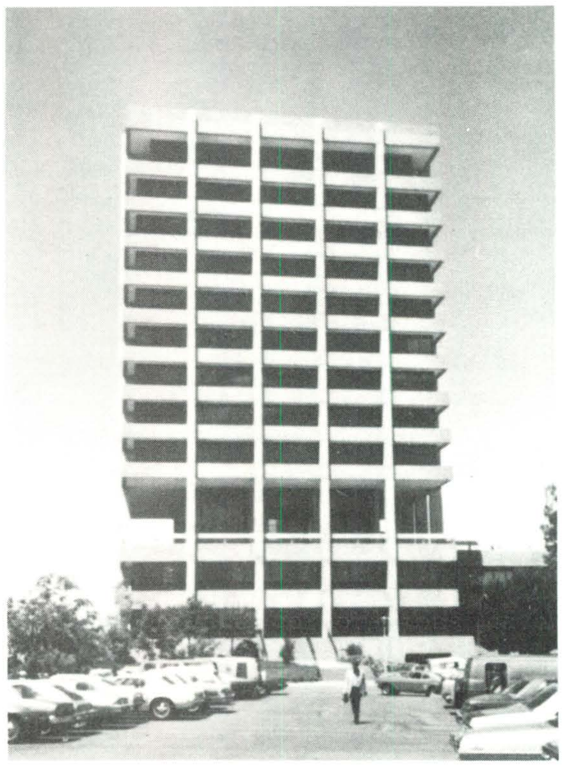
California's Hospital Act of 1972, which resulted from the 1971 San Fernando earthquake experience, has significant implications in that attempts at damage control became mandatory when the State preempted new hospital construction from local control. This legislation followed the precepts of the Field 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 that it must remain "functional" in order to perform all necessary services.

Planning Considerations

Most of the larger governmental agencies and private corporations have disaster response plans that include priority arrangements for the use of temporarily leased equipment (e.g., earth moving equipment). In each case, the agency or corporation has stated that it expects the contractor to supply the required equipment on demand following an earthquake. Response planners should verify that their suppliers do not have similar contracts with several agencies or corporations which, in effect, "overbooks" their equipment.



High-rise office building at California State University, Hayward.

HOSPITALS AND THE HAYWARD FAULT

Emphasis

The principal concerns addressed in this planning scenario relate to the earthquake vulnerability of the major transportation and utility lifelines. However, disaster response planners, when engaged in allocating priorities, must give highest attention to saving lives. Hospital buildings are absolutely vital in this regard as are their staff personnel and other medical resources including medical supplies and equipment both on-site and in warehouses, bloodbank structures and their contents, clinical laboratories at hospitals and elsewhere, ambulance services, and nursing homes.

The principal document containing a review of earthquake effects on these medical resources is "A Study of Earthquake Losses in the San Francisco Bay Area", by the National Oceanic and Atmospheric Administration (NOAA), a report prepared for the Office of Emergency Preparedness (1972). In general, the findings in that report are applicable today for most of the Richmond - Berkeley - Oakland - San Leandro - Hayward areas, since the major population changes in the Bay area have occurred elsewhere. Newer medical care procedures, the number of beds, and similar changes do not appear to have significantly revised the general findings of this earlier report.

A general acute-care hospital is defined as a facility having a patient capacity of 99 beds or more. While there are more than 120 general hospitals located in the nine Bay area counties, this study is limited to the 37 major facilities (including a military hospital) located in Alameda, Contra Costa, and Santa Clara Counties. Although smaller hospitals with less than a 99-bed capacity were not reviewed, the problems faced by them are similar to those of larger facilities. (For a complete regional inventory of all types of medical facilities located in the Bay area, refer to "Health Facilities, Directory, January 1981", volumes 1 and 2, by the California Department of Health Services, Licensing and Certification Division.)

A summary inventory of general, acute-care hospitals with 99 beds or more in Alameda, Contra Costa, and Santa Clara Counties is given in Table 3. These totals are in constant change as obsolete facilities are closed and remodelling or new construction of other hospitals is completed. A large percentage of the new hospitals constructed under the Hospital Act of 1972 have some type of structural steel framing and many are limited to four or five stories in height.

Seismic Considerations

As previously discussed under the section heading, "Special California Earthquake Legislation", new hospitals are receiving special earthquake attention. For emphasis, this discussion is restated here. 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 preempted new hospital construction from local control. This legislation 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 that it must remain "functional" in order to perform all necessary services.

There are eight hospitals located within one mile of the Alquist-Priolo zone on the Hayward fault. One of these hospitals is within the zone and another is near the boundary. Almost all buildings at these sites were constructed before the enactment of the 1972 legislation. Table 4 summarizes the number and bed capacity of hospitals located within a mile of the Alquist-Priolo zone.

Alameda County's Fairmont Hospital in San Leandro is clearly identified as being in the Alquist-Priolo special studies zone with some buildings on active traces of the Hayward fault. As a consequence of previous studies at this facility, the County has closed some buildings. The results of several detailed studies of this hospital site may be found in Hart et al., (1982).

The San Fernando earthquake of 1971, in which four major hospital buildings were severely damaged and mostly evacuated, indicates that it is highly conceivable that many hospital facilities constructed prior to the passage of the Hospital Act are subject to severe damage during a major earthquake. It is not unrealistic to consider that a major hospital may become an added burden rather than an asset in the post-earthquake period.

Another important consideration is access to and from hospital sites. Even though the buildings may survive, the facility may be of limited value if access is cut off or restricted due to a landslide, a collapsed freeway structure, or building debris on nearby streets.

Hospitals are also dependent on off site public utilities for long term continuous operations. Hospitals do maintain emergency electric generators, but such systems can only meet demands on a limited basis for a limited period of time. Routinely 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 highly 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 the contents.

Planning Considerations

While for the purposes of this scenario we state that hospital structures in and near the Alquist-Priolo zone will be evacuated, there exists ample experience to show that these structures can survive quite well even when located adjacent to surface fault rupture. Appropriate studies and resulting actions such as those taken at the Fairmont Hospital could be undertaken for other hospitals (and the results made public). Mitigating the hazards at a particular site should include methods to maintain 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.

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 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 public loss of confidence for whatever reasons.

TABLE 3

NUMBER AND BED CAPACITY OF GENERAL ACUTE-CARE HOSPITALS IN ALAMEDA, CONTRA COSTA, AND SANTA CLARA COUNTIES CAPACITY OF 99 BEDS OR MORE

County	Number of Hospitals	Bed Capacity
Alameda	19	4,501
Contra Costa	7	1,667
Santa Clara	11	4,111
TOTAL	37	10,279

Source: Department of Health Services, Licensing and Certification Division: Directory (January, 1981), plus update to April 3, 1984.

TABLE 4

HOSPITALS WITHIN ONE MILE OF THE ALQUIST-PRIOLO SPECIAL STUDIES ZONE

County	Number of Hospitals	Bed Capacity	Locations Relative to Alquist-Priolo Special Studies Zone
Alameda	7	2,057	1 within zone; 1 near zone boundary 5 within 1 mile of zone
Contra Costa	1	246	1 within 1 mile of zone
Santa Clara	0	0	---------
TOTALS	8	2,303	

Planning Scenario

For planning purposes, all hospital buildings on a trace of the Hayward fault are considered seriously damaged.

Of the eight hospitals in or within one mile of the Alquist-Priolo zone, three have access problems, principally due to damage to freeway structures. Access is severely limited for those hospitals located east or north of I-580.

Surface faulting cuts off most public utility services to the major hospitals located east of the Hayward fault and in the east Oakland - San Leandro area. Due to loss of public utilities, reduced public confidence in structures in and near the surface rupture, and to access problems, all hospitals in or within one mile east of the fault zone are closed and patients transferred elsewhere.

PUBLIC SCHOOLS

General Characteristics

Public school buildings are reasonably well distributed throughout populated areas and are normally in a safe condition after an earthquake. As a result, these structures can provide a major resource for mass shelter and feeding whenever homes are destroyed or otherwise rendered uninhabitable.

While this discussion is directed towards public schools, the general remarks and scenario are generally applicable to private schools. Seismic safety requirements for new private schools built since 1933 were, in most cases, those used by public schools. This most likely would not be true for older or leased buildings, and probably not true for churches used as schools.

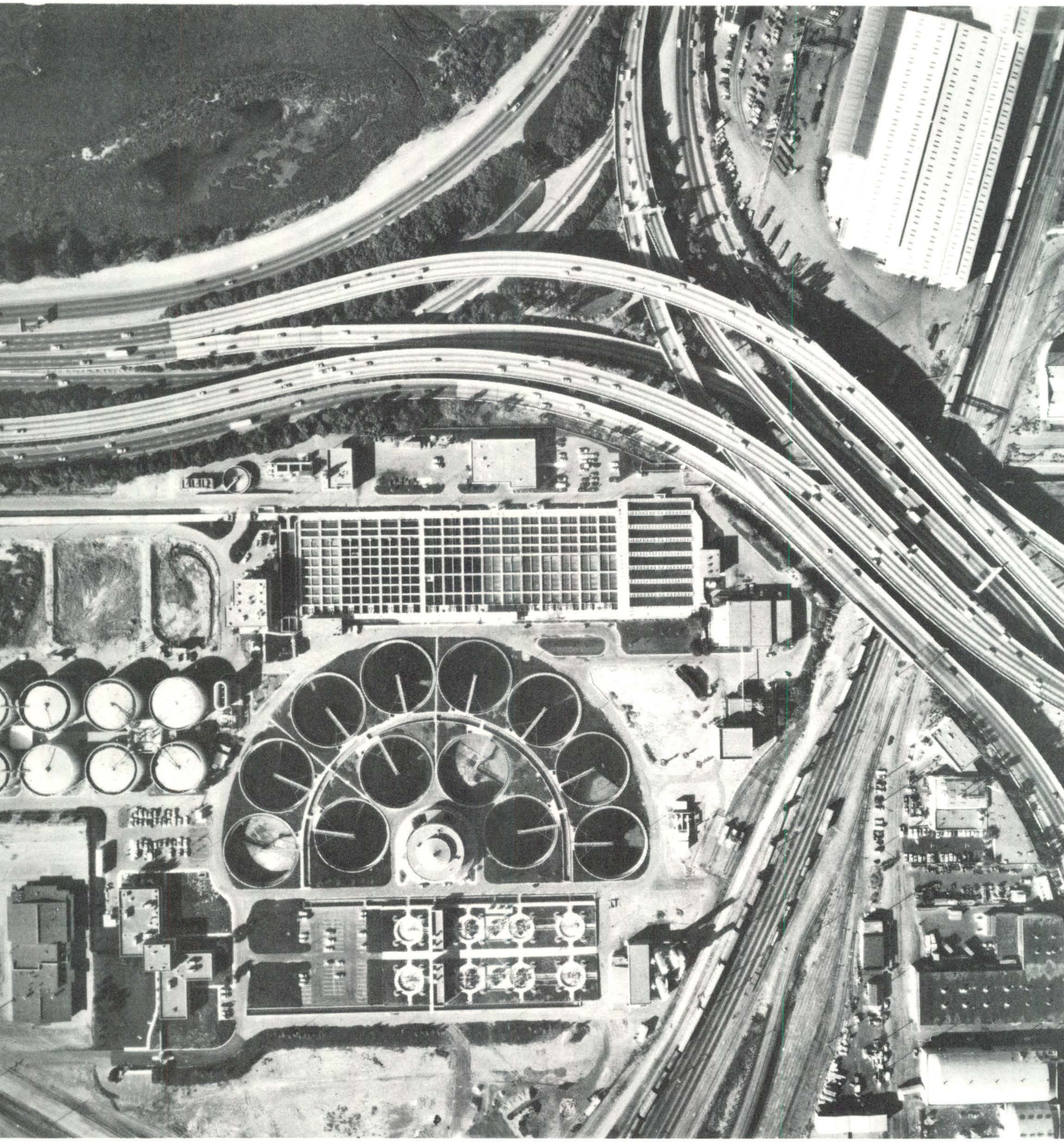
Maps 3-J and 3-U show the locations of intermediate schools, high schools, community colleges, and universities in the three East Bay counties. Elementary schools are too numerous to plot on maps of this scale.

Seismic Considerations

As has been discussed in a previous section, public schools have been given special legislative attention with respect to earthquake safety since the 1933 Long Beach earthquake. This legislation, commonly known as the Field Act, has been successfully implemented through strictly enforced design and construction practices.

Section 6.

TRANSPORTATION LIFELINES



The Bay Bridge east approach interchange (I-80/580, S.R. 17), main line railroads, and EBMUD's Special District Number 1 waste water treatment plant.

HIGHWAYS

General Characteristics

In California about 37% of the 175,000 miles of maintained highways are located in urban areas and only about 9% of these are State highways. In the San Francisco Bay area, the State highway system includes almost all of the heavy-duty traffic arteries and carries over 65% of the traffic volume. The San Francisco Bay area is served by the CALTRANS District 4 office in San Francisco, which covers most of the area, and by the District 10 office in Stockton, which serves the Vallejo, Benicia, and Fairfield areas.

The major corridors for highway traffic in the East San Francisco Bay are:

- Three major north-south routes: Interstate 580, Route 17, and Route 238.
- One major access route on the north and east: Interstate 80.
- Five major routes to the west from the East Bay: Route 17 (Richmond-San Rafael Bridge), Interstate 80 (Bay Bridge), Route 92 (San Mateo Bridge), Route 24 (Dumbarton Bridge), and Route 37 in the north Bay.
- Two major routes to the east from the East Bay: Route 24 (Caldecott Tunnel) and Interstate 580.
- Interstate 680 provides an additional route to the east from southern Alameda County and Santa Clara County via Mission Pass.

There are alternative surface streets which can be used to bypass most major freeways, but primary access to the west and east from the urban East Bay is limited to the San Francisco Bay crossings, the two routes through the East Bay hills to the east, and Interstate 80.

Seismic Considerations

Based on the seismic intensity distribution predicted for this scenario earthquake, over 500 miles of State highways and over 1,200 State bridges in the San Francisco Bay area will experience an intensity of VIII or greater. A recent federal highway study (Vulnerability of Transportation Systems to Earthquakes -- U.S., FHWA/RD-81/128, October, 1982) considers intensity VIII-IX to be the threshold of critical damage to highways.

As a result of the 1971 San Fernando earthquake, the Department of Transportation implemented design criteria and details for bridges which results in significantly higher seismic resistance. This dramatic change in design means that bridges built before 1971 have considerably less seismic resistance than post-1971 bridges, and that most future damage due to shaking will be to these older structures.

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

Although it is expected that the retrofit structures will have a higher threshold of damage, the retrofit does not guarantee against damage or collapse. It is expected that the damage suffered to retrofit bridges will be more readily repairable as a result of the retrofit program. It must be emphasized that a retrofit bridge which is heavily damaged, though not collapsed, may still be unusable for many days after the earthquake until necessary reinforcement or other repair can be accomplished.

The magnitude of movements and settlements due to liquefaction and soil failures is difficult to predict, but based on experience with previous events, much of the anticipated damage is expected to be in the form of settlement of high fills and soils near stream channels and bodies of water. Many lengthy sections of freeway near the Bay margins are subject to damage resulting from ground failure.

Planning Considerations

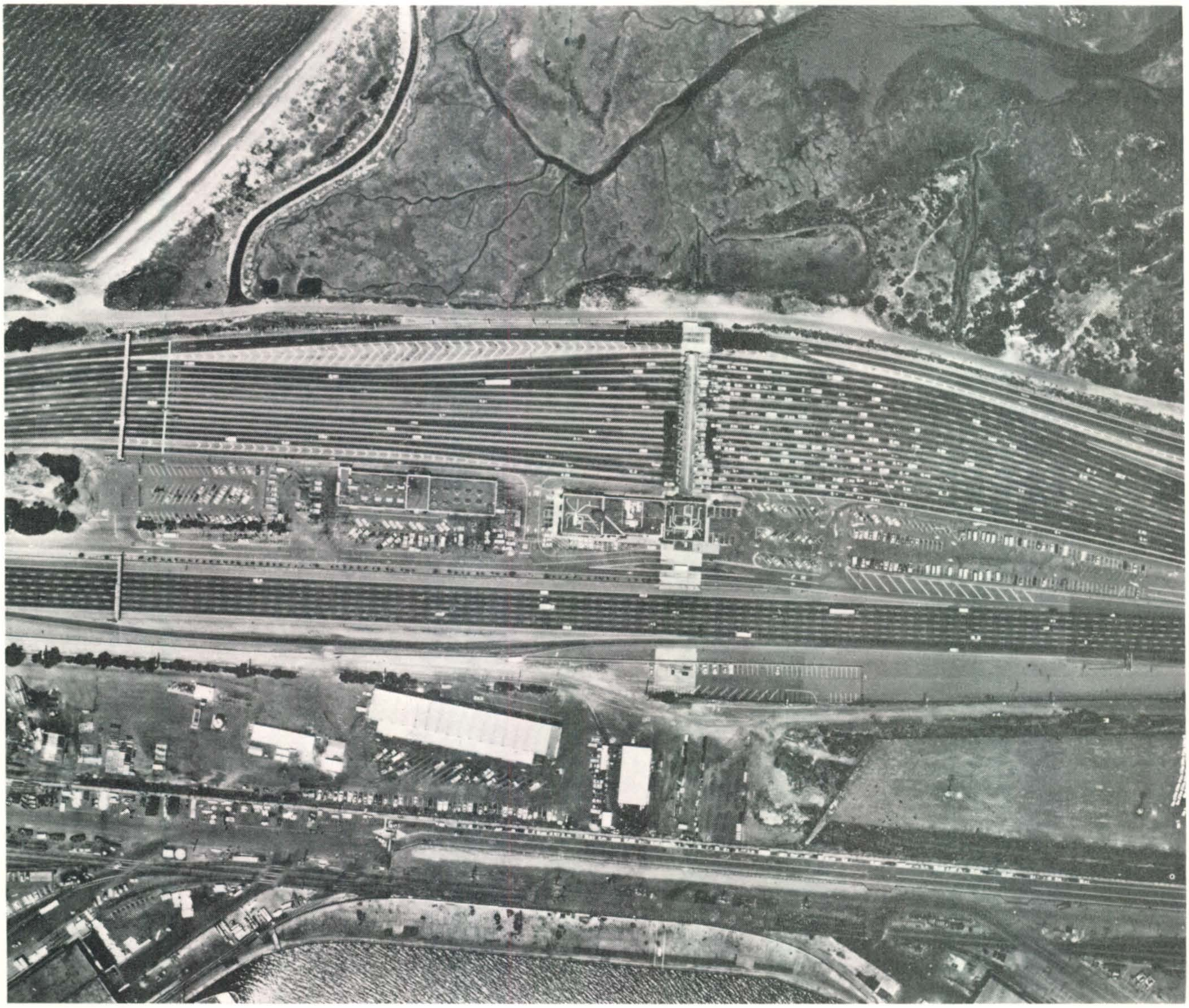
Emergency planners need to identify major emergency corridors that can be most readily opened immediately following the earthquake. In contrast to some segments of the freeway system which are above or below grade with many structures subject to damage, alternative emergency routes should be selected which are at grade, wide, not likely to be significantly affected by fallen powerlines or other obstructions, and not flanked by larger buildings that are likely to be damaged. Selection of emergency corridors is especially important throughout the urban East Bay and in eastern Santa Clara County, where significant damage is expected. Wherever possible, alternate corridors should be established so that flexibility is achieved.

The utilities and local government agencies should identify all installations and facilities that they will need to rapidly inspect, repair, operate, or otherwise have access to in this emergency. Emergency planners then need to examine available routes to these and other 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.

Emergency response plans for highways 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 will be limited to the highest emergency priorities.

Planning Scenario

This scenario is intended for planning purposes only and is generally pessimistic in its overall effect. In the East Bay, Route 17 from Richmond to San Jose suffers the worst damage and is blocked by a few damaged bridges and severe pavement distortion. Hundreds of vehicles are trapped and abandoned along Route 17 and the other major freeway routes in the East Bay. Gigantic traffic jams result on Highway 101 and Route 17 south from San Jose, on Route 101 in Marin County and on Interstates 580 and 80 east of the Bay area. The tunnels under the estuary to Alameda are closed to traffic due to water leaking into the tunnel sections. The San Francisco-Oakland and Richmond-San Rafael Bridges are both closed at their east ends due to settlement and distortion of the approach highway sections. The Bay bridges crossing at San Mateo and Dumbarton are also closed to traffic due to approach fill distortion and settlements at both ends. The Golden Gate Bridge is open to limited traffic due to damage to the approach structures in the Presidio area. Surface streets in the East Bay are considerably restricted because of fires, blockades, and rubble. All non-essential in-bound traffic to the Bay Area is retarded at checkpoints and is redirected around the area. Outbound traffic moves with delays and detours on the limited open arteries.



Toll plaza area at the east approach to the San Francisco-Oakland Bay Bridge.

Damage Assessments

Damage assessments have been postulated for certain major highway facilities as set forth below. The statements regarding the performance of facilities are hypothetical and intended for planning purposes only. They are not to be construed as site-specific engineering evaluations. Locations of facilities are shown on Map No. 3-HA. Routes not discussed may be assumed to be open with delays due to heavy traffic and obstructions.

ROUTE - COUNTY

Interstate 80 - San Francisco Co.

Blocked at the Bay Bridge east approach interchange (Interstates 80/580 and Route 17) due to severe soil and structure failures. It is not expected to be able to open the Bay Bridge within 72 hours; however, an all-out effort could possibly open the Bridge to limited traffic in about 36 hours. The Bridge is available to emergency traffic between San Francisco and Yerba Buena.

-Alameda Co.

Generally impassable from the Bay Bridge to Albany due to soil failures and bridge damage. Limited light emergency traffic with some detours may be restored in 24 to 36 hours. The Bay Bridge east approach interchange (Interstates 80/580 and Route 17) is closed due to severe soil and structure failures. It is not expected to be able to open the Bay Bridge within 72 hours; however, an all-out effort could possibly open the Bridge to limited traffic in about 36 hours.

-Contra Costa Co.

Restricted by pavement rupture in the Richmond area, but traffic is moving slowly through the area. Several bridges along Route 80 between El Cerrito and Pinole are damaged and restricting traffic; however, detours are available via interchange ramps and surface streets. Traffic will be limited to one lane through this area for 24 to 36 hours.

Interstate 280 - San Francisco Co.

Partially blocked by a slide at Potrero Hill. Traffic through the area is limited to a single lane. Normal traffic through the area can be restored in 24 to 36 hours. Traffic is also blocked at the I-280/Route 101 interchange by heavy bridge damage. A single lane of traffic can be restored through the interchange area in 12 to 18 hours. Surface street detours with significant delays are available through the area.

Interstate 480 (Embarcadero) - San Francisco Co.

Closed due to structural damage. This bridge structure is opened to light emergency traffic in 12 to 18 hours.

Interstate 580 - Alameda Co.

Closed from the Bay Bridge to Castro Valley due to major bridge damage. Detours and/or clearing can be expected to permit limited emergency traffic in 12 to 18 hours. Route 580 from Castro Valley to Dublin is open with several surface street detours around heavily damaged bridges. Traffic is restricted to one lane in several sections. This situation is not likely to improve in less than 72 hours. Route 580 from Dublin eastward is generally open with many delays and several detours.

Interstate 680 - Contra Costa Co.

Closed immediately south of the Benicia-Martinez Bridge due to severe pavement settlement. The route is only passable to high-clearance, four-wheel-drive vehicles. Single-lane, light, emergency traffic is established through this area in less than 8 hours.

-Alameda Co.

Closed from the Alameda-Santa Clara County line north to the Washington Boulevard overcrossing in Fremont due to extensive pavement disruption caused by surface rupture. Significant damage in the Mission Boulevard interchange area restricts use of Mission Boulevard. Other surface street detours are available.

Route 1 - San Francisco Co.

Open with delays at the south approach to the Golden Gate Bridge. The approach structures to the Bridge have been damaged and traffic is limited to one lane through this area. Improved traffic capacity can be established in about 18 hours.

-San Mateo Co.

Closed at the Devils' Slide due to a major slip-out. The highway through this area will not be reopened in less than 72 hours.

Route 4 - Contra Costa Co.

Closed between I-80 and I-680 due to several small landslides and damage at the Alhambra Avenue undercrossing. Single-lane traffic with detours can be established through the area in 12 hours.

Route 13 - Alameda Co.

Closed from Route 24 to I-580 due to major bridge damage and pavement disruption resulting from surface faulting. Limited single-lane emergency traffic with detours may be restored in 24 to 36 hours.

Route 17 - Contra Costa Co.

Closed at the Richmond-San Rafael Bridge due to severe settlement and distortion of east approaches. It is not expected that the Bridge will be reopened to general traffic in less than 72 hours; however, the Bridge is expected to be available for limited emergency traffic in 36 hours.

-Alameda Co.

Closed from Albany to Milpitas due to damage to several bridges and considerable pavement damage, including several sections which have settled more than 2 feet. Limited emergency traffic with some detours may be restored in 24 to 36 hours. Improved airport access at Hegenberger and Davis Streets can be obtained in about 4 hours via surface streets. Many bridges along Route 17 are heavily damaged but still standing. Some of the damaged bridges can carry light traffic (no trucks); a few select bridges could be strengthened (or bypassed) to permit limited truck traffic in about 36 to 48 hours.

-Santa Clara Co.

Closed from Milpitas to Route 101 due to damage to several bridges and considerable pavement damage including several sections which have settled more than 2 feet. Limited emergency traffic with some detours may be restored in 24 to 36 hours. Many bridges along Route 17 are heavily damaged but still standing. Some of the damaged bridges can carry light traffic (no trucks); a few select bridges could be strengthened (or bypassed) to permit limited truck traffic in 36 to 48 hours.

Route 24 - Contra Costa Co.

Restricted to a single lane east of the Caldecott Tunnel due to slides. Improved detours through the area can be made available in 24 to 36 hours.

-Alameda Co.

Open through the Caldecott Tunnel, but access through the heavily damaged Route 13/24 interchange is restricted to one intermittent lane. Improved detours through the area can be made available in 24 to 36 hours.

Route 37 - Solano Co.

Closed between Sears Point and Vallejo due to extensive settlement and shifting of the roadway. Some portions of the highway are under water. The route is only passable to high-clearance, four-wheel drive vehicles. Single-lane, light, emergency traffic is established through the damaged area in 24 to 36 hours.

-Sonoma Co.

One lane open to emergency traffic between Black Point and Sears Point due to moderate settlement and shifting of the roadway. Single-lane traffic is established through the area in less than 24 hours.

Route 61 (Posey Tube) and Webster Street Tube - Alameda Co.

Closed to traffic due to damage and water in the tubes. Repairs will take over 72 hours. Access to Alameda is still possible via bridge although two of the lift bridges serving Alameda are damaged and cannot be opened. This will restrict ship movement in the channel area for over 72 hours.

Route 82 (El Camino Real) - San Mateo Co.

Open with delays and several detours to avoid damaged structures and debris.

Route 84 (Dumbarton Bridge) - Alameda Co.

Closed to traffic due to moderate soil failures at the east and west approaches. Limited one-lane access for emergency vehicles may be possible in 18 to 24 hours. The Niles Canyon road (Niles to Sunol) is closed due to extensive slides and bridge failures. This route cannot be opened within 72 hours.

-San Mateo Co.

Closed at the east and west approaches to the Dumbarton Bridge due to settlement and distortion of the approach pavement. Limited one-lane access for emergency vehicles may be possible in 18 to 24 hours.

Route 92 (San Mateo Bridge) - San Mateo Co.

Closed at the east and west approaches to the Bridge due to severe settlement of the approach pavement. Limited one-lane access for emergency vehicles may be possible in 18 to 24 hours.

Route 101 - Marin Co.

Open to traffic with a few detours around minor slides and bridge damage in the San Rafael area.

-San Francisco Co.

Blocked at the I-280/Route 101 interchange by major bridge damage. A single lane of traffic can be restored through the interchange area in less than 18 hours. Surface street detours with significant delays are available.

-San Mateo Co.

Closed due to minor pavement settlement north of San Francisco Airport and in the Foster City area. Access to the Airport is possible via Route 82 (El Camino Real). Route 101 north and south from the Airport can be opened in 12 to 18 hours to single-lane traffic with some detours on surface streets.

-Santa Clara Co.

Closed from Palo Alto to Route 17 due to minor pavement settlement and bridge damage. This segment can be opened in less than 12 hours to single-lane traffic with some detours on surface streets . Route 101 south from Route 17 is open with delays due to detours and heavy traffic.

Route 237 - Santa Clara Co.

Closed between Mountain View and Milpitas due to pavement settlement. Portions of the highway are under water in the Alviso area. This route will not be reopened in less than 72 hours.

San Pablo Dam Road - Contra Costa Co.

Closed indefinitely due to a major landslide along the west shore of San Pablo Reservoir five miles east of Interstate 80.

AIRPORTS

General Characteristics

The major commercial airports in the San Francisco Bay area are:

San Francisco International
Metropolitan Oakland International
San Jose Municipal

Oakland Airport is actually two airports...the larger international facility and the older North Field. The latter is capable of some jet traffic. The major military fields are:

Alameda Naval Air Station
Moffett Naval Air Station
Travis Air Force Base (near Fairfield, outside the major damage area)

Other close-in secondary airports that could have a support role in a major earthquake response effort include facilities at Hayward, Livermore, Concord, Napa, Palo Alto, San Jose, and Santa Rosa. Locations of all airport facilities in the study area are shown on Map 3-HA.

The Oakland and San Jose airports, the two major commercial airports closest to the Hayward fault, account for about 20% of the total passenger traffic in the San Francisco Bay area. In 1981, Oakland International's commercial air passenger traffic totaled 2.54 million and San Jose Municipal's was 2.82 million. By comparison, San Francisco International totaled 20.92 million. Clearly, the support facilities and operating personnel for handling air traffic at San Francisco International are dominant and, therefore, this airport must be carefully examined as a potential resource despite any potential damage that might occur there.

Small commercial airports, such as Hayward Municipal, could play an important role in the event of the postulated earthquake, but additional manpower and equipment support would have to be brought in.

All airports are dependent on electric power for continued full operation, including the supply of fuel for aircraft. However, PG&E power is not mandatory for landing and takeoff under emergency conditions.

Seismic Considerations

Earthquake problems related to airports may be placed into one of three general categories:

1. Ground access and egress to the airport (including all utilities).
2. Damage to buildings (including control towers) and to facilities other than runways (including off-site flight control centers).
3. Damage to runways and taxiways.

Access to the Airports:

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

Damage to Structures:

Ample experience exists showing that airports can remain functional to some degree even if control towers collapse, or equipment within them becomes nonfunctional--provided the runways remain intact. However, even if the control tower is earthquake resistive and the equipment remains functional, broken windows may let the elements in. Among broken glass and shifted and fallen equipment, and with the prospect of aftershocks, controllers often lose confidence in the safety of the tower.

Control towers inspected for this report are earthquake resistive and are expected to remain safe despite glass breakage. Much equipment is not anchored, probably will topple or fail, and some will become inoperable. Earthquake-braced standby power exists and is expected to remain functional, and 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 these handicapped conditions.

The 1964 Alaskan earthquake provides an example of airports continuing to operate even after a magnitude 8.3 event. A total of 13 airports were found to have had runway or taxiway damage out of 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 in order 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 destroy the operational capabilities of nearby airports, which are in areas not subject to ground failure.

Runway Damage:

Runway damage can render an airport inoperable for substantial periods of time. Runway damage is a direct function of the strength characteristics of the underlying soils. In this context, all major airfields (commercial and military) around the Bay are underlain by soft soils and Bay mud. Major differential settlements are a distinct probability that could result in inoperable runways.

Planning Considerations

Airborne transport will play a vital role in the transport of people and materiel 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 planning for distribution of materiel by helicopter, highway, rail, and marine transport. Integrating these various delivery systems to accomplish this mission will be challenging. Use of helicopters within the heavily damaged areas is seen as an extremely important function requiring appropriate planning.

Secondary airports for distribution of supplies and equipment need to be evaluated in terms of auxiliary electrical power supply, integrity of airport buildings, and vulnerability of access routes in order to finalize transportation plans. A plan of action, with established equipment and supplies and listed tangible resources for a sustained effort, should be prepared. Facilities suitable for helicopter operations within the stricken area should be selected, particularly in Alameda and Contra Costa Counties. A means for identification and clearance of personnel who are essential to the emergency response efforts at airports should be established. Such a system should assure that these personnel can secure official assistance in getting to their areas of responsibility when access is restricted due to traffic jams or other blockages. Developing such a system is of the highest priority because the expertise of these personnel is crucial to the planned emergency response. Planners should also consider segments of certain strategically located freeways that might be available and of optimum use for small aircraft and helicopters engaged in response and recovery operations (Ilan Elson-Schwab, personal communication, 1985).

Planning Scenario

Emergency air transport into the stricken region is vital to response activities during the first 72 hours following the earthquake. Because of expected damage to major airport facilities, notably the runways and land access routes, San Francisco International and Metropolitan Oakland International Airports, as well as Alameda Naval Air Station, will be unavailable for major airborne relief operations (C-141 aircraft and massive logistics). San Jose Municipal and, possibly, Moffett Field will be the only major close-in facilities able to accept immediate large-scale emergency aid from outside the area. Travis Air Force Base near Fairfield is the logical choice as a backup airport in the event that these two airports are more severely damaged than predicted in this scenario. Buchanan Field (near Concord), Livermore Airport, and Hayward Airport are small facilities that will be available with limitations.

San Francisco International Airport, Oakland International Airport, and Alameda Naval Air Station are built upon fill overlying soft Bay mud. The scenario event will damage the runways at these airports and make them inoperable for large aircraft operations.

Only San Jose Municipal, Moffett Field, and Buchanan Field near Concord have a good chance of surviving the earthquake without serious disruption of runways. For planning purposes, one of the runways at Oakland International Airport (North Field) is assumed to be available for small aircraft and helicopter operations. Buchanan Field will be subjected to less shaking than the others but, similar to Hayward Municipal Airport, it can support only the smaller C-130 aircraft used in emergency operations. C-130's require at least 5,000 ft. of runway and pavement strength to withstand 130,000 lb. wheel weights (dual tandem). Only San Jose Municipal Airport remains as a close-in airport that is large enough for C-141 aircraft. C-141's require at least 5,000 feet of runway and sufficient pavement strength to withstand 250,000 lb. wheel weights (dual). Detailed engineering-geologic studies of these three airports, particularly San Jose Municipal Airport, may suggest warranted improvements in emergency handling facilities. Outlying airports such as Travis Air Force Base, and the Sacramento and Stockton Airports, will be available, but the response effort would be delayed because of the necessity to transport cargo over land a greater distance to the stricken area.

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. 3-HA.

MAP NO.	AIRPORT - COUNTY

A1 San Francisco International Airport (SFO) - San Mateo Co.

Limited use.

SFO is built entirely on fill (Nichols and Wright, 1971), and the water table is within 5 feet of the surface (Webster, 1973). The SFO area was filled by using construction procedures designed to displace the Bay mud (R.D. Borcherdt, personal communication, 1981), but its effectiveness in preventing runway damage during large earthquakes remains to be established. The NOAA report (1972, p. 169) predicted that SFO would be closed for several weeks after a magnitude 8.3 earthquake on the San Andreas fault. Although the shaking intensity in the scenario event on the Hayward fault will be about one intensity unit less, ground failure effects due to liquefaction will be about the same. Runway damage will take at least 72 hours to repair. Practical land access to San Francisco Airport due to freeway and other highway damage could temporarily isolate the airport and nearby facilities. Fuel supplies to SFO via trans-Bay pipeline will be interrupted due to pipeline damage. Ground transport between this facility and the East Bay would be difficult given the projected damage to the trans-Bay bridge approaches. In summary, principal restraint on use of this facility will be damage to runways. Most cargo handling facilities should remain functional. Limited use by smaller aircraft and cargo helicopters is seen as viable.

A2 Metropolitan Oakland International Airport (OAK) - Alameda Co.

Limited Use.

OAK is built entirely on Bay fill (Nichols and Wright, 1971), and the water table is within 5 feet of the surface (Webster, 1973). It is not likely to be useable for large transport cargo aircraft. According to the NOAA report (1972, p. 169), a M8.3 event on the San Andreas fault would close OAK for up to a week. A smaller event on the closer Hayward fault would produce similar ground failure effects due to liquefaction. Runway damage will take at least 72 hours to repair.

At the Oakland International Airport, three fuel depots exist with fuel provided by pipelines from refineries in Contra Costa County. These lines generally follow the Southern Pacific Railroad right-of-way to the Airport, and then continue across the Bay to San Francisco Airport. Pumping of fuel depends on electric power. The Airport has four emergency electric power generators. In an emergency, one generator is to be used to operate the runway lights, a second for the buildings, a third for parking areas and roadways, and a fourth for use by the Federal Aviation Administration (FAA). All generators are located together in one building at the airport.

Principal access to OAK is by way of the Nimitz Freeway (State Route 17). There are four principal routes which cross over or under this freeway to gain access to the Airport: Hegenberger Road, 66th Avenue, 98th Avenue, and Davis Street. Between the Nimitz Freeway and the Airport these four routes join and cross over poor ground. Access is also possible via the Bay Farm Island Bridge from Alameda, but only limited access to Alameda from Oakland is probable. Overpass failures and soil failures are potential sources of short-term airport access problems.

Runways at the older Oakland Airport facility (North Field) involved less fill material and consequently, these runways may have a better prospect of retaining their structural integrity than those of the newer facility. Accordingly, one of the several runways at OAK is assumed to be available for limited use by small aircraft. Consequently, OAK is regarded as being available for a close-in staging area for helicopter transport of emergency needs throughout the damaged area. Both North field and the newer facilities have the same ground access problems.

A3 Alameda Naval Air Station (NAS) - Alameda Co.

Closed.

Alameda NAS is built entirely on Bay fill (Nichols and Wright, 1971), and the water table is within 5 feet of the surface (Webster, 1973). It is unlikely to be useable for large transport cargo aircraft. According to the NOAA report (1972, p. 169), a M8.3 event on the San Andreas fault would close Alameda NAS for up to a week. A smaller event on the closer Hayward fault would produce similar ground failure effects due to liquefaction. Runway damage will take at least 72 hours to repair. The likelihood of damage to the limited number of ground access routes to Alameda is a further constraint on the operational capability of this facility for emergency response purposes.

A5 San Jose Municipal Airport - Santa Clara Co.

Open.

To estimate the conditions of the runways following the scenario earthquake with any confidence would require more analysis. Webster (1973) states that the water table at this location is mostly at depths greater than 20 feet, but Laird et al., (1979, p. 42) indicate the water table is within 10 feet of the surface. According to Troup (1981) "water table depths vary throughout the Airport. A soils investigation by Woodward-Clyde Consultants on May 1, 1981, located water table depths in the 15- to 16-foot range with one test hole showing a depth of only 13 feet." Perkins and others (1981) state that this is not an area of high liquefaction potential, but according to the County of Santa Clara Planning Department (1976, p. 53) it is in an area of possible liquefaction. Within the first 4-12 feet, only one of 150 borings had liquefiable unconsolidated material at or near the runway (Troup, 1971). According to Troup (1981), test borings do not indicate great liquefaction potential. However, the existence of compressible materials underlying the runways and the varying structural sections due to stage construction of the runways suggest a potential problem of differential settlement. Therefore, it is possible that the runways would not be open or available for emergency purposes. The Airport terminal building was designed to support a second story that was never built. However, an analysis based on new earthquake standards to determine the adequacy of the structure was not done (Troup, 1981). There is a generator for indoor lighting, etc., but none for fuel pumps (Verne B. Troup, Deputy Director Airport Planning and Development, oral communication, 1981). Runway length is 8,900 feet, which is sufficient for large-scale rescue operations. According to the NOAA report (1972, p. 169), a M8.3 event on the San Andreas fault would not close the runways at San Jose Municipal for more than a few hours. A smaller event on the closer Hayward fault would produce similar shaking intensities and minor damage to earthquake resistant Airport facilities.

A6 Moffett Field Naval Air Station - Santa Clara Co.

Limited Use.

The water table is within 5 to 10 feet of the surface (Webster, 1973). Only the northern tip of the runway is built upon Bay fill (Nichols and Wright, 1971), but liquefaction may be likely at the site (Perkins and others, 1981). The longest runway is 9,000 ft. and maximum allowable wheel weight is 257,000 lb. gross load weight (dual tandem wheel load capacity) which is sufficient for C-141 aircraft. It is constructed of asphalt/concrete. Its location on Bay mud in an area of high water table make the runways susceptable to damage. There should be only minor damage to earthquake-resistant Airport facilities.

A7 Hayward Municipal Airport - Alameda Co.

Limited Use. (Helicopter)

The water table here is at depths of 5 to 20 feet (Webster, 1973), the Airport is not built on Bay mud (Nichols and Wright, 1971), and the liquefaction potential is not high (Perkins and others, 1981). The length is sufficient (5,156 ft), and the "dual tandem wheel load capacity is 300,000 lbs. gross load weight, more than sufficient for the C-130" (Castenada, 1981), but the dual wheel capacity (190,000 lbs.) is insufficient for C-141 aircraft. Both aircraft require 5,000 feet of runway for operation. Castenada (1981) anticipates that large fire suppression apparatus would need to be moved from Oakland Airport, for example, to accommodate the emergency activities at Hayward involving large aircraft. Lanferman and Danehy, (1981) stated, "Your office inquired about liquefaction at the Hayward Airport and your assessment appears correct. However, [we] have since become aware that the enclosed channel of Sulphur Creek extends under the main runways (roughly east-west across the north-westerly end of the runways) and any failure of that structure may cause isolation of the complete southwest-northeast runway". Steve Krone, Operations Manager, (personal communication, 1986) suggests, however, that "Even if the enclosed channel of Sulpher Creek failed, use of the acceleration taxiway would yield approximately 5,400 feet of useful runway. While this configuration may not be appropriate for normal day-to-day operations, it might be deemed adequate for an emergency situation. It is anticipated that any damage to the conduit could be repaired on an emergency basis without unreasonable delay, returning the full length available to 6,047 feet (acceleration taxiway included)."

Considering the various uncertainties and its proximity to the fault, prudent planning suggests that Hayward Municipal Airport should not be relied upon for incoming air cargo. This facility could, however, be a valuable staging area for helicopter operations. Fuel and emergency supplies could be trucked to this staging area through the nearby I-580 corridor from the east.

A8 Buchanan Field - Contra Costa Co.

Limited Use (C-130 aircraft or smaller).

The facility is not built upon Bay fill (Nichols and Wright, 1971). Liquefaction potential is not high (Perkins and others, 1981). Buchanan Field is 23 ft. above sea level and the water table is at a depth of 6 ft. There is an emergency generator for the tower, but none for night operation of runway lights or for fuel pumps (Vance Roskelley, Airport Operations Supervisor, oral communication, 1981). Buchanan Field's longest runway is 5,000 ft. with a maximum weight allowed of 90,000 lb. (dual) and 140,000 lb. (dual tandem). It can handle DC-9 and C-130 aircraft, but not the C-141 aircraft necessary for large-scale emergency operations. It is estimated that the field could comfortably handle six (6) C-131 size aircraft at a time, parking them on the inactive major runway and possibly as many as twelve (12) in a cramped situation, or the same number of large turbine helicopters with similar parking arrangements.

Air Navigational Aides: The F.A.A. dictates that, in an emergency situation, Field Sector Maintenance Personnel are first to make certain the microwave link repeater stations (off the airport) are functioning properly before attending to communications at Buchanan. The tower does have a backup communications system ready should the active system fail.

Aircraft Fuel: No need to fuel the large aircraft is anticipated because they could fuel at the airports on the other end of their flight. Helicopters have a shorter range and would need fueling services. About

3,000 to 12,000 gallons of jet fuel should be on hand to fuel helicopters, although the Martinez Shell Oil Refinery (7 miles away) usually stores some jet fuel and, if need be, the helicopters could refuel at the refinery.

Airport Lighting: The control tower has an auxiliary generator for communications only (Walford and Kermit, 1981). An auxiliary 200 kw power generator is needed for runway and taxiway lighting (44 kw) and to power the terminal building (156 kw), to enable its use as a coordination and relief center. Also needed are smaller portable generators with lighting to illuminate the aircraft loading and unloading areas.

Roadway Access to Field: At the beginning of a 3 or 4 day weekend, vehicular traffic on Interstate 680 is bumper to bumper, stop and go. For that reason, I personally do not believe that ground traffic to and from this Airport will be possible for several hours. The main access to the Airport is John Glenn Drive off Concord Avenue on the south side of the Airport which has moderately heavy traffic except at commute times when it is stop and go. Access will be available from Highway 4 to Solano Way to Highway 4 frontage road to Marsh Drive to the west side of the Airport. There is also an off-ramp southbound from Interstate 680 at Pacheco to Contra Costa Boulevard to Center Street onto the west side of the Airport (Walford and Kermit, 1981).

According to the NOAA report (1972, p. 169), a M8.3 event on the San Andreas fault would not close the runways at Buchanan Field for more than a few hours. A smaller event on the much closer Hayward fault would produce similar shaking intensities and minor damage to earthquake-resistant airport facilities.

A9 Travis Air Force Base - Solano Co.

Open.

The facility is not built upon material with high liquefaction potential (Perkins and others, 1981). The area is not underlain by Bay mud and it is not subject to liquefaction (Sedway/Cook, 1977, p. 4a). The chances for Travis AFB surviving the earthquake in a fully operational condition are excellent.

Typical Bay area airport runway constructed on fill overlying potentially unstable soils, including Bay mud.

BAY AREA RAPID TRANSIT (BART)

General Characteristics

The San Francisco Bay Area Rapid Transit (BART) District is a public agency created by California State legislation in 1957. BART opened in 1972 with limited service, and by 1974 was in full service over its present day, 71.5-mile system. The system reaches from the cities of Concord in the east to Daly City in the west, and in the East Bay from Richmond to Fremont. The major part of the system is located in the East Bay counties of Contra Costa and Alameda and, consequently, much of it is near the Hayward fault.

BART is a heavy-rail transit system that operates on electric power. Power for all operations of the system, including the running of trains, is provided by the Pacific Gas and Electric Company (PG&E). The system depends on electric power from this utility and cannot operate trains without it.

Of the entire 71.5-mile system, about 23 miles are elevated track supported on reinforced concrete columns and beams. Other portions of the system consist of underground track in the downtown areas of Oakland, Berkeley, and San Francisco, the trans-Bay tube beneath San Francisco Bay and one major tunnel, a twin-bore through the Berkeley Hills that carries passengers to communities in the eastern valleys of Contra Costa County. There are a total of 34 BART stations, all of which were completed during the 1970s of modern, reinforced concrete or steel-frame construction. Map 3-T shows these various elements of the system.

The administrative center of BART is located in two buildings in downtown Oakland. One building contains the main operating center and computer systems in addition to headquarters administrative offices. This facility has an emergency power generator. Other emergency generators for various purposes are located elsewhere.

According to BART's 1984/85 (fiscal year) Annual Report, trains on week-day runs carried out about 212,000 week-day passenger trips. Total passenger service amounted to about 60,800,000 passenger trips on an annual basis.

Seismic Considerations

There are certain key characteristics of the system which are of special interest relative to its performance during earthquakes: (a) the two tunnels consisting of the trans-Bay tube and the Berkeley Hills twin tunnels, (b) the elevated track portions of the system, and (c) portions of the system routed beneath overpasses or major interchanges such as I-580 and State Route 24 in Oakland. The seismic hazards to the BART system have been well studied and steps were taken to minimize these hazards both at the time of design and construction and subsequent thereto.

Special research was conducted on the seismic stability of the Bay muds before the trans-Bay tube was constructed, including the monitoring of all seismic events for their effects on Bay muds. However, there was no opportunity to record site-specific strong motion on Bay mud from any nearby damaging earthquakes nor has there been significant site related experience since construction.

Many miles of elevated track are laid upon precast concrete beams supported by poured-in-place reinforced concrete columns. Considering structural similarities and proximity to the earthquake source, the performance of these elevated rapid transit structures could approximate that of freeway structures in the San Fernando shock, some of which were heavily damaged. It is probable, however, that the BART structures will perform better.

BART rail lines intersect the Hayward fault inside the Berkeley Hills tunnels. At the fault crossing, the tunnel lining was strengthened, instrumented, and other steps taken to minimize the effects of recognized fault creep. These precautions were not intended, however, to eliminate the effects of fault offset of 5 to 10 feet that would accompany a major earthquake as postulated in this scenario.

The BART system is designed to withstand the anticipated shaking effects of a 1906-type earthquake. It has other built-in features that are helpful in reducing damage from an earthquake, such as a very heavy car base, and wide-gauge track (5'6" vs. 4'8 1/2" for common rail carriers).

Planning Considerations

Although the BART system as a whole will survive well, service will be greatly impaired. Even after service is restored, trans-Bay and underground patronage may be significantly reduced due to psychological reasons. Continuing aftershocks, some of which will further damage already battered structures, may heighten fears.

Service to eastern Contra Costa County will be discontinued for an extended period due to fault rupture in the Berkeley Hills tunnels.

Planning Scenario

The scenario event will immediately trip at least 4 of BART's strong motion recorders located in their stations near the Hayward fault. Alarms at these stations will alert the on-duty agents (as, no doubt, will the shaking from the event!).

Electric power from PG&E is expected to be out throughout the East Bay, thereby eliminating power for the trains. Passengers in a disabled train on an elevated section of track will have to walk to the next section if other rescue is not provided. People stranded in subways, tunnels, and the trans-Bay tube can leave on foot. The trans-Bay tube can be cleared of trains with the use of diesel-powered locomotives, thus opening a walkway between San Francisco and the East Bay.

The very large majority of the elevated spans will survive with no damage. For scenario purposes, four spans are projected to fail or have significant structural damage, eliminating service until temporary repairs are made.

A horizontal displacement averaging 5 feet on the Hayward fault will close the tunnel through the Berkeley Hills for an indefinite period of time. The chance of a train being in the tunnel at the time of the earthquake and striking the blockage at the fault rupture can be computed, and casualties estimated.

The system would be shut down while damage is assessed and repairs made. In the interim, portions of the system could be available. However, it would be of limited use for transport of emergency needs such as food and medical supplies because BART's structures and clearances are not adequate for heavy or bulky equipment.

Back-up electric power generators for support facilities will remain in service since they are appropriately earthquake braced. Their fuel supplies are adequate for several days, depending on demands made on the generation system. Six independent BART communications systems exist, and most are expected to function after the earthquake.

For planning purposes, BART will be shut down in San Francisco for a minimum of 3 days before local, limited service will be restored. Local and limited restoration of service in the East Bay will be influenced by the priorities given to power restoration, temporary repairs, and restoration of rider confidence.

Damage Assessments

Damage assessments have been postulated for certain BART 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. 3-T.

MAP NO.	FACILITY - COUNTY

T1 BART Trans-Bay Tube - San Francisco/Alameda Co.

Although the tube is not ruptured, the system is without power. Both ends of the tube have flexible joints for coping with some differential movement. Passengers will be able to walk out of the tube on foot. Diesel locomotives at the BART Oakland shop are available to pull the trains out the east end if not blocked by obstructions between the shop and the tube. After the trains are cleared, the Hi Rail vehicles will be able to traverse the Bay via the tube, but these vehicles do not have substantial load capacity, either for passengers or supplies. Soil conditions near the east end of the trans-Bay tube are similar to those at the east approach to the Bay Bridge, which is expected to experience failures (CDOT, 1985).

T2 BART Subway/San Francisco - San Francisco Co.

The subway is not damaged extensively, but the system will be shut down for a minimum of 72 hours as a result of lack of electrical power and time required for damage assessment and necessary repairs.

T3 BART Subways/Oakland and Berkeley - Alameda Co.

The subways are not seriously damaged, but the system is out of service until damage assessment and necessary repairs allow limited operations in the East Bay.

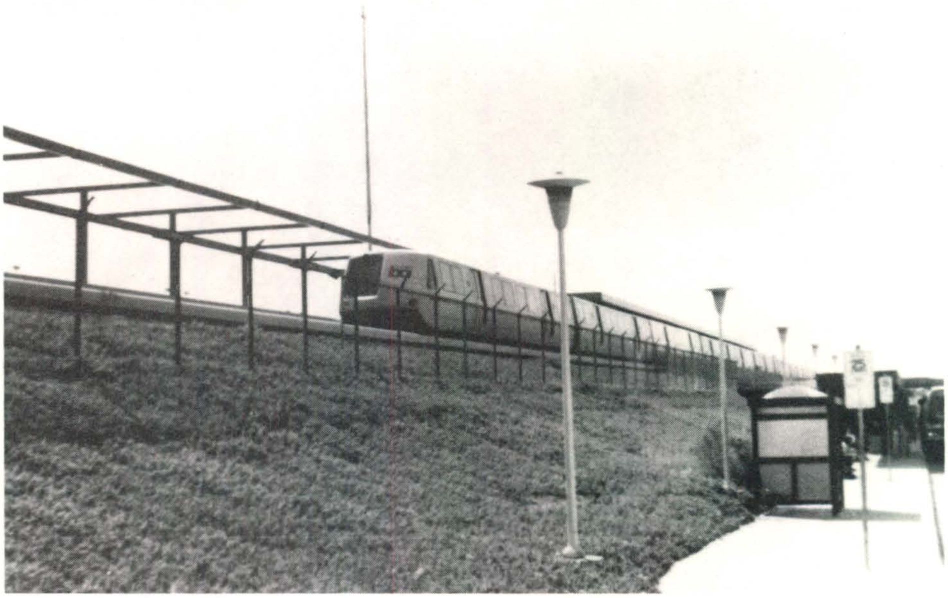
T4 BART Elevated Sections - Alameda/Contra Costa Co.

The elevated sections are designed to withstand the anticipated shaking effects of a M8.3 earthquake on the San Andreas fault west of San Francisco. It is highly probable, however, that throughout the system at least a few elevated spans fail and result in closure.

T5 BART Berkeley Hills Tunnel - Alameda/Contra Costa

Between Rockridge and Orinda stations, the twin BART tunnels pass through the Berkeley Hills, crossing the Hayward fault approximately 1,000 feet from the west portal. The tunnels are approximately 3 miles long, 17.5 feet in diameter, and are separated by a distance of about 100 feet. Sudden displacement of the Hayward fault of the amount postulated to accompany this scenario earthquake (5 to 10 feet) would effectively block the tunnels. Continuing aftershocks would impede efforts to restore this facility for several weeks.

For planning considerations, the possibility of a train approaching or crossing the fault zone at the time of an earthquake capable of causing substantial fault offset needs to be considered. Obviously, such a disastrous circumstance would result in derailment and conceivably many deaths and injuries depending on passenger load.



BART Station at Fremont

RAILROADS

General Characteristics

Railroad access to the San Francisco Bay area from outside the affected area is important for vital emergency freight haulage. The railroad network for the San Francisco Bay area is shown on Map 3-RM. Most of the principal railroad routes have not materially changed since originally constructed in the 1800's.

All the major rail lines serving the Bay area from the east cross the Hayward fault. Only the Southern Pacific coast route from Los Angeles and the low-capacity lines in Napa, Sonoma, and Marin Counties do not. Since the 1906 San Francisco earthquake, bridges have been improved or replaced, many grade separations constructed, and fills consolidated over time.

Seismic Considerations

Damage to be expected is similar to that experienced in the 1906 San Francisco earthquake. The following is extracted from the "Transactions of the American Society of Civil Engineers" (1907), specifically, the Report of the Committee on the Effect of the Earthquake on Railway Structures:

> "Embankments. Embankments across marshes, or with soft strata underlying them, settled more or less. In some cases, the settlement was vertical; in other cases, there was considerable horizontal with the vertical movement.

> At one point on the marsh between Benicia and Suisun, on the Southern Pacific, the settlement was 11 ft.; at another point, 5 ft. These were nearly vertical.
>
> Between Niles and San Jose, on the Southern Pacific, there was at one point a displacement of 3 ft. horizontal, but the vertical displacement was only 6 in. (p. 258).
>
> Trestles. The damage to trestles was small, except on the North Shore Railroad (ed. note: this line no longer exists), where a trestle of framed bents on piles, 600 ft. long and 70 ft. high, was thrown down, and portions of another trestle were thrown entirely off the piles, the piles themselves being moved downstream. These trestles were across soft ground, and near the fault line (p. 214-215).
>
> Draw-Bridges. Draw-bridges across the little creeks and inlets around San Francisco Bay, being generally on soft ground, were affected by a slight movement of their piers, in many cases, resulting in the bridge binding so that it could not be opened until some repairs were made.
>
> The draw-bridge at Black Point, over Petaluma Creek, on the Sonoma Branch of the California Northwestern, was open at the time of the earthquake, and was thrown off its center 2 ft. to the east and 1 ft. to the north. This is a steel structure, 220 ft. long, on four iron caissons, filled with concrete, on pile foundations (p. 259):
>
> Fixed Bridges. With a few exceptions, fixed bridges were not affected seriously. The bridges over the Russian River, at Healdsburg, and at Bohemia, on the California Northwestern, were both shifted slightly on the piers at one end.
>
> The bridge across the Pajaro River, near Chittenden, on the Southern Pacific, was badly damaged. The "line of fault" (ed. note: 1906 San Andreas surface rupture) crosses this bridge near the west end (p.259).
>
> Tunnels. In general, tunnels seem to have been affected only by the displacement or loosening of the material in the sides and roof, caused by the shaking of the ground. The effect of this was to crush the timbers." (p. 261).

Many of the roadbeds in "poor ground areas" have been compacted by the many years of usage since 1906 and, for a lesser magnitude earthquake, may perform substantially better than they did previously. Railway bridges generally do not suffer serious damage except in areas subject to ground failure or surface fault rupture. Bridge damage, when it does occur, however, generally involves a lengthy repair time. Significant settlement of approach fills require repair before bridge structures can be used. Railroad tunnels experience severe damage in areas affected by permanent ground movements due to landslides or surface fault rupture, but rarely suffer internal damage from ground shaking.

Rail facilities are also highly vulnerable to closure by collapse or major damage to the many freeway overcrossings and other grade separation structures that have been constructed during recent years.

Planning Considerations

Railroad companies possess substantial in-house repair capabilities, plus extensive experience with outside contractors from all parts of the nation. Major washouts, landslides, and derailments are not uncommon. It is reasonable to assume that the railroads will be able to solve most 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 many others dependent on rail service. Failures that involve both the railroad and other transportation facilities and/or utilities may result in problems of jurisdiction and work priorities.

The main rail lines and rail terminals in the East Bay are generally located in poor ground areas where soil failures are to be expected. Rail facilities extend to and within the many major port facilities, industrial plants, and military installations in the area, most of which are also in poor ground areas. Priorities given to rail repairs in these areas should be considered in the context of the users' needs and ability to avail themselves of prompt rail restoration.

Emergency planning for rail transport of relief equipment and supplies will involve the siting of suitable temporary terminals just beyond locations where the major rail lines are likely to be interrupted. To the extent possible these terminals should be located near a major highway route or airport facility. The railheads of Benicia and Vallejo should be examined to determine their adequacy for transport of heavy equipment from rail to barge.

Planning Scenario

The rail lines leading to the urban Bay area from the east including the various structures that cross or encroach upon these lines are subject to major damage. For planning purposes, therefore, all rail transport between the Bay area and the Sacramento and San Joaquin Valleys will be unavailable for the initial 72-hour post-earthquake period. After that, routes will be opened on a limited basis to the Port Chicago and Livermore areas. Service from Los Angeles to San Jose will be available in 12 hours and will be extended to San Francisco on a limited basis within 72 hours.

From the south, rail access will be terminated at the Coyote Creek overcrossing south of San Jose State University and at the Mountain View railroad overhead on the Peninsula. From the San Joaquin Valley, the two major rail corridors will be closed in Niles Canyon east of Fremont and in northern Contra Costa County east of Martinez. The remaining major rail corridor from the north and east will be temporarily closed by ground failure in the crossing of Suisun Marsh southwest of Fairfield. The assumed rapid repair of this main line will allow for transport of heavy equipment and supplies by rail to suitable docking facilities at Benicia where barges can be loaded for transport to areas of need around the Bay. Marine facilities at Vallejo will also be accessible to the railroad via the rail line from Fairfield through Jameson Canyon to Vallejo.

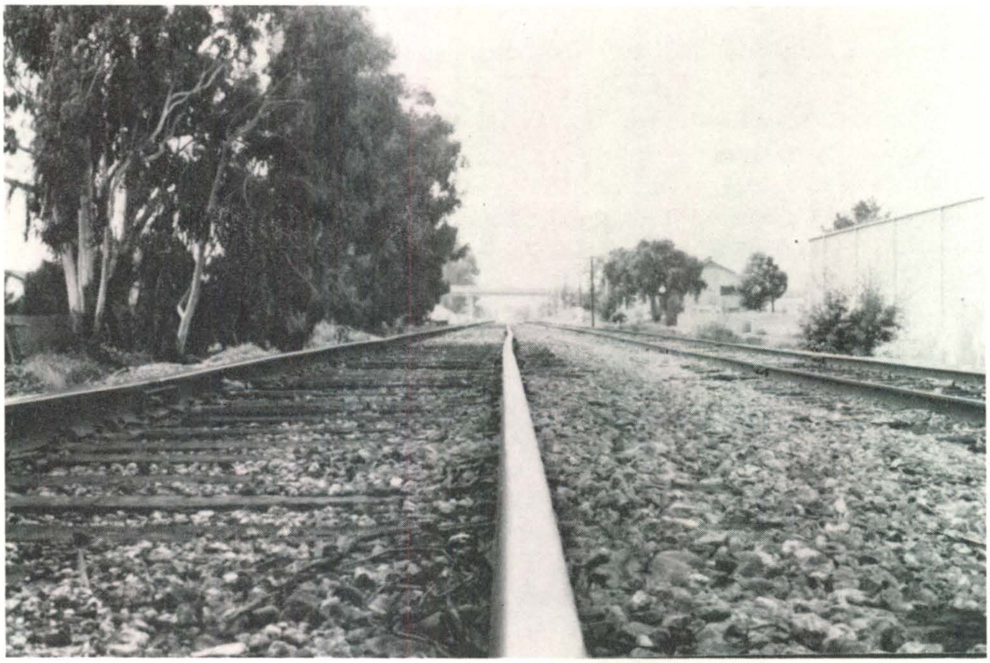
The rail closure near Port Chicago suggests that the Naval Weapons Station might be considered as a convenient terminal for some rail transported material. Similarly, the closure in Niles Canyon suggests the same possible use for Camp Parks.

Rail facilities serving the urban areas around the Bay are also highly vulnerable to damage. While some segments of these lines may be operational, their probable overall utility will be minimal and localized.

Because track alignments must be precise and the track clear of debris, it is expected that those routes experiencing ground failure would not be operable within the first 72 hours after the earthquake.

Movable-span railroad bridges are subject to misalignment due to earthquakes, and extended closures will be required for repairs. For planning purposes, all movable-span bridges located westward of and including the Martinez-Benicia Bridge will be closed for 24 hours for inspections. It is also assumed that all movable-span railroad bridges in the communities between Richmond and Fremont in the East Bay will remain closed for a minimum of 1 week for repairs. The possibility exists that the Martinez-Benicia lift-span could be jammed in its down position for an extended period with a resulting impact on delta shipping.

Since the scenario fault displacement is 5 to 10 feet in a horizontal direction (strike-slip), grade repairs at the fault rupture will be comparatively easy to accomplish since minimal cuts and fills are required.



Deformation of railroad track at the crossing of the Hayward fault in Fremont.

Damage Assessments

Damage assessments have been postulated for certain railroad 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 3-RM.

MAP NO.	FACILITY - COUNTY
R6	Southern Pacific/Suisun Marsh - Solano Co.

Closed for up to 36 hours.

The tracks were disrupted here during the 1906 event due to liquefaction and ground settlement of up to 11 feet (Youd and Hoose, 1978).

R7 Terminal Areas/West Oakland - Alameda Co.

Terminal yards of the major railroads, including rail facilities at the Oakland Army Terminal and Naval Supply Center suffer damage resulting from ground failures. Structural failures at the I-80/580/Route 17 interchange blocks the mainline tracks at this location. Access to the area is impaired.

R9 SP South Bay Crossing between Fremont and Redwood City - Alameda/San Mateo Co.

Closed.

R10 SP Commuter Station - San Francisco Co.

Closed.

R11 SP Commuter Line - San Mateo/San Francisco Co.

Closed. Reopened on a limited basis in 12 hours.

R12 Western Pacific and Southern Pacific/Niles Canyon - Alameda Co.

Closed for more than 72 hours.

Sunol is the westernmost access to the Bay area along this route. The tracks are closed due to slides and bridge failure similar to those involving the highway through Niles Canyon (CDOT, 1985).

R13 SP and A T & SF East of Martinez - Contra Costa Co.

Closed for up to 36 hours.

The westernmost rail access to the Bay area is disrupted along both main lines east of Martinez.

R15 WP Vicinity of San Jose State University - Santa Clara Co.

Northernmost rail access to the East Bay is disrupted by ground failures near the Coyote Creek overcrossing south of San Jose State University.

R16 Mountain View RR Overhead - Santa Clara Co.

Northernmost rail access to San Francisco on the Peninsula is disrupted by the failure of the Mountain View railroad overhead which is "substandard" (Eggleston, 1980). Route cleared through this area within 12 hours.

R17 Northwestern Pacific at Petaluma River - Sonoma Co.

Southernmost access to the Bay area cut off by track disruption due to liquefaction failures along the Petaluma River.

R18 San Francisco Municipal Railway - San Francisco Co.

Temporarily shut-down by lack of electrical power with subsequent limited operations.

R19 Northwestern Pacific at Schellville - Sonoma Co.

Closed by rail disruption due to liquefaction between Schellville and San Rafael.

R20 SP at Napa River Crossing - Napa/Sonoma Co.

Closed between Napa Junction and Schellville due to bridge damage at the crossing of the Napa River.

R21 SP to Vallejo via Jameson Canyon - Solano/Napa Co.

Open.

In wet weather, landslides may cause minor disruption of tracks in Jameson Canyon between Cordelia and Napa Valley, but otherwise the route to Mare Island Strait will be accessible.

R22 <u>SP spur to Camp Parks (near Pleasanton) - Alameda Co.</u>

Open.

Possible westernmost terminal on this line.

R24 <u>Naval Weapons Station Terminal - Contra Costa Co.</u>

Open.

Possible westernmost terminal on this line.

R25 <u>Port Chicago Terminal - Contra Costa Co.</u>

Closed due to ground failures and disruption of rails.

R26 <u>SP and WP between Fremont and Oakland - Alameda Co.</u>

Closed due to damage to bridges.

R27 <u>SP between San Jose and San Leandro - Alameda Co.</u>

Closed due to ground failures and track disruption.

R28 <u>Mare Island Bridge - Napa Co.</u>

Closed due to bridge damage.

R29 <u>Mare Island Strait Terminal - Solano Co.</u>

Southernmost access to the Bay area along this line. Open and usable for marine transport, although access depends on assumed minor problems along route through Jameson Canyon (R21).

R30 <u>SP and A T & SF at San Pablo - Contra Costa Co.</u>

Both main line routes are disrupted by surface offset along the Hayward fault.

R31 <u>SP and WP-Niles/Irvington Area - Alameda Co.</u>

Fault displacement disrupts the tracks at multiple crossings of the Hayward fault in this area. For the 1868 earthquake Lawson (1908,p. 443) reported the damage from fault rupture to the Southern Pacific tracks at Irvington, as follows: "Thru the north side of town a crack split the hillside, opening 7 or 8 inches and showing a fault of 8 or 10 inches. It crost (sic) the county road 500 feet north of the Southern Pacific Railway Depot. The railroad tracks north of the station were badly twisted for several hundred yards."

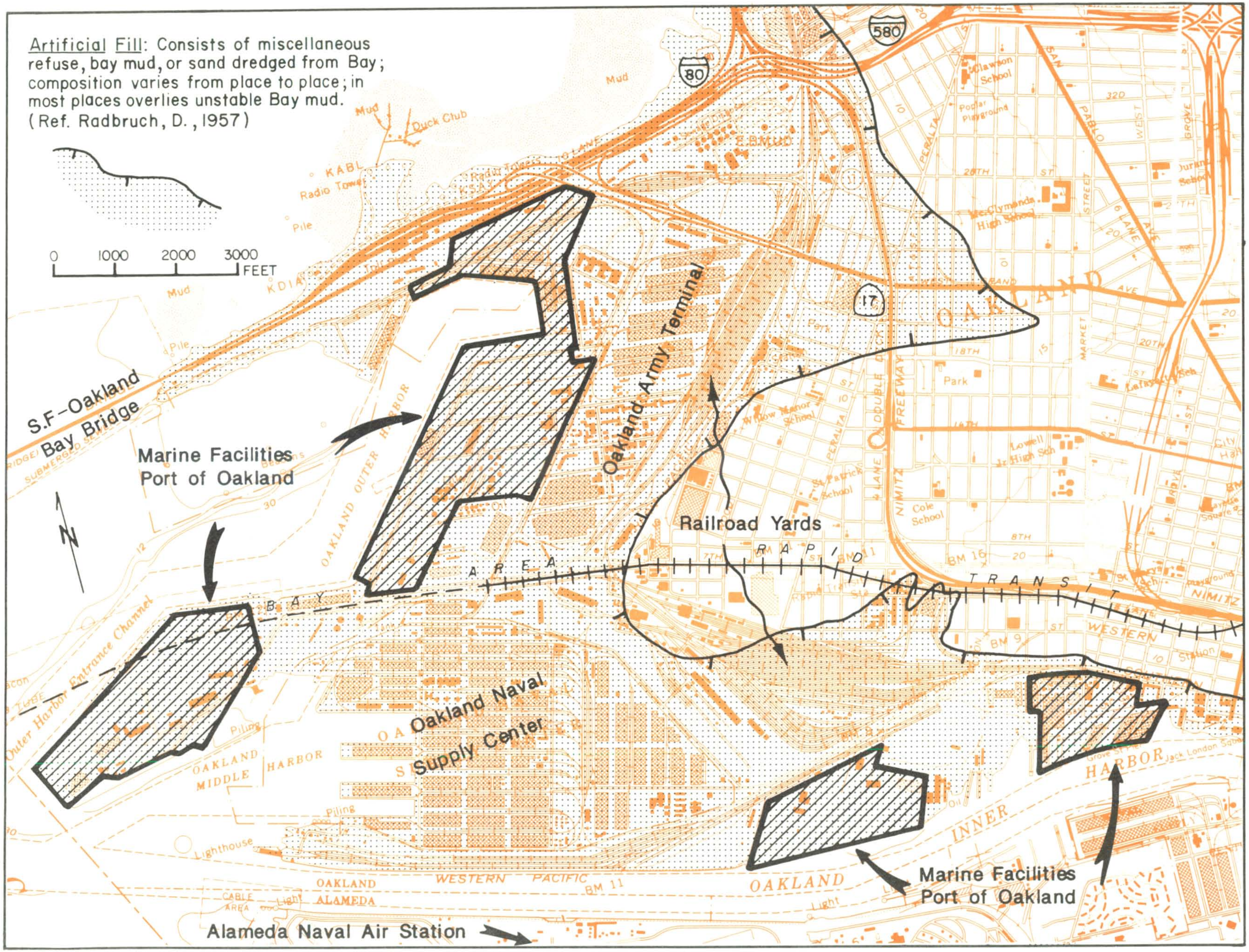
MARINE FACILITIES (PORTS)

General Characteristics

The two major nonmilitary port facilities in the East Bay are located at Oakland and Richmond. Other commercial port facilities are located on San Pablo Bay and in the Carquinez Straits. Across the Bay, the principal port facilities are those of the Port of San Francisco.

The Port of Oakland is the largest container port on the Pacific Coast, and the second largest in the United States. The Port receives and dispatches about 11 million revenue tons of cargo annually. Along its 19 miles of waterfront are 475 acres of container terminal facilities and support services. These include 28 berths of which 17 serve container, combination container/breakbulk, and roll-on/roll-off ships. There are 21 container cranes, and an additional 75 acres for cargo uses. The Port is served by three transcontinental railroads (Map 3-RM). Southern Pacific and Western Pacific railroad terminals are located in the Oakland Port area. The Santa Fe terminal is in Emeryville and connected to the Port via belt line.

The Port of Richmond is much smaller in size than the Oakland facility. The large majority of its shipments and of the other facilities on San Pablo Bay and in the Carquinez Straits are oil related. Container handling facilities are available at Richmond.



Topographic Base Reduced from U.S. Geological Survey 1:24,000-Scale Map Series.

Figure 9. Major transportation lifelines located on artificial fill in west Oakland.

Seismic Considerations

Experience from the 1906 San Francisco earthquake provides a basis for estimating the probable damage to Bay area port facilities. Damage patterns to equipment such as rail mounted cranes can be judged from the 1964 Alaskan earthquake experience.

In 1906, the earthquake performance of the pile supported docks along San Francisco's waterfront was excellent, although the soil in some of the nearby fills settled several feet. Pile supported structures have generally performed well in earthquakes, with the major exceptions being due to submarine landslides such as those observed at Seward, Alaska, in 1964. However, major submarine landslides are not expected in San Francisco Bay.

Quay wall structures have often failed in the past. Quay walls are docks which consist of waterfront masonry walls with earthen fills behind them; these earthen fills provide dock space. Most of the previous quay wall failures can be attributed to what is now understood to be soils that liquefy during earthquakes. The design and construction of recent earthen fills at the Port of Oakland have included provisions to reduce the potential of soil failures.

Most of the docks in the Bay area are pile supported and, overall, marine facilities are not expected to be greatly affected insofar as the pile supported docks are concerned. Pipelines from storage tanks to docks will be ruptured where they cross areas of structurally poor ground in the vicinity of the docks. Restricted access to docks due to damage to freeways and nearby surface streets will be more common than significant damage to the pile supported docks. In general, docks and crane operating areas are pile supported while storage and access areas are on more vulnerable filled land.

Bayside port facilities at San Francisco, Oakland, Richardson Bay, Richmond, and Carquinez Straits will be generally accessible to tug and barge traffic. Marine facilities south of Hunters Point on the Peninsula and San Leandro in the East Bay will, however, be inaccessible to both tug and barge movement.

It is expected that damage to most dry cargo port facilities and marinas should be less than in previous severe quakes due to modern building techniques and facility spacing. However, the failure of quay walls and lateral displacement at container terminals could be expected to be severe so that operations could be drastically curtailed. Inasmuch as these facilities are constructed on filled land, cranes could be derailed, tracks could become misaligned, and automatic shore-side container storage and distribution cells could be warped.

Rail mounted cranes, such as those used for containers, are often dislodged from their rails during an earthquake, but they do not turn over unless the supporting dock fails. These derailed cranes can be remounted on their rails by the use of jacks and other means, but skilled labor and time are involved.

Generally speaking, dry bulk cargo and container operations could be expected to come to a halt due to access problems and shifts in landfill areas. Over a short period, or even a moderately long period, this shutdown would have no significant effect on lifeline functions in an earthquake impacted area due to the consumer nature of modern inbound cargos. Vessels destined for an impacted port area would be diverted at sea to alternate port facilities or delayed in arrival to an impacted area.

Most vessel cargo transfer operations are self-contained so that, except for container ships without cranes, cargo operations could be continued after a major earthquake to the limit of shoreside support. The controlling factors will be restricted road access, pipeline breaks, and filled land failures in the vicinity of piers and terminals.

At liquid handling facilities, no significant damage to either vessels or piers is expected. However, shore pipeline failures can be expected, and even if no failure occurred, cargo operations will cease until all systems have been thoroughly checked.

Small craft facilities may suffer minor damage through ruptured pipelines and slides under piers from adjacent filled land. The most significant impairment would probably be closure of waterways in some areas. In the south San Francisco Bay and the southern half of the East Bay areas, dredged channels could be expected to shift so the small craft in the vicinity of Redwood City and south, and craft in the Alameda-San Leandro areas would be confronted with blocked channels. The north Bay and nearby Delta areas are expected to be accessible by small craft.

Planning Considerations

Port facilities in San Francisco are expected to remain 90% operational after the postulated earthquake on the Hayward fault, particularly after power is restored. The port can be a major resource for receiving emergency supplies and equipment.

However, there may be problems if long distance shipments are involved. Truck traffic to and from the port will have to be routed south of the Bay area via undamaged routes. Some rail freight from the east destined for San Francisco can be routed via Los Angeles. Land freight from the north of San Francisco will be limited by highway capacity and by road damage.

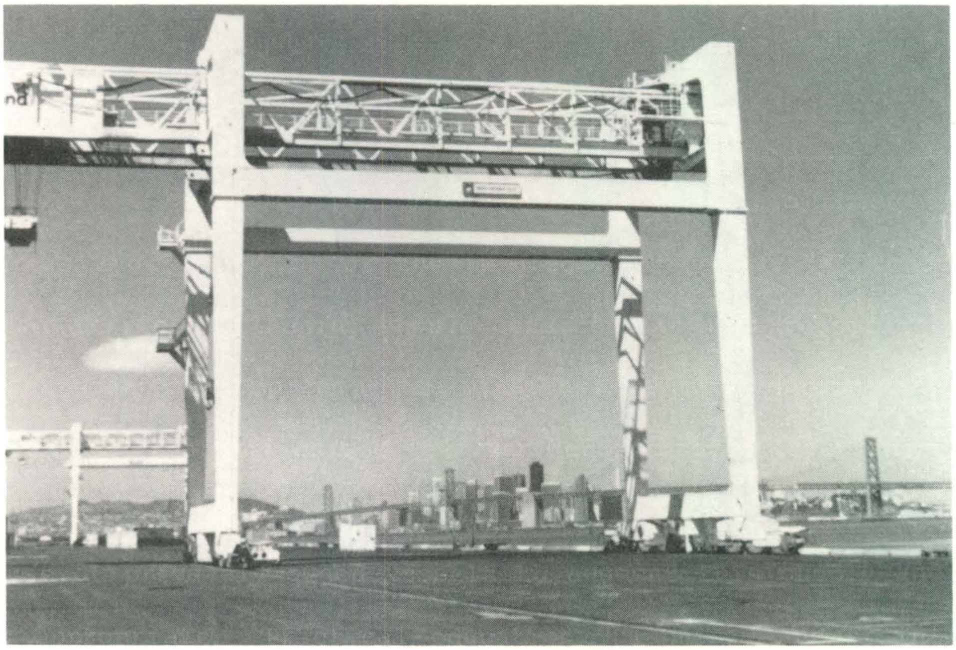
Marine shipping to and from Stockton and Sacramento would be restricted if the railroad bridge over the Carquinez Strait is jammed by the effects of earthquake shaking when the bridge is in a closed position.

The use of tugs and barges to transport heavy equipment and supplies to the San Francisco and Marin Peninsulas appears to be a viable emergency response procedure. Assuming that most of the docks in the heavily damaged areas will be usable, availability of emergency power and off-loading capabilities will be required. Use of barge transport will necessitate coordinated planning for loading of needed materiel at a dockside facility adjacent to a marshalling depot or railhead with available loading capabilities.

Transport of emergency personnel and equipment into these same heavily damaged areas and evacuation of the injured will be a vital function of the numerous Bay ferries. Planning should consider the most feasible terminals on both ends in order to complete these missions. Again, coordination with other ground transport capabilities will be required for efficient transfers.

The use of privately owned vessels to augment this supply and evacuation effort is appropriate. Practical education, planning, and training programs to implement this participation should be initiated.

The various roles that marine transport can assume in the emergency response efforts and the extent of marine transport resources should be determined. Locations with suitable land access and loading capabilities, that are most likely to be available for post-earthquake access to marine transport, should be selected. Port facilities outside the heavily damaged areas should be coordinated with ground transport to identify the most efficient means of transporting the injured, materiel, etc.



Rail mounted crane at the Port of Oakland.

Planning Scenario

Damage Assessments

Damage assessments have been postulated for certain port 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 3-RM.

MAP NO. FACILITY - COUNTY

M1 San Francisco Waterfront - San Francisco Co.

Along the San Francisco waterfront there are numerous failures of quay walls, disruption of waterfront rail facilities, derailment of cranes and railroad cars, ruptured pipelines, etc. Docks are generally pile supported, however, and most are accessible for emergency response operations. Access to the waterfront is impaired by debris and damage along many approach streets. San Francisco port facilities remain 90% functional; truck access routes are also 90% functional. Immediately after the shock, rail access is severely restricted for shipments to and from the area.

M2 Port of Oakland - Alameda Co.

The Port of Oakland has problems such as soil failures beneath streets within the port areas, slumped fills at some facilities, and derailed cranes. Temporary repairs to roads and equipment are expected to restore 90% of the Port's functional capabilities within a week. However, major problems arise from external sources, such as restoration of electric power and repair of access routes.

Operation of the Port of Oakland is dependent on electricity supplied by the Pacific Gas and Electric Company (PG&E). Truck access to the Port of Oakland is via freeways (lengthy portions are elevated) or across freeways via grade separations. Access from the freeways to the port facilities is by one of three streets, each of which also have grade separations. Soil conditions are poor in both these access corridors and the port areas. Soil failures on these truck access routes are likely. Rail access is also through poor soil areas and failures along rail access routes are also likely.

Rail access to the Port of Oakland will be restored on a limited basis in 2 weeks. Repair work will include the removal of debris from fallen structures on the tracks and realignment of tracks which have been displaced by ground failure.

Truck access to the Port of Oakland will be restored on a limited basis in one week by using city streets, thereby bypassing freeway pavements that fail due to liquefiable soils or from collapsed or damaged overpasses.

As a consequence, it is improbable that the Port of Oakland will remain functional due to circumstances not within the Port's control. Similar problems exist for the ports at Richmond and Carquinez.

M4 <u>Richmond - Contra Costa Co.</u>

Port facilities at Richmond sustain localized ground failures disrupting rail and street access. Damage to oil pipeline and storage facilities near the harbor poses a threat of contamination and fire. Oil shipments will be a function of the damage to the Chevron Refinery as well as to the pipelines transporting petroleum products.

M5 <u>Alameda/San Leandro Bay Area - Alameda Co.</u>

Small craft facilities in the San Leandro and Alameda areas are closed by blocked channels.

M6 <u>South Bay - San Mateo/Santa Clara Co.</u>

All marine facilities at Redwood Creek, Palo Alto, and Alviso Channel are inoperable and inaccessible due to damage caused by liquefaction.

M7 <u>Petaluma River - Sonoma Co.</u>

The Petaluma River channel is blocked.

M8 <u>Benicia/Vallejo - Solano Co.</u>

Damage to marine facilities and appurtenant rail connections at Benicia and Vallejo will be minor. After repairs to the main line tracks across Suisun Marsh (see note R6) and minor repairs due to landslides in Jameson Canyon (see note R21) rail service to these two Bayside facilities will be available in 36 hours.

Section 7.

UTILITY LIFELINES

The Hayward fault crossing of Route 24 in the Route 13 interchange area near Lake Temescal and PG & E's Claremont substation.

COMMUNICATIONS

The following discussion of communication systems was prepared by the Department of General Services, Office of Telecommunications, in conjunction with the Communications Sub-Committee of the Direction and Control Committee, OES Earthquake Task Force.

General Characteristics and Seismic Considerations

Telephone communications will be adversely affected due to overloading resulting from post-earthquake calls within the area and from the outside. This situation will be further complicated by physical damage to equipment due to ground shaking, loss of service due to loss of electrical power and subsequent failure of some auxiliary power sources.

Not all of the systems in the region are set up to process emergency calls automatically on previously established priority bases. Thus, overloading of equipment still in service could be very significant.

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 post-earthquake communications scenario has been treated as a matrix of events that would reduce the effectiveness of systems rather than completely destroy them. It is also assumed that portions of many systems could be repaired to a limited extent by resourceful operators. Criteria such as geographical coverage, the number of system elements, and functional integration were considered in estimating the post-earthquake effectiveness of a particular system. With the maximum capacity of any system represented as 100%, most systems operate at approximately 85% because of ongoing maintenance. The effects of the scenario earthquake must be applied to this ratio to determine the degree to which the overall effectiveness is reduced. "Effectiveness" is defined as the ability of a system to perform to its design limits and provide the intended service.

This communications scenario is described in subsections, each of which treats one of the following generic systems: telephone, radio, microwave, satellite, data, and commercial broadcast.

Telephone Systems

Telephone systems are mutually interdependent because of a vast, complex, interconnected network, yet they are also self-supporting on a local basis. One service provided by the telephone companies is intraexchange traffic, i.e., calls between telephones within the area served by a single central office or "exchange." Another is interexchange service where calls are switched between two central offices within a region. There is a third service, similar to interexchange, where calls are routed to a long-distance facility. Each of these services can be provided by a variety of system configurations.

The telephone companies have installation standards that 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 addressed here. It is therefore quite difficult to forecast the detailed effects of a major earthquake on telephone systems. There are, however, a number of outcomes that can be anticipated: hardware damage such as underground cable failure in areas of liquefaction, damage to surface cable carriers, system-call saturation during post-earthquake recovery, and access problems for repairs.

Our evaluation of system performance takes into account the likelihood of any or all of these events occurring and subjectively applies this evaluation to an effectiveness scale, as shown on Map 3-C. The effectiveness scale essentially is an attempt to quantify the ability of public safety agencies to conduct recovery efforts by using the telephone system. It is not directly applicable to the general performance of the system nor to the public's ability to use the system.

The effectiveness scale has then been applied to a three-day time frame. Four patterns of effectiveness over time were distinguished and used as the basis for zoning the study area (Zones A, B, C, and D on Map 3-C). Zone A will fair best and Zone D the worst.

Some basic assumptions have been made: (1) the shaking intensities used in this scenario are shown on Map 3-S; (2) areas experiencing intensity VIII (MM) or greater will have some 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) interexchange facilities will be difficult to access, but would remain essentially intact; (8) shortly after the event, numerous relatively simple failures will occur, for example, "off-hook" condition produced by intense shaking. Coupled with intense call saturation, these will effectively disable the telephone networks for approximately 6 hours.

Specific Vulnerabilities

The most vulnerable aspects of telephone systems are the computers used to switch message traffic. All are environmentally sensitive and may be mounted on false floors. The performance of these computers is not easily associated with a time frame because of the long-term effect of environmental control failure. Call saturation, resulting in local station and all trunks being busy, is the most obvious system access problem that can be predicted. Most telephone systems presently are working at or near capacity for normal traffic; the systems will be saturated easily by the sudden activity following an earthquake. Most exchanges, however, have the capability through the switching computers to control system load by limiting access to only predesignated circuits. Another potential problem is emergency power. While the telephone systems work mostly on battery power, with propane or gasoline backup generators to provide charging, the generators depend on batteries for starting and fuel lines and tanks for continued operation. If emergency power does fail, system performance on batteries will degrade at a significant rate.

Assuming the earthquake will occur outside normal business hours, a number of staffing problems must be considered when evaluating telephone system performance in the scenario. The first concern of telephone company employees will be assessment of their own immediate condition; second, they will be concerned about 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 of the employees will suffer casualties and will be confronted with mobility problems on streets and highways. The repair vehicle fleets will probably be generally inaccessible to staff for several hours and, in some cases, will probably be immobilized by facility failure. In systems that must revert to operator intercept, where all dialed calls go to an operator, fatigue would curtail effectiveness. The same fatigue will apply to central office personnel. Further, if the event occurs other than during normal working hours, the telephone companies will probably be without upper-echelon management and supervisory personnel during the initial post-earthquake hours; the transportation situation may be magnified because these personnel often live further from their office than journeymen. Another portion of staff will be unavailable because of normal vacation and illness.

It is likely that telephone company mobilization plans will be difficult to implement because of the exercise of other priorities by local and State government as well as limited transportation. The thousands of repair parts and materials needed for recovery may also be difficult to obtain.

In summary, the effects of a major earthquake on telephone systems will be dynamic and dependent on a multitude of events rather than on any single factor. This overall evaluation, thus, is highly subjective and must be considered only as a public safety planning document.

Post-Earthquake Telephone System Effectiveness

In the San Francisco Bay area the volume of calls that would follow the scenario earthquake would depend on the time of day that it occurred. After normal business hours, the immediate effect would not be as heavy and paralyzing to the telephone system in San Francisco, for example, with its high business concentration, as it would be in more heavily residential areas. Although the system in San Francisco has line access control, it is more isolated systemically. That is, unlike the Los Angeles metropolitan area, for example, it is very dependent on a few telecommunications arteries. Key system facilities are located near areas that will experience intense shaking. It is likely that the telephone systems in and to the south of San Francisco will have failures not readily compensated by alternative traffic routing. It is also probable that the recovery effort will be delayed because many company employees live outside the city limits and important transportation routes will be impassable.

The Oakland-East Bay and San Jose areas have a substantial number of telephone facilities located in areas subject to severe shaking and high probability of ground failure. Access to accomplish repairs will be a major problem. There are several telephone routing options with systems in this region having line access control and predesignated public safety circuits.

There is a very good system in San Francisco for identifying important public safety telephone circuits. These dedicated lines should be minimally disrupted. San Francisco's effectiveness rating, however, is quite low because local agencies will presumably require a great amount of outside assistance; the ability of the telephone system to meet these needs will be limited.

In Marin County, telephone system vulnerability was revealed during the 1982 storms. The geography and demography is such that alternate routing is limited. Key central offices are located in areas expected to suffer intense shaking. Many access routes may be impassable. This area is particularly susceptible to underground cable and surface cable carrier failure. Line load control is available but would not alleviate other systemic problems.

Because of shaking patterns corresponding with key facility locations, the area is likely to experience complete localized telephone failures on a block-by-block basis.

EDITORIAL NOTE: Scawthorn *et al.*, (1984) investigated the fire related aspects of the 1984 Morgan Hill earthquake (M6.2). Though their observations relate to an event of much smaller impact than the scenario earthquake, valuable insights relating to communications are offered, as follows:

"Communications were highlighted as an extremely necessary but vulnerable link in the firefighting effort. Reports of fires are too dependent on the telephone system. San Jose had a pull-box system until several years ago, when it was removed, and now relies solely on the telephone system for fire reports. Note that both major fires in San Jose were reported by citizens driving to fire stations. Fortunately, the stations were manned at the time. Had the units been out of the station at an emergency, the delays would have increased even more, causing small fires to become larger. In a larger earthquake, some damage to telephone equipment should be planned for. Immediately following the earthquake, Pacific Telephone experienced an increase of 84% over usual telephone use. The system is designed to handle this overload by causing a slowdown in response (delays in receiving a dial tone of about 30 seconds were experienced in this earthquake), which can be perceived as "the phones are out". The public and emergency officials must be educated to expect less than ordinary telephone response in a major earthquake, and to be prepared with alternative communication methods (e.g., the public should know the location of the nearest fire station; emergency officials should have in place standing automatic damage reconnaissance plans, involving aerial reconnaissance, block-by-block "windshield surveys" or other methods of quickly assessing the size of the problem, in order to optimally allocate resources)."

Radio Systems

Radio systems will generally operate at 40% effectiveness for the first 12 hours after the earthquake, increase to 50% for the second 12 hours, then begin a slow decline to approximately 40% within 36 hours. The long-term implications are that individual systems gradually will become less useful to the overall recovery effort when supplanted by systems relocated from outside the disaster area. It is unlikely that public safety radio systems would become saturated with non-critical communications from mobile units; it is clear, however, that radio traffic densities on redundant (non-emergency designated) channels would increase, particularly when remote base station and repeater failures would tend to limit the number of redundant channels available. Nonetheless, after 12 hours, at which time the number of operable units will have declined (with exhaustion of emergency power fuel) and recovery efforts will have restored some order, the radio traffic density problem will ease.

For each of the various components of a radio system, we anticipate specific effects under the scenario. These effects are described in the following component discussions:

Radio Control Consoles

Radio control consoles generally fall into three categories: self-contained tabletop base stations, tabletop control consoles for remote base stations, and full-size consoles using electronic circuitry (often very sophisticated) to control remote base stations. Both tabletop models are vulnerable to earthquake damage because they are rarely secured. While the self-contained station is more likely to remain functional than other types (since it doesn't rely on remote equipment), it is often not supplied with emergency backup power. System designs using control stations normally have such backup power provisions. Control consoles rely either on telephone or microwave circuits to access remote equipment. We do not anticipate continued microwave operation and cannot recommend telephone lines as an alternative, though such dedicated control circuits are more likely to remain functional than conventional telephone service. Sophisticated consoles are better protected against physical damage and normally have emergency power available, but they rely on telephone and microwave circuits and have an added problem of repair complexity. If a key component of a large console fails, many radio sub-systems would be fragmented, placing the burden of communications on outlying stations that are also vulnerable to earthquake damage. Further, software-based consoles would probably face additional complications within 12 hours. We estimate that self-contained tabletop base stations would be 40% effective, tabletop control consoles 55% effective, and large consoles 50% effective.

Base Stations

Radio base stations are often located on the roof of the same building housing the control console. In such cases, the condition of the building would determine post-earthquake performance. Even if cabling between the two units was to fail, base stations can be operated on-site via a microphone provided within the equipment cabinet. Dispatchers, however, are not normally aware of this and even more rarely have the key needed to gain access to the microphone. Remote base stations, located in a different building or in a mountaintop radio vault are subject to potential structural damage. Stations atop buildings are probably less vulnerable to wiring and component malfunctions than other installations but share the threat of telephone circuit interruption. We estimate that effectiveness will be 70% for local base station installations and 55% for remote stations, declining after 12 hours as emergency-power fuel supplies become exhausted.

Repeaters (mobile relays)

Repeaters are not dependent on control circuits and are normally provided with backup emergency power. Generally located atop mountains, they are vulnerable to structural, electrical, and other internal damage. Depending on the proximity of the fault source, they are more likely to experience technical problems than base stations. We estimate that repeaters will be 60% effective, declining as emergency power supplies are exhausted and technical problems develop, becoming 40% effective after 24 hours.

Antennas

We do not believe that antennas will fail on a large scale. Antennas and related structures should remain 70% effective.

Hand-held and Portable Two-way Radios

It is probable that hand-held radios will be valuable to field units during the first 12 hours after a major earthquake, particularly in a system that does not use repeaters. In any case, there are problems with charging and distributing batteries which have a life of about 12 hours. A unit equipped with one fully charged backup battery would be operational for no more than 24 hours. Without a large supply of backup batteries, these units are of limited benefit to the overall recovery effort.

Mobile (Vehicular) Radios

Assuming that gasoline supplies will be scarce and that transportation systems would be disrupted, the value of mobile radios would coincide with their distribution at the time of the disaster. We estimate that, functionally, high-powered mobile radios would be 75% effective for the first 12 hours, declining thereafter because of fuel and battery problems. At the same time, the mobile radio system as a whole would doubtlessly be compromised because of the distribution of the units. It is more realistic to consider mobile radios approximately 60% effective initially, declining thereafter. This estimate is for public agencies; should an earthquake occur after working hours, the effect on commercial systems will be more severe.

HAM and Other Amateur Radio

Amateur radio stations are subject to the hazards outlined earlier. A particularly vulnerable point is emergency power; most home base stations do not have backup facilities. Nonetheless, there is an extensive vehicular radio and repeater system in the amateur radio service. Much of the first post-disaster intelligence would come from this private sector resource and, as demonstrated in the 1985 Mexico earthquake, radio amateurs may be the only means of reaching the outside world. The amateur radio service should remain more than 50% effective because of pre-organization and the long distance capabilities of the equipment.

Citizens' Band Radio

We do not believe that CB radios will have an appreciable effectiveness in the public agency recovery effort, although there would be some post-disaster intelligence value. The units are too low-powered and are susceptible to frequency saturation. It is possible that CB "zones," each zone using a predesignated channel, could be established within neighborhoods for the self-help effort. Being the most accessible two-way communications resource available for the general public, Citizens' Band could be a significant element in the smaller recovery "cells" if users receive prior education and orientation.

Radio Common Carrier (RCC)

Radio common carriers will be subject to the events noted earlier for public agencies.

Aircraft and Marine Radio Communication

These radio services will be at least 80% effective provided that airfields are nominally accessible and there are no severe conditions that would significantly disrupt moored maritime resources. While there is much potential within either service for providing good quality emergency communications, existing land-based systems are completely incompatible. The overall effectiveness of marine radio must be equated to prior frequency coordination for marine transport systems. The relative importance of these radio services would increase as recovery efforts get underway.

Microwave Systems

Microwave systems have all the vulnerability of other radio systems plus additional problems related to narrow frequency tolerances, software controlled switching systems, and sensitive gain (directionability) tolerances. Additionally, many systems are not point-to-point but are linked through several points. The likelihood of failure in any one link is fairly great; therefore, we feel that microwave systems, with the possible exception of telephone microwave systems, will not extend beyond the affected disaster regions. Some circuits may remain operable on a point-to-point basis. It is estimated that most microwave systems would be 30% effective or less.

Satellite Communications

Remote satellite terminals relying on telephone or microwave circuits will be 40% to 50% effective, similar to radio base stations. Station proximate terminals will have a greater likelihood of survival approximating 70%. Because the satellites themselves are impervious to earthquake damage, they are one of the most significant resources for supplanted communications systems.

Data Communications

Communications systems used to support computers will be 40% effective. When facilities are not physically damaged, failures in air conditioning and environmental control systems may gradually reduce effectiveness.

Commercial Broadcasters

Some commercial stations generally will be able to provide emergency public information to the stricken area.

Medical Services Radio Systems

The VHF medical services radio frequencies are crowded and poorly coordinated. UHF repeater systems, while less saturated, are more vulnerable to damage and failure. There are insufficient channels dedicated to telemetry; these would be saturated and, therefore, virtually useless in any earthquake in which there is a large number of casualties. The hospital-to-hospital systems are also expected to fail. We do not anticipate medical radio services to function at an appreciable level of effectiveness.

General Comments on the Communications Scenario

The lack of emergency power has been the primary cause of radio and microwave communications failure in past disasters. Poor installation practices and inadequate preventative maintenance of backup power equipment contribute to a high failure rate.

The availability of repair parts and the ability to transport them are other factors when considering both short- and long-range implications. We believe that supplanted communications systems will be needed as local systems suffer earthquake-caused and normal equipment malfunctions for which there are no repair parts.

The current state of technology is such that communications technicians have specialized areas of expertise. The tools, test equipment, and repair parts they use are often suited only for the particular type of equipment a particular specialist works with. As a result, one specialist would have difficulty repairing equipment that is outside his area of specialization. Most radio technicians, for example, are unable to repair microwave equipment, military staff are unable to repair some types of public radio equipment, and microwave specialists are unable to assist telephone staff. This problem is further compounded by the unique characteristics of many systems otherwise generically related. Depending on the time of day the earthquake occurs, the number of technical staff available for repair services could range between 20% and 50% of the total for the first 24 hours. If it occurs between 1600 and 0600 hours, approximately 20% may be available in the first 24 hours, 40%

in 48 hours, and 70% in 72 hours. If the disaster occurs between 0600 hours and 1600 hours, some personnel would be disabled, isolated, or occupied with verifying the status of their families: 50% will be available for the first 24 hours, 60% in 48 hours, and 70% in 72 hours. The effectiveness of technical personnel is severely affected by the availability of transportation. In many cases, for example, helicopters would be needed for access to remote sites. Technical staff would only be able to support the continued operation of systems at a level of post-disaster effectiveness. After approximately one week, system performance would begin improving.

The regulation of communications has necessarily separated users to avoid mutual interference. One result of this separation is mutual exclusion. Except in rare circumstances, two adjacent communications systems are physically or functionally incompatible. The greatest danger to a post-earthquake recovery effort is the absence of an adequate interface between systems. This applies equally to local systems and systems drawn from outside the disaster area.

Planning Considerations

A general communication plan should be developed for use, following the earthquake, by appropriate agencies and personnel with emergency response roles. This plan should anticipate the needs of the most vital parties.

Reliance on emergency telephone communications should be kept at a minimum. A strategy should be developed for communication to the general public that relies on the capabilities of surviving commercial radio and television stations.

An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan.

A survey of existing critical communications facilities should be undertaken by structural engineers leading to development of improved equipment installation standards.

There is need for a continuing technical examination and overview of alternative means of communication (e.g., satellite) with the object of working out regional plans for communication between emergency workers and the public at large.

Planning Scenario

On Map 3-C, there are no notations for specific sites or facilities. As explained on the map, areas are zoned according to the level of telephone system effectiveness expected during the first three days following the earthquake. Four levels of expected effectiveness, ranging from highest to lowest, are shown. Zone A areas are those expected to have the highest levels of post-earthquake effectiveness, and Zone D areas the lowest.

ELECTRICAL POWER

General Characteristics

The principal distributor of electrical power throughout the San Francisco Bay area is the Pacific Gas and Electric Company (P.G.&E.). Power facilities within the planning area include four major power plants (two in San Francisco and two in Contra Costa County at Antioch and Pittsburg), several small power plants, and an extensive network of major substations and interconnecting transmission lines that comprise the regional framework for the local distribution systems (see Map 3-E). Other major power facilities in the region that contribute significantly to the electrical power needs of the Bay area are located at Moss Landing and at The Geysers but these will not be significantly impacted by this scenario earthquake.

Seismic Considerations

Power Plants

According to the NOAA report (1973, pg. 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 (M6.4) was negligible though estimated ground motion at this plant was intensity VIII (MM). Plants, auxiliary switchyards, and other ancillary facilities located in areas of high ground water or poor soil conditions (such as Bay mud), however, are susceptible to significant damage as a result of ground failure.

The capacity of the major power generating facilities affected by this earthquake, aggregating about 7000 MW, is principally derived from the Moss Landing Power Plant, the four major plants in the Bay area, and those at The Geysers. Given the assumptions set forth in the damage assessments that follow, it is possible that only about two-thirds of this locally generated capacity may be available for some extended period following the scenario earthquake. This conclusion is based on the possibility of damage to transmission lines as well as damage to the affected plants and their related facilities.

While the impact of potential loss of this locally generated capacity is significant, the net impact on the heavily damaged metropolitan service area can be ameliorated. Because P.G.&E. has access to other sources of power from outside the affected area, it will be possible to reroute power to some consumers. Consumption of power will be far less than normal while both power generation and consumer facilities are being gradually restored. For planning purposes, all emergency operations and support systems necessary for responding to the scenario earthquake should be reviewed for alternate power sources.

Substations

Transmission substations are essential to the routing of locally generated power and of power available from outside the region affected by the earthquake. These major substations, which contain banks of switches, circuit breakers, and massive transformers, are particularly vulnerable to damage by earthquake shaking. In addition to the major transmission substations through which high voltage is routed, many small local substations provide the vital links in the electrical power distribution network.

The conclusions of this investigation regarding the substations are in general agreement with those presented in the NOAA report. "Despite their good anchorages to power poles, to rails, and the like, many hundreds of (pole-mounted distribution) transformers will be knocked out, and some will burn as they have in other earthquakes. Switch-gear damage will result in serious power outages. Failure of porcelain insulators will additionally result in significant numbers of power failures". It is important to note the distinction between transmission and distribution transformers. Replacement of a large transmission transformer can take several days, with resulting implications on the extent and duration of power outage. The availability of replacement high-voltage equipment is another vital planning consideration.

Transmission Lines

Transmission towers and lines are principally subject to damage through secondary effects such as landslides and other ground failures. Conductor lines swinging together (usually distribution lines) could cause many burn-downs.

Within the planning area, numerous major transmission routes traverse extensive areas subject to intense shaking or ground failure. Major 230 kv transmission lines serving the San Francisco Peninsula are routed across and around the perimeter of the south Bay and along the west Bay margin to San Francisco. Similar high-voltage lines serving Marin County traverse southern Napa and Sonoma Counties. Lengthy segments of these facilities are located in Bay mud subject to ground failure. Other major transmission lines, particularly those located near and across the Hayward fault in Contra Costa and Alameda Counties, are vulnerable to surface fault rupture and landsliding.

In view of the fact that numerous major routes are exposed to these hazards over extensive distances, it is a reasonable expectation that some of these major lines will be out of service because of damaged and collapsed towers. While the loss of a few towers would not pose a formidable situation, damage could be widespread and significantly compounded by landslides during a wet winter season or by fire caused by fallen lines during the dry season.

Planning Considerations

The occurrence of the scenario earthquake will have a significant impact on many of the major facilities that comprise the complex electrical power network serving this major urban area (See Map 3-E.). Damage to power plants and their ancillary facilities within the planning area and in adjacent areas affected by the earthquake can be expected to result in a reduction of about a third in the combined generating capacity. The impact of this reduction in local output is lessened, however, 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 scenario earthquake. Immediate concerns will focus on repairs necessary to restore power within the damaged areas of greatest need. Major restoration problems include repairs necessary to route power through the major substations, restoration of damaged and collapsed transmission line towers, reactivation of equipment at local substations, and replacement of fallen poles, burned transformers, etc.

On Map 3-E, numerous substations are located within areas of predicted intensity IX and in areas having potential for ground failure. Based on this intensity pattern, it is a reasonable expectation that each of these stations will sustain some damage. In the absence of site-specific engineering and geologic evaluations, it is prudent for emergency planning purposes to conclude that damage is likely to occur at some substations sufficient to seriously impair or curtail their performance. It should be noted that the utility has considerable flexibility with regard to routing power flow and, therefore, temporary reassignments may be possible.

Recovery time for transmission of electrical power will vary from place to place in the Bay area, but Alameda and Contra Costa Counties can be expected to be without power for the most lengthy period. Steinhardt (1978) points out that "in a great earthquake, a large number of users will be without power, temporarily at least, and that.... It is reasonable to expect that the rate of service restoration will exceed the rate of recovery of customer demand." On the other hand, the NOAA report (1972, p. 182-183) states that "the repair of the very extensive damage will require logistic support which, in our opinion, will require many days to restore even all vital services. It must be remembered that blocked streets and roads, higher priority medical requirements, and aftershocks preclude any perfect response effort to the power outages to be expected. The unexpected can and does happen as it did in the power blackouts a few years ago in the northeastern states."

Society has evolved to where it is highly dependent upon a continuous supply of electrical power to meet a myriad of everyday needs. Indeed, the human environment within modern high-rise structures is entirely controlled by it. Consequently, all individuals as well as all entities responsible for maintenance of lifelines and critical facilities, should examine their ability to function in the event of a prolonged absence of electrical power.

ALL CRITICAL FACILITIES IN THE SAN FRANCISCO BAY AREA SUCH AS HOSPITALS, FIRE AND POLICE STATIONS, EMERGENCY COMMUNICATIONS AND OPERATIONS CENTERS, AND WATER PUMPING STATIONS WILL REQUIRE STANDBY GENERATING EQUIPMENT AND EMERGENCY FUEL SUPPLIES.

At the individual citizen level, the following comments are pertinent. Discussing the lack of electrical power in Santa Cruz County that resulted from landsliding during the intense storm of January 4, 1982, Stegner (1982) concluded:

"It may be a long time before we need to dig out our old boy scout manuals again, but, while we sit around waiting for the killer earthquake that everybody seems to regard as inevitable, we might take a lesson from the killer storm that nobody expected. The difference between misery and comfort, relatively speaking, may be no more than a can of kerosene and a can of gasoline in the garage, a can of soup in the larder, and a half dozen flashlight batteries in the kitchen drawer. What was the motto? Be prepared?"

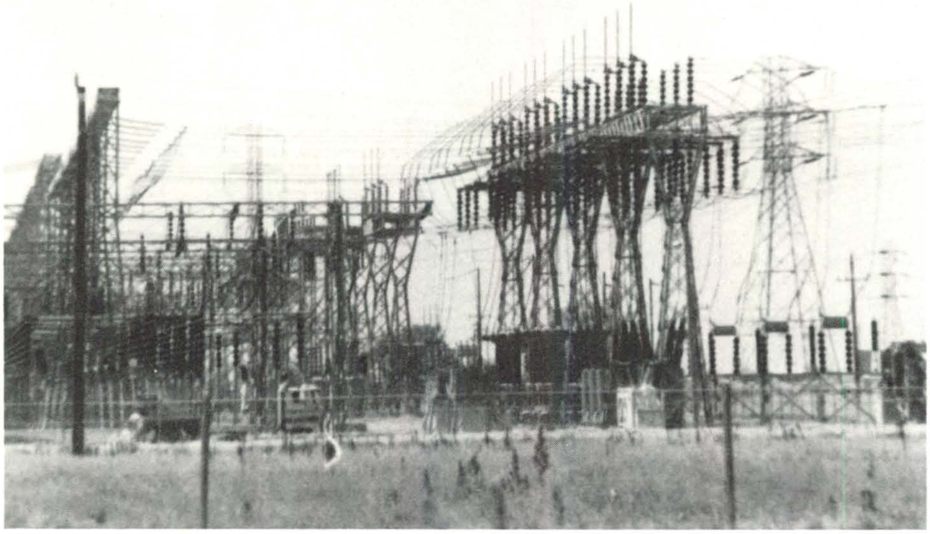
An intensive public education program to condition people to expect power outage after the earthquake is clearly appropriate.

The critical power corridors and facilities should be examined in light of the best geologic data available to assess the vulnerability of specific elements in the electrical power network. Capability to respond and accomplish timely repairs to a widespread affected area as described in this scenario needs to be evaluated further. Other lifelines that are discussed in this report, especially water supply, waste treatment, and communications, will be affected by interruptions in electrical power. Strategies for repair of facilities must take into account the post-earthquake feasibility of ground, marine and air transportation. Strategies for rerouting power into the area to augment decreased capacity within the region should also be emphasized. Public education should be undertaken to prepare people to contend with the power outages.

Planning Scenario

It is a reasonable judgment that, during some portion of the first 72-hour period following the earthquake, virtually all portions of the planning area will have experienced some loss of power, at least temporarily. It is reasonable, for planning purposes, to consider about a third of the service connections in the planning area to be without power for 24 hours. In the urban sections of Oakland and other East Bay cities, the power outage should be considered at 100% for 24 hours, and thereafter at 75% for an additional 24 hours. This means that 75% of the customers have no power and not that all customers are limited to 25% of demand. The power outage for San Francisco should be considered at 50% for 24 hours, and thereafter at 25% for an additional 24 hours.

Electrical power facilities in the East Bay are particularly vulnerable to damage from the scenario earthquake, and the time that it will take to restore full power under the best of conditions could be prolonged. While the resources may be available to rapidly deal with repairs to the system, the confusion and damage to such lifelines as communications and highways will create a substantial challenge. Realistically, power is unlikely to be restored to many areas for extended periods of time. Emergency planning for power-dependent systems such as communications, water supply, fire fighting, and waste treatment should be cognizant of this likelihood.



Elements of a major Bayside power transmission substation vulnerable to damage from high intensity shaking and potential ground failure.

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 3-E.

MAP NO. FACILITY - COUNTY

E1 Moss Landing Power Plant - Monterey Co.

Moss Landing Power Plant is located on Monterey Bay, some 50 km or 30 miles south of the southern limit of surface rupture on the Hayward fault, as assumed in this scenario. The 1868 Hayward earthquake produced intensity VII effects in the Moss Landing/Santa Cruz area. The 1836 earthquake, also attributed to the Hayward fault, caused "...havoc in Monterey and Santa Clara, and arousing great fear among the people. Intensity was apparently at least VII (R/F) at Monterey and Mission Carmel." (Louderback, 1947). This area suffered extensive ground failure due to liquefaction during the 1906 earthquake (Youd and Hoose, 1978). It is considered unlikely, however, that damage from this scenario earthquake would seriously impact plant operations.

E2 Potrero and Hunters Point Power Plants - San Francisco Co.

The Potrero and Hunters Point Power Plants, located near the Bay margin and subjected to intense shaking and ground failure, are shut down for more than 72 hours.

E3 Pittsburg and Contra Costa Power Plants - Contra Costa Co.

Though the prospects of significant damage to these plants is probably remote, both the plants and their related facilities are located on or near Bay mud, which may be subject to ground failure. For planning purposes, therefore, we have assumed that sufficient damage will occur to plant facilities to reduce the combined power output of the two plants by 30 percent.

E4 Moraga Transmission Line - Contra Costa Co.

This power transmission line to the East Bay crosses a large landslide immediately west of the Moraga substation, and while the substation will survive both the shaking and a reactivation of the landslide, the transmission line will not.

E5 The Geysers Geothermal Area - Sonoma/Lake Co.

Currently, some fifteen power plants in The Geysers Geothermal Area have a total generating capacity of about 900 MW. Turbines are driven by steam piped to the plants from some 200 wells. Power generation at The Geysers is not affected by this earthquake.

E6 Richmond/Antioch Fuel Line - Contra Costa Co.

The oil supply pipeline between Richmond and the Pittsburg and Contra Costa Power Plants crosses areas susceptible to ground failure. A specially designed pipe crossing of the Hayward fault in San Pablo minimizes damage at this location. For planning purposes, the line may be quickly repaired, but there may be extensive delays in obtaining fuel from this source (see section on "Petroleum Products."). The availability of electrical power for pumping and the integrity of pumping equipment may be the most critical considerations.

E7 Oakland Power Plant - Alameda Co.

This relatively small plant is susceptible to intense shaking and ground failure. For planning purposes, this plant is shutdown for more than 72 hours.

E8 Martin Substation - San Mateo Co.

This substation is located in an area of predicted intensity VIII shaking and possible ground failure. Some damage to equipment at this station is a reasonable expectation. Routing of power through this critical facility constitutes a major consideration in the planning for restoration of power to San Francisco. This facility is deemed to be 90% functional after 24 hours.

E9 Ignacio Substation - Marin Co.

This critical substation handles all power routed south into Marin County. Prudent planning should allow that this facility, founded on shallow Bay mud, is seriously damaged by shaking or ground failure.

E10 Claremont Substation - Alameda Co.

This facility, located within the Alquist-Priolo special studies zone, is heavily damaged and 100% nonfunctional.

E11 Fremont Substation - Alameda Co.

This facility, located within the Alquist-Priolo special studies zone, is heavily damaged and 100% nonfunctional.

E12 Newark Substation - Alameda Co.

This major substation, vulnerable to intense shaking and potential ground failures, is heavily damaged.

E13 Transmission Lines/North of San Pablo Bay - Sonoma Co.

Ground failures damage several towers resulting in shutdown of this transmission line.

E14 Transmission Lines/East of San Jose - Santa Clara Co.

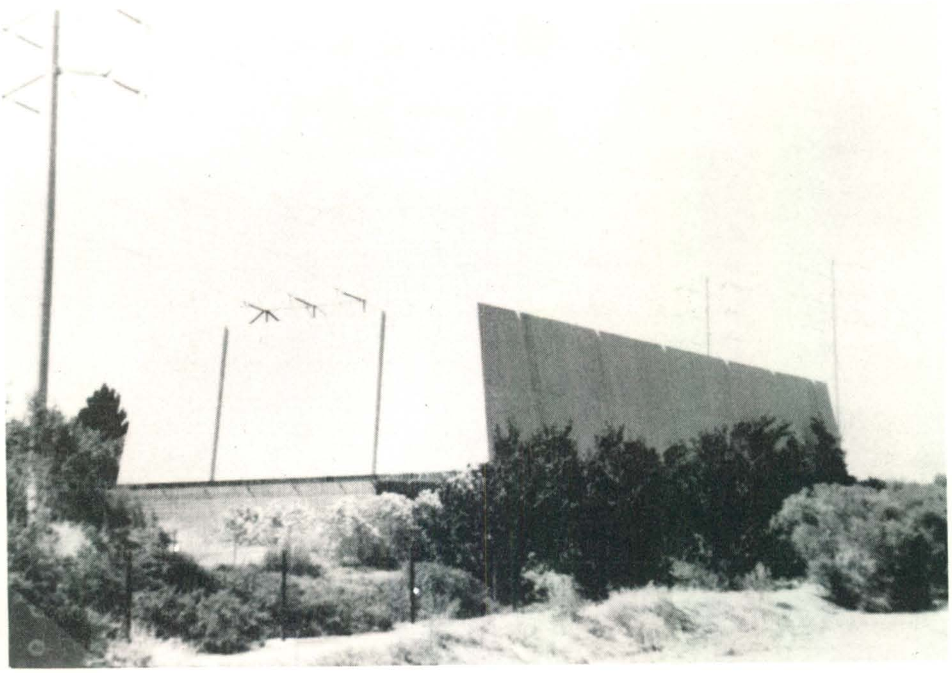
Landslides damage several towers south of Calaveras Reservoir resulting in shutdown of this transmission line.

E15 Transmission Lines/Foster City Area - San Mateo Co.

Ground failures damage towers south of Foster City resulting in shutdown of this transmission line.

E16 Transmission Lines/Fremont - Alameda Co.

Surface rupture has collapsed two towers, resulting in shutdown of these power lines. Fallen lines, surface rupture along I-680, and damage to major gas transmission lines create a major problem and closure of I-680 at this location.



Fremont Substation

WATER SUPPLY

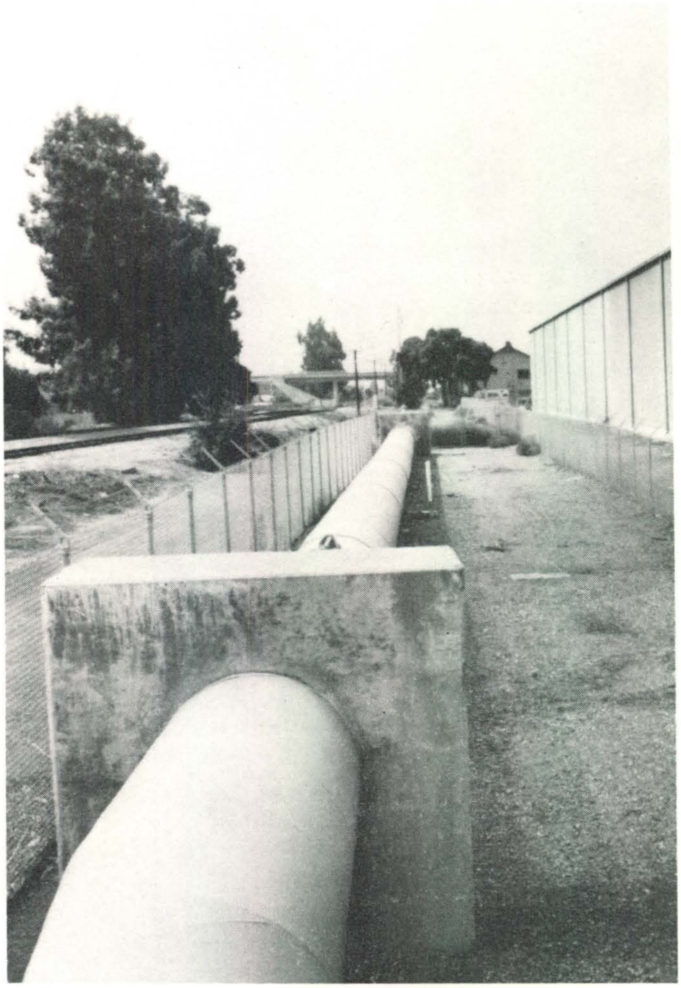
General Characteristics

The major aqueducts that convey water from distant locations to virtually all parts of the planning area, including the cities of San Francisco and Oakland, are shown on Map 3-W. Also shown are local storage reservoirs, the principal transmission pipelines, and their relationships to the Hayward fault.

The city of San Francisco and a number of municipal utilities in San Mateo, Santa Clara, and Alameda Counties receive water imported from the Tuolumne River in the western Sierra Nevada via the Hetch Hetchy Aqueduct which is operated by the City of San Francisco. The south Bay area and Livermore Valley have received imported water from the South Bay Aqueduct since 1965. Santa Clara County will soon receive its first water deliveries from the U.S. Bureau of Reclamation's (USBR) San Felipe Project (water from San Luis Reservoir via Pacheco Tunnel). Most of the East Bay receives its water from the Sierra Nevada via the East Bay Municipal Utility District's (EBMUD) Mokelumne Aqueducts. Contra Costa County imports water via the Contra Costa Canal from the Sacramento-San Joaquin delta.

Southern Sonoma County is dependent on the Petaluma and Sonoma Aqueducts to deliver water south from the Russian River. Southern Solano County receives water via USBR's Putah South Canal, from which water is also delivered to southern Napa County through facilities of the North Bay Aqueduct. Marin County is largely dependent upon locally developed water storage facilities.

In addition to imported water supplies, many communities of the Bay area are also dependent to various degrees on groundwater. In the Santa Clara Valley, for example, more than half of the water supply is from groundwater. The county-wide Santa Clara Valley Water District manages this major resource as well as the imported water supplied to the many water retailers throughout the County.



Major water transmission pipeline at a crossing of the Hayward fault in Fremont. This section of the pipeline has been constructed on the surface to accommodate fault creep and facilitate repairs necessitated by fault rupture.

TABLE 6

Water Retailers and Water Sources in the East Bay and Santa Clara Valley

Municipal Agency	Source of Water
Hayward	Hetch Hetchy
Cupertino	Groundwater, South Bay Aqueduct
Gilroy	Groundwater
Milpitas	Hetch Hetchy
Morgan Hill	Groundwater
Mountain View	Groundwater, Hetch Hetchy
Palo Alto	Hetch Hetchy
San Jose	Groundwater, South Bay Aqueduct, Hetch Hetchy
Santa Clara	Groundwater, South Bay Aqueduct, Hetch Hetchy
Sunnyvale	Groundwater, South Bay Aqueduct Hetch Hetchy

Water Agency	Source of Water
East Bay Municipal Utility District (serving East Bay from Crockett to North Hayward)	Mokelumne Aqueducts
Alameda County Water District (serving Union city, Newark and Fremont)	Groundwater, South Bay Aqueduct Hetch Hetchy
California Water Service Company (serving parts of Los Altos, Cupertino, Sunnyvale, Mountain View)	Groundwater, South Bay Aqueduct
Campbell Water Company (serving parts of Campbell)	Groundwater, South Bay Aqueduct
Great Oaks Water Company (serving South San Jose)	Groundwater
Purissima Hills County Water District (serving parts of Los Altos Hills)	Hetch Hetchy
San Jose Water Works (serving parts of San Jose, Campbell, Saratoga, Monte Sereno, Los Gatos	Groundwater, Surface Reservoir Storage, South Bay Aqueduct
Moffett Naval Air Station	Hetch Hetchy
Stanford University	Groundwater, Surface Reservoir Storage, Hetch Hetchy

Seismic Considerations

EBMUD's water system is particularly vulnerable to damage resulting from a major earthquake on the Hayward fault, especially to the tunnels that cross the fault and where filled lands exist. That portion of the system west of the fault serving the East Bay communities from San Pablo to Hayward (but not including Hayward) is particularly vulnerable. This assessment of earthquake hazards and potential damage focuses principally on EBMUD, but the statements are also applicable to the other water utilities that serve the communities south from Hayward to the San Jose area.

Creep on the Hayward fault has been noted in EBMUD's Claremont Tunnel (Blanchard and Laverty, 1966) where a total of 17 centimeters (cm) of lateral movement occurred between 1929 and 1966 (4.5 mm/yr). A similar amount of horizontal creep has been observed where San Francisco's Hetch Hetchy steel pipe aqueducts cross the Hayward fault in Fremont, but without noticeable damage to either of these two surface lines.

Within the past 10 years, EBMUD has conducted a program in which all of the weaker dams in their system were rebuilt to improved seismic standards. This program has reduced the potential for possible catastrophic dam failure to the extent that this prospect is not regarded as a credible part of this scenario. Smaller distribution reservoirs, however, may present problems, particularly those within the Alquist-Priolo special studies zone in Berkeley and in the hills elsewhere along the zone.

Long-term construction programs to reduce earthquake vulnerability are continuing. For example, in Oakland a new 48-inch line has been built at some distance away from the fault to parallel and provide bypass capability for the existing Sequoia Aqueduct.

Accepting the likelihood that a major earthquake will ultimately disrupt one or more tunnels that cross the fault, supplies necessary for tunnel repairs have been stockpiled east of the fault at Orinda Filter Plant and are clearly marked and located outdoors.

EBMUD's many pumping stations are dependent on PG&E for electric power, and on-site emergency standby power cannot replace this source. One of three pumping units of the Maloney Pumping Plant near El Sobrante uses natural gas. Portable electric generators provide emergency power for many pumping stations. Fire engine booster connections between zones are in place.

While San Francisco and the Peninsula receive water from the Hetch Hetchy lines that cross the Hayward fault, storage behind Crystal Springs Dam is more than sufficient for the west Bay for the duration of any aqueduct closures.

It is expected that distribution reservoirs will suffer moderate damage. Underground reservoirs, with column and beam support roofs, could suffer extensive roof collapse. Distribution reservoirs of welded or bolted steel construction will suffer little damage, but pipe connections will be severed in some cases. Redwood tanks are not expected to perform well when subjected to heavy shaking.

Pumping plants will suffer damage closely related to the soil materials on which they were constructed, and damage will be primarily related to pipeline rupture and electrical control center damage.

Distribution pipelines vary from 2 inches to 54 inches or more in diameter in approximately 3,400 miles of pipe in the EBMUD system. Pipe materials vary from cast iron to welded steel and asbestos cement to a variety of plastic materials. The damage to distribution pipelines is expected to vary with pipe materials, soil type, topography, and design installation practices, as well as the shaking intensity and degree of ground failure. For this reason, installation of automatic water shut-down equipment should, in most cases, be avoided.

It is anticipated that all water systems within the region will suffer some damage. Depending on local conditions, the population impact may be small, or catastrophic. In areas of intense shaking and/or ground failure, it will not be unusual to find that there are 2 to 4 main breaks in every residential block where cast iron or asbestos cement pipe is used. Where such general damage to the water distribution system occurs, restoration of water mains begins at the lowest topographic point, progressing uphill so that broken sewers in the same areas do not contaminate still broken water lines.

The difficulty in determining the extent of damage to the distribution system is that leaks may not be locatable until water pressure is restored. For this reason, it will take weeks to totally repair damage in densely populated areas. Fresh water for domestic purposes will have to be supplied by tanker trucks to affected neighborhoods. Fire fighting efforts will in some areas be seriously hampered during the first 72-hour period, and possibly for as long as two weeks. This condition derives not only due to a lack of water, but also because of blocked streets, insufficient manpower, and possibly structurally damaged fire stations.

As in 1906, distribution system damage and water outages will occur in the structurally poor ground areas bordering the Bay. Elsewhere, the water distribution system is expected to remain mostly intact, and significant outages will be few and controllable, commensurate with availability of spare pipe, fittings, degree of repair crew efforts and accessibility. For scenario purposes, 90% of the water outages in the structurally poor ground areas should be restored within 3 weeks by above-ground piping similar to that which was used in San Fernando.

Water treatment plants close to the Hayward fault, or those built in structurally poor foundation material, may experience differential settlement significant enough to shut down for damage assessment and repairs. The ability to bypass these plants and to provide emergency chlorination will be crucial during the initial 72 hour post-earthquake period.

Chlorine facility anchorage and chlorine spill control programs will determine the degree to which chlorine spills threaten population near both water and waste treatment plants.

Planning Considerations

The water supply to the Bay area is provided by several systems. The vulnerability of each of these systems must be appraised. The individual components of each system--the water source, aqueducts, local storage reservoirs (including dams), pumping stations, transmission pipelines, and distribution lines must be viewed in the context of the entire system and its performance. Impairment of any one major element could seriously compromise the performance of the entire system. For emergency planning purposes, it is important to recognize that this effect makes each system's overall performance more vulnerable than casual examination of individual components might suggest. Disruption of water service in the East Bay cities due to earthquakes will not result from poor planning, but rather, from geologic and geographic conditions.

It is essential that all water agencies examine their transmission and distribution systems 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.

Capabilities to provide emergency distribution of water using ground transportation needs to be planned in areas identified as having a significant possibility of water system damage.

While there should be ample water storage in the numerous Bay area raw water reservoirs to satisfy all water demands during the period aqueduct repairs are in progress, damage to treatment plants and distribution systems may prevent deliveries to all service areas. In the short term, the loss of electrical power will prevent pumping water to many areas at higher elevations and, therefore, only undamaged gravity systems will be able to provide a continuous water supply. This makes earthquake-resistant storage important in the East Bay hills and on the Marin and San Francisco Peninsulas where a substantial population resides at higher elevations.

In the EBMUD service area, it is unlikely that the entire system would be incapacitated. Initial efforts would be directed to damage assessment and water redistribution. EBMUD has six water treatment plants, 165 distribution reservoirs, and 120 distribution pumping plants. Adjustment of valves in the distribution system permits water deliveries by many different routes.

As has been noted, a number of public utilities provide water to the various communities in the San Francisco Bay 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 at district boundaries. During a recent several year drought in which southern Marin County's water supply essentially ran out, an interconnection from East Bay Municipal Utility District to Marin Municipal

Water District was provided by a lengthy temporary pipeline over the Richmond-San Rafael Bridge. A major earthquake on the Hayward fault at that time would have been disastrous for Marin. Similar connections are in continuous planning and implementation stages.

It is perhaps appropriate at this time for federal and state planners to examine the possibilities of funding adequate-size interconnections between water supply utilities. Interconnecting pipe and appropriate valving between adjacent aqueducts and major distribution lines lying between the San Andreas and Hayward faults is one possibility. It should be recognized that this would be an unbalanced mutual aid plan in some cases. For example, Crystal Springs Reservoir will probably be able to supply San Francisco when either fault ruptures. This is not true for the East Bay cities. This need not preclude an examination based on federal, state, and local viewpoints and higher public needs.

Planning Scenario

For disaster response planning purposes, the 5 foot average displacement along the Hayward fault will heavily damage all major tunnels and aqueducts that cross the fault zone. Similar damage will occur to the many treatment facilities and distribution water lines that cross the fault. The flow of water crossing the fault will be reduced to 10-30% for the first 24 hours. For a period of time (1 day minimum, 3 days maximum), some segments of the population will be asked to use emergency supplies, boil their water, or take other safety measures against contamination.

The 54" welded steel pipeline from Sobrante Filter Plant that crosses the fault at San Pablo will be ruptured. Because it is accessible, this line could probably be returned to service within 48 hours. The EBMUD system west of the Hayward fault could well be dependent on treated water supplies via this route for two weeks. Untreated water should be available to the system from Upper San Leandro Reservoir, but damage to treatment and distribution facilities located near and across the fault at this location could involve an extended period for repairs.

For purposes of disaster response planning, Berryman Reservoir in Berkeley is assumed to fail, and Summit Reservoir at Kensington in Berkeley is assumed to be badly leaking. Both threaten downstream populations. Other reservoir damage will occur, but will not present significant risks to downstream populations.

Older reinforced concrete structures, such as those located at filtration plants along the fault, will be damaged and some partial failures will occur. Equipment repairs and water bypasses will render the water supply system functional in several days.

Due to the public's crucial need for water, it is assumed that highest priorities will 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 all areas east of the fault in the Berkeley/Oakland hills will be delayed and, when available, is expected to be on a restricted basis. Many lines in and near the Alquist-Priolo zone 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.

Water supply systems are expected to be moderately to severely crippled in this major scenario earthquake. Restoration of full service could take months.

(See Page 190 for "Damage Assessments" of Water Supply and Waste Water Facilities)

The two trans-Bay Hetch Hetchy pipelines at the Hayward fault crossing in Fremont.

WASTE WATER

General Characteristics

Many sewage treatment plants, or waste water disposal facilities, are located throughout the study area (Map 3-W). For functional reasons, these are generally located along the Bay margins. Some of these systems involve gravity flow from the service area to the plant with discharge in an outfall line to the Bay. Others require pumping for all or part of their operation. A notable example of the latter is the "Super Sewer" between San Leandro and Fremont (and from the Livermore Valley). The major treatment facilities of EBMUD's Special District Number One, located adjacent to the Port of Oakland at the eastern end of the Bay Bridge and its approaches, are highly dependent on electric power for pumping and other uses.

Waste water treatment plants have only limited storage capacity. If the treatment sequence cannot be reestablished before storage capacity is exceeded, then the waste water will be discharged with emergency treatment to reduce pollution hazards. Damage to system components at facilities along the Bay margin and prolonged lack of electrical power for pumping will necessitate sewage discharge directly into the Bay at designated bypass locations. In the Bay area, the general discharge of raw sewage can be expected to pollute most waterways, channels, harbors, and beaches, posing a public health risk requiring public notice.

Seismic Considerations

The vast majority of the many wastewater treatment plants are located on structurally poor ground that is highly susceptible to failure. Individual massive structures, however, may be well designed and supported by piling or, in some instances, by specially engineered fills intended to compensate for the poor soil conditions. In general, the contiguous trunk sewers and outfalls are similarly located in structurally poor ground.

The impact of the earthquake may be considered from three standpoints: a. Damage to the collection system, b. Damage at the treatment plants, and c. Discharge of untreated or poorly treated sewage into the Bay.

Damage to collection systems will be similar to that experienced by water supply systems. Landslides, particularly at the end of a prolonged wet season, will cause extensive damage to the collection system in the hill areas. Soil liquefaction in the structurally poor ground areas will also damage the collection system--see Map 3-W to identify areas where outages are most likely to occur. Temporary facilities on every city block, such as the portable sanitary facilities used on construction sites, will probably have to be provided as they were after the 1971 San Fernando earthquake. Alternatively, temporary housing must be used or raw sewage may be allowed in open trenches, an obviously undesirable solution.

Buildings and other special structures found at treatment plants are usually earthquake resistive. In poor ground areas, the larger buildings and other major structures are normally on pilings and should survive without any major structural damage. Internal appurtenant piping and equipment are generally earthquake braced, and intended for heavy duty. However, equipment cannot function without electric power. Building penetrations by pipes or conduits will be likely points of damage.

Damage is likely in structures containing rotating equipment or other moving devices, with the damage being due to the wave action of sloshing (oscillating) liquids. Differential settlements are expected where underground piping and sewer lines are laid in trenches and then connected to buildings on piling. The result of these differential settlements is to break the settling pipe (in soil) where it joins the building (on piling).

The quantity of waste water to the treatment plants is expected to diminish immediately after the earthquake due to the closure of industrial plants and the reduction in the supply of potable water.

Planning Considerations

Massive discharge of raw or poorly treated waste water into the Bay will undoubtedly cause public concern. While it may be rational to give low priority to restoring these facilities, it seems appropriate to review this with the environmental agencies at all levels of government. At the least, public announcements should be readied for distribution immediately after the earthquake. Review of the adequacy of chlorination storage, piping, and machine tie-down is of utmost concern. Adequate chlorine spill control programs are vital for all affected waste water stations.

Planning Scenario

For planning purposes, the flow capacity of the collection system in the landslide areas and in the poor ground areas as shown on Map 3-W will be reduced by 50%, and 50% of the area will be nonfunctional. The main collectors in these areas will be damaged, but will retain 75% of their capacity wherever gravity flow is possible.

Lines from the hillside areas that cross the Hayward fault will be sheared and unable to carry fluids. Open trenches may be used to carry raw sewage for short distances. Alternatively, planners will have to provide for emergency housing or temporary sanitary facilities.

Treatment plants will shut down due to lack of power. EBMUD's special electric power system which uses methane gas from its treatment plant will be unable to support full plant function. Power requirements will diminish as the quantity of arriving waste water diminishes, but almost concurrently the production of methane fuel will be similarly reduced.

Restoration of power will be a function of priorities. It is probable that preference will be given to direct life support operations such as water systems, hospitals, housing, transportation, and others. If so, then emergency treated raw sewage will be discharged into the Bay for an extended period. This condition is expected to exist for up to one month at EBMUD's Special District Number One (located adjacent to the Port of Oakland) as well as at other waste water facilities.

Damage Assessments

(Water Supply and Waste Water Facilities)

Damage assessments have been postulated for certain water supply and 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 evaluations. Locations of facilities are shown on Map 3-W.

MAP NO.	FACILITY - COUNTY

W4 Hetch Hetchy Pipelines (Trans-Bay lines) - Alameda Co.

The Hetch-Hetchy Aqueduct pipelines are severely damaged by fault rupture where they cross the fault just west of Paseo Padre Parkway in Fremont, resulting in substantial water loss at this location until shut-off valves are activated.

W5 Hetch Hetchy Pipelines (south Bay route) - Alameda Co.

These Hetch-Hetchy pipelines are severely damaged by fault rupture where they cross the fault at the Interstate 680/Mission Blvd. interchange in Fremont. Water loss from these pipelines further complicates matters at this major highway interchange, already damaged by fault rupture.

W6 Oakland/Alameda Estuary Crossing - Alameda Co.

Two of three cast-iron pipelines that cross the estuary supplying the city of Alameda rupture.

W7 Penitencia Water Treatment Plant - Santa Clara Co.

This water treatment plant and adjacent South Bay Aqueduct terminal facility are inoperative for more than 72 hours because of seismically triggered landslide displacements.

W8 South Bay Aqueduct - Alameda/Santa Clara Co.

This facility of the State Water Project, conveying water to the Santa Clara Valley Water District, is damaged at several locations between Mission San Jose and the terminal facility (see W7 above) as a result of fault rupture and seismically triggered landslide displacements.

W10 Bon Tempe Water Treatment Plant - Marin Co.

The Bon Tempe treatment plant will be out of service because of landslide damage and electrical power failure.

W11 Southern Marin Pipeline - Marin Co.

This section of the Southern Marin Pipeline from Bon Tempe treatment plant is ruptured due to slope failure.

W13 North Bay Aqueduct - Solano/Napa Co.

Facilities of the Putah South Canal and North Bay Aqueduct are undamaged; some damage does occur at the treatment plant in Jameson Canyon.

W14 Petaluma Aqueduct - Sonoma/Marin Co.

This facility is damaged by shaking and ground failure near Novato.

W15 Well Field at Fremont - Alameda Co.

Water supplies from this well field operated by the Alameda County Water District at Fremont are interrupted due to loss of power and damage to facilities. The earthquake and continuing aftershocks produces excessive turbidity for an indefinite period, with the loss of some wells.

W16 Berryman Reservoir - Alameda Co.

This reservoir and dam in the Berkeley Hills is, for the purposes of emergency planning, assumed to fail as a result of fault rupture.

W17 Summit Reservoir - Contra Costa/Alameda Co.

This reservoir is assumed to be damaged and leaking to the extent that the downslope population within a limited affected area must be evacuated.

W18 San Pablo Tunnel - Contra Costa Co.

This raw water supply tunnel is effectively closed where it passes through the fault zone beneath the Berkeley Hills between San Pablo Reservoir and the west tunnel portal in El Cerrito.

W19 San Pablo Pipeline - Contra Costa Co.

This major water supply line from Sobrante Filter Plant to the East Bay distribution system sustains major damage where it crosses the fault on El Portal Drive in San Pablo. Rapid repairs to this line will be required to furnish water to the system.

W20 Claremont Tunnel - Alameda Co.

This primary conveyance facility supplying treated water from the Orinda treatment plant to the metropolitan area is ruptured where it crosses the fault in the Berkeley Hills. Continuing aftershocks and post-earthquake movements along the fault zone complicate efforts to accomplish rapid and effective repairs.

W21 39th Avenue Distribution Reservoir - Alameda Co.

This open-cut distribution reservoir sustains direct damage due to fault displacements but poses no threat of failure.

W22 Chabot Water Treatment Plant - Alameda Co.

This standby treatment facility and piping for water from Lake Chabot sustains major damage resulting from nearby fault rupture and related ground deformation.

W23 Transmission Pipelines/Fremont - Alameda Co.

Major water transmission pipelines of the Alameda County Water District are ruptured by fault displacements at several locations in Fremont.

W24 Bay Farm Island Pipeline - Alameda Co.

This water pipeline serving Bay Farm Island sustains major damage at the crossing of San Leandro Bay from Alameda.

W25 Upper San Leandro Filter Plant Raw Water Lines-Alameda Co.

Surface rupture results in major damage to the two pipelines that supply raw water to this plant, putting the plant out of service for at least a week.

W26 EBMUD Special District Number One Waste Treatment Plant - Alameda Co.

Normally providing treatment for up to 170 million gallons per day of waste water, this major East Bay facility is shut down for a minimum of 30 days as a result of damage to equipment, structures, and interconnecting pipelines.

W27 Facilities of East Bay Dischargers Authority - Alameda Co.

Located largely within the area subjected to high-intensity shaking and potential for ground failure, this system is highly vulnerable to damage. Many miles of reinforced concrete pipe (33-96 inch diameter) traverse the mud flats and salt marshes along the East Bay margin; six pumping plants and a dechlorination facility are similarly located. Differential movements and related ground failure cause damage to both the pipeline and the plants at various locations. Effluent pumping through Dublin Canyon from Amador-Livermore Valley is temporarily curtailed by rupture of the export pipeline at the fault crossing near Mission Boulevard and San Lorenzo Creek west of Castro Valley.

NATURAL GAS FACILITIES

General Characteristics

Natural gas is supplied to the San Francisco Bay area by the Pacific Gas and Electric Company (PG & E). Routes of the major natural gas transmission pipelines that serve the Bay area are shown on Map 3-G. Also shown are the major regulating stations and storage facilities (holders).

Seismic Considerations

The primary impact on natural gas facilities in the Bay area will be the widespread damage to the distribution system resulting from surface rupture along the 100-km length of the fault zone from San Pablo to near San Jose. Horizontal displacement averaging 5 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 in streets due to broken gas mains. Structural fires will occur as a result of broken service connections.

The gas supply to the East Bay will be interrupted where the large diameter transmission pipelines are ruptured by fault offset at San Pablo and Fremont. In addition to major damage at the fault crossings, other elements of the gas transmission system are vulnerable to damage by ground failures, temporarily disrupting supplies to other parts of the Bay area.

Many breaks and leaks will also occur in the distribution system throughout the Bay area, predominantly in those low-lying areas closer to the Bay margins where ground failures will occur as a result of liquefaction or settlement. In the East Bay, these areas include parts of San Pablo and Richmond, those portions of Oakland and Alameda in proximity to the Oakland-Alameda Estuary, and near Newark (generally west of Route 17); in the south Bay, in the Milpitas-Alviso area; and on the San Francisco and Marin Peninsulas.

Planning Considerations

The major problem area will be in the East Bay and, in particular, along and near the fault. Fault rupture across the multitude of residential streets and major thoroughfares will pose a formidable situation.

As a result of damage to transmission facilities, natural gas will be unavailable to all of the East Bay from San Pablo on the north to Milpitas on the south. Repairs to transmission facilities can be accomplished rapidly, however, and restoration of gas service to the area can then begin. Restoration within the distribution system is a gradual process, however, 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)."

Thus, while gas supplies to most areas of the East Bay will be restored rapidly, some areas near and east of the fault, could be without gas for as long as several weeks.

Damage to facilities serving the south Bay and San Francisco Peninsula will be mimimal and necessary repairs accomplished rapidly. Only those limited areas where poor ground conditions result in substantial damage to distribution systems will restoration of service be prolonged. Throughout the north Bay, only minimal damage to isolated segments of the distribution system is anticipated, with restoration of service proceeding rapidly.

Planning Scenario

Damage Assessments

Damage assessments have been postulated for certain natural gas 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 3-G.

MAP NO. LOCATION - COUNTY

G1 Pipelines/Richmond Area - Contra Costa Co.

Pipeline damage occurs due to ground failures, notably in the Richmond harbor area.

G2 Pipelines/Vicinity of SFO - San Mateo Co.

Rupture of old pipeline sections occurs due to ground failure caused by liquefaction.

G4 Milpitas Terminal/Vicinity of Coyote Creek - Santa Clara Co.

This critical facility and the major gas transmission pipelines routed through it are located in an area that experienced significant and varied ground failures during the 1906 earthquake (Youd and Hoose, 1978). Intense shaking (predicted intensity IX) and ground failures result in some damage to gas facilities in this area, with pipe structure connections at the terminal facility most vulnerable. The integrity of this facility is crucial to the continued supply of gas to the San Francisco Peninsula. With gas supplies from the East Bay and Livermore Valley interrupted by fault rupture, the south Bay and San Francisco Peninsula will depend on supplies routed from the south through the Santa Clara Valley.

G6 Pipelines/East of Fremont - Alameda Co.

Several hundred feet of one transmission pipeline is badly bent and leaking as a result of a seismically triggered landslide in the hills east of Fremont.

G7 Pipeline/Oakland to San Jose - Alameda Co.

The pipeline is damaged along this route due to ground failure caused by liquefaction.

G8 Pipelines/Oakland Waterfront - Alameda Co.

Pipeline damage occurs due to ground failure caused by liquefaction.

G9 Distribution System/San Pablo to Milpitas - Contra Costa/Alameda/Santa Clara Co.

Thousands of broken and leaking mains, valves, and service connections occur along and adjacent to the zone of surface rupture from San Pablo to southeast of Milpitas.

G10 Pipeline Fault crossings/San Pablo - Contra Costa Co.

One of two major natural gas transmission pipelines is leaking badly at the fault crossing in San Pablo.

G11 Pipeline Fault crossings/Fremont - Alameda Co.

Two of three natural gas transmission pipelines, crossing the East Bay Hills near Mission Pass, are damaged and leaking where they cross the fault between Durham Road and Olive Avenue west of Mission San Jose. The southerly two of these lines cross the fault and I-680 adjacent to major electrical transmission line towers. These damaged gas lines, a collapsed tower, and freeway damage close this route at this location. The third pipeline crosses the fault about a mile to the north.

G12 Gas Storage Facilities - Alameda/Contra Costa Co.

The low-pressure gas storage facilities (holders) at Richmond, and 50th Avenue (Oakland), have lost their water seals and develop temporary leaks. The holders are not crucial to the supply system, however, and can be by-passed.

PETROLEUM REFINERIES AND PRODUCTS

General Characteristics

The six major petroleum refineries in the San Francisco Bay area are located near the Carquinez Strait, at distances ranging from 3 to 14 miles from the Hayward fault. All are subject to damage by shaking from a major earthquake on that fault (See Map 3-P). The largest of these refineries is operated by Chevron, USA, (formerly Standard Oil) in Richmond. Most of this plant is located on structurally poor ground 3 to 4 miles from the fault.

Principal scenario emphasis is given to the Chevron refinery because it is the largest in the Bay area and the closest to the Hayward fault. Postulated damage patterns described for the Chevron refinery will be similar, but probably less, at the other refineries located near Rodeo, Martinez, and Concord.

Oil arrives by ship and by pipeline to the refineries, and the refined products are delivered throughout the Bay area, the State, and out of state via pipeline, truck, and ship.

The major oil companies have very large internal financial capabilities, manpower, and other resources located throughout the nation. The companies can call on these resources when needed. While self-sufficient in this sense, restoration of functions vital to public needs requires liason and coordination with local disaster response planners. For example, electric power and water are vital for day-to-day refinery operations, but are not under the control of the oil companies.

Seismic Considerations

Earthquake damage to petroleum related facilities may be placed into one of three categories. First, damage may occur to the incoming oil transportation facilities such as pipelines from the oilfields or marine terminals. Second, the refinery may (a) suffer direct damage such as broken piping, ruptured 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, such as those to San Francisco and Oakland Airports.

Major refineries have normally been conservatively designed and constructed to meet the state-of-the-art of earthquake engineering. Older established refineries have some facilities that are decades old. Earthquake standards have changed considerably since the first refinery construction. It follows that older construction will have some significant deficiencies by today's standards. Retrofitting is often expensive and not cost-effective, similar to the retrofitting of older commercial structures in San Francisco, Oakland, Berkeley, and Richmond. Consequently, earthquake damage is to be expected, and experience around the world confirms this.

Refineries are extremely complex facilities, and the prediction of their behavior during a major earthquake is beyond the scope of this study. Refining or storage facilities at each of the major refineries (see Map 3-P) are located upon or in proximity to the estuarine Bay mud and marsh deposits that are most susceptible to ground motion amplification and liquefaction with possible ground failure. Site-specific studies will be required to determine the vulnerability of each facility's refining and storage capability. Facilities utilized for the manufacture, processing, and storage of various petrochemicals warrant special attention to reduce the risk of a potentially widespread release of toxic emissions.

During the 1971 San Fernando earthquake (M6.4), damage to refineries in the area was limited to flanges, internal piping, and some storage tanks. Production was curtailed at one refinery located 11 miles from the epicenter when utility failures limited production.

Pipelines designed to carry products under high pressure are inherently strong. The result has been generally good performance by these types of pipelines in earthquakes. For example, a large diameter, interstate, natural gas line was not damaged where it crossed the White Wolf fault during the 1952 Kern County earthquake. Fuel lines were undamaged during the 1979 Imperial Valley (M6.6), California, earthquake. Natural gas transmission lines crossing Turnagain Arm of Cook Inlet at Anchorage experienced no damage in the 1964 Alaska earthquake despite the poor ground. A major water line (Hetch Hetchy) to San Francisco performed without damage in the 1906 earthquake, even though founded on Bay mud. On the other hand, major natural gas distribution lines in San Fernando failed during the 1971 earthquake. Experience shows that damage occurs in geologically unstable areas, but not necessarily to every line.

The several major petroleum product pipelines that serve the Bay area cross extensive areas of structurally poor ground near the Bay margin. Ground failures resulting in abrupt differential movements could cause pipe rupture in these areas. Pipe connections at terminal facilities are also vulnerable due 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 the fluids are ignited as storm waters wash them into sewers.

Shut-off valves installed on many of these pipelines will automatically function 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, however, so in the event of a major earthquake and possible large-scale power loss, these valves would not perform.

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 earthquake. In the 1952 Kern County earthquake, the Paloma Cycling Plant survived the earthquake quite well until two large butane spheres collapsed, releasing quantities of highly volatile material. The gaseous material spread out over the area and was ignited one and a half minutes later. The 1964 Niigata, Japan, earthquake resulted in fire at the Showa Oil Company refinery which burned continuously for over 350 hours. Isolated instances of fire at failed storage tanks have also been noted, for example, at Seward following the 1964 Alaska earthquake and tsunami.

The low earthen embankments used as retention dikes around fuel and oil storage tanks, evaporation ponds and waste containments are subject to failure resulting 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 emergency planning program. Donovan et al. (1982) studied the seismic risk of earthen embankments in the East Bay.

Damage to storage tanks is common due to the sloshing of liquids which damages or destroys the fixed or floating 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.

Planning Considerations

The indirect effects of damage to a major entity such as a public utility may have significant impact on other vital entities. For example, the loss of electric power and water to refineries will impact fuel availability.

Emergency planning should provide for distribution of fuel to those locations designated for emergency response operations, including airports. Adequate emergency power and pumping capability should be available at fuel storage locations for refueling of helicopters and other emergency vehicles.

All of the petroleum product pipelines that serve the metropolitan area should be examined in detail relative to their vulnerability to ground failure. Several lines cross the Hayward fault and will be subject to rupture.

The adequacy and locations of automatic shut-off valves should be examined on all product lines and remedial measures undertaken, as appropriate. 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. Predetermination of fuel storage facilities throughout the area would facilitate planning of other emergency response efforts that will be dependent on these sources of fuel.

Planning Scenario

Direct damage to the Chevron refinery (and to the other 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, ruptured tanks, buckled steel stacks, stretched anchor bolts for steel processing towers, and extensive elongation of cross-bracing. Older steel tanks that are not anchored to their concrete saddles will shift and break piping. The overall direct damage will be minimal.

For planning purposes, refinery fires should be anticipated following the earthquake. These fires will be suppressed within hours by plant personnel with their normal fire suppression systems that include the use of water from the Bay. A greater hazard is the possible release of toxic air emissions from petrochemical processing or storage facilities.

The refinery will be shut down for inspections 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 EBMUD water transmission pipelines will be damaged by faulting, and restoration priorities to customers will favor human rather than industrial needs.

Petroleum products available at Chevron are, for planning purposes, adequate for 5 days of normal demand. Priorities and other restrictions could lengthen this 5-day post-earthquake supply. It should be remembered that gas stations will not be able to pump gasoline without electric power. Also, truck transport of fuel supplies to parts of the Bay area will be slowed due to the damaged highway network.

Refineries east of the Hayward fault will, presumably, be less severely shaken and have lesser damage. All will be shut down for 48 hours for inspections and repairs, returning to 75% of normal operations within a week.

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 3-P.

MAP NO.	FACILITY - COUNTY
P1	Terminal Facilities at Richmond - Contra Costa Co.

Poor ground conditions and differential movements at the junctures of pipelines and terminal facilities results in moderate damage.

P2 Terminal Facilities at San Jose - Santa Clara Co.

This area near the mouth of Coyote Creek suffered extensive ground failure due to liquefaction during the 1906 earthquake (Youd and Hoose, 1978). Pipelines and terminal facilities in this area are damaged due to ground failures.

P3 Pipeline/Oakland to San Jose - Alameda/Santa Clara Co.

Ground failures along this route cause some pipeline damage.

P4 Pipeline/San Francisco Bay Crossings - Alameda/San Mateo Co.

Differential movements result in damage where the pipelines enter the Bay, but the Bay crossings themselves survive.

P5 Pipeline/Albany to Oakland - Alameda Co.

Some pipeline damage occurs due to ground failures.

P6 Pipeline/Richmond to Martinez - Contra Costa Co.

Some pipeline damage occurs due to ground failures.

P7 Pipeline Fault Crossing, Oakland/Vicinity of Mormon Temple Landslide - Alameda Co.

Pipeline ruptures due to fault displacement and landslide movement. A reactivation of this landslide within the Hayward fault zone has previously caused pipeline rupture at this location. (This product pipeline is currently inactive.)

P8 Fuel Terminals at Oakland International Airport - Alameda Co.

Pipelines at the fuel storage facilities are damaged.

P9 Pipelines/Martinez Area - Contra Costa Co.

Ground failures cause numerous instances of damage to the many pipeline facilities in this area.

P10 Pipeline/Sunol Valley - Alameda Co.

One of two product pipelines is damaged by a seismically triggered landslide.

P13 Pipeline Fault Crossing at Point Pinole - Contra Costa Co.

Damage occurs to the 12" fuel oil pipeline due to fault displacement in an extremely narrow well-defined zone along the Hayward fault. Although the pipeline accommodates aseismic creep in the area (measured at 3-5 mm/year), it is unlikely to withstand the offset hypothesized in the scenario event.

An adjacent pipeline carrying fuel oil from the Chevron refinery in Richmond to the power plants along the Bay [see Map 3-E, location E6] is engineered to accommodate some horizontal offset at the fault crossing.

P14 Pipeline Fault Crossing at San Pablo - Contra Costa Co.

Damage occurs to the Chevron fuel oil pipeline due to fault offset.

P15 Pipeline Fault Crossing at San Pablo - Contra Costa Co.

Damage occurs to the Chevron crude oil pipeline to the Richmond refinery due to fault offset.

P16 Pipeline Fault Crossing at San Pablo - Contra Costa Co.

Damage occurs to the fuel oil pipeline to the OAK and SFO terminal facilities due to fault offset.

P17 Pipeline Fault Crossing at San Pablo - Contra Costa Co.

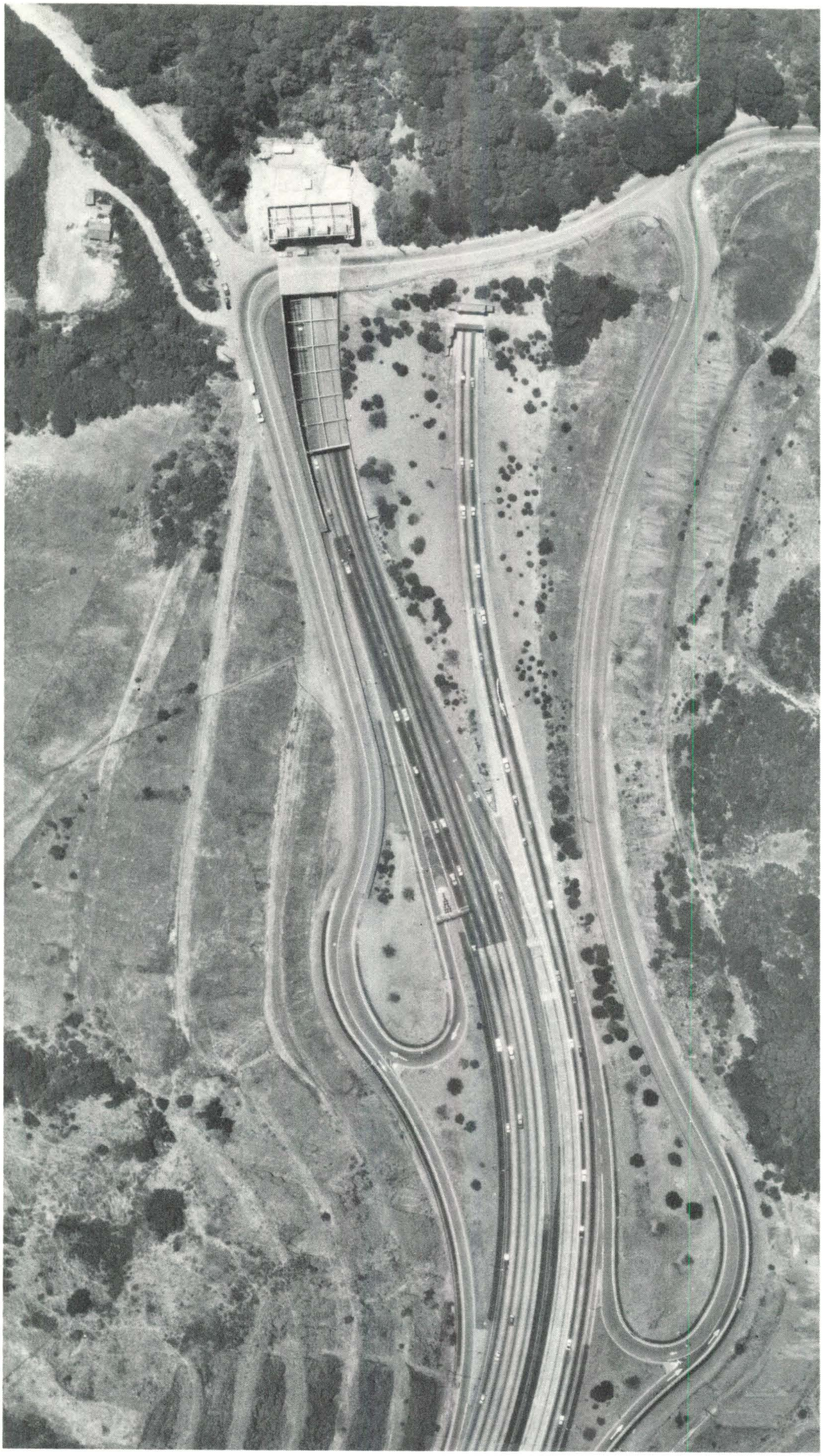
Damage occurs to the fuel oil pipeline to the Richmond terminal facilities due to fault offset.

P18 Pipeline Fault Crossings at Fremont - Alameda Co.

These two product pipelines to the San Jose terminal facilities are ruptured by fault offset.

Section 8.

LIFELINE CORRIDORS



East portal of the Caldecott Tunnel.

LIFELINE CORRIDORS

Having considered the various major lifelines affected by this scenario earthquake and the conditions that could prevail during the immediate post-earthquake hours and days, it is evident that many locations and critical facilities merit special attention by emergency planners. One obvious planning need involves the major transportation and utility lifeline corridors.

As a result of favorable topographic conditions, former trails and wagon roads evolved into today's major transportation routes. These natural transportation corridors are commonly shared by various major utility lifelines. The resulting concentration of major lifeline facilities within these restricted corridors presents situations where (a) many different facilities are exposed to the same hazards, (b) failure of one may have a significant impact on the integrity of others, and (c) the total impact of numerous failures within these restricted corridors could create situations more difficult to contend with than envisioned by individual lifeline operators.

Major transportation routes to the East Bay, excluding the trans-Bay bridges from the Marin and San Francisco Peninsulas, consist of five primary routes...Interstate 80 from the north and east, State Route 24 (Caldecott Tunnel) from the Walnut Creek area, Interstates 580 (Dublin Canyon) and 680 (Mission Pass) from the Livermore Valley, and parallel Interstate 680 and State Route 17 from San Jose and points south. The trans-Bay bridges are not considered in this discussion because the bridges are assumed to be unavailable for immediate post-earthquake assistance purposes, either for a large earthquake in the East Bay or on the San Andreas fault. For a large earthquake anywhere in the Bay area, however, post-earthquake transportation needs to and from the metropolitan area will be highly dependent on the integrity of the aforementioned routes.

Three important corridors are discussed below. These particular locations are not to be construed as necessarily the most important nor the only areas of special concern. They are intended only to illustrate the nature and scope of some of the problems that could arise and, thereby, to demonstrate that (a) effective emergency planning by lifeline operators must include consideration for the potential impact that damage to other lifelines may have on their facilities, and (b) that planning for post-earthquake recovery operations must involve close cooperation between all of the many concerned agencies.

The San Pablo Corridor

Near the northern end of the East Bay urban area, the city of San Pablo occupies a two-mile-wide access corridor through which numerous transportation and utility lifelines serve the Bay area. Bounded on the east by San Pablo Ridge and on the west by San Pablo Bay, all lifelines entering the metropolitan area through this corridor cross the Hayward fault (see figure 11) and, consequently, all are vulnerable to major damage by surface fault rupture. In addition, west of the fault all are vulnerable to a shaking intensity of IX (MM) in an area with a high potential for ground failure. The major transportation and utility lifelines that cross the Hayward fault within this corridor include:

1. Interstate 80 - The principal access route to the Bay area from the northeast.

2. Former U.S. 40 (San Pablo Avenue) - A parallel alternative route to Interstate 80.

3. San Pablo Dam Road - Secondary route to eastern Contra Costa County.

4. Two transcontinental railroads (Southern Pacific and Santa Fe).

5. EBMUD's major water transmission pipeline providing treated water to the East Bay service area from San Pablo Reservoir via the El Sobrante Treatment Plant.

6. EBMUD's "Crockett Aqueduct" serving the communities between San Pablo and Crockett.

7. Two major imported natural gas transmission pipelines.

8. Several petroleum product transmission pipelines importing fuels for local distribution, including supplies for Oakland and San Francisco International Airports.

9. One petroleum (crude) pipeline.

10. One 115 kv electrical power transmission line.

11. A fuel line from the Chevron refinery to the PG & E power plants in eastern Contra Costa County.

In addition to these major lifelines, the many residential streets that also cross the fault zone within this corridor contain the usual water, natural gas, and electrical services. Within a mile of the fault are numerous public schools, Contra Costa College, Brookside Hospital, a distribution reservoir (EBMUD's North Reservoir, 79 million gallon capacity) and an oil tank farm.

Given this scenario earthquake with a projected fault offset of 5 to 10 feet, or even a smaller offset, there is an obvious potential for major damage within this corridor. Problems arising from the rupture of certain of these lifelines could, in turn, seriously impede efforts to cope with the many other emergency response efforts. In addition, control of certain failures could be delayed for an extended period until appropriate assistance becomes available.

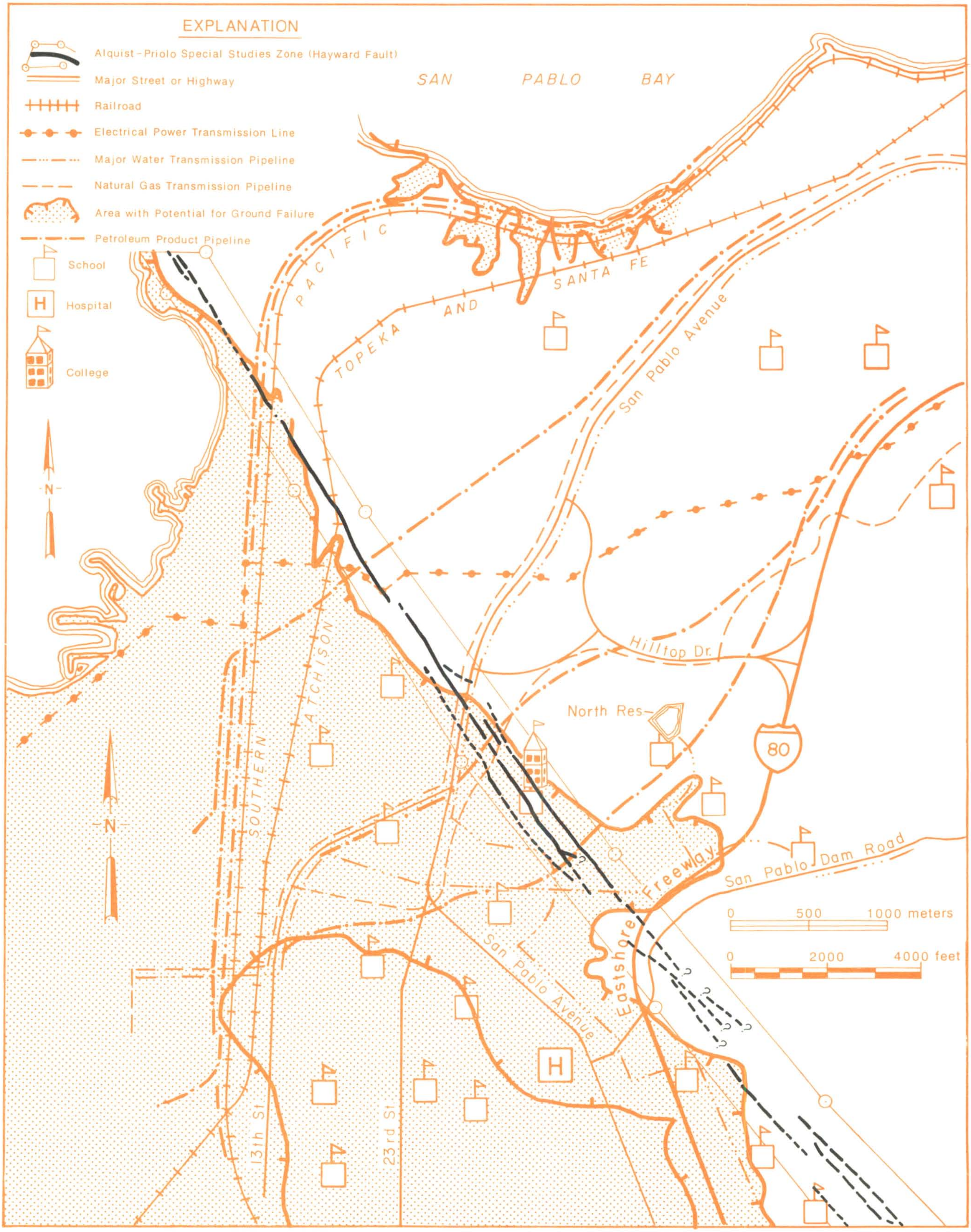


Figure 11. Major Lifelines and other critical structures proximate to the Hayward fault in the San Pablo corridor. Pipelines shown are only representative and are neither necessarily complete nor accurately located.

To illustrate the nature of some of the problems that could arise, consider the following: All along Interstate 80 from the Bay Bridge to the Carquinez Bridge, violent shaking begins and sudden surface rupture occurs across the traffic lanes at the fault crossing just north of the San Pablo Dam Road exit. Drivers are challenged to maintain control of their vehicles, many lose control and collisions occur. Several highway bridges are damaged and there are many injuries. The freeway is effectively blocked and, depending on the time of day, a massive traffic jam could rapidly ensue as traffic comes to a halt all along this route. Anyone who has experienced traffic conditions in the area following a minor freeway accident will appreciate this potential situation. Vehicles attempting to leave the freeway and progress via San Pablo Avenue or other city streets are immediately frustrated, for most streets are blocked by debris or other obstructions. Many drivers, recognizing what has happened and considering all the ramifications, abandon their vehicles creating further complications when efforts are eventually made to clear this route.

Along the fault many houses have been torn from their foundations. Everyone is outside in their yards or in the streets. A few fires have broken out as a result of broken gas lines. There is no electrical power and water pressure is nil or rapidly diminishing due to ruptured mains. Traffic signals are inoperative. If it is night, there are no lights, except for hand-held lights and those of a few vehicles that may be attempting to move. The fires can't be reported because the telephones are out, and emergency medical aid is unavailable. Local police and fire department staff are overwhelmed and those on duty are understandably concerned about their own families and homes.

The loss of electrical power will, in the absence of other means, gradually curtail the flow of fluids from the various ruptured pipelines, but locally, large quantities of water and fuels have been spilled. Pressure-activated valves on the natural gas transmission lines close upon sensing the drop in pressure resulting from pipe rupture, but gas leaks from these lines and in the distribution system pose the threat of a major fire. EBMUD's pipeline from San Pablo Reservoir is heavily damaged where it crosses the fault on El Portal Drive, discharging water in the area of the break. Petroleum fuels have been spilled from damaged pipelines crossing the fault near Contra Costa College.

It will be hours before personnel from the various utilities can organize and begin to cope even with the most critical problems. Remember too, that this is not the only area affected. Similar damage exists all along the fault for some 60 miles to the southeast--through El Cerrito, Berkeley, Oakland, San Leandro, Hayward, and Fremont to San Jose.

The confusion that could exist within this corridor would be monumental if it involved only the needs of the residents in attempting to cope with their local problems. Coupled with the added confusion that could result from damage to any one of the numerous major lifeline facilities that traverse this corridor, it is evident that this segment of the fault is one of the more critical to be considered in the development of emergency preparedness and response plans.

The Fremont - Milpitas Corridor

Between Fremont and Milpitas in southern Alameda County the tidal marsh lands of southern San Francisco Bay encroach upon the East Bay Hills. Many major lifelines traverse this narrow 1- to 2-mile wide corridor which generally parallels the Hayward fault. Included are the two major freeways that connect the South Bay with the East Bay, the Nimitz Freeway (State Route 17) and Interstate 680. At the northern end of this corridor, many of these major transportation and utility lifelines cross the Hayward fault, having entered the East Bay from the Sunol-Livermore Valley area in the vicinity of Mission Pass.

This area is significant because (a) it represents one of the two major concentrations of lifelines subject to direct damage by surface rupture on the Hayward fault, and (b) damage to major utility lifelines could complicate efforts to maintain these vital transportation routes between the cities south and east of the Bay. Thus, this area, like the San Pablo corridor, could become a major problem area with the potential to impede post-earthquake response and recovery efforts.

At the northern end of this narrow corridor in the Irvington District of Fremont the numerous major facilities subject to direct damage by surface rupture include:

1. Interstate 680 - Principal route east from the south Bay, through Mission Pass.

2. Hetch Hetchy Aqueduct pipelines (trans-Bay route).

3. Southern Pacific and Western Pacific rail lines.

4. A major electrical power transmission corridor with multiple tower lines routed to PG & E's Newark substation (2 miles west of the fault) The city of San Francisco's Hetch Hetchy power lines are also in this corridor..

5. PG & E's Fremont substation and two adjacent high-voltage electrical power transmission lines.

6. Three principal natural gas supply lines that cross the fault between Durham Road and Olive Avenue (routed to the Irvington terminal).

7. Two of the three petroleum product pipelines that provide fuel to distribution terminals in San Jose.

8. A major local water transmission pipeline that crosses the fault near the intersection of Washington Boulevard, Driscoll Road, and Osgood Road.

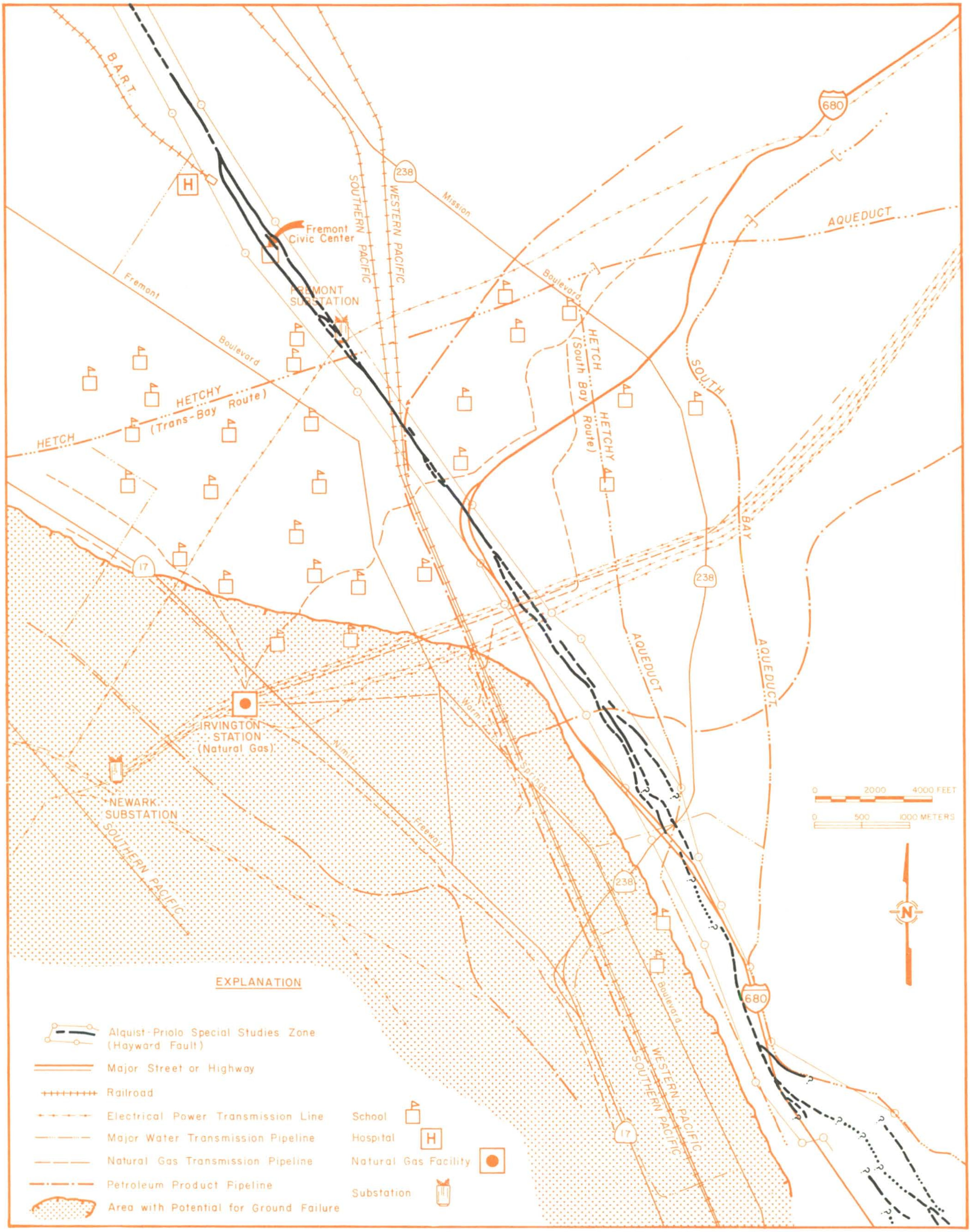


Figure 12. Major lifelines and other critical structures proximate to the Hayward fault in the Fremont area. Pipelines shown are only representative and are neither necessarily complete nor accurately located.

Major lifeline facilities in the Irvington area not subject to surface rupture but subject to damage by shaking and ground failure include:

1. Nimitz Freeway (Route 17).

2. Hetch Hetchy pipeline-South Bay route. (These lines are subject to damage by surface rupture further south where they cross the fault at the Mission Boulevard/I-680 interchange.)

3. Newark Substation - One of PG & E's major electrical power transmission substations in the south Bay area.

4. Irvington Terminal - Major terminal facility for the natural gas lines referred to above, with connections north to the East Bay and south to San Jose.

5. A local water distribution reservoir (Middlefield Reservoir).

Other important structures within a mile of the fault zone include the Fremont Civic Center, a major hospital and several public schools.

Given this scenario earthquake, the Nimitz Freeway (State Route 17) is expected to sustain major damage both to the roadway and to structures throughout its length (CDOT, 1985). Thus, for planning purposes, this route should not be considered available for post-earthquake use. The remaining principal route, Interstate 680, will be subjected to pavement disruption and possible bridge damage both at the fault crossing between Durham Road and Washington Boulevard in Fremont and again further south where it follows the fault south from the Mission Boulevard interchange to the Alameda-Santa Clara County line. Damage at the Mission Boulevard/I-680 interchange as a result of fault rupture, compounded by rupture of and water loss from both the Hetch Hetchy pipelines and other water utilities that cross the fault in the interchange area, could temporarily block both I-680 and Mission Boulevard north of this interchange. In addition to the effects of fault rupture, I-680 north of the county line to Washington Boulevard could be temporarily obstructed by damaged bridges, collapsed towers and fallen power lines, ruptured and leaking pipelines, and abandoned vehicles. Consequently, only Warm Springs-Fremont Boulevard could be available as a viable route connecting the East Bay with San Jose.

In summary, a high concentration of major lifeline facilities exists in the Irvington District of the city of Fremont, most of which are vulnerable to major damage by fault rupture. This concentration of potential damage is located within and near the northern end of the narrow corridor between Fremont and Milpitas. The high probability of major damage to both of the principal freeways that traverse this corridor necessitates thoughtful planning.

State Route 24-Caldecott Tunnel

State Route 24 and, in particular, the Caldecott Tunnel through the Berkeley Hills, is another critical location requiring special attention by emergency planners. This route provides the principal access between the predominantly residential areas of Walnut Creek-Diablo Valley in eastern Contra Costa County and the urban areas of San Francisco, Oakland, and Berkeley. This route is vital to post-earthquake assistance and recovery operations, and any prolonged closure or restricted use would seriously impair these efforts.

The purpose of this discussion is to stress the importance of this facility. Although there are other major lifelines that cross the Berkeley Hills and the Hayward fault in this vicinity (notably, the BART tunnels and EBMUD's Claremont Tunnel) this brief discussion is concerned only with the potential impact of the scenario earthquake on Route 24.

Route 24 crosses the Hayward fault at Lake Temescal, about 1 mile west of the west tunnel portals. To the southeast, the fault occupies the rift valley shared with the Warren Freeway (Route 13); to the northwest, the fault briefly parallels and crosses Tunnel Road (and the BART tunnels and EBMUD's Claremont

Tunnel, at depth), passing through residential areas and onto the University of California campus. For the purposes stated above, the following damage scenario is postulated:

1. Surface fault rupture disrupts all traffic lanes on Route 24, buckling the pavement and impeding or blocking traffic flow. The same conditions described above on Interstate 80 apply here. This and other damage to the adjacent Route 13/24 interchange restricts traffic to one intermittent lane (CDOT, 1985).

2. The Warren Freeway (Route 13) to the southeast is closed by the effects of surface rupture and damage to bridges (CDOT, 1985). Depending on the time of day, hundreds of cars may be stranded and subsequently abandoned along this route.

3. Tunnel Road (Route 13) from Route 24 to Berkeley is disrupted by the surface rupture with damaged retaining walls, broken utility lines, and other obstructions on the roadway. This narrow roadway is closed between Route 24 and Claremont Avenue.

4. At the east tunnel portals, landslides restrict the roadway to a single lane (CDOT, 1985).

5. These same landslides block access to Fish Ranch Road, eliminating this alternative secondary route over the hills to Berkeley.

6. CALTRANS auxiliary electrical power is activated, maintaining lighting in the tunnels, but the ventilation system has been damaged and is inoperative. There is damage to the west portal structures.

7. It has been assumed elsewhere in this scenario that San Pablo Dam Road would be closed indefinitely by a major landslide near San Pablo Reservoir, thereby eliminating this alternative route to the East Bay from Orinda.

Given these conceivable circumstances and the critical need to maintain this transportation corridor between the East Bay and eastern Contra Costa County, emergency planners must be concerned with all factors that bear on the integrity of this facility and the integrity of the few limited alternative routes. It is important to remember, also, that this particular damage scenario is not dependent on the occurrence of a M7.5 earthquake. A similar scenario could result from a significantly smaller event.

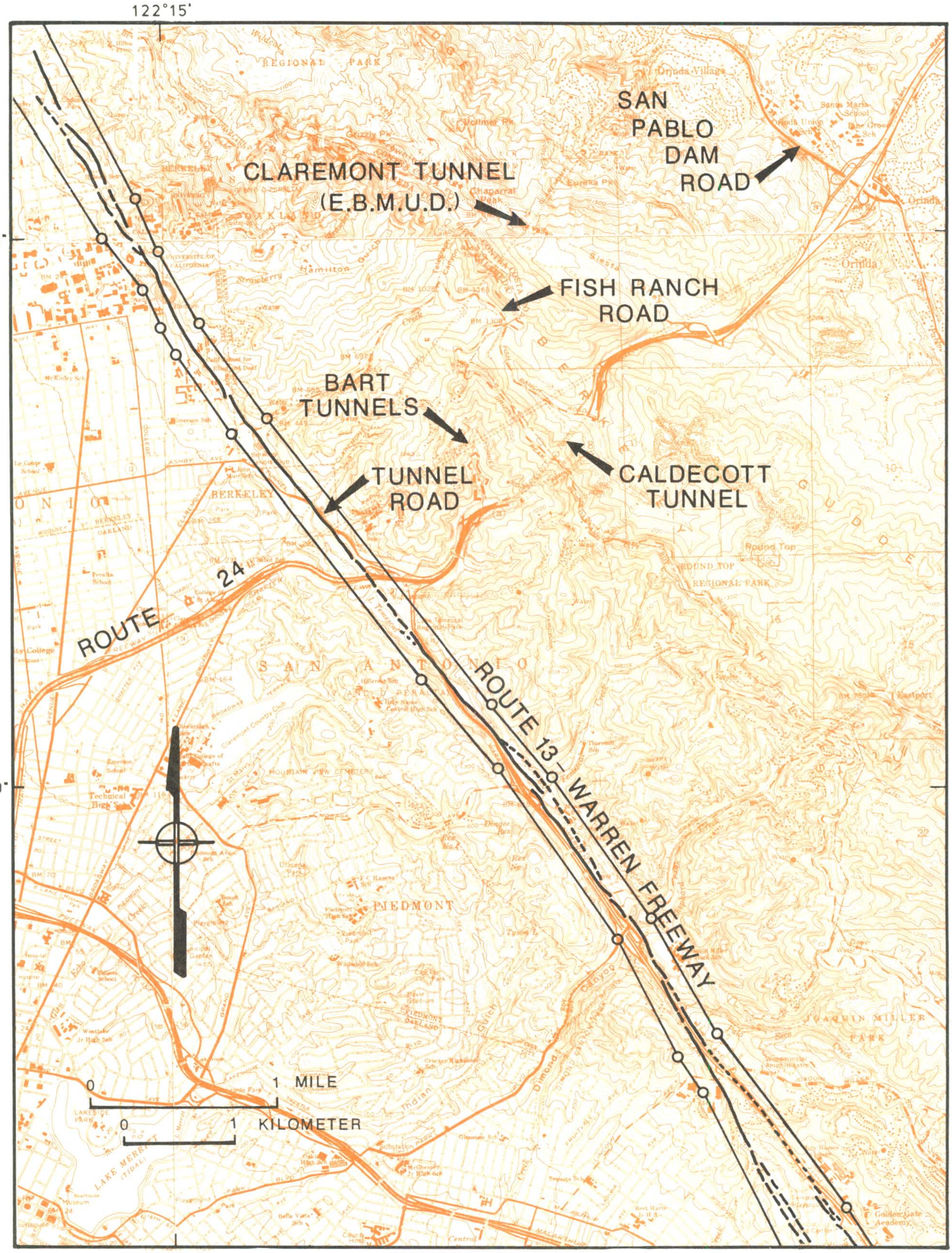


Figure 13. The Hayward fault in the vicinity of State Route 24 and the Caldecott Tunnel.

GLOSSARY

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.
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.
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 watersaturated 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 (see Appendix A).
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
Richter Magnitude Determination

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.

Appendix A (continued)

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 [VIII – R.F.]

Frightened all—general alarm, all ran outdoors.
Some, or many, found it difficult to stand.
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 [VIII+ to IX – R.F.]

Fright general—alarm approaches panic.
Disturbed persons driving motor cars.
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 [IX+ R.F.]

Panic general.
Cracked ground conspicuously.
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 [X R.F.]

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.
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.

RICHTER MAGNITUDE SCALE

The Richter magnitude scale is named after the late Dr. Charles F. Richter, Professor of Seismology at the California Institute of Technology. On this scale, an earthquake's magnitude is expressed in whole numbers and decimals. However, Richter magnitudes can be confusing and misleading unless the mathematical basis for the scale is understood. It is important to recognize that magnitude varies logarithmically with the wave amplitude of the earthquake motion recorded by a seismograph. Each whole number step of magnitude on the scale represents an increase of 10 times in the measured wave amplitude of an earthquake. Thus, the amplitude of an 8.3 magnitude earthquake is not twice as large as a shock of magnitude 4.3, but 10,000 times as large.

Richter magnitude can also provide an estimate of the amount of energy released during an earthquake. For every unit increase in magnitude, there is a 30-fold increase in energy. For the previous example, a magnitude 8.3 earthquake releases almost one million times more energy than one of magnitude 4.3.

An earthquake of magnitude 2 is the smallest quake normally felt by humans. Earthquakes with a Richter magnitude of 7 or more are commonly considered to be major. The Richter magnitude scale has no fixed maximum or minimum; observations have placed the largest recorded earthquakes in the world at about 8.9 (and the smallest at -3). Earthquakes with magnitudes smaller than 3 are called microearthquakes.

Richter magnitudes are not used to estimate damage. An earthquake in a densely populated area that results in many deaths and considerable damage may have the same magnitude as an earthquake that may do nothing more than frighten the wildlife when located in a remote area.

Appendix B

1986 Population and Housing Data for the Nine San Francisco Bay Area Counties

POPULATION RESEARCH UNIT
DEPARTMENT OF FINANCE
STATE OF CALIFORNIA

SUMMARY REPORT

ALAMEDA CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

PAGE 1
DATE PRINTED 04/29/86

CITY	POPULATION TOTAL	POPULATION HOUSE-HOLDS	POPULATION MOBILE HOMES	POPULATION GROUP QUARTERS	HOUSING UNITS TOTAL	HOUSING UNITS SINGLE	HOUSING UNITS 2 TO 4	HOUSING UNITS 5 OR MORE	HOUSING UNITS MOBILE HOMES	HOUSING UNITS OCCU-PIED	HOUSING UNITS % VACANT	POP. PER HOUSE-HOLD
ALAMEDA	75232	65541	4049	9691	29170	13452	5238	10424	56	28182	3.39	2.326
ALBANY	15216	15049	0	167	7097	4039	772	2286	0	6912	2.61	2.177
BERKELEY	107202	96203	35	10999	46622	20270	10151	16164	37	45246	2.95	2.126
DUBLIN	17793	17793	0	0	5502	4257	53	1192	0	5328	3.16	3.340
EMERYVILLE	4652	4650	8	2	3203	456	481	2258	8	2715	15.24	1.713
FREMONT	153531	151611	1320	1920	52819	37988	1553	12651	627	52021	1.51	2.914
HAYWARD	100580	99031	3147	1549	38464	23250	2546	10820	1848	37560	2.35	2.637
LIVERMORE	53981	53812	762	169	18832	15214	959	2191	468	18426	2.16	2.920
NEWARK	37314	37314	74	0	11351	9930	416	986	19	11056	2.60	3.375
OAKLAND	354197	345156	317	9041	153389	75064	27763	50377	185	145895	4.89	2.366
PIEDMONT	10455	10455	0	0	3863	3745	73	45	0	3780	2.15	2.766
PLEASANTON	45371	45271	425	100	15299	12231	702	2021	345	14800	3.26	3.059
SAN LEANDRO	66017	65694	1211	323	29282	19181	2370	6975	756	28392	3.04	2.314
UNION CITY	49429	49056	1349	373	14770	10594	1323	2131	722	14562	1.41	3.369
TOTAL INCORPORATED	1090970	1056636	12697	34334	429663	249671	54400	120521	5071	414875	3.44	2.547
UNINCORPORATED	117210	112906	1052	4304	45589	33754	3108	7983	744	44437	2.53	2.541
TOTAL COUNTY	1208180	1169542	13749	38638	475252	283425	57508	128504	5815	459312	3.35	2.546

SUMMARY REPORT

CONTRA COSTA CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

CITY	POPULATION TOTAL	HOUSE-HOLDS	MOBILE HOMES	GROUP QUARTERS	HOUSING UNITS TOTAL	SINGLE	2 TO 4	5 OR MORE	MOBILE HOMES	OCCU-PIED	% VACANT	POP. PER HOUSE-HOLD
ANTIOCH	49322	49048	252	274	18136	13626	1586	2781	143	17451	3.78	2.811
BRENTWOOD	5412	5374	258	38	1935	1400	122	248	165	1818	6.05	2.956
CLAYTON	4867	4867	15	0	1591	1566	8	13	4	1562	1.82	3.116
CONCORD	107877	107011	2763	866	42245	27856	2543	10026	1820	41101	2.71	2.604
DANVILLE	28104	28012	10	92	9778	8997	345	431	5	9354	4.34	2.995
EL CERRITO	23412	23367	131	45	10153	7600	1299	1175	79	9898	2.51	2.361
HERCULES	10137	10137	12	0	3110	2676	116	314	4	3053	1.83	3.320
LAFAYETTE	22691	22526	0	165	9065	7251	486	1328	0	8710	3.92	2.586
MARTINEZ	27458	26785	6	673	11494	8792	1028	1671	3	10658	7.27	2.513
MORAGA	15422	14379	0	1043	5260	4253	280	727	0	5184	1.44	2.774
PINOLE	15096	15085	0	11	5521	4697	228	596	0	5410	2.01	2.788
PITTSBURG	40545	40303	963	242	14182	11104	1209	1363	506	13467	5.04	2.993
PLEASANT HILL	29359	28897	42	462	12090	8681	430	2946	33	11914	1.46	2.425
RICHMOND	78606	77937	89	669	30497	21747	4878	3836	36	29428	3.51	2.648
SAN PABLO	21355	20892	1043	463	9157	4487	1499	2390	781	8605	6.03	2.428
SAN RAMON	26417	26417	0	0	8583	7402	138	1043	0	8344	2.78	3.166
WALNUT CREEK	60187	59173	15	1014	27576	13880	3198	10487	11	26641	3.39	2.221
TOTAL INCORPORATED	566267	560210	5599	6057	220373	156015	19393	41375	3590	212598	3.53	2.635
UNINCORPORATED	157768	155918	4413	1850	58550	49483	3069	3317	2681	57225	2.26	2.725
TOTAL COUNTY	724035	716128	10012	7907	278923	205498	22462	44692	6271	269823	3.26	2.654

POPULATION RESEARCH UNIT
DEPARTMENT OF FINANCE
STATE OF CALIFORNIA

SUMMARY REPORT

MARIN CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

DATE PRINTED 04/29/86

CITY	POPULATION TOTAL	POPULATION HOUSE-HOLDS	POPULATION MOBILE HOMES	POPULATION GROUP QUARTERS	HOUSING UNITS TOTAL	HOUSING UNITS SINGLE	HOUSING UNITS 2 TO 4	HOUSING UNITS 5 OR MORE	HOUSING UNITS MOBILE HOMES	HOUSING UNITS OCCU-PIED	HOUSING UNITS % VACANT	POP. PER HOUSE-HOLD
BELVEDERE	2352	2352	0	0	1006	872	71	63	0	959	4.67	2.453
CORTE MADERA	8478	8455	0	23	3552	2686	273	593	0	3466	2.42	2.439
FAIRFAX	7381	7367	0	14	3503	2507	601	395	0	3334	4.82	2.210
LARKSPUR	11388	11190	296	198	5763	2310	510	2777	166	5665	1.70	1.975
MILL VALLEY	13008	12734	16	274	5901	4230	649	1014	8	5756	2.46	2.212
NOVATO	45357	44288	758	1069	16941	11959	1454	3024	504	16629	1.84	2.663
ROSS	2746	2646	0	100	961	873	0	88	0	938	2.39	2.821
SAN ANSELMO	12082	11957	0	125	5408	4160	431	817	0	5264	2.66	2.271
SAN RAFAEL	45212	43992	802	1220	20033	10966	2372	6293	402	19806	1.13	2.221
SAUSALITO	7558	7558	140	0	4487	2004	1402	985	96	4344	3.19	1.740
TIBURON	8096	8046	2	50	3415	2606	285	523	1	3264	4.42	2.465
TOTAL INCORPORATED	163658	160585	2014	3073	70970	45173	8048	16572	1177	69425	2.18	2.313
UNINCORPORATED	63405	59492	588	3913	25598	19760	1837	3487	514	24209	5.43	2.457
TOTAL COUNTY	227063	220077	2602	6986	96568	64933	9885	20059	1691	93634	3.04	2.350

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NAPA CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

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CITY	POPULATION TOTAL	HOUSE-HOLDS	MOBILE HOMES	GROUP QUARTERS	HOUSING UNITS TOTAL	SINGLE	2 TO 4	5 OR MORE	MOBILE HOMES	OCCU-PIED	% VACANT	POP. PER HOUSE-HOLD
CALISTOGA	4218	4110	758	108	2045	1167	138	292	448	1911	6.55	2.151
NAPA	55579	54724	1374	855	22928	16429	2040	3440	1019	22090	3.65	2.477
ST. HELENA	5163	5076	381	87	2397	1445	180	537	235	2288	4.55	2.219
YOUNTVILLE	3136	1722	398	1414	890	559	45	55	231	867	2.58	1.986
TOTAL INCORPORATED	68096	65632	2911	2464	28260	19600	2403	4324	1933	27156	3.91	2.417
UNINCORPORATED	36550	33753	2046	2797	14749	10453	869	910	2517	12411	15.85	2.720
TOTAL COUNTY	104646	99385	4957	5261	43009	30053	3272	5234	4450	39567	8.00	2.512

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SAN FRANCISCO CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

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CITY	POPULATION TOTAL	HOUSE-HOLDS	MOBILE HOMES	GROUP QUARTERS	HOUSING UNITS TOTAL	SINGLE	2 TO 4	5 OR MORE	MOBILE HOMES	OCCU-PIED	% VACANT	POP. PER HOUSE-HOLD
SAN FRANCISCO	741568	716209	386	25359	322706	111930	71438	139095	243	310041	3.92	2.310
TOTAL COUNTY	741568	716209	386	25359	322706	111930	71438	139095	243	310041	3.92	2.310

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SAN MATEO CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

CITY	POPULATION TOTAL	POPULATION HOUSE-HOLDS	POPULATION MOBILE HOMES	POPULATION GROUP QUARTERS	HOUSING UNITS TOTAL	HOUSING UNITS SINGLE	HOUSING UNITS 2 TO 4	HOUSING UNITS 5 OR MORE	HOUSING UNITS MOBILE HOMES	HOUSING UNITS OCCU-PIED	HOUSING UNITS % VACANT	POP. PER HOUSE-HOLD
ATHERTON	7943	7462	0	481	2532	2438	28	66	0	2466	2.61	3.026
BELMONT	25100	24567	0	533	10149	6320	251	3578	0	9966	1.80	2.465
BRISBANE	3071	3071	56	0	1436	916	182	296	42	1400	2.51	2.194
BURLINGAME	27130	26679	0	451	12940	6281	1024	5635	0	12666	2.12	2.106
COLMA	717	717	0	0	312	230	72	10	0	298	4.49	2.406
DALY CITY	82373	81866	801	507	28339	17667	2504	7703	465	27617	2.55	2.964
EAST PALO ALTO	18939	18889	331	50	6894	3435	191	3055	213	6611	4.11	2.857
FOSTER CITY	26666	26661	13	5	10169	5970	391	3800	8	9901	2.64	2.693
HALF MOON BAY	7921	7919	664	2	2967	2132	260	190	385	2858	3.67	2.771
HILLSBOROUGH	11038	11038	0	0	3686	3588	53	45	0	3549	3.72	3.110
MENLO PARK	28203	26986	8	1217	12231	7237	1642	3344	8	11896	2.74	2.268
MILLBRAE	20606	20367	22	239	7899	5598	431	1859	11	7681	2.76	2.652
PACIFICA	37492	37367	87	125	13316	10162	623	2478	53	12987	2.47	2.877
PORTOLA VALLEY	4289	3988	2	301	1410	1338	8	63	1	1354	3.97	2.945
REDWOOD CITY	58527	57462	1060	1065	24686	13798	2206	8054	628	24056	2.55	2.389
SAN BRUNO	35174	35114	28	60	14787	9461	1251	4068	7	13968	5.54	2.514
SAN CARLOS	26428	26239	22	189	10922	8023	619	2266	14	10729	1.77	2.446
SAN MATEO	83376	82907	35	469	35498	19818	2926	12734	20	34816	1.92	2.381
SOUTH SAN FRANCISCO	52187	52183	447	4	18707	12766	1748	3858	335	18391	1.69	2.837
WOODSIDE	5537	5526	0	11	1980	1764	43	173	0	1930	2.53	2.863
TOTAL INCORPORATED	562717	557008	3576	5709	220860	138942	16453	63275	2190	215140	2.59	2.589
UNINCORPORATED	54394	52936	1353	1458	20237	16615	1049	1792	781	19418	4.05	2.726
TOTAL COUNTY	617111	609944	4929	7167	241097	155557	17502	65067	2971	234558	2.71	2.600

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SANTA CLARA CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

CITY	POPULATION TOTAL	POPULATION HOUSE-HOLDS	POPULATION MOBILE HOMES	POPULATION GROUP QUARTERS	HOUSING UNITS TOTAL	HOUSING UNITS SINGLE	HOUSING UNITS 2 TO 4	HOUSING UNITS 5 OR MORE	HOUSING UNITS MOBILE HOMES	HOUSING UNITS OCCU-PIED	HOUSING UNITS % VACANT	POP. PER HOUSE-HOLD
CAMPBELL	34503	34314	481	189	15045	7647	2506	4552	340	14636	2.72	2.344
CUPERTINO	38754	38225	8	529	14220	10298	1445	2471	6	14078	1.00	2.715
GILROY	26892	26690	654	202	8668	5454	932	1950	332	8312	4.11	3.211
LOS ALTOS	27614	27180	2	434	10214	8996	296	921	1	9937	2.71	2.735
LOS ALTOS HILLS	7934	7872	7	62	2631	2428	52	144	7	2557	2.81	3.079
LOS GATOS	28224	27408	190	816	11607	8025	1051	2413	118	11289	2.74	2.428
MILPITAS	43418	41346	629	2072	13028	10286	1445	884	413	12757	2.08	3.241
MONTE SERENO	3469	3465	35	4	1175	1154	13	3	5	1147	2.38	3.021
MORGAN HILL	20803	20477	1365	326	6596	4823	523	622	628	6369	3.44	3.215
MOUNTAIN VIEW	62160	61407	1666	753	29920	10152	2522	16127	1119	28569	4.52	2.149
PALO ALTO	56831	55317	120	1514	24554	15732	1926	6794	102	23619	3.81	2.342
SAN JOSE	713385	704720	19715	8665	243117	161364	22873	49041	9839	235342	3.20	2.994
SANTA CLARA	89834	86928	421	2906	35757	19559	3437	12473	288	34906	2.38	2.490
SARATOGA	29810	29318	0	492	9948	9151	278	519	0	9779	1.70	2.998
SUNNYVALE	114334	113483	5988	851	47400	24110	4521	15149	3620	46041	2.87	2.465
TOTAL INCORPORATED	1297965	1278150	31281	19815	473880	299179	43820	114063	16818	459338	3.07	2.783
UNINCORPORATED	105131	96617	281	8514	33710	27588	2039	3811	272	32272	4.27	2.994
TOTAL COUNTY	1403096	1374767	31562	28329	507590	326767	45859	117874	17090	491610	3.15	2.796

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SOLANO CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

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CITY	POPULATION TOTAL	POPULATION HOUSE-HOLDS	POPULATION MOBILE HOMES	POPULATION GROUP QUARTERS	HOUSING UNITS TOTAL	HOUSING UNITS SINGLE	HOUSING UNITS 2 TO 4	HOUSING UNITS 5 OR MORE	HOUSING UNITS MOBILE HOMES	HOUSING UNITS OCCU-PIED	HOUSING UNITS % VACANT	POP. PER HOUSE-HOLD
BENICIA	21178	21121	509	57	7972	5763	976	988	245	7775	2.47	2.717
DIXON	10137	10107	46	30	3360	2511	308	520	21	3177	5.45	3.181
FAIRFIELD	67820	64031	1537	3789	22417	15872	1298	4449	798	21813	2.69	2.935
RIO VISTA	3390	3387	163	3	1451	1027	80	232	112	1405	3.17	2.411
SUISUN CITY	15317	15317	61	0	4951	3930	461	505	55	4591	7.27	3.336
VACAVILLE	53128	47196	1937	5932	17013	12383	1669	2058	903	16491	3.07	2.862
VALLEJO	90313	87357	1706	2956	33078	23851	4180	3971	1076	32005	3.24	2.729
TOTAL INCORPORATED	261283	248516	5959	12767	90242	65337	8972	12723	3210	87257	3.31	2.848
UNINCORPORATED	18263	18141	1289	122	6649	5330	362	417	540	6143	7.61	2.953
TOTAL COUNTY	279546	266657	7248	12889	96891	70667	9334	13140	3750	93400	3.60	2.855

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SONOMA CONTROLLED COUNTY POPULATION ESTIMATES FOR 1-1-86

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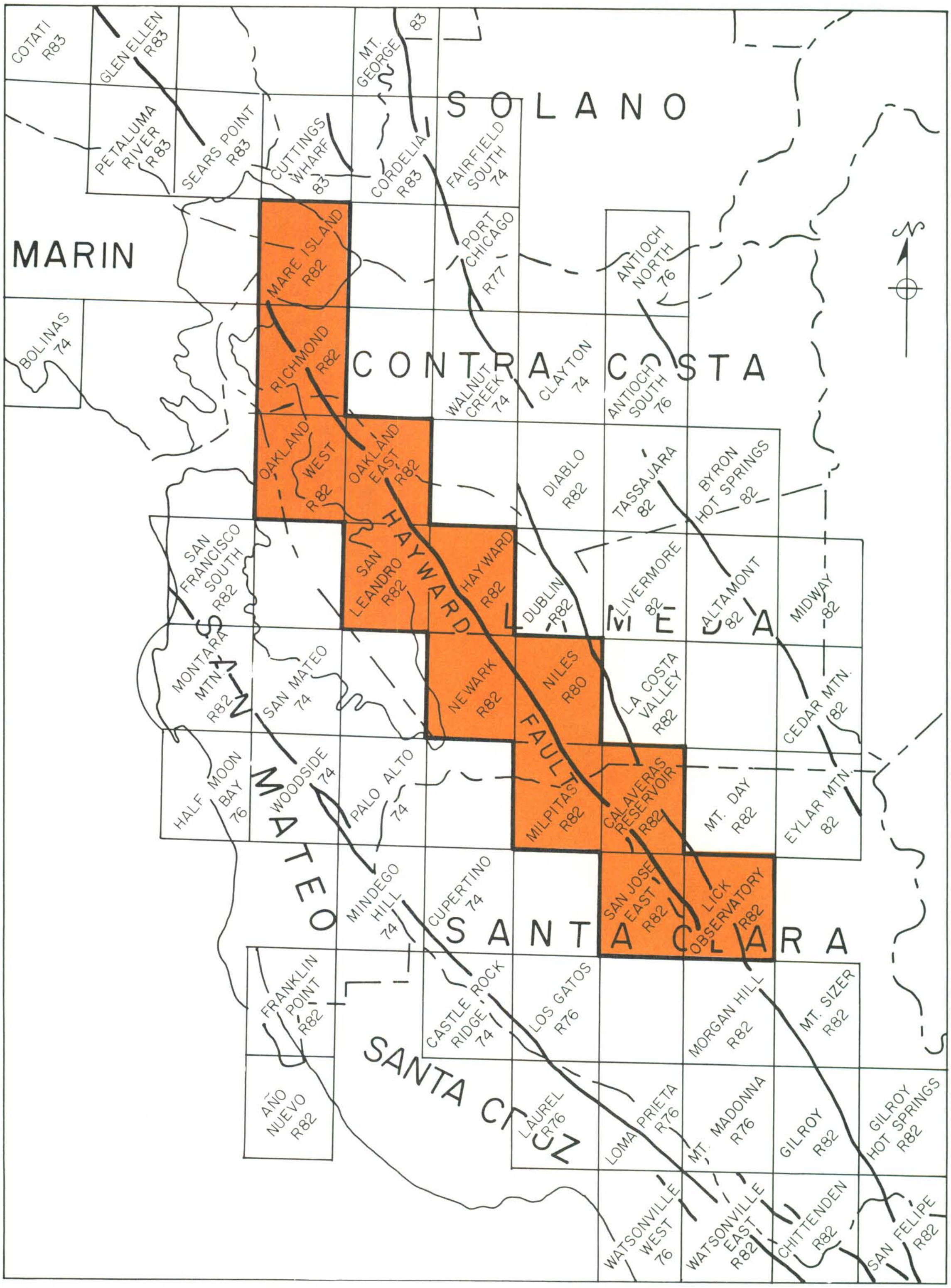
	POPULATION				HOUSING UNITS							POP. PER HOUSE-HOLD
CITY	TOTAL	HOUSE-HOLDS	MOBILE HOMES	GROUP QUARTERS	TOTAL	SINGLE	2 TO 4	5 OR MORE	MOBILE HOMES	OCCU-PIED	% VACANT	
CLOVERDALE	4375	4184	243	191	1856	1325	113	229	189	1745	5.98	2.398
COTATI	4340	4326	182	14	1837	1057	183	491	106	1766	3.86	2.450
HEALDSBURG	8286	8152	134	134	3470	2703	376	304	87	3352	3.40	2.432
PETALUMA	38400	37991	1447	409	14945	11403	945	1810	787	14528	2.79	2.615
ROHNERT PARK	29674	29655	2318	19	12205	7136	917	3028	1124	11432	6.33	2.594
SANTA ROSA	97644	96086	3055	1558	41978	29137	3669	7265	1907	40074	4.54	2.398
SEBASTOPOL	6227	6035	83	192	2732	1927	263	477	65	2625	3.92	2.299
SONOMA	7081	6902	462	179	3463	2339	301	500	323	3322	4.07	2.078
TOTAL INCORPORATED	196027	193331	7924	2696	82486	57027	6767	14104	4588	78844	4.42	2.452
UNINCORPORATED	143323	139133	8622	4190	59436	45917	4791	4079	4649	53078	10.70	2.621
TOTAL COUNTY	339350	332464	16546	6886	141922	102944	11558	18183	9237	131922	7.05	2.520

Appendix C

Alquist – Priolo Special Studies Zone Maps (12) for the Hayward Fault



INDEX TO ALQUIST-PRIOLO SPECIAL STUDIES ZONES MAPS FOR THE HAYWARD FAULT

Appendix D

Earthquake Planning Scenario Maps

INDEX TO EARTHQUAKE PLANNING SCENARIO MAPS

Planning Area 3 - The Hayward Fault

Map	Subject
3-S	Seismic Intensity Distribution
	Medical and Educational (Mass Care) Facilities
3-N	General Acute Care Hospitals and Skilled Nursing Facilities
3-J	Public Intermediate Schools (Jr. High)
3-U	Public High Schools, Community Colleges and Universities
	Transportation Lifelines
3-HA	Highways and Airports
3-T	Bay Area Rapid Transit Facilities
3-RM	Railroads and Marine Facilities
	Utility Lifelines
3-C	Communications
3-E	Electrical Power Facilities
3-W	Water Supply and Waste Water Facilities
3-G	Natural Gas Facilities
3-P	Petroleum Fuels