NOAA-A STUDY OF EARTHQUAKE LOSSES IN THE SAN FRANCISCO BAY AREA-Data an

S. DEPARTMENT OF COMMERCE / National Oceanic & Atmospheric Administration
Environmental Research Laboratories

A STUDY OF EARTHQUAKE LOSSES IN THE SAN FRANCISCO BAY AREA

Data and Analysis

A Report Prepared For
The
OFFICE OF EMERGENCY PREPAREDNESS

1972

U.S. DEPARTMENT OF COMMERCE / National Oceanic & Atmospheric Administration
Environmental Research Laboratories

A STUDY OF EARTHQUAKE LOSSES IN THE SAN FRANCISCO BAY AREA

Data and Analysis

A Report Prepared For
The
OFFICE OF EMERGENCY PREPAREDNESS

1972

ACKNOWLEDGMENTS

NOAA personnel involved in the writing of this report were as follows:

S. T. Algermissen, principal investigator
W. A. Rinehart
James Dewey

Principal consultants to this report were as follows:

Karl V. Steinbrugge, chief consultant
Henry J. Lagorio
Henry J. Degenkolb
Lloyd S. Cluff
Frank E. McClure
Stanley Scott
Richard F. Gordon

The staff of the Office of Emergency Preparedness often supplied information and gave useful advice, and in this regard the assistance of Mr. Robert Olson was of particular help.

PURPOSE OF THIS REPORT

The purpose of this report is to provide the Office of Emergency Preparedness and the State of California with a rational basis for planning earthquake disaster relief and recovery operations in the San Francisco Bay area. The maps, tables and other data in this report have been prepared for this particular purpose only. Application of the material in this report to other types of analyses should be undertaken with considerable care and due attention to the limitations and restrictions placed on the data and conclusions stated in this report.

Table of Contents

PART A: ISOSEISMAL STUDIES 1

PART B: CASUALTIES AND DAMAGE

Section 1: Introduction 1

Section 2: Bases for Analysis 8

Section 3: Effects on Local Medical Resources 34
- Major Hospitals 34
- Health Manpower 55
- Medical Supplies 61
- Bloodbanks 68
- Hospital Reserve Disaster Inventory (HRDI) Modules . . . 76
- Packaged Disaster Hospitals 80
- Clinical Laboratories 87
- Ambulance Services 93
- Nursing Homes 102

Section 4: Demands on Medical Resources 108
- Deaths and Injuries, Excluding Dams 108
- Dams 126

Section 5: Effects on Immediate and Vital Public Needs . . . 133
- Public Structures 133
- Communications 146
- Transportation 153
- Public Utilities 172
- Schools 188
- Mercantile, Industrial, and Warehousing 194
- Homeless 200
- Fire Following Earthquake 208

Selected Bibliography 215

PART A

ISOSEISMAL STUDIES

INTRODUCTION

In recognition of a need for effective predisaster planning for a major earthquake catastrophy, the Office of Emergency Preparedness (OEP) entered into an agreement with the Earth Sciences Laboratories of the National Oceanic and Atmospheric Administration (NOAA) whereby NOAA, together with consultants, would undertake a study of an earthquake-prone metropolitan area in order to determine the life loss and earthquake damage potential of the area. Special emphasis in the study was to be on estimating damage to facilities particularly critical to disaster relief and recovery. The San Francisco Bay Area was the area chosen for the study. Results of the study will serve as important input to a disaster preparedness plan currently being formulated by OEP.

STATEMENT OF THE PROBLEM

The problem was to determine the earthquake damage to critical facilities in the San Francisco Bay Area for a range of earthquakes of various magnitudes which might occur along faults known to be active in historic times. The following six earthquakes were simulated: shocks with magnitudes of 8.3, 7.0 and 6.0 with epicenters located on the San Andreas fault near San Francisco and three earthquakes with the same magnitudes with epicenters located on the Hayward fault near Hayward. The rationale for the selection of these six earthquakes is given in a later section.

PROJECT DESIGN

The project was divided into two separate areas of work:

1. The estimation of the distribution of intensity of shaking during each of the six postulated earthquakes, and
2. Estimation of life loss and the extent of damage to those facilities deemed critical to disaster recovery and relief.

The estimated distribution of Modified Mercalli intensities in each of the six earthquakes was taken as a measure of the intensity of shaking. Isoseismal maps were prepared for each of the six postulated earthquakes. The extent of damage to structures and life loss in each of the six earthquakes was then estimated on the basis of isoseismal maps. The selection of the earthquakes and preparation of the isoseismal maps was done in the Earth Sciences Laboratories (ESL) of NOAA while the estimation of damage and life loss was accomplished by consultants. Certain damage estimates, for example, estimates of the number of dwellings damaged by surface faulting and the total number of dwellings likely to be damaged in each of the six earthquakes, were computed by ESL using techniques developed in an earlier study (1).

MAJOR EARTHQUAKES OF THE BAY AREA

Earthquakes with the magnitudes in the range of those postulated in this study have occurred in the San Francisco Bay Area in the past 140 years (see Figure 1). Of these, the earliest large shock known historically occurred on June 10, 1836, on the Hayward fault in the East Bay area. Louderback (2) rated this earthquake as intensity X (Rossi-Forel;* equivalent to between X and XI on the Modified Mercalli scale) in the epicentral area. He suggests that the 1836 shock

*The Rossi-Forel (RF) intensity scale was the first generally accepted scale to quantify damage to structures due to earthquakes. The scale was adopted in 1883 and was used widely in seismological and engineering literature. As a result of advances in building technology, the scale became out-of-date. A scale suggested by Mercalli in 1902 and modified by H. O. Wood, and Frank Neumann in 1931 is currently used in the U. S. In general, the following equivalence between the two scales is valid:

RF	I	I-II	III	IV-V	V-VI	VI-VIII	VIII-	VIII+-IX	IX+	X	X	
MM	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII

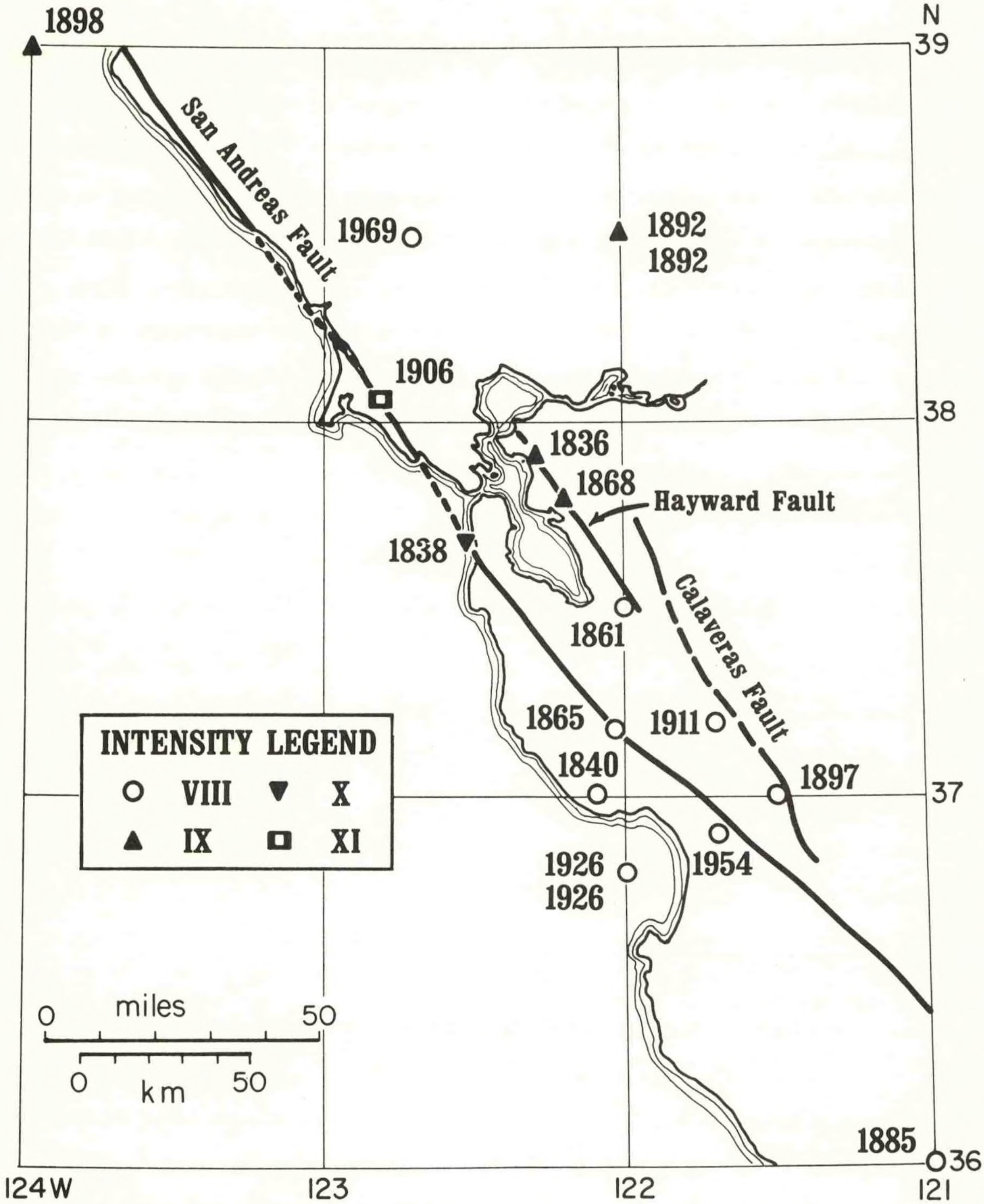


FIGURE 1. San Francisco Bay Area showing the location of major, historical earthquakes.

may have been somewhat stronger than the shock of 1868 which also occurred on the Hayward fault.

The next severe shock occured in late June, 1838 on the San Andreas fault in the hills just west of Palo Alto. Louderback (2) compared this earthquake in size with the shock of April 18, 1906, again assigning an intensity X (Rossi-Forel). At the time of the earthquake in 1838, the business district of today's city of San Francisco was called Yerba Buena. It consisted of not more than seven or eight buildings and the immediate area had no more than 50 inhabitants. Because of the low population density and few buildings in the area it is difficult to estimate the maximum intensity of this shock.

Five and six story buildings had been built in San Francisco by 1865, and the population was about 150,000 when an earthquake occurred on October 9. The contemporary newspaper accounts of the earthquakes were the first observations to recognize that well built structures on "good ground" survive the shaking effects of earthquakes better than structures on "made-ground" (3).

> It is a noticeable fact that not one building having walls properly secured and laid in cement, with sound foundations, suffered by the earthquake in the least.

It is estimated that in the epicentral region to the south of San Francisco, in the hills between Santa Cruz and San Jose, the intensity was at least MM-VIII.

Three years later, in 1868, the Bay Area was rocked by a severe earthquake which produced the first loss of life in the Bay Area due to earthquakes and caused about $350,000 property damage to the growing city of San Francisco. On the made ground in the city and the mud flats all around the Bay, damage to structures was severe. This earthquake, centered in the East Bay area, with its epicenter on the Hayward fault near the town of Hayward, was approximately as large as the 1836 shock on the same fault. This shock produced the greatest damaging effect of any of the pre-1906 earthquakes.

The most significant earthquake in the history of the Bay Area in terms of lives lost and property damage was the earthquake of April 18, 1906. Surface faulting nearly 270 miles in length, from San Juan Bautista on the south to Point Arena on the north was observed. Displacements of up to 21 feet were recorded in the San Andreas rift zone north of San Francisco. The earthquake was felt 350 miles away in Coos Bay, Oregon; Winnamucca, Nevada and Los Angeles. The earthquake severed water mains in San Francisco, Santa Rosa, and Fort Ross depriving fire-fighting units of the necessary water supply. Seven hundred lives were lost during the earthquake and conflagration that followed. Four hundred million dollars worth of property was destroyed. Detailed accounts of the earthquake and damage resulting from it can be found in the comprehensive Carnegie Commission report (4) and other sources (5, 6).

Many other earthquakes have occurred in the Bay Area in historical times but in general, they have caused only minor damage. On March 22, 1957, an earthquake of magnitude 5.3 occurred just south of the city of San Francisco that damaged principally frame houses just west of Daly City. The earthquake was not of high intensity or of long duration. Nearby multistory buildings, generally designed to be earthquake resistant, had no structural damage (7).

CURRENT SEISMICITY OF THE SAN FRANCISCO BAY REGION

The largest earthquakes to have occurred in the Bay Area in the past seven years were the magnitude 5.6 and 5.7 Santa Rosa earthquakes of October 2, 1969. During this seven-year period, some portions of the San Andreas and Hayward faults have been active with small earthquakes. Appreciable moderate earthquake activity occurs away from these two faults, for example, on the Calaveras fault zone which passes through the East Bay hills east of the Hayward fault, and on some of the small unnamed faults which are common in the California Coast Ranges.

Small episodic earth movements, in the order of a few centimeters per year, take place along active faults south and east of the bay area. These movements, which do not generate seismic waves, are termed creep. Figure 2 (taken from 8)

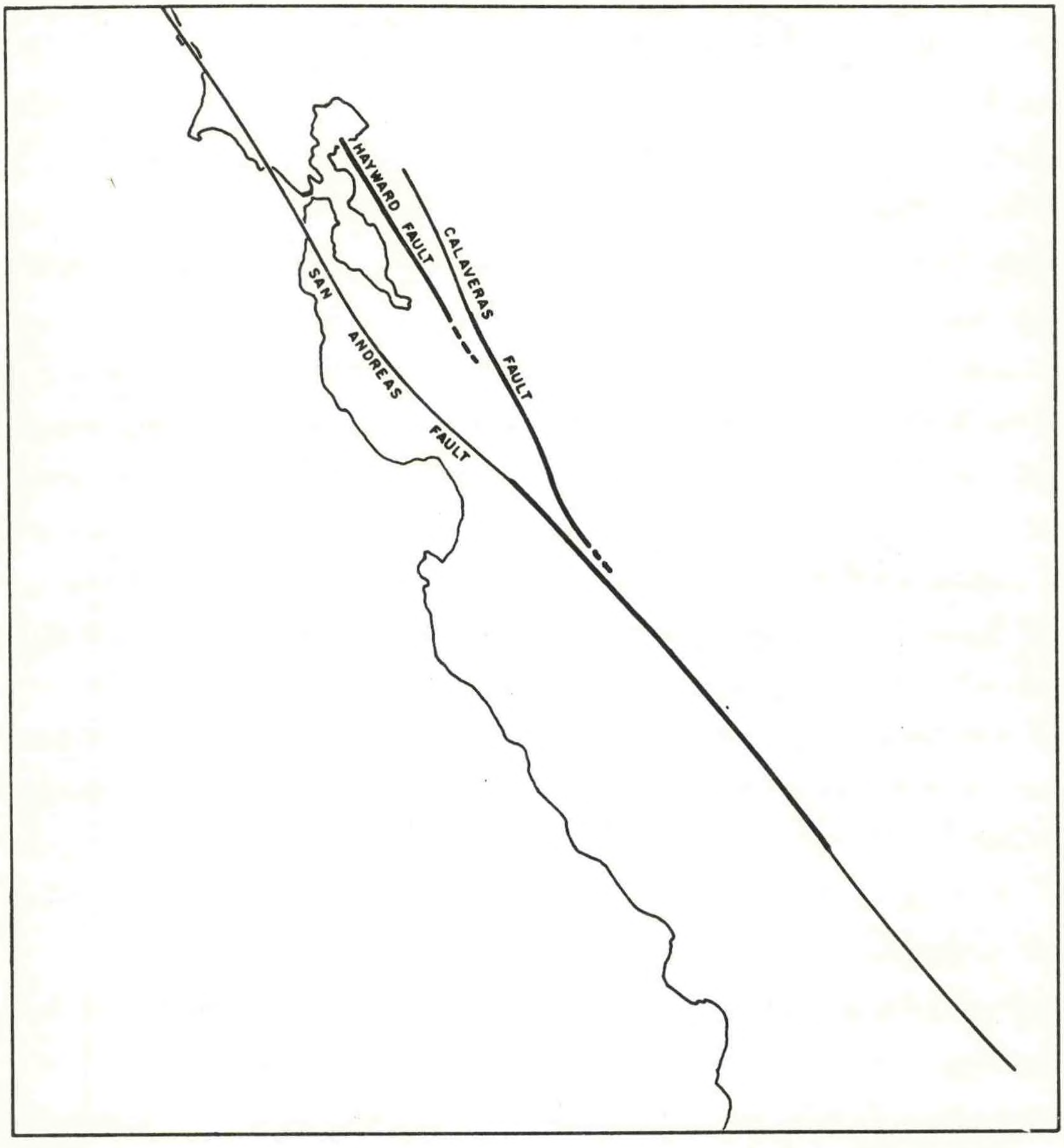


FIGURE 2. San Andreas, Hayward, and Calaveras faults, showing location of active fault slippage (thick lines). (After Nason, 6)

shows areas which have measurable creep on the San Andreas, Hayward, and Calaveras faults. In the past large earthquakes have occurred on the Hayward fault where creep is measured today, but it is significant that no creep has been detected on the San Andreas fault in the San Francisco Bay area which was the locus of the great 1906 earthquake. The relationship between creep and the occurrence of earthquakes is being studied at the present time by a number of university and government scientific groups.

FREQUENCY OF OCCURRENCE OF DAMAGING EARTHQUAKES

Estimation of the frequency of earthquake occurrence has been approached in a number of ways. By plotting the log of the number of earthquakes per year against magnitude and calculating a regression curve for the data, or a subset of the data, an estimate of the frequency of occurrence of earthquakes may be obtained. This often used technique for estimating earthquake frequency is heavily dependent upon the sample size and completeness.

Another technique that has been much used to estimate return periods of floods and severe storms (9) and which has also been used to estimate earthquake return periods (10) is the extreme value statistical approach (11). Extreme value statistics were applied to the San Francisco Bay Area set of data. The data were grouped in two-year periods over the past 172 years. The area from which the data sample was drawn is shown in Figure 3. From this analysis, (Figure 4) the return periods for the postulated earthquakes of magnitudes sufficiently large to produce damage at intensity VIII, IX, and XI (earthquakes of magnitude 6.0, 7.0, and 8.3 respectively) are 17, 32, and 170 years. In an independent evaluation of earthquake recurrence on the San Andreas fault, Wallace (12) used as his basic data the geologically long history of slip rates on the fault. For magnitudes 6.0, 7.0, and 8.0 he estimates the return period to be 5, 15, and 102 years with a possible error of a factor of two. His estimates of return period are of the same order as the statistical analysis of the historical record of earthquake occurrence.

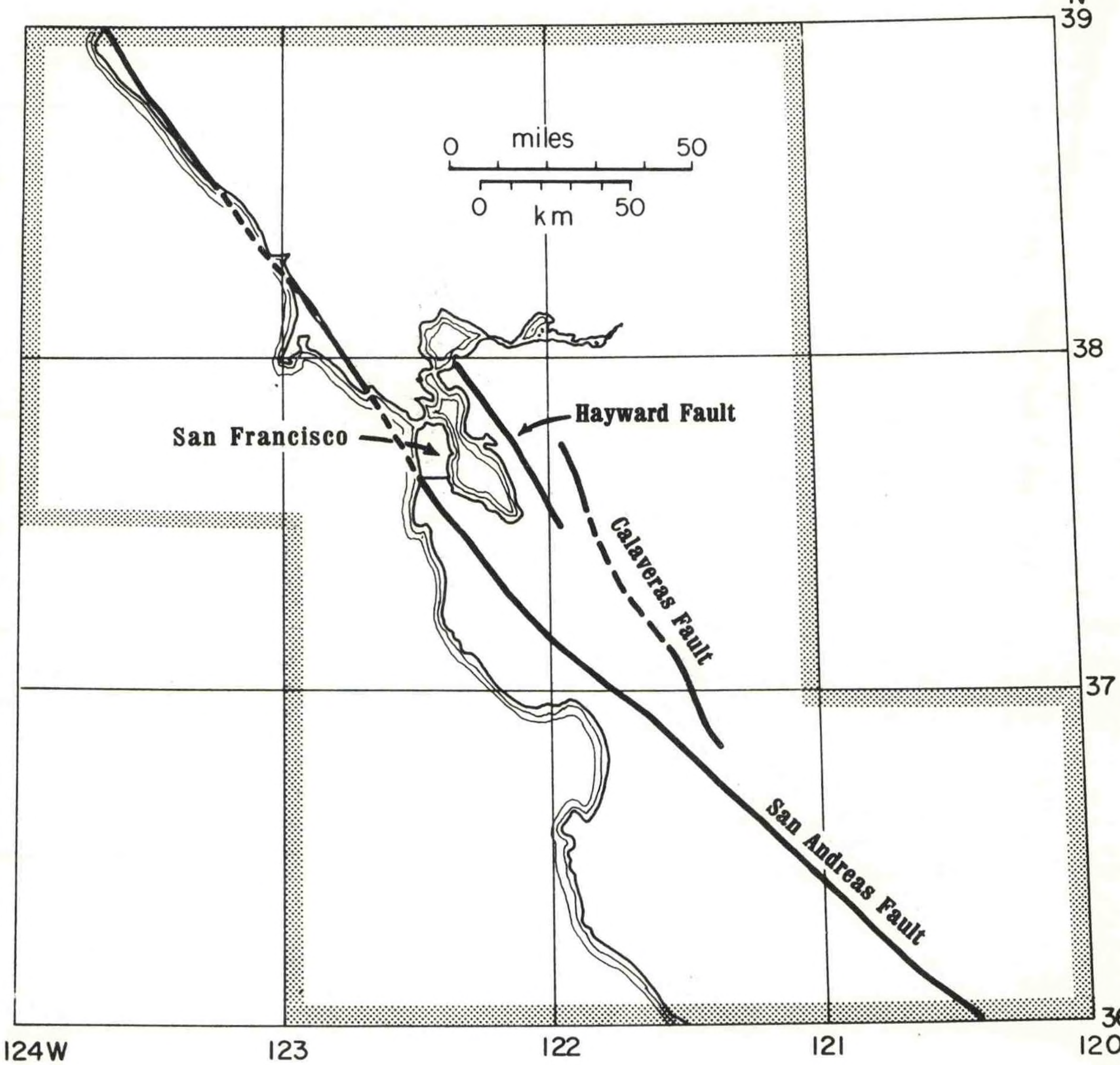
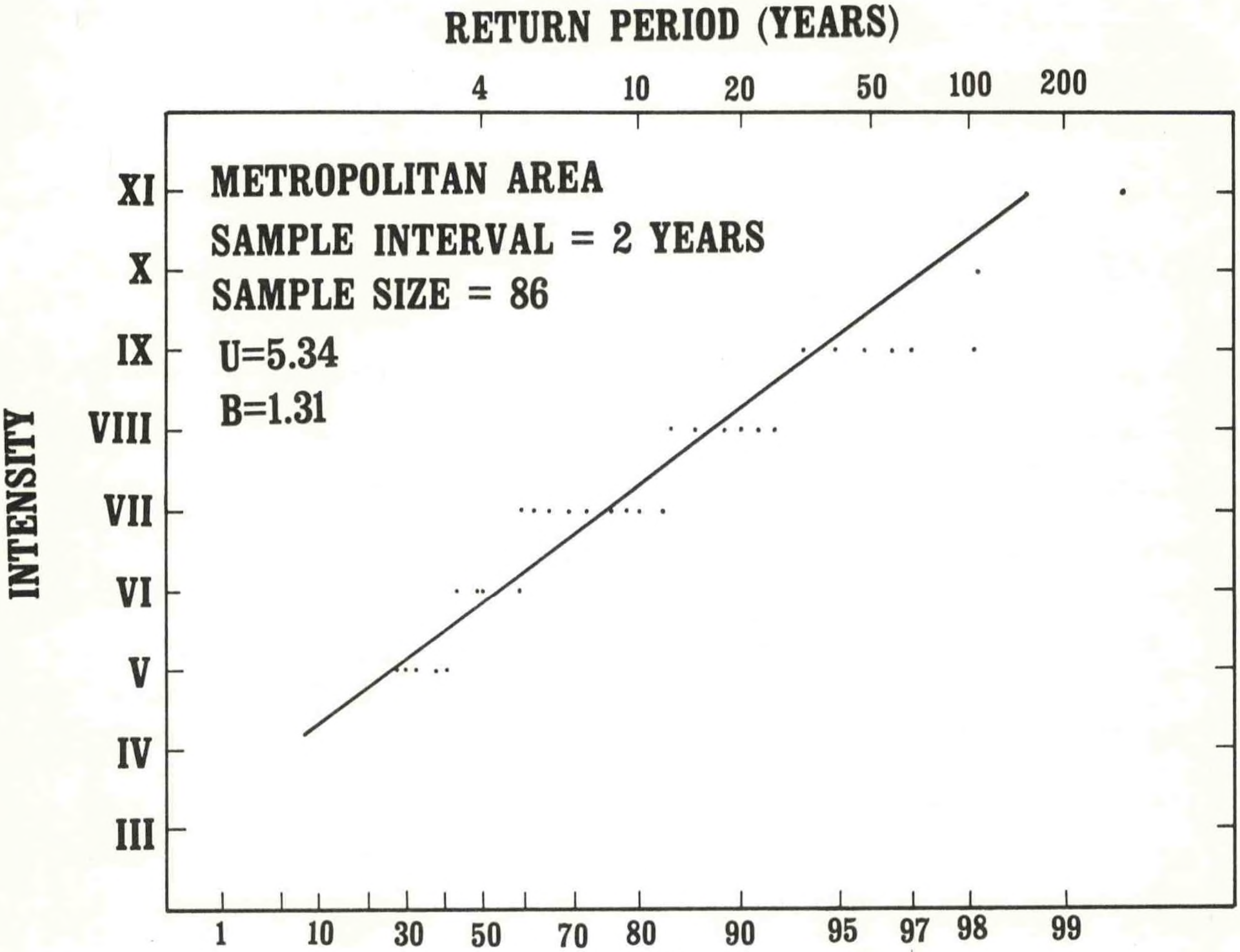


FIGURE 3. Location area from which extreme value statistic data were drawn.



$$P(I_i) = \left[\frac{100(i-0.44)}{(n-0.12)}\right]$$

FIGURE 4. Biannual maximum intensity distribution of earthquakes in the San Francisco Bay Area from 1799 to 1971.

RATIONALE FOR THE SELECTION OF THE SIX EARTHQUAKES

Using the empirical relationship between magnitude and intensity given by Gutenberg and Richter (13) for metropolitan centers in California,

$$M = 1 + \frac{2}{3} I_o$$

and, also, considering that no significant amount of structural damage occurs to reasonably well constructed buildings at MM intensity lower than VII, magnitude 6.0 was selected as the smallest earthquake on either the San Andreas or Hayward fault for consideration in this study. While critical facilities would not be destroyed at intensity levels below VII, loss of life might occur in unusual situations. The important point is that damage and life loss estimated to occur as a result of earthquakes with magnitudes less than six, are not likely to be beyond the capability of the local community to respond.

The selection of the magnitude 8.3 earthquake on both faults was based on the following rationale:

1. The 1906 earthquake is the largest shock that has occurred on the San Andreas fault in the historical record, and while it may be possible for larger earthquakes to occur on the San Andreas fault, the 1906 earthquake is certainly near the upper limit of shocks that may be expected to occur in this area.
2. It was advantageous to use an 8.3 magnitude earthquake as the largest probable shock for purposes of this study because of the tremendous quantity of data on the intensity of shaking available in the report of the Carnegie Commission (4) for this magnitude earthquake.

Surface breakage along the Hayward fault during the two major historical earthquakes was recorded from San Pablo to Mission San Jose in 1836 (2), and between Oakland and Warm Springs in 1868 (4). These breaks, which have been studied by Radbruch (14), are 72 and 40 kilometers in length. Wallace (12) and Bonilla (15), using data for continental United States earthquakes, give graphical relationships between the magnitude of an earthquake and the length of surface breakage. On these graphs are plotted bounding curves which suggest that for a 72 km. surface break, as observed for the 1836 shock on the Hayward fault, the magnitude of the earthquake would be in the range of 6.0 to 7.6. The exact length of faulting on the Hayward fault is not well known. For example, the possibility exists that faulting extends to the north beneath San Pablo Bay. Thus, an analysis of a major shock of magnitude 8.3 on the Hayward fault was included in this study for earthquake disaster planning purposes, even though the possibility of an earthquake of this magnitude on the Hayward fault is considered remote. The 1838 shock on the San Andreas fault was of a possible magnitude 7.0 size. The bounding curves of Wallace's (12) graphs suggest a magnitude of 5.1 to 7.2 for the 40 km. surface break of the 1868 Hayward earthquake. It was thus reasonable to include analyses of magnitude 7.0 earthquakes on the San Andreas and Hayward faults in this study.

DATA USED IN THE STUDY

To construct the isoseismal maps of the six postulated earthquakes, two basic sources of data were used: the descriptions of shaking and destruction of buildings recorded in various post-earthquake studies and maps of the surficial geology of the Bay Area.

The damage descriptions of the 1906 earthquake reported in 1908 by the Carnegie Commission (4), were reevaluated on the Modified Mercalli intensity scale and were then used as control observations in the plotting and contouring of the isoseismals for the proposed magnitude 8.3 earthquake on both the San Andreas and Hayward fault. The destructive effects of the 1868 earthquake in the San Francisco Bay Area (3, 4, 5) were used, where possible, to control the distribution of isoseismals in the area for the magnitude 7.0 earthquakes. The damage distribution in the 1957 Daly City earthquake (7) were used as guidelines in preparing the isoseismal map for the magnitude 6.0 shocks. The complete isoseismal pattern of numerous earthquakes in California (1) was used to get the general elliptical outline of the isoseismals prior to adjusting them for the effect of local variations in geology.

Numerous other studies such as those of Idriss and Seed (16), Borcherdt (17), and Gibbs and Eaton (18) were evaluated and, where possible, used to estimate intensities likely to result from the six postulated earthquakes in the Bay Area.

The regional geology of the San Francisco Bay Area was obtained from various sources. Large scale geologic maps were used whenever possible for this control. For the San Francisco, Concord, Mt. Tamalpais, San Mateo, and Hayward quadrangles, the San Francisco Folio (19) was used. For areas outside these five quadrangles, the San Francisco, San Jose, and Santa Rosa regional maps were used (20). The location of the traces of the San Andreas and Hayward fault were plotted from the maps of the Carnegie Commission report (4) and the recent studies of Radbruch (14), and Brown (21). The Bay margins and land fill areas were obtained from the U. S. Geological Survey basic data contribution No. 9 (22) and other maps available to NOAA (23).

CONSTRUCTION OF THE ISOSEISMAL MAPS

The length of the fault trace for each postulated earthquake was obtained from Wallace's (12) graphical relationship. A narrow band, one-half to one kilometer wide was plotted along the fault traces as an area of highest intensity resulting from displacement and vibrational damage.

The expected intensity for any other site, away from the fault traces was taken to be a function of the close-in intensity, the distance from the earthquake source, and the site geology. The decrease of intensity with distance was taken from empirically determined graphs showing intensity as a function of distance. The dependence of intensity on site geology was taken from empirically determined relationships, which relied on the observations at or near the sites for the April 18, 1906 earthquake and the March 22, 1957 earthquake, on accelerograph records, and on other studies of site amplification (16 and 17). For example, it was found that at a distance of 30 kilometers from the San Andreas fault the intensity on young bay mud was approximately three intensity units higher than on granite or on the metamorphosed rocks of the Franciscan formation at the same distance. Figures 5, 6 and 7 are examples of the six maps prepared for this study.

It should be clearly understood that the isoseismal maps prepared for this study are regional in character and were proposed as a guide and basis for the estimation of damage to facilities critical for the planning of disaster relief and recovery operations in the Bay Area. These maps were used as background material by the consultants to NOAA to estimate damage. In many cases, the consultants had additional data available to them to aid in the estimation of potential damage. Thus, the intensity maps prepared are intended to be a general guide to the probable distribution of intensity in the specified earthquake. For a detailed evaluation of a particular site, these maps must be used in conjunction with other geological and engineering data that may be available. No attempt was made to define landslide areas nor the damage resulting from landslides.

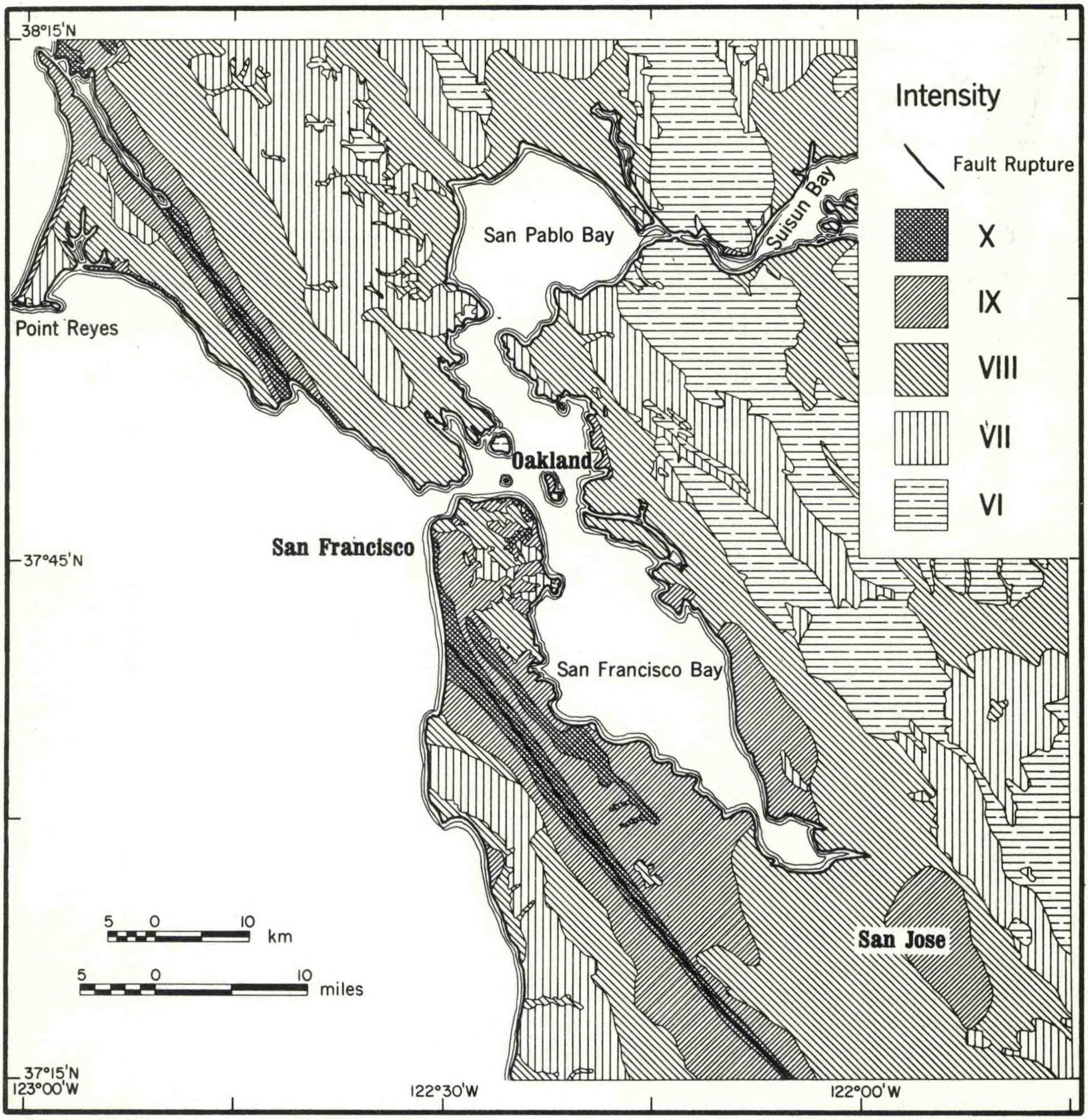


FIGURE 5. Intensity distribution from a magnitude 8.3 earthquake on the San Andreas fault.

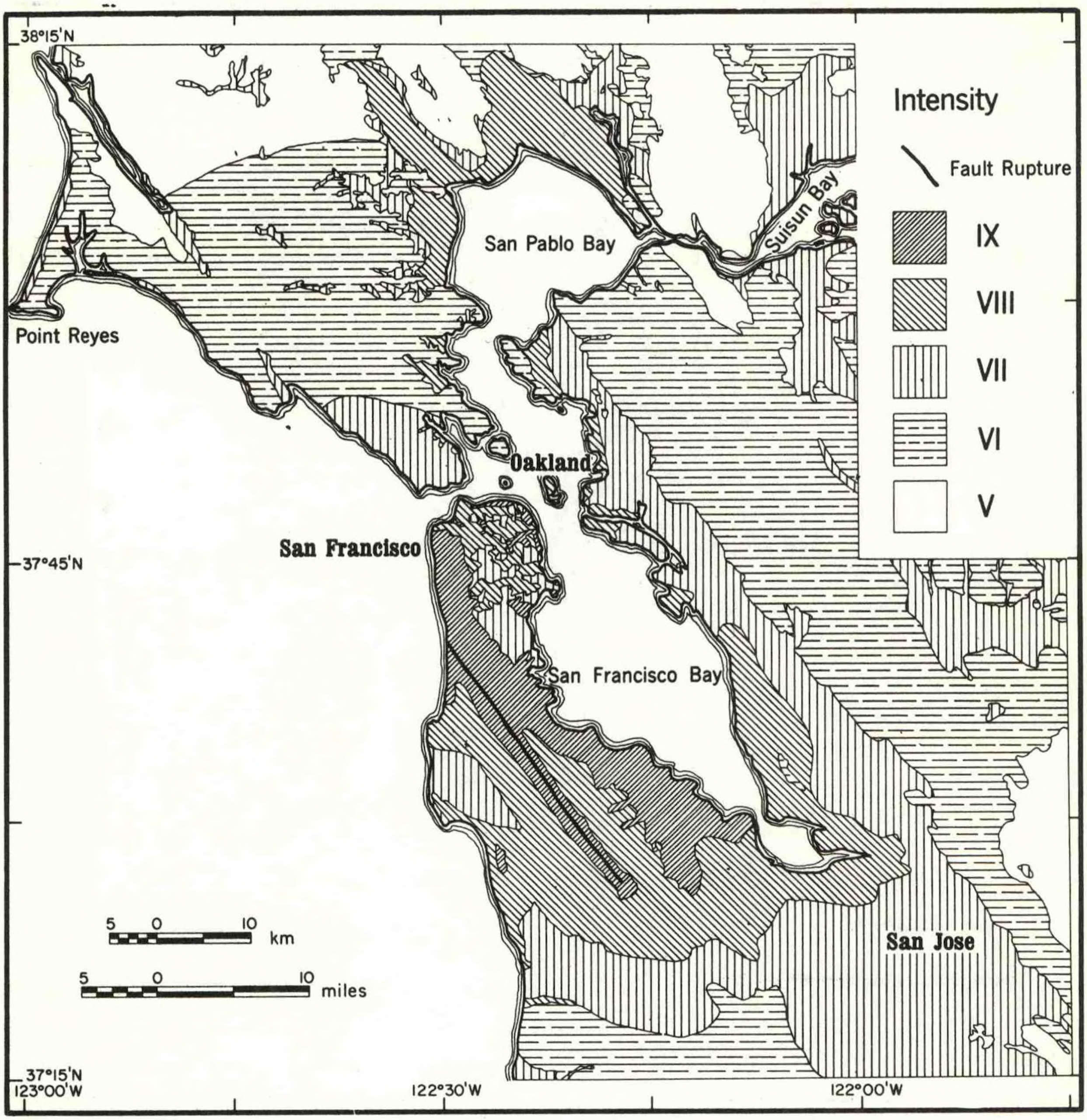


FIGURE 6. Intensity distribution from a magnitude 7 earthquake on the San Andreas fault.

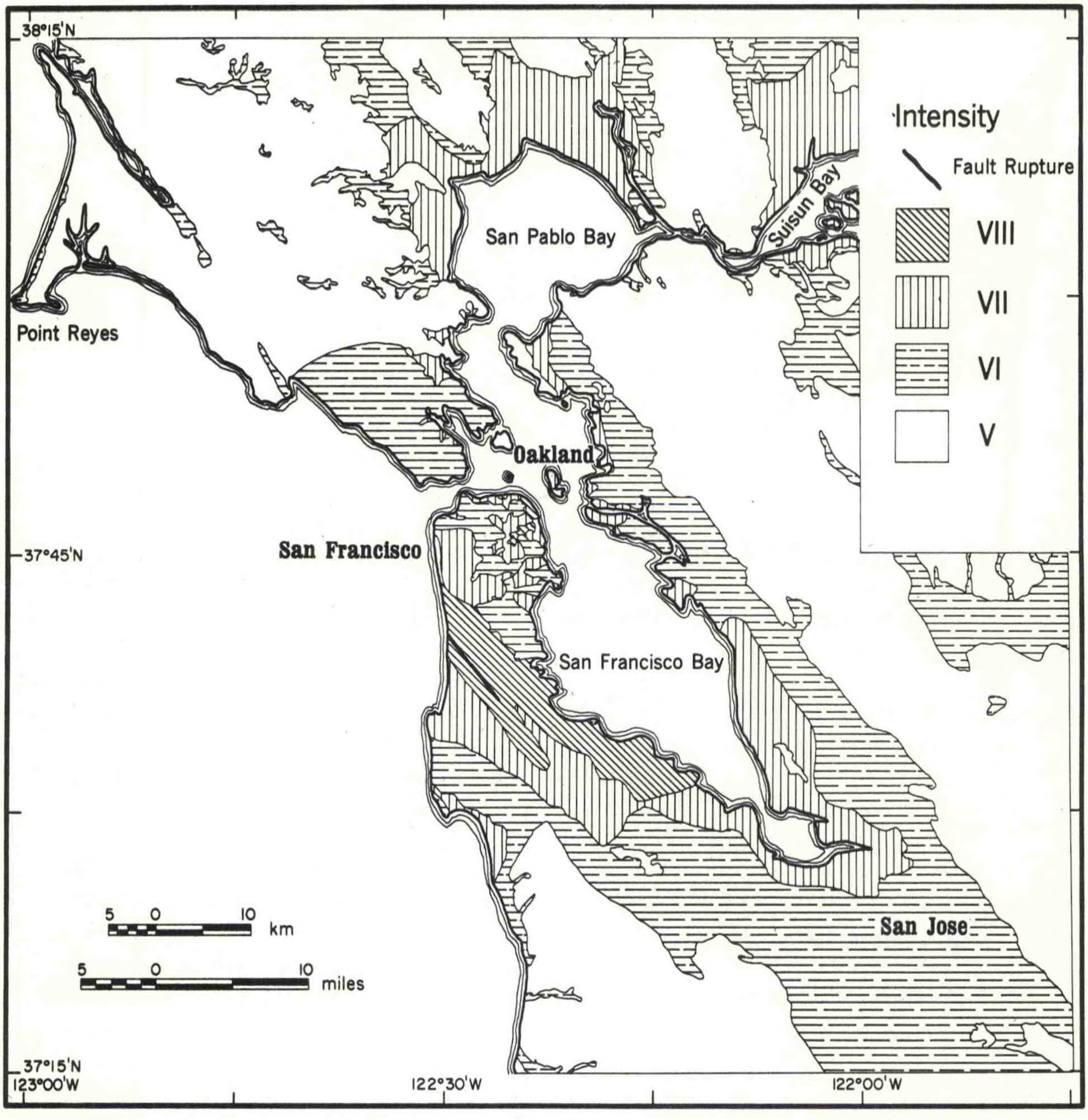


FIGURE 7. Intensity distribution from a magnitude 6 earthquake on the San Andreas fault.

TABLE 1

MODIFIED MERCALLI INTENSITY SCALE*

I. Not felt. Marginal and long-period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

---

*The version of the scale given above was published by Richter (24), and is a slight abridgment of the original scale. Richter also included the description of the types of construction included here. The original scale was published in 1931 by H. O. Wood and Frank Neumann (25).

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

<u>Definition of Masonry A, B, C, D:</u>

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

REFERENCES

(1) Algermissen, S. T., Stepp, J. C., Rinehart, W. A., and Arnold, E. P., "Studies in Seismicity and Earthquake Damage Statistics, 1969, Appendix B," A report prepared for Department of Housing and Urban Development, Office of Economic and Market Analysis, 68 p. (1969).

(2) Louderback, G. D., "Central California Earthquakes of the 1830's." Bull. Seism. Soc. Am., 37:33-74 (1947).

(3) Huber, W. L., "San Francisco Earthquakes of 1865 and 1868," Bull. Seism. Soc. Am., 20:261-272 (1930).

(4) Lawson, A. D., "The California Earthquake of April 18, 1906, Report of the State Earthquake Investigation Commission," Two volumes and Atlas, Carnegie Institution of Washington (1908), (reprinted, 1969).

(5) Freeman, John R., "Earthquake Damage and Earthquake Insurance," McGraw-Hill Book Co. Inc., 904 p. (1932).

(6) Gilbert, G. K., Humphrey, R. L., Sewell, J. S., and Soule, Frank, "The San Francisco Earthquake and Fire of April 18, 1906, and Their Effects on Structures and Structural Materials, U. S. Geological Survey Bull. No. 324, 170 pp. (1907).

(7) Steinbrugge, K. V., Bush, V. R., and Zacher, E. G., "Damage to Buildings and Other Structures during the Earthquake of March 22, 1957," Special Report 57, California Division of Mines, pp. 73-106 (1959).

(8) Nason, R. D. "Preliminary Instrumental Measurements of Fault Creep Slippage on the San Andreas Fault, California," Earthquake Notes, Vol. XL, No. 1, 7-10 (1969).

(9) Gumbel, E. J., "The Statistical Forecast of Floods," Bull. 15, Ohio Water Resources Bd., Columbus, Ohio, pp. 1-21 (1949).

(10) Nordquist, J. M., "Theory of Largest Values Applied to Earthquake Magnitude," Trans. Am. Geophy. Union, 26:29-31 (1945).

(11) Gumbel, E. J., "Statistical Theory of Extreme Values and Some Practical Applications," National Bureau of Standards, Applied Mathematics Series, 33, U. S. Govt. Printing Office, 51 p. (1954).

(12) Wallace, R. E., "Earthquake Recurrence Intervals on the San Andreas Fault, Geo. Soc. Am. Bull., 81:2875-2890 (1970).

(13) Gutenberg, B., and Richter, C. F , "Earthquake Magnitude, Intensity, Energy, and Acceleration (Second Paper)," Bull. Seism. Soc. Am., 46:105-146 (1956).

(14) Radbruch, D. H., "Map Showing Recently Active Breaks along the Hayward Fault Zone and the Southern Part of the Calaveras Fault Zone, California," Open file map, U. S. Geological Survey.

(15) Bonilla, M. G., "Historic Surface Faulting in Continental United States and Adjacent Parts of Mexico," U. S. Geological Survey Open File Rept. 36 pp., U. S. Atomic Energy Comm., Rept. TID-24124 (1967).

(16) Idriss, I. M., and Seed, H. B., "An Analysis of Ground Motions during the 1957 San Francisco Earthquake," Bull. Seism. Soc. Am., 58:2013-2032 (1968).

(17) Borcherdt, R. D., "Effects of Local Geology on Ground Motions near San Francisco Bay," Bull Seism. Soc. Am., 60:29-62 (1970).

(18) Gibbs, J. F., and Eaton, J. P., "A Digitized Seismic Susceptibility Map of San Francisco Bay Region, California," U. S. Geological Survey Open File Map (1971).

(19) Lawson, A. C., "Geologic Atlas of the United States, San Francisco Folio, No. 193," U. S. Geological Survey (1914).

(20) "Geological Atlas of California," California Division of Mines and Geology, San Francisco, 1961, Santa Rosa, 1963, San Jose (1966).

(21) Brown, R. D., Jr., "Faults that are Historically Active or That Show Evidence of Geologically Young Surface Displacement, San Francisco Bay Region," Progress report, San Francisco Bay Region Environment and Resources Planning Study, Basic Data Contribution 7, (1970).

(22) Nichols, D. R. and Wright, N. A., "Preliminary Map of Historic Margins of Marshlands, San Francisco Bay, California, San Francisco Bay Region Environment and Resources Planning Study," Basic Data Contribution 9, (1971).

(23) Pacific Fire Rating Bureau, "Filled Ground Regions in Alameda, Albany, Berkeley, El Cerrito, Emeryville, Oakland, Richmond, San Leandro," and a portion of San Francisco, (1959 and 1961).

(24) Richter, C. F., "Elementary Seismology," W. H. Freeman and Co., Inc., 768 p. (1958).

(25) Wood, H. O., and Neumann, F., "Modified Mercalli Intensity Scale of 1931," Bull. Seism. Soc. Am., 21:277-283 (1931).

PART B

CASUALTIES AND DAMAGE

Section 1: Introduction

OBJECTIVE

The objective of this report is to provide usable data for earthquake planning by the Federal Government and by the State of California. The main thrust of this report is directed towards the vital human needs which are required immediately after the disaster. As such, three major subject areas have been identified and are discussed in the three major sections of this report:

A. Effects on local medical resources

B. Demands on medical resources, and

C. Effects on immediate and vital public needs.

Heavy emphasis, therefore, is placed on the earthquake effects to local hospitals, local medical personnel, and local medical supplies. This information coupled with the estimates on the number of injured will allow projections of the overall medical requirements. The need for immediate medical help during any natural disaster is obvious and so is the need for mobilizing non-local medical resources within hours after the event. This report is an evaluation of these immediate needs for Federal and State Government planning. As a result, heavy emphasis has been given to subject areas A and B, above, and lesser attention to other types of information.

The large majority of the people in the affected areas will not have vital immediate needs other than the basic requirements of adequate food , shelter, and water supplies. The need for an adequate supply of water for human consumption, plus the possible need for fire fighting equipment and resources, is more vital than shelter or food in the first day or two that follow the disaster. This immediate need for water cannot be met in terms of hours if the water system is out of service. The large number of earthquake resistive structures found in the public school systems throughout the San Francisco Bay Area is a major resource for temporary housing and feeding. Stocks of non-refrigerated foods will last for days, and certainly can be judged adequate until emergency supplies are brought in and distributed. Outside of the medical problems, principal emphasis is given to the problems of water supply disruption and other equally pressing problems of immediate public need. Emphasis has not been given to damage and resulting dollar losses whenever substantial and vital human needs were not present; for example, the failure of dikes around lightly populated areas was not considered, although the economic loss could be substantial. Road and bridge damage which did not seriously disrupt vital transportation may be cited as a second example. Additionally, the temporary loss of jobs as a result of damage to factories and other places of employment, the loss of supply lines to and from these places of employment, and other economic dislocations are secondary to the purpose of this report. Bay pollution problems from oil, chemicals, and raw sewerage are also given secondary attention since human needs must come first.

In summary, the purpose of this report is to give emphasis on the vital human needs required immediately after one of the postulated shocks on the San Andreas or Hayward faults. This report is not to be all things to all agencies, and many agencies having responsibilities in the secondary interest areas will have to develop substantial amounts of corollary and compatible damage data through their own studies.

A magnitude 8.3 earthquake centered on the Hayward fault poses a special problem. This postulated shock should result in a length of fault rupture far in excess of the generally accepted length of the Hayward fault. The general information in Table 1 is pertinent with regard to the slippage effects of surface strike-slip faulting such as has repeatedly occurred on the Hayward fault. The usually known length of the Hayward fault is about 45 miles. However, from Table 1, the length of faulting on this fault would be about 200 to 300 miles in an 8.3 event if past experience is to be considered. On the other hand, it should be noted that from the standpoint of the effects of surface fault displacement alone, it does not make much difference whether we consider an 8.3 or 7.5 shock because in both instances the length of faulting would be centered through the populated areas of the East Bay. It usually does not make much difference to structures crossing the fault whether the displacement is 7 feet based on a magnitude 7.5 event or 20 feet based on a magnitude 8.3 event. In both cases, damage from surface faulting will be severe. (The additional problems of the geographic distribution of damage other than that caused by faulting are considered in the isoseismal study portion of this study.)

TABLE 1

STRIKE-SLIP FAULT CHARACTERISTICS
(Applicable to San Andreas and Hayward faults)

Earthquake Magnitude	Length of Faulting (miles)	Total Surface Displacement, in Feet	
		Horizontal	Vertical
6	15 - 20	3	0.5
7	40 - 50	5	1
8.3	200 - 300	20	5

USE OF THIS REPORT

The numerical values associated with each problem area, such as damage to and life loss in hospitals, represent reasonable maximum expected conditions. In other words, these values are credible; they have experienced data and/or experienced judgment behind them. The quality of the numbers will vary depending upon the extrapolation (if any) from experience data, the reliability of the assumptions supporting the calculations, and the quality of the judgment behind the decisions.

It is most improbable that the maximum values established for each problem type will occur simultaneously in any given earthquake. One is tempted to assign probability values to the numbers given in each problem area and thereby develop the most likely scenario to occur in real life. On the other hand, each agency should be able to respond to the maximum set of circumstances that it can reasonably expect (in other words, the values given in this report). This latter point of view has been adopted and therefore the available resources for this study have been allocated towards the accumulation and analysis of additional data rather than towards the most probable scenario.

It must be clearly understood that no two similar magnitude earthquakes give identical damage results. The rate of energy release may be different, focal depths may vary, and the center of energy release may vary considerably from the epicenter. While these variations will affect some numbers given in this report, these variations are not expected to significantly change the agency response requirements.

In addition to the possible variations in seismological parameters, the response of buildings and structures to earthquake ground motions are not as well understood as some persons might expect. Surprises have occurred in every destructive earthquake, and these are a major reason for the many reports emanating from the 1971 San Fernando shock. The expected seismic performance of any particular building can be stated in only a probabilistic sense. As a result, this report generally states its findings on a class of construction basis, or by a geographic grouping, or on some other compatible basis.

Summing the totals of the losses for various situations must be done with understanding and judgment. For example, maximum landslide hazard conditions occur in the wet season while maximum fire hazard conditions occur in the summer season. For a second example, the population density shifts to dwellings and apartment houses during the night hours while a differently distributed situation 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).

Unanticipated events occur in almost every earthquake. A destructive shock may occur on an unexpected fault as it did in the 1971 San Fernando shock; however, this is not considered credible for a great earthquake. Alternately, the earthquake could occur during the height of the Christmas shopping season. In the San Francisco area, the earthquake could occur on one of those few days each year when the ground fog halts all air transportation for hundreds of miles around, thereby restricting aid via air. These are possible events and in a sense create "surprise" situations. While these events are possible and credible, they are sufficiently improbable that they have not been considered in this report. On the other hand, no agency solution to a given situation should be so rigid as to preclude the unexpected which invariably occurs in some aspects of every great earthquake disaster.

Some comment on dollar losses is in order. Dollar losses can be estimated on the basis of replacement costs or on the basis of actual cash value (or appraised value), among other methods. The difference between replacement cost and actual cash value may be significant in some cases. For example, a study of the 1952 Kern County earthquake showed that the actual cash value of buildings in Bakersfield at the time of the 1952 shocks was 36% of the replacement value of these buildings.* If, for example, the damaged hospitals discussed in Section 3 of

*"Studies in Gathering Earthquake Damage Statistics," Frank E. McClure. (Report prepared for ESSA, U. S. Department of Commerce, 1967.)

this study were to be replaced, the cost would be on a replacement value basis insofar as the public loss was concerned. On the other hand, if the Bakersfield experience figure is assumed to apply, then the actual loss would be only about 1/3 of the replacement cost. It must be borne in mind that the dollar loss is a function of a financial viewpoint. When dollar losses are given in this report, it is important to note the context in which they are given.

LIMITS OF AREA OF STUDY

The study area as covered in this report is defined as being limited to the 9 Bay Area counties surrounding the body of water known as San Francisco Bay, which in actuality comprises three bays, San Francisco Bay, San Pablo Bay, and Suisun Bay. See Figures 1 and 2 for a general identification of the study area as further delimited by the isoseismal lines determined by the Environmental Research Laboratories of the National Oceanic and Atmospheric Administration (NOAA). The 9 Bay Area counties are listed below with the total resident population of each county as given by the 1970 U. S. Census Report.

County	Total Population
Alameda	1,073,184
Contra Costa	558,389
Marin	206,038
Napa	79,140
San Francisco	715,674
San Mateo	556,234
Santa Clara	1,064,714
Solano	169,941
Sonoma	204,885
Total	4,628,199

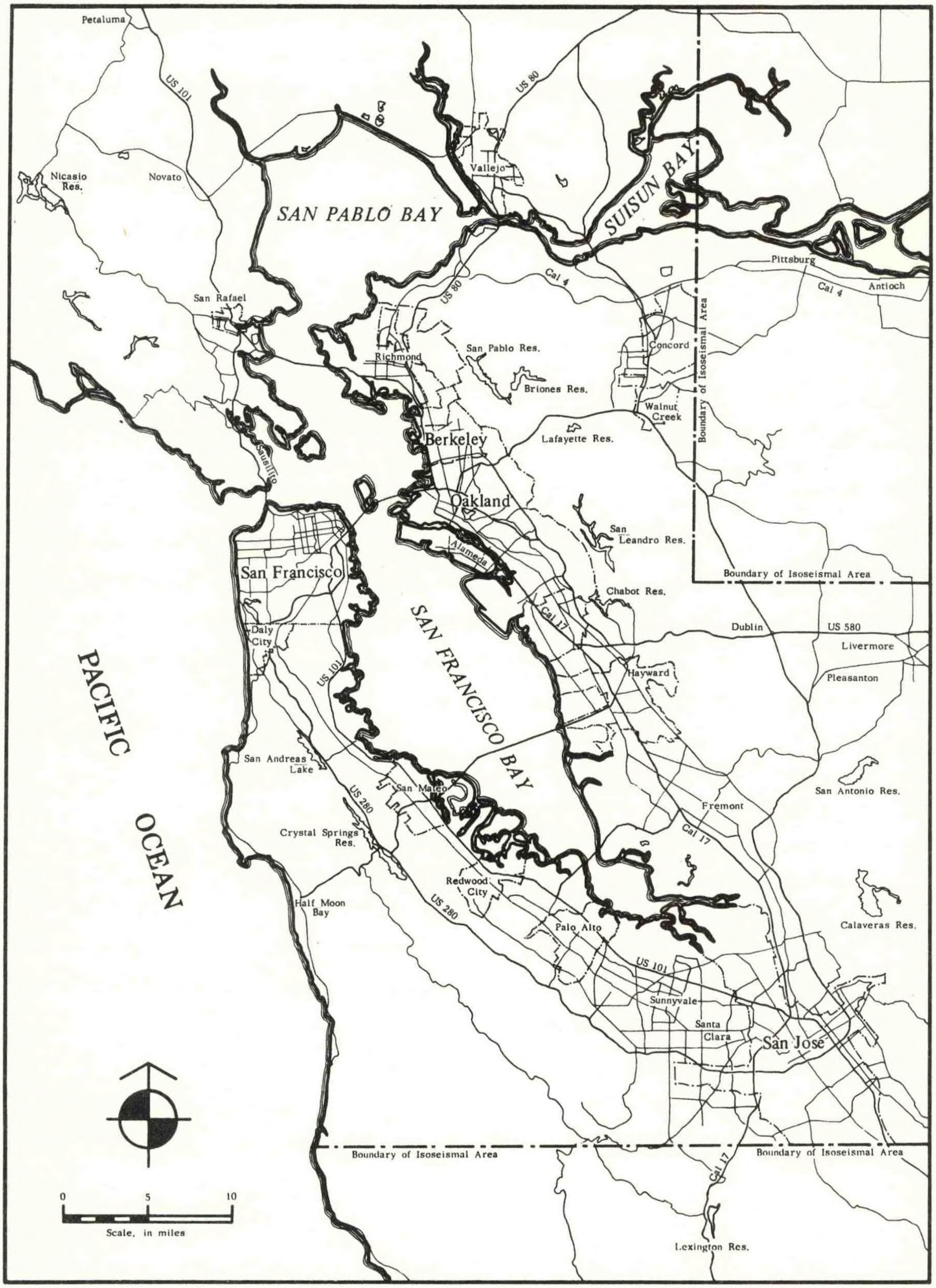


FIGURE 1. Isoseismal study area.

Section 2: Bases for Analysis

This section is a general discussion of the bases used in this report for determining the potential casualties and property damage for the 6 specific earthquakes chosen for study in the San Francisco Bay Area. The methods vary in keeping with the importance of the particular topic and the types of data which were available. More specific information on certain aspects of the methodology used for particular occupancies and the supporting rationale will be found in the various sections discussing the particular occupancies.

Studies on projected earthquake casualties and damage must be a combination of several important factors:

1. Data from relevant earthquakes,
2. Theoretical considerations, both scientific and engineering,
3. Experience which must be tempered with engineering judgment, and
4. Time of day and season of year when the earthquake strikes.

The aforementioned four factors must be contained in any methodology for determining the life hazard and property damage potentials; the balance of this section of the report is a general discussion of these factors.

DATA FROM RELEVANT EARTHQUAKES

A list of United States earthquakes having particular significance to the purposes of this report is given in Table 2. It is of particular interest to note that the death toll to date has never exceeded 1,000 in any single United States earthquake disaster. This low death toll is in sharp contrast to those from some foreign earthquakes, and it is of value to briefly examine this contrast.

For one case, the Agadir, Morocco earthquake of 1960 has been assigned the moderate Richter magnitude of 5.5 to 6 by various authorities. The most prevalent construction material was older masonry which varied from stone (with mortar of mud and sand) to more modern construction of stone or clay tile with mortar ranging from weak mud and sand to good quality sand-cement. None of the masonry was reinforced. The second most prevalent type of construction was usually a very poor quality reinforced concrete which had not been designed to resist earthquake forces. In other words, Agadir was "a disaster waiting to occur," and the estimated 12,000 deaths and 12,000 injured out of a population of about 33,000 is quite understandable when the buildings collapsed due to ground shaking.

For a second case, the Dasht-e-Bayaz, Iran, earthquake of August 31, 1968 struck villages of adobe or mud wall construction, with domed adobe brick roofs or vault roofs. The structures were built in clusters and separated by very narrow streets. With general building collapse and with debris covering the streets after the shock, it is little wonder that 1,200 out of 1,700 inhabitants were killed at Dasht-e-Bayaz and 1,400 died in Kakhk out of a population of 4,400.

In the authors' opinion, the heaviest ground shaking at Agadir and at Dasht-e-Bayaz most likely did not exceed that in the heaviest shaken areas of the 1971 San Fernando shock. Many other foreign examples can be cited; in almost all cases the masonry would be of extremely poor quality and construction would be completely different from American practice.

The two foregoing examples were related to ground shaking and not to geological hazards. The May 31, 1970 Peruvian earthquake may be cited as an

TABLE 2

SELECTED U. S. EARTHQUAKES, 1811-1971

Name of Earthquake	Date and (local) Time	[1] Epicenter Location	[2] Maximum Modified Mercalli Intensity	[1] Richter Magnitude	Approximate Length of Surface Faulting (miles)	[3] Lives Lost	[4] Dollar Loss	Remarks
New Madrid, Missouri	Dec. 16, 1811 (about 2:15 AM) Jan. 23, 1812 (about 8:50 AM) Feb. 7, 1812 (about 10:10 AM)	36 N, 90 W	XII (for each shock)	Over 8	See remarks	1 death	---	Richter assigned a magnitude of greater than 8 based on observed effects. Surface faulting possibly occurred: see Fuller, p. 58 (Bibliography).
Charleston, S. Carolina	Aug. 31, 1886 (9:51 PM)	32. 9 N, 80. 0 W	X	---	None	27 killed outright, plus 83 or more from related causes.	$5,000,000 to $6,000,000	---
San Francisco Calif.	Apr. 18, 1906 (5:12 AM, PST)	38 N, 123 W	XI	8. 3	190 minimum 270 possible	700 to 800 deaths.	$400,000,000 incl. fire; $80,000,000 earthquake only.	Portions of the San Andreas fault are under the Pacific Ocean.
Santa Barbara, Calif.	June 29, 1925 (6:42 AM)	34. 3 N, 119. 8 W	VIII-IX	6. 3	None	12 to 14 deaths.	$6,500,000	The dollar loss is for the City of Santa Barbara: losses elsewhere were slight.
Long Beach, Calif.	Mar. 10, 1933 (5:54 PM, PST)	33. 6 N, 118. 0 W	IX	6. 3	---	Coroner's report: 86. 102 killed is more probable.	$40,000,000 to $50,000,000	Epicenter in ocean. Associated with Inglewood fault.
Helena, Montana	Oct. 12, 1935 (0:51 AM, MST)	46. 6 N, 112. 0 W	VII	---	None	---	$50,000	First of three destructive shocks: Oct. 12, 18, and 31.
Helena, Montana	Oct. 18, 1935 (9:48 PM, MST)	46. 6 N, 112. 0 W	VIII	6. 25	None	2 killed, "score" injured.	$3,000,000 to over $4,000,000	---
Helena, Montana	Oct. 31, 1935 (11:38 AM, MST)	46. 6 N, 112. 0 W	VIII	6. 0	None	2 killed, "score" injured.		---
Imperial Valley, Calif.	May 18, 1940 (8:37 PM, PST)	32. 7 N 115. 5 W	X	7. 1	40 minimum	8 killed outright, 1 died later of injuries.	$5,000,000 to $6,000,000	M. M. IX for building damage and M. M. X for faulting.
Santa Barbara, Calif.	June 30, 1941 (11:51 PM, PST)	34. 4 N, 119. 6 W	VIII	5. 9	---	None killed, 1 hospitalized.	$250,000	Epicenter in ocean.
Olympia, Washington	Apr. 13, 1949 (11:56 PM, PST)	47. 1 N, 122. 7 W	VIII	7. 1	None	8 deaths	$15,000,000 to $25,000,000	---
Kern County, Calif.	July 21, 1952 (4:52 AM, PDT)	35. 0 N, 119. 0 W	XI	7. 7	14	10 of 12 deaths in Tehachapi	$37,650,000 to buildings $48,650,000 total. (incl. Aug. 22 aftershock).	M. M. XI assigned to tunnel damage from faulting: vibration intensity to structures generally VIII, rarely IX. Faulting probably longer, but covered by deep alluvium.
Bakersfield, Calif.	Aug. 22, 1952 (3:41 PM, PDT)	35. 3 N, 118. 9 W	VIII	5. 8	None	2 killed and 35 injured in Bakersfield.	See above.	Aftershock of July 21, 1952.

Fallon-Stillwater, Nev.	July 6, 1954 (4:13 AM, PDT)	39.4 N 118.5 W	IX	6.6	11	No deaths, several injuries.	$500,000 to $700,000, incl. $300,000 to irrigation system.	M. M. IX assigned along fault trace; vibration intensity VIII. First of two shocks on same fault.
Fallon-Stillwater, Nev.	Aug. 23, 1954 (10:52 PM, PDT)	39.6 N 118.5 W	IX	6.8	19	No deaths.		M. M. IX assigned along fault trace: vibration intensity VIII. Second of two shocks on same fault.
Fairview Peak, Nevada	Dec. 16, 1954 (3:07 AM, PST)	39.3 N, 118.1 W	X	7.1	35	No deaths.	---	M. M. X assigned along fault trace; vibration intensity VII. Two shocks considered as a single event from the engineering standpoint.
Dixie Valley, Nevada	Dec. 16, 1954 (3:11 AM, PST)	39.8 N, 118.1 W	X	6.8	30	No deaths.	---	
Eureka, Calif.	Dec. 21, 1954 (11:56 AM, PST)	40.8 N, 124.1 W	VII	6.6	None	1 killed	$1,000,000	---
Port Hueneme, Calif.	Mar. 18, 1957 (10:56 AM, PST)	34.1 N, 119.2 W	VI	4.7	None	No deaths.	---	Epicenter in ocean.
San Francisco, Calif.	Mar. 22, 1957 (11:44 AM, PST)	37.7 N, 122.5 W	VII	5.3	None	No deaths, about 40 minor injuries.	$1,000,000	---
Hebgen Lake, Montana	Aug. 17, 1959 (11:37 PM, MST)	44.8 N, 111.1 W	X	7.1	14	19 presumed buried by landslide, plus probably 9 others killed, mostly by landslide.	$2,334,000 (roads and bridges) $150,000 (Hebgen Dam) $1,715,000 (landslide correction)	M. M. X assigned along fault trace. Vibrational intensity was VIII maximum. Faulting complex, and regional warping occurred. Dollar loss to buildings relatively small.
Prince William Sound, Alaska	Mar. 27, 1964 (5:36 PM, AST)	61.1 N, 147.5 W	---	8.4	400 to 500	110 killed by tsunami; 15 killed from all other causes.	$311,192,000 (incl. tsunami)	Also known as the "Good Friday Earthquake". Fault length derived from seismic data.
Puget Sound, Washington	Apr. 29, 1965 (8:29 AM, PDT)	47.4 N, 122.3 W	VIII	6.5	None	3 killed outright, 3 died from heart attacks.	$12,500,000	M. M. VII general, M. M. VIII rare.
Parkfield, Calif.	June 27, 1966 (9:26 PM, PDT)	35.54 N, 120.54 W	VII	5.5	$23\frac{1}{2}$ and $5\frac{1}{2}$	No deaths.	Less than $50,000	Damaging earthquakes in same area in 1901, 1922, and 1934. The 1966 shock had peak accelleration of 50% G.
Santa Rosa, Calif.	Oct. 1, 1969 (9:57 PM, PDT)	38.47 N, 122.69 W	VII-VIII	5.6	None	No deaths. 15 injuries. 1 heart attack.	$6,000,000 to buildings. $1,250,000 to contents.	Two shocks considered as a single event from the engineering standpoint.
Santa Rosa, Calif.	Oct. 1, 1969 (11:20 PM, PDT)	38.45 N, 122.69 W		5.7	None			
San Fernando, Calif.	Feb. 9, 1971 (6:01 AM, PST)	34.40 N, 118.40 W	VIII-IX	6.6	12	58 deaths. 5,000 reported injuries.	$478,519,635	Many reported injuries were minor, but public or charitable services requested.

ABBREVIATIONS:

M. M. = Modified Mercalli Intensity

PST = Pacific Standard Time

PDT = Pacific Daylight Time (Subtract 1 hour for Pacific Standard Time)

MST = Mountain Standard Time

AST = Alaska Standard Time

FOOTNOTES:

[1] Slight variations will be found in various publications.

[2] M. M. Intensities are those assigned by the U. S. Coast & Geodetic Survey (now NOAA) when available.

[3] Original sources do not always clearly indicate if deaths include those attributable to exposure, unattended injury, heart attacks, and other non-immediate deaths.

[4] Value of dollar at time of earthquake. Use of these figures requires a critical examination of reference materials since the basis for the estimates vary.

example of large life loss due to a special geologic hazard. The single, most devastating event was the large debris avalanche that originated from the north peak of Huascaran, falling 12,000 feet and traveling 7 miles at an average speed of 200 miles an hour to destroy the villages of Yungay and others. This debris slide took a toll of about 25,000 to 30,000 lives. Clearly, this life loss was related to a special geologic hazard, and it was of a type that can be identified before the event.

The three foregoing examples make it readily evident that earthquake data used for the purposes of this report must be founded on information from comparable construction and comparable earthquake geologic hazards. These data are best obtained from a study of United States earthquakes, plus a few selected foreign earthquakes such as the 1967 Caracas, Venezuela and the 1960 Chilean earthquakes.

It is far beyond the report's scope and space allotment to review in detail the life loss and property damage data contained in studies of past American earthquakes. The Bibliography to this report cites most of the important reports and papers used for this study. It is, however, appropriate to briefly review some of these data.

San Fernando Earthquake of February 9, 1971

The 1971 San Fernando earthquake is being thoroughly studied by many authorities, including the authors. Far better data on life loss, injuries, and property damage are available for this disaster than for any other American earthquake. The recency of this disaster, and the continuing attention being paid to it, warrants more than cursory attention. The most important source of relevant data in print or in press known to the authors is "Earthquake Damage and Related Statistics" by Steinbrugge and Schader (in press, among others to be published by the National Oceanic and Atmospheric Administration (NOAA) of the U. S. Department of Commerce). The following is quoted from the Steinbrugge and Schader study:

The Los Angeles County Coroner's office reported 58 deaths [Table 3] directly attributable to the February 9th earthquake out of a current County population of 7,032,000. The collapses at the Veterans Hospital in the foothills of San Fernando Valley immediately claimed 41 lives; 6 died later as a result of injuries sustained. This was the largest life loss at one location incident to the earthquake. Three deaths occurred at the Olive View Hospital; one due to falling building materials, and the remaining 2 when life supporting power supplies failed. One death occurred in the roof collapse of the old brick masonry Midnight Mission (a charitable facility) located in downtown Los Angeles. If the shock had occurred minutes before, the death toll would have been greatly increased when the upper dormitory area had been fully occupied. The one death occurred when reportedly an occupant had left the building, but was standing in front of it. A collapsing freeway bridge killed two persons when their truck was trapped under a fallen span located in the heavily shaken area of San Fernando Valley. One person died from injuries resulting in a fall from the freeway. Four deaths occurred in dwellings. Heart attacks reportedly took 9 lives; however, the County Coroner's report does not list these.

Information on injuries and other earthquake related emergency cases was compiled by the Hospital Council of Southern California. The information in this paragraph and in Table [4] is based on their compilation. A total of 127 hospitals responded to their survey with results as shown in Table [4]. In addition, the Red Cross treated minor injuries for more than 3,000 persons. Thus, one may conclude that the reported injuries and related problems exceeded 5,000, and that thousands of minor self-treated injuries remained unreported.

In Table [4], it is important to note that emotional reactions and cardiac problems existed. The psychological aspects of earthquakes have not been adequately studied. Additionally, 3 of the 4 greatest problem areas were related to pre-earthquake engineering and/or planning,

TABLE 3

LIFE LOSS, SAN FERNANDO EARTHQUAKE
From Los Angeles County Coroner's Records

Olive View Hospital		3
Patients	2	
Employees	1	
San Fernando Veterans Administration Hospital		41
Patients	31	
Employees	10	
Victims from Veterans Administration Hospital whose deaths occurred at other hospitals		6
Deaths from residences		4
Deaths from collapse of freeway overpass		2
Death in fall from freeway overpass		1
Death from collapsing wall		1
Total		58

Note: Deaths from reported heart attacks or natural causes attributed to the earthquake are not included.

TABLE 4

INJURIES AND RELATED PROBLEMS, SAN FERNANDO EARTHQUAKE
From Hospital Council of Southern California
Records, April 1971, 127 Hospitals Reporting

Date	Outpatients Treated	Inpatients Admitted	Total
Feb. 9	1,524	161	1,685
Feb. 10	437	30	467
Feb. 11	367	24	391
Totals	2,328	215	2,543

Outpatient Injuries or Problems	
Lacerations	44%
Fractures or related	18%
Emotional reaction	9%
Contusions	8%
Cardiac	6%
Remainder	15%

Inpatient Sick or Injured, Excluding Transfers	
Fractures	26%
Cardiac	19%
Head injuries	12%
Psychiatric	12%
Burns	7%
Remainder	24%

Disaster Activity Causing Hospital Problems, In Order of Importance

Communications
Patient emotion
Water shortage or contamination
Power and/or fuel
Patient transportation
Personnel identification
Personnel and/or supply transportation
Physician coverage
Nursing coverage
Shortage of medical supplies
Clerical assistance
Shortage of blood type

Continuation of quotation:

and not directly to any medical deficiencies.

The resources of metropolitan Los Angeles were more than adequate for housing and feeding the displaced persons, and the large majority of persons having these problems were able to take care of their own needs. Despite the foregoing, one relief agency (The American National Red Cross) reported for the period of February 9 through March 5, 1971 that they fed and housed 17,000 persons at 10 public schools used as shelters. About 175,100 meals were served by the Red Cross (66,500 in shelters which also housed refugees plus 108,600 at mass feeding locations). The availability of undamaged earthquake resistive Field Act schools greatly facilitated the emergency housing and feeding, and this type of facility is an important consideration in earthquake disaster planning.

The total loss to buildings and structures, excluding land and building contents, has been estimated from available data by the authors at $478.5 million, with a breakdown of this value given in Table [5]. The quality of the $478.5 million dollar estimate has improved over earlier estimates now that eligible public agencies and local public jurisdictions have filed their claims for reimbursement of expenses under Public Law 91606 to the Office of Emergency Preparedness. However, it may well be that some of these claims reflect improvements over and above the actual loss when defining loss as the cost of replacement in kind.

Undoubtedly, some incompatible data exist in the back-up material for Table [5]. Value can be based on replacement value, current market value, assessed value, among others. Loss can be insured loss (a dollar deductible may have been applied before the loss was paid), loss as defined by the cost to bring the structure back to its original (not new) condition, and loss as defined by actual repair costs, among others. These variables in definitions, plus political and emotional

TABLE 5

SUMMARY OF EARTHQUAKE LOSSES
SAN FERNANDO EARTHQUAKE

Sector	Dollar Loss	Reference
Private Sector:		
Buildings, excluding land and contents:		
Los Angeles City	$170,300,000	
San Fernando City	35,500,000	Table 7
Elsewhere	18,500,000	Table 7
Non-building structures, excluding land	35,000,000	Authors' estimate
Public Sector:		
Los Angeles City	103,300,000	*O. E. P.
San Fernando City	200,000	*O. E. P.
Los Angeles County	100,000,000	**L. A. C. E. C.
Other local jurisdictions	5,000,000	*O. E. P.
Porter Ranch (aftershock damage)	8,000,000	*O. E. P.
Utilities	22,000,000	*O. E. P.
Total	$497,800,000	

*Office of Emergency Preparedness, Executive Office of the President.
**Los Angeles County Earthquake Commission Report, 7-1-71.

considerations, can lead to inconsistencies when unqualified data are compiled from many sources.

Tables [6] and [7] state the losses to privately owned properties in the various cities and other jurisdictions throughout the damaged areas. The dollar losses may be crude guesses by local authorities in rare cases.

Detailed information on losses to dwellings, high-rise buildings, light industrial buildings, hospitals and medical buildings, and mobile homes are discussed elsewhere in this paper.

The best summary of insurance losses to date is contained in a statement by Lawrence C. Baker, Jr., Chief Deputy Insurance Commissioner, State of California, before the U. S. Senate Committee on Public Works, June 11, 1971, in San Fernando. Table [6] from Mr. Baker's statement, updated by him to December 16, 1971, shows that reported insurance losses paid to that date amounted to $48,574,452 from 9,099 claims.

(end of quotation)

Much additional text and tabular information exist in the aforementioned report, particularly for dwellings, light industrial buildings, and hospitals; the information on hospitals is presented in this report as Table 8.

Prince William Sound, Alaska Earthquake of March 27, 1964

The Prince William Sound, Alaska earthquake ("Good Friday" earthquake) is important for the usable data on modern earthquake resistive construction and its effect on reducing casualties. Tsunami (seismic sea wave) resulted in 110 deaths; only 15 died from other causes including building collapses. (Tsunami is not a significant hazard in the San Francisco Bay Area). The major landslides which resulted in a few casualties in Anchorage and also resulted in extensive

TABLE 6

LOS ANGELES CITY DAMAGE, SAN FERNANDO EARTHQUAKE
From Los Angeles Department of
Building and Safety as of June 28, 1971
(Revised 12-17-71)

Item	Units	Buildings	Estimated Dollar Loss
Unsafe for human occupancy--posted "unsafe":			
Single family dwellings	0	415	$ 10,400,000
Apartments	1,149	54	11,500,000
Non-residential commercial and industrial	0	382	38,200,000
Major and moderate damage--remaining occupied:			
Single family dwellings	0	2,469	24,700,000
Apartments	0	192	7,700,000
Non-residential commercial and industrial	0	883	17,700,000
Minor damage:			
Single family dwellings	0	13,711	6,900,000
Apartments	0	1,748	17,500,000
Non-residential commercial and industrial	0	5,698	5,700,000
Other damage (estimated):			
Unreported damage	0	0	30,000,000
Personal property and inventory	0	0	50,000,000
Totals	1,149	25,552	$220,300,000

TABLE 7

BUILDING DAMAGE OUTSIDE OF CITY OF LOS ANGELES, SAN FERNANDO EARTHQUAKE
Does not include publicly owned structures. Data from various sources, revised 12-16-71.

City	Buildings Damaged	Posted Unsafe	Buildings Demolished or to Be Demolished: Residential	Commercial	Churches and Schools	Damaged Chimneys	Estimated Total Dollar Loss
Alhambra	55	15	0	5	0	400	$ 2,000,000
Beverly Hills	135	0	0	2	0	1,000	800,000
Burbank	445	25	3	3	1	500	4,000,000
Compton	0	0	0	0	0	0	10,000
Glendale	(a)	31	13	23	5	3,250	2,000,000
Long Beach	(a)	0	0	0	0	0	(a)
Pasadena	10	4	0	0	1	2,000	2,500,000
San Gabriel	0	0	0	0	0	30	9,000
Santa Monica	20	1	0	0	0	30	50,000
South Pasadena	20	1	0	0	0	300	275,000
Vernon	30	5	0	0	0	0	100,000
Los Angeles County including Newhall, Saugus, and Valencia areas	(d) 1,720	97	15	9	0	(a)	(e) 6,800,000
San Fernando City	(b) 1,520	437	95	(c) 123	3	390	35,500,000
							$54,044,000

(a) Not available
(b) All categories
(c) Posted "unsafe"
(d) May include cases of "chimney only" damage
(e) Reported by Los Angeles County Earthquake Commission Report

TABLE 8

HOSPITALS--SAN FERNANDO VALLEY
Data compiled by Pacific Fire Rating Bureau

	Facilities and Services												Earthquake Damage and Losses							
				Pre-Eq.	Licensed Bed Use***							Est. Repl. Value,	Dollar Loss		Bed	Shut-Down		Start-Up		
	Location - City	Owner-ship*	Year Founded**	Licensed Bed-Capac.	A. C.	Mat.	Ped.	Psy.	R-C	E. C.	Other	Bldg. & Equip. ($ Millions)	Building	Equipment	Loss	Date	Time	Date	Time	Remarks
1	Burbank	N. P.	1905	115	108	7						2.0	0	0	0	-	-	-	-	
2	Burbank	N. P.	1944	370	324	23	23					11.0		-	0	-	-	-	-	
3	Canoga Park	Prop.	1968	72								2.2	2,000	1,000	0	-	-	-	-	
4	Canoga Park	Prop.	1958	112	108		4					2.0	0	0	0	-	-	-	-	
5	Canoga Park	Prop.	1962	116	116							2.0	0	0	0	-	-	-	-	
6	Canoga Park	Prop.	1962	80	64	13	3					2.75	50,000(combined)		0	-	-	-	-	
7	Encino	Prop.	1954	189	144		18				17	6.6	0	0	0	-	-	-	-	
8	Encino	N. P.	1955	152	104	34	14					2.1	0	0	0	-	-	-	-	
9	Glendale	N. P.	1947	98	84	14						3.0	0	0	0	-	-	-	-	
10	Glendale	N. P.	1905	380	252	27	17	60	24			11.4	-	-	0	-	-	-	-	
11	Glendale	N. P.	1954	152								5.3	-	-	0	-	-	-	-	
12	Glendale	N. P.	1926	310	270	28	12					10.9	20,000	0	0	-	-	-	-	
13	Glendale	Prop.	1955	31	27	4						0.9	0	0	0	-	-	-	-	
14	Glendale			22								0.66	0	0	0	-	-	-	-	
15	Granada Hills	N. P.	1966	201	169	16	16					6.0	5,000	0	0					
16	North Hollywood	Prop.	1969	73	59	8	6					2.2	0	0	0	-	-	-	-	
17	North Hollywood	Prop.	1952	84	84							2.5	5,000	5,000	0	-	-	-	-	
18	Northridge	N. P.	1955	206	134	13	28	11	20			6.0	300,000	55,000	0	-	-	-	-	
19	Olive View	L.A.Co.	1920	888	120(post EQ)			100			25				643	2/9/71	10 A. M.	9/71	-	1,5 (OV)
	a. Medical Treatment and Care Bldg.											25.0	25,000,000			-	-	-	-	
	b. Psychiatric Bldg.											6.0	6,000,000			-	-	-	-	
	c. Central Heating Plant											1.5	375,000				-			
20	Pacoima	N. P.	1957	110	82			28				4.75	6,000,000(combined)		110	2/9/71	6 A. M.	3/2/71	-	5 (PL)
21	Panorama City	N. P.	1962	321	202	41	32			46		9.1	250,000(combined)		0	-	-	-	-	
22	Panorama City			96								3.0	-	-	-	-	-	-	-	
23	San Fernando	N. P.	1961	259								9.0	4,000,000	1,000,000	209	2/9/71	3 P. M.	3/72(tent.)		2,5 (HC)
24	San Fernando	Prop.	1922	69	69							1.4	1,000	1,000	0	-	-	-	-	3
25	Sepulveda	F. G.	1955	906	385			341	80		100	30.0	900,000(combined)		0	-	-	-	-	
26	Sherman Oaks	Prop.	1959	160	148		12					4.8	0	0	0	-	-	-	-	
27	Sun Valley	Prop.	1967	111	99	12						4.0	1,000	0	0	-	-	-	-	
28	Sylmar	F. G.	1926	365								15.0	10,000,000(combined)		365	2/9/71	6 A. M.	-	-	5 (VET)
29	Van Nuys			113								3.0	500	0	0	-	-	-	-	
30	Van Nuys	Prop.	1929	66	66							2.0	0	0	0	-	-	-	-	
31	Van Nuys	N. P.	1958	281	235	28	18					18.0	70,000	5,000	0	-	-	-	-	
32	Van Nuys	N. P.	1964	63								2.0	0	0	0	-	-	-	-	
33	Woodland Hills	N. P.	1921	180	73			10		97		5.0	0	0	0	-	-	-	-	
	Totals			6,652								223.06	52,078,500	1,067,000	1,327					

*N. P. - Non-Profit Prop. - Proprietary L. A. Co. - L. A. County F. G. - Federal Gov't.
**All structures on site not necessarily erected this date.
***A. C. - Acute General Ped. - Pediatrics R-C - Rehab. -Convalescent.
Mat. - Maternity Psy. - Psychiatric E. C. - Extended Care

REMARKS:
1. Hospital not operating at licensed capacity.
2. In-patient facilities temporarily closed.
3. Only hospital functioning within 5 mile radius after earthquake.
4. Cottage style (58 occupancy) on grounds.
5. OV-Olive View, PL-Pacoima Lutheran, HC-Holy Cross VET-Veterans

NOTE: Where replacement values were unknown a value of $20,000 to $35,000 per bed was used.

property damage are a type of geologic hazard which can and have been identified in the San Francisco Bay Area.

Modern precast concrete performed poorly when compared with other construction materials; undoubtedly similar problems will occur in California on a much greater scale in the event of the maximum credible earthquake. Multistory building damage in Anchorage is given in summary form in Table 9.

This 8.4 Richter magnitude earthquake was slightly greater than the 1906 San Francisco shock with its magnitude of 8.3; both shocks are of upper limit magnitudes to be considered in this report. It follows, then, that the data from the 1964 Alaskan shock are representative of the upper limit damage under similar epicentral distances and similar geologic environments for similar construction.

Kern County, California Earthquakes of July 21, 1952 and August 22, 1952

Substantial amounts of engineering data were collected after the 1952 Kern County shocks. From the standpoint of this study, probably the data on reinforced and non-reinforced unit masonry are the most useful.

Unreinforced unit masonry with its weak sand-lime mortar was common in the heavily hit areas. Damage to brick and concrete brick was severe, just as it has been in all other moderate or greater shocks. Destruction to this type of construction in the town of Tehachapi was particularily severe. In Bakersfield, which was less heavily shaken than Tehachapi but also had aftershock damage, cumulative losses to the unit masonry are given in Table 10.

It has been noted upon examining Table 10 that hollow concrete block performed better than did brick or concrete brick. Hollow concrete block was a relatively new material at the time of the earthquakes insofar as its general use in Kern County. As a result, most of it contained at least some reinforcing steel in selected grout-filled cells, and the buildings normally had at least some minimal form of earthquake bracing. It was therefore not surprising to find that hollow concrete block performed much better than did the other unit masonry materials. Despite the damage listed in Table 10, only two lives were lost and 35 persons

TABLE 9

DAMAGE TO MULTISTORY BUILDINGS IN ANCHORAGE, ALASKA

Building Name and Occupancy	Year Built	Stories	UBC Seismic Zone	Structural System: Frame	Structural System: Floors	Structural System: Exterior Walls	Structural System: Core	Principal Lateral Force Bracing System	% Damage (of replace-value)	Remarks
Airport Control Tower	1952	6 and basement	?	R/C	5 and 6 inches R/C	Insulated metal	None	R/C frame	100	Also damaged in 1954 shock.
Anchorage-Westward (hotel)	1960 1964	14 and basement	3	Steel, with some R/C columns	$5\frac{1}{2}$ to $6\frac{1}{2}$ inches R/C on MD on steel beams	Insulated metal and R/C	See remarks	R/C shear walls	12	Landslide shifted building about 1 foot. R/C around elevators not a major core.
Cordova (office)	1960	6 and basement	2 (?)	Steel	$2\frac{1}{2}$ inches R/C on MD on steel joist and beams	Insulated metal and 4 inches R/C	R/C	Steel moment connections; shear walls in R/C core	20	
Elmendorf Hospital	1955	7 and basement	3	R/C	6 inches R/C	Nonstructural hollow concrete block	R/C	R/C shear walls	1 (see marks)	Lower height buildings not listed. Structural damage 1 percent; nonstructural greater.
Four Seasons (apartments)	1964	6	3	None	8 inches prestressed post-tensioned R/C; tendons not grouted	Plastered studs	R/C	Shear walls in R/C central core	100	Lift slab using steel columns.
Hill (office)	1962	8	3	Steel (see remarks)	5 inches R/C on steel beams	Insulated metal	R/C	Shear walls in R/C central core.	20-25	Central core was R/C bearing.
Knik Arms (apartments)	1950	6 and basement	2	Incomplete R/C	$5\frac{1}{2}$ inches R/C	R/C	R/C	R/C shear walls	Negligible	Building moved 10 to 11 feet, due to landslide.
Mt. McKinley (apartments)	1951	14 and basement	2	R/C (see remarks)	$5\frac{1}{2}$ inches R/C on R/C beams	R/C bearing	R/C	R/C shear walls	40	R/C interior beams and columns. Walls bearing. Almost identical to 1200 L Building.
1200 L (apartments)	1951	14 and basement	2	R/C (see remarks)	$5\frac{1}{2}$ inches R/C on R/C beams	R/C bearing	R/C	R/C shear walls	30	R/C interior beams and columns. Walls bearing. Almost identical to Mt. McKinley Building.
Penney (department store)	1962	5	3	None	10-inch R/C slabs on R/C columns	Precast R/C on 2 sides; R/C on 4 sides.	Essentially none	R/C exterior walls	100	Some hollow concrete block exterior walls.
Providence Hospital	1961	5 and basement	3	steel	$5\frac{1}{4}$ inches R/C on MD on steel beams	Insulated metal	R/C	Shear walls in R/C central core	$2\frac{1}{2}$	Stair and elevator tower and lower height buildings not listed.

ABBREVIATIONS:
UBC - Uniform Building Code
R/C - Reinforced concrete. Poured-in-place unless otherwise specified.
MD - Metal deck. Usually having trade name "Corruform" or "Cofar".

SOURCE: Environmental Science Services Administration, "The Prince William Sound, Alaska, Earthquake of 1964 and Aftershocks," Vol. II, Part A, page 216, (1967).

injured in Bakersfield in the August 22, 1952 shock.

Only a small amount of earthquake resistive reinforced brick construction existed, with the major exception being one public school complex. This school complex, with 15 earthquake resistive brick buildings, performed quite well and the overall damage was less than 1%. No collapses or near collapses occurred.

Large life loss has been associated with the failure of non-earthquake resistive brick and other non-reinforced unit masonry structures. The 1952 Kern County earthquakes convincingly showed the effectiveness of earthquake bracing in significantly reducing life hazards.

San Francisco, California
Earthquake of April 18, 1906

The 1906 San Francisco earthquake, of particular significance since it represents excellent past experience in the area under study, had a Richter magnitude approaching the probable upper limit, and seismologically and geologically it represents one of the shocks listed in the scenario of this report. Data on this shock were well gathered, and much of it is of current relevance.

The San Andreas fault rupture extended 190 miles from San Juan in San Benito County to Point Arena in Mendocino County; then it may have continued under the Pacific Ocean to enter land at Shelter Cove in Humboldt County. The faulting certainly extended for 190 miles, and possibly as far as 270 miles. The horizontal fault displacement was not less than 10 feet for most of its length. In places it measured more than 15 feet and in one marshy ground area it measured as much as 21 feet. The closest San Andreas fault breakage to San Francisco was 1 1/2 mile from the city limits. The financial and commercial center of the city, which was 9 to 10 miles from the fault rupture, contained a number of multistory buildings, many of which are still in existence.

Statistics regarding life loss vary widely, and many contemporary publications quote figures that are unsubstantiated. The statistics given in Table 11 are believed to be among the more accurate of those known to the authors.

In addition to Table 11, another source which is authoritative is the report of the army relief operations (Greely, 1906), which makes its count on a somewhat different basis from that given in Table 11. The following paragraph (p. 176) is quoted from the Greely report:

> Of deaths and injuries from earthquake and fire, which were enormously exaggerated in current dispatches, the roll, including all bodies discovered and those who have since died of injuries, is as follows: San Francisco, 304 known; 194 unknown (largely bodies recovered from the ruins in the burned district); in addition 415 were seriously injured. In Santa Rosa there were 64 deaths and 51 seriously injured; in San Jose, 21 deaths and 10 seriously injured; and at Agnew's Asylum, near San Jose, 81 deaths.

A total life loss of 700 to 800 is a reasonable figure, with the bulk of this loss being in San Francisco, which had an estimated population in 1905 of 400,000.

Property damage in the City of San Francisco has been estimated by various reliable authorities. The Manson Subcommittee on Statistics used assessor's records and placed the building loss (excluding contents) at $105,008,480. The Chamber of Commerce in their report (1906) approached the problem differently using extrapolated insurance data and derived a loss of about $350 million for buildings and their contents for San Francisco. The probable loss including consequential damages of all kinds, was estimated by the Committee of Five (1906) to the "Thirty-Five [Insurance] Companies" at $1 billion. It is reasonable to use a figure of $400 million for direct earthquake and fire loss to buildings and to their contents for San Francisco and the outlying areas.

The 3-day conflagration following the earthquake caused substantially more damage than did the earthquake. The area of the burned district covered 4.7 square miles, comprising 521 blocks of which 13 were saved and 508 burned. One count of burned buildings was as follows:

TABLE 10

FLOOR AREAS OF STRUCTURES WITH MASONRY WALLS, WOOD FLOORS AND WOOD ROOFS

Wall	Torn Down	Repaired	Repair or Demolition Undecided	Undamaged	Total
Brick	16%	42%	20%	22%	100% (2,717,410 s. f.)
Concrete Brick	20%	40%	36%	4%	100% (230,950 s. f.)
Concrete	6%	12%	6%	76%	100% (1,186,680 s. f.)
Hollow Concrete Block	2%	6%	*	92%	100% (488,525 s. f.)

*Negligible

Source: Bull. Seism. Soc. Am., Vol. 44, page 250 (1954)

TABLE 11

LIFE LOSS IN SAN FRANCISCO

Killed outright and accounted for at the Coroner's office.	315
Shot for crime	6
Shot by mistake	1
Reported missing and not accounted for	352
Total	674

Source: "Report of the Sub-Committee on Statistics", Marsden Manson, Chairman (1907?).

Wooden framed buildings	24,671
Brick--Classes C and B	3,168
Brick and wood (unclassified)	259
Fireproof Class A	42
Stone	15
Corrugated iron (wooden frame)	33
	28,188

Conflagration following earthquake is a distinct hazard for all cities in earthquake-prone areas. However, fire does not automatically follow a major earthquake; if it does, the reasons should have been apparent before the event. Therefore, it is of value to briefly review the background for the San Francisco fire. The National Board of Fire Underwriters (1905) published a report before the earthquake and summarized their findings as follows:

> In view of the exceptionally large areas, great heights, numerous unprotected openings, general absence of fire-breaks or stops, highly combustible nature of the buildings, many of which have sheathed walls and ceilings, frequency of light wells and the presence of interspersed frame buildings, the potential hazard is very severe.
>
> The above features combined with the almost total lack of sprinklers and absence of modern protective devices generally, numerous and mutually aggravating conflagration breeders, high winds, and comparatively narrow streets, make the probability feature alarmingly severe.
>
> In fact, San Francisco has violated all underwriting traditions and precedent by not burning up. That it has not done so is largely due to the vigilance of the fire department which cannot be relied upon indefinitely to stave off the inevitable.

Actuality was worse than the prediction since portions of the water system were severely damaged by the earthquake. All of the three conduits from the main storage reservoirs to San Francisco were damaged or destroyed where they crossed the San Andreas fault and where they crossed marshy areas. Only the Lake Honda Reservoir of the distributing reservoirs (of a total of 3) was damaged by the earthquake; however, when the fire in San Francisco was under control, this reservoir still contained more than one-sixth of its capacity. One supply conduit from the main storage reservoirs was repaired in 3 days, and at no time during the conflagration were all of the distribution reservoirs empty.

Hundreds of pipe breaks occurred in the city distributing system, principally where the lines crossed filled ground and former swamps. Equally serious was the fact that probably thousands of service pipes were broken by earthquake motions and by the collapse of burning buildings. Water in vital portions of the distribution system therefore was not available to fight the fire, although it was available in the Western Addition residential section of San Francisco during the entire conflagration.

The 1906 earthquake marked the first test of multistory steel frame buildings and the largest test to date in the United States of this construction type near to a great earthquake. A total of 17 structures ranging in height from 8 to 16 stories, with one at 19 stories, experienced the earthquake. Four additional structures were under construction. Extensive nonstructural earthquake damage was common, and a few had known structural damage in the form of sheared bolts, bent I-beams, torn gusset plates, and the like. The actual extent of the earthquake damage (as opposed to the well-documented fire damage) is inadequately known and has been the subject of some dispute. Obviously the 3 days between the earthquake and the end of the conflagration did not allow for adequate inspections. None of these multistory buildings was so heavily damaged as to be unsafe. The earthquake clearly showed that total destruction to multistory steel frame structures of the type then in existence is not to be expected. (Their counterparts in reinforced concrete did not exist at that time.)

General Comments

By no means have all of the data for each of the selected earthquakes been discussed; see the Bibliography to this report for a reasonably complete listing. However, the foregoing review shows the nature of the data which are used as the basis for this report.

Substantial emphasis has been given to building damage. The importance of adequate building damage data in connection with casualty estimates cannot be over-estimated. Ground shaking does not kill people; it is the collapse of man-made structures such as buildings and dams which creates casualties during severe ground shaking.

The hazards of earthquake geologic hazards of faulting, structurally poor ground, and landsliding can and have been identified, and are discussed elsewhere in this report. Fortunately, tsunami is not a significant hazard in the San Francisco Bay Area and it will therefore be given only cursory attention.

THEORETICAL CONSIDERATIONS

Theoretical considerations include, among others, the mathematical determination of a structure's expected performance in an earthquake having a given Richter magnitude. The mathematical analyses must include the response of structures to horizontal and vertical dynamic forces. The analysis should also consider all site characteristics such as soils and geologic hazards.

The foregoing mathematical studies, if made by the authors, would cost millions of dollars if done for all structures; time requirements would also be prohibitive. On the other hand, sufficient data can be (and has been) compiled for a sufficient number of structures to allow the authors to adequately estimate the degree with which the mathematical analysis was made by the original designers of the structure. Additionally, compiled data give the standards used in the original design and their degree of adequacy to satisfactorily perform in a given earthquake. The approach used in this study, then, is to review the building's original design criteria on a class rating basis in which a group of structures similar in construction material type, occupancy type, and earthquake resistance characteristics are evaluated together. The results are average values for the probable damage and dollar loss.

Based on the theoretical determined building damage, it is possible then to develop relationships between casualties and damage. Again, care must be used; a building may be an effective 100% loss from a dollar standpoint but casualties might be few. For examples, one might cite the Penney Building in the 1964 Alaskan shock and the new multistory Olive View Hospital in the 1971 San Fernando shock; life losses were less than 1% of actual occupancy in each of these total property losses.

The use of theoretical methods, by themselves, has numerous weaknesses. First, earthquake forces generated in moderate to great magnitude shocks are still imperfectly known. For example, the 1971 San Fernando earthquake is the best ever recorded from a strong motion standpoint, both in number of records and in the strength of the earthquake. While a strong motion acceleration of 1.25g was the recorded maximum, due to special site conditions surrounding the instrument's location many authorities believe a factor of about 0.75g might be more satisfactory.* Others disagree. Obviously, a 25% to 50% difference of opinion on the earthquake design force (which is based on the g-value) will lead to quite different casualty and dollar loss figures if no other factors are considered. On the other hand, on a class rating approach, the overall life loss and damage patterns from the 1971 San Fernando earthquake were within keeping with expected values.

Building codes normally determine the criteria used for the design of a building. The seismic provisions in these codes change over the years, constantly improving or being revised to meet new construction types. These codes, from their origins to the present date, and their degrees of enforcements, are well known to the authors. Space requirements make it inappropriate here to discuss the history and changes in the seismic provisions of building codes; this information has been given in detail in many papers, some of which have been included in the selected bibliography to this report.

Building codes have been often criticized, and rightly so, but beyond question the seismic provisions have, and do represent, the concensus of the current thinking of the structural engineering profession and earthquake sciences. Lastly, the intent of the codes, as expressed in the "Recommended Lateral Force Requirements and Commentary" (Seismology Committee, Structural Engineers Association of California, 1968) is as follows (page 33):

*"g-value" is the accelleration due to gravity force, and is one measure of the strength of an earthquake at a particular site.

1. Resist minor earthquakes without damage,
2. Resist moderate earthquakes without structural damage, but with some non-structural damage,
3. Resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as non-structural damage.

Obviously, the poor performance of the new Olive View Hospital buildings in the 1971 San Fernando earthquake exceeded the intent expressed in the document by the Structural Engineers Association of California. While there may be some valid criticisms regarding the building's design and construction, the new Olive View Hospital structures were designed by competent engineers, the plans were reviewed by a public authority deemed superior to most, and construction (and inspection) were also considered to be competent. Obviously, the sum total of the foregoing was not sufficient. It is not the point here to judge these particular buildings, but to point out that the sole reliance on building codes, without judgment, will lead to erroneous results, normally underestimating casualties and dollar losses when used by the inexperienced.

EXPERIENCE

Appropriate experience, which forms the basis for informed critical judgment, is vital for the synthesis of theoretical considerations and the inadequate and/or incomplete data from relevant earthquakes into usable information. As has been mentioned, the earthquake data and experience must be relevant; the 70% death factor in the 1968 Dasht-e-Bayaz, Iran shock is useless in this study. On the other hand, the death toll of about 0.1% of San Francisco's population in 1906 is relevant since much of the present construction is similar to that in 1906.

The consultants for this study were chosen, in part, for their extremely wide experience in earthquake design and earthquake effects. They have field inspected and often reported on all significant earthquakes to have occurred in the United States in the past quarter-century, as well as many of the more significant foreign shocks.

In addition to their first-hand studies of earthquakes, they have made retrospective studies of numerous other shocks, including among others: 1940 El Centro (California), 1933 Long Beach (California), 1925 Santa Barbara (California), and 1906 San Francisco (California).

Earthquake geologic hazards of faulting, landsliding, and structurally poor ground have been equally well studied. Possibly over 75% of all known historic instances of surface faulting have been studied by one or more of the consultants, for example.

The need for judgment based on experience is vital in the evaluation of the Modified Mercalli intensity maps. The authors of the Modified Mercalli Scale stated when they introduced the scale in the Bull. Seism. Soc. Am., 21:277 (1931):

> To evaluate intensity critically, account must be taken of duration of shaking; nature of ground underneath locality and whether surface is level, gently sloping or steep; whether observers were outdoors, or indoors, in what kind of structure, on what floor, whether quiet or active, and if active how occupied; also whether the motion is rapid or slow, simple or complex, and whether it begins gradually or abruptly. This requires experience. Because of the entry of these factors in different degrees no intensity scale of this kind is suitable for general use, even though correct estimates might often be made.

The lowest intensity values rely heavily on human reactions, the middle range intensity values principally relate to building damage, and the highest intensity values are strongly influenced by geologic effects. Human reactions, building damage, and geologic effects are not truly compatible. For example, items have not fallen from shelves in buildings adjacent to major fault scarps. New building materials, new construction techniques and new design methods have complicated the application of the Modified Mercalli scale. For example, long period ground motions can selectively damage taller multistory buildings, leaving the small one- and two-story "collapse hazard" buildings undamaged; this information is not reflected in the present intensity scale. For another example, the phrase "good construction" used in the scale has different meanings depending on the earthquake provisions in the building codes in different areas. In some areas, brick walls must be heavily reinforced with steel to be classified as "good construction," while in other areas the walls require no reinforcement to be classified as "good construction."

TIME OF DAY AND SEASON OF YEAR

The number of injuries sustained as the result of an earthquake is highly dependent on the time of day that the shock occurs. In this report, therefore, the exact timing of the earthquake has been accepted as one of the variables. Accordingly, for the purposes of the study, three respective times of day have been assumed as follows:

(1). 2:30 a.m., when the greatest proportion of the population would be at home in bed.

(2). 2:00 p.m., when the greatest proportion of the population would be away from home.

(3). 4:30 p.m., the beginning of the rush hour.

The season of year, namely wet or dry season, has a substantial effect on the conflagration potential as well as the landslide potential.

Section 3: Effects on Local Medical Resources

Major Hospitals

DATA COLLECTION

In this report a major hospital facility is defined as one having a patient occupancy capacity of 100 beds or more. Thus, while there are more than 119 general hospitals located in the 9 Bay Area counties, this report limits itself to the 85 major hospitals, including military, mental health, VA Hospital facilities and university medical centers, with bed capacities of 100 or more which are located in the study area as listed in Table 12. It is to be understood that these totals are in constant change as obsolete facilities are closed and remodelling or new construction of other hospitals is completed.

Although small hospitals with less than a 100 bed capacity were not reviewed as part of this report, the problems to be faced by them during a natural disaster will be similar in scope and characteristic, generally speaking, to those faced by the major hospitals analyzed herein. For the sake of completeness however, a complete regional inventory of all types of health facilities as licensed by the California State Department of Public Health is given in Table 13. Except for the university medical centers, military, and VA hospitals with bed capacities over 100 considered in this report, all other medical facilities not licensed by the State of California have not been analyzed.

TABLE 12

INVENTORY OF MAJOR MEDICAL HOSPITALS
WITH CAPACITIES OF 100 BEDS OR MORE

	Type of Hospital Facility							
	General		Military		Mental Health		VA	
County	No.	Total Bed Cap.	No.	Total Bed Cap.	No.	Total Bed Cap.	No.	Total Bed Cap.
Alameda	20	4,435	1	1,150			1	502
Contra Costa	7	1,414					1	498
Marin	3	594						
Napa	2	252			1	3,450		
San Francisco	19	8,040	1	900	1	105	1	409
San Mateo	8	2,420					1	1,046
Santa Clara	11	3,798			1	2,922		
Solano	3	444						
Sonoma	2	442			1	3,470		
Totals	75	21,839*	2	2,050	4	9,947	4	2,455

Sources: (a) "Hospitals, Nursing Homes and Health Facilities", Bureau of Health Facilities Licensing and Certification, Department of Public Health, State of California: March 31, 1971.

(b) "Statistical Abstract", Four County Bay Area Community Shelter Plan, Prepared for the Association of Bay Area Governments by Wilbur Smith & Associates, Inc. , May 1970.

Note: Statistics include major hospitals not licensed by the Bureau of Health Facilities Licensing and Certification, Department of Public Health, State of California, such as: university hospitals, university medical centers, etc.

*As compared with 22,701 for all hospitals, including less than 100 bed hospitals.

TABLE 13

COMPLETE REGIONAL INVENTORY OF ALL HEALTH FACILITIES
As licensed by the State of California

County	Hospitals		Nursing Homes		Home Health Agency	Clinic	Mental Health	Mental Retard	All** Other
	No.	Total Bed Cap.	No.	Total Bed Cap.	No.	No.	No.	No.	No.
Alameda	25	4,643	106	5,962	7	3	1	4	2
Contra Costa	11	1,679	36	2,707	5	6	0	5	1
Marin	6	769	14	1,192	3	0	0	0	1
Napa	2	252	12	717	2	0	0	1	0
San Francisco	23	7,453	32	2,134	6	13	0	5	2
San Mateo	9	2,459	29	2,349	3	1	0	1	2
Santa Clara	14	3,951	56	4,446	4	3	4	4	3
Solano	6	636	10	840	2	1	0	1	0
Sonoma	11	859	22	1,532	2	0	0	0	0
Totals	107	22,701	317	21,900*	34	27	5	21	11

*Total bed capacity is comprised of the inventory of hospitals and nursing homes. Bed capacities for all other categories are either non-existent or incidential and therefore not listed.

**Includes Establishments for Handicapped and Alcoholism Hospitals.

Source: "Hospitals, Nursing Homes and Health Facilities", Bureau of Health Facilities Licensing and Certification, Department of Public Health.

Sources of Data

Identification and location of the major 100 bed hospital facilities were made through use of the 1971 edition of the bulletin published by the California State Department of Public Health entitled: "Hospitals, Nursing Homes and Related Health Facilities." Data regarding specific hospitals was obtained from the Bureau of Planning and Construction, Department of Public Health, State of California, located in Sacramento.

In the case of the military and mental health hospital facilities, a direct interview occurred with a staff member or an administrator of all the units listed in this report. Use was also made of the "Statistical Abstract - Four County Bay Area Community Shelter Plan" prepared in May 1970 for the Association of Bay Area Governments (ABAG).

Regarding VA hospitals, general data was received from staff at the VA regional unit located in the City of San Francisco for three of the hospital facilities. Specific data on the VA hospital located in Livermore, Alameda County, was collected by an on-site interview with an administrator of the facility. Reference was also made to the "Statistical Abstract" report prepared for ABAG as mentioned in the preceding paragraph.

Data Collection Methodology

Once the major hospitals were identified in the subject area, pertinent data was then collected and documented on each physical facility listed. Hospitals were inspected in the field by an engineer in order to confirm the following data:

Year Built.	General Description.
Location & Orientation.	Building Shape.
Type of Construction.	Structural Characteristics.
Number of Stories.	Type of Facility.
Size in Square Foot Area	Bed Capacity.

Individual hospital files on record with the Bureau of Planning and Construction, California Department of Public Health, were made available for this study. Extensive use was made of the Bureau's "Seismic Safety Study," completed in 1957, which evaluated those major hospitals licensed by the Bureau and built before 1957. Additional information was made available through personal interviews with the Bureau's staff members for hospitals constructed since that date.

Each military hospital and major mental health facility in the 9 Bay Area counties was field surveyed for pertinent information. In consideration of the fact that these hospital facilities represented huge complexes covering large acreage, site plans or master plans of the entire area were obtained to illustrate the over-all layout of the individual units in relationship to accessibility and circulation routes insofar as possible. A report written by a structural engineer of the Sacramento Military Branch on the "Seismic Design Considerations," March 1971, of Letterman Hospital and the Western Medical Institute of Research, Presidio of San Francisco was reviewed.

Information regarding the distribution of professional medical specialists over the 9 Bay Area counties was obtained from the 1970 Directory issued by the Board of Medical Examiners, Department of Consumer Affairs, State of California. Additional data on specific hospital personnel was obtained from administration members of representative hospitals in the subject area and correllated with information received from other sources.

In addition to Tables 12 and 13 mentioned in the preceding paragraphs regarding hospitals and their bed capacities, Table 14 gives the geographical distribution by county of the professional medical specialists in the Bay Area. Figure 2 illustrates the location and geographic distribution of the major hospitals in the isoseismal area considered by this study.

ANALYSIS

The tactical and logistic problems to be faced by major hospitals and other health facilities during and after a severe earthquake will be considerable including many which will be unexpected. It is clear that the care of the injured immediately following the main shock would become one of the greatest area-wide problems. Although an attitude may be adopted in which it could be assumed that most of the hospitals would be in operation, the San Fernando earthquake of 1971 indicates that it is highly possible that many more hospital facilities and medical

TABLE 14

PROFESSIONAL MEDICAL MANPOWER RESOURCES BY COUNTY

County	Physicians and Surgeons	Podiatrists	Veternarians	Registered Nurses
Alameda	2,120	58	111	5,392
Contra Costa	863	17	64	2,824
Marin	843	19	45	1,584
Napa	215	4	13	663
San Francisco	3,033	104	47	5,611
San Mateo	1,059	34	66	3,468
Santa Clara	2,254	43	101	5,865
Solano	208	6	15	724
Sonoma	343	14	50	1,027
Totals	10,938	299	512	27,158

Sources:

Physicians & Surgeons, Podiatrists, and Veternarians: 1970 Directory issued by the Board of Medical Examiners, Department of Consumer Affairs, State of California. Sacramento July 1970. (Note: Statistics on veternarians related to data reported in 1968.)

Registered nurses: "Health Manpower, A County and Metropolitan Area Data Book", as of 1966, Public Health Service Publication No. 2044.

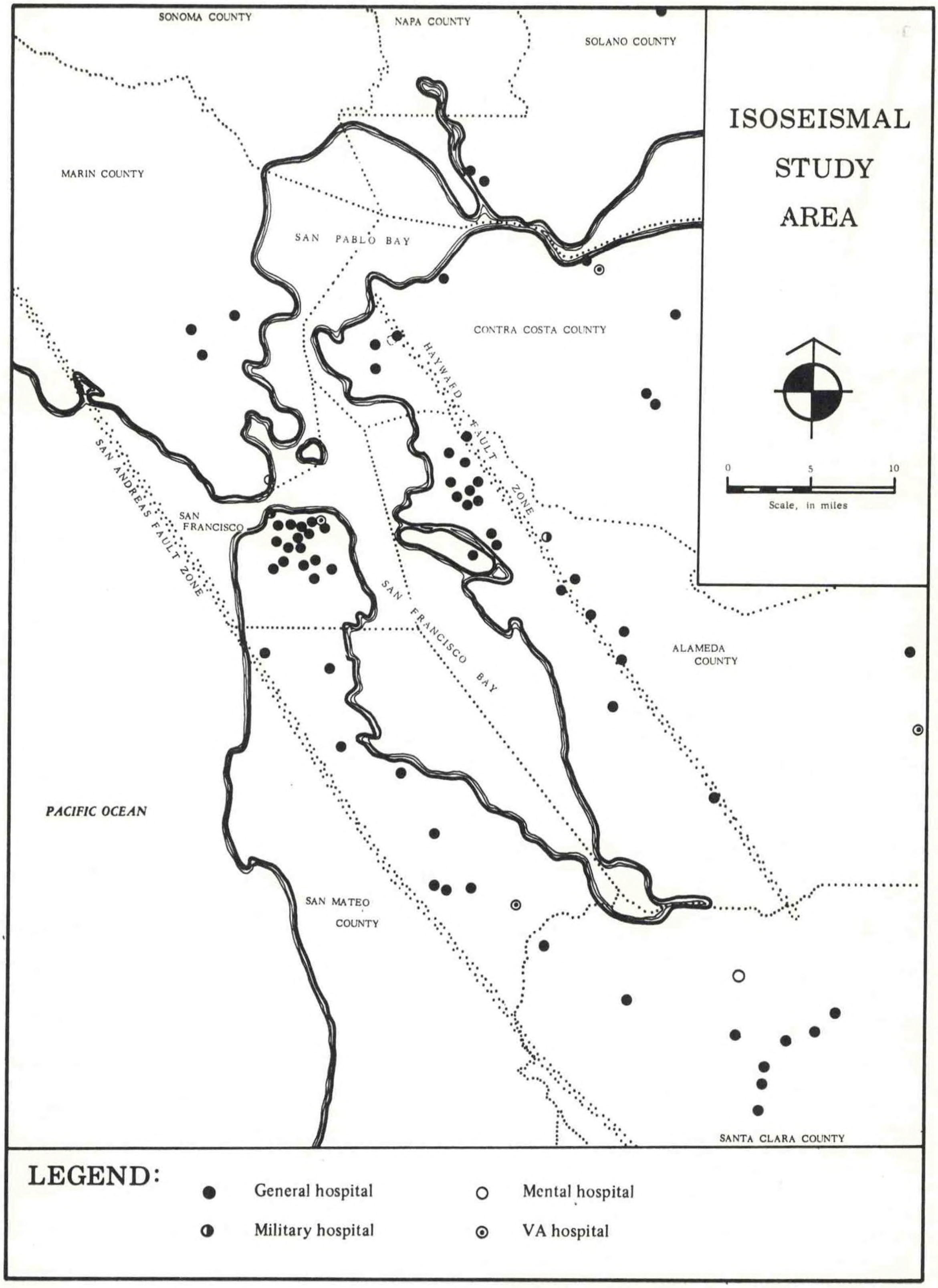


FIGURE 2. Medical facilities -- major hospitals. Locations are <u>approximate</u> with respect to fault zones; see text.

centers could be more severely damaged than originally suspected probable and thus be critically handicapped in useful post-earthquake recovery. Using the 1971 San Fernando earthquake as a model, it is not unrealistic to envision possibilities wherein a major hospital facility may become a burden rather than an aid after a major earthquake. In this regard all the hospitals in the 9 Bay Area counties therefore require close examination.

Analysis of health facilities is complicated by the fact that many hospitals are composed of several buildings, built at different times with varying construction materials and physical configurations. In meeting the needs of an expanding population in the San Francisco Bay Area and in recognizing the advantages of new technological equipment, hospital buildings may be renovated or enlarged by the addition of annexes attached to the original building three or four times within a period of twenty years. Thus although a major medical facility may have the most modern equipment available, it may be located in an old structure, or although a new addition may have been completed in 1971, the main control center to the communication system could still be housed in the part of the building complex constructed before 1933. Table 15 gives an indication of the dates of construction, or age, of some of the original parts of the building complexes which are still being used in certain operations of the major hospitals located in the study area.

There are two phases to meeting emergency health planning problems. The first is the immediate post-disaster life saving phase. The concerns at this time are with the need of immediate medical attention in the care of the injured. The second phase is concerned with the basic health problems and everyday needs of the survivors. This can be a protracted period of time wherein time and supplies are available to deal with the survivors. Both of these phases have been given consideration in the analysis of the major medical facilities made in this report.

Figure 2 indicates the locations and geographic distribution of the major hospitals in the isoseismal area considered by this study. It can be seen from this map that some of the hospitals, particularly those on the east side of San Francisco

Bay, are located in zones subject to a high risk potential in regard to known fault lines in the area. Of the several major hospital facilities located in the East Bay, seven general hospitals and one military hospital are located on or immediately adjacent to the Hayward fault and five others are located near-by. It seems reasonable to expect ground ruptures through several of the 8 hospital sites in even moderate earthquakes on the Hayward fault. Many of the hospitals will suffer from access to and from their building sites being cut-off due to collapse of freeway overpasses and consequently alternate secondary routes will be used. Also damage to service utilities will restrict hospital functions.

The building analysis was concluded from data compiled specifically for this study. In several cases, construction drawings were available and in other specific situations the author had personal knowledge of the hospital facility. Life hazard and property damage conclusions were derived from correlation of the isoseismal maps with the known earthquake resistance of each class of structural system. Comparisons were also made on performance of specific hospitals at various levels of ground motion experienced during past major earthquakes such as those which occurred in the 1906 San Francisco, 1971 San Fernando, 1969 Santa Rosa, 1957 San Francisco and other similar shocks.

In order to derive the number of deaths and injuries associated with the six postulated earthquakes, comparative studies were completed to determine the effects at various times of day on the actual occupants of the hospitals as follows:

(a). Number of patients related to the hospital's bed capacity; i.e. the occupancy ratio which is currently at about the 90% level.

(b). Number of staff on duty.

(c). Number of out-patients in hospital.

(d). Number of doctors in hospital.

(e). Number of visitors (an average of one visitor per bed/patient).

The number of deaths and injuries reported in this section of the report refer only to those casualties resulting to the actual occupants of the hospital buildings or those on the hospital grounds at the time when the postulated earthquake occurs.

Wet seasonal or dry seasonal effects were not considered in this phase of the study.

Tables 15, 16, and 17 supply important information regarding construction types, construction dates, and heights of the major hospitals surveyed as part of this study. It is significant to note that 40% of the major hospitals still use portions of their building complexes which date back prior to 1933, the expected performance of which is therefore questionable. In regard to construction types, 5% of all the major hospitals located in the 9 San Francisco Bay Area counties are of brick construction of the type which performs poorly even during moderate earthquakes. According to Bureau of Planning and Construction (Sacramento), one of these in the City of San Francisco was constructed in two periods, 1916 and 1934, and is known to have brick masonry filler walls, with questionable mortar joints, designed to serve as lateral bracing against earthquake loading. This construction type performs poorly even in moderate shocks. Many of the parapets in this building are also reported to be in very poor condition.

In regard to the heights of the major hospital buildings, it is noted that 54% of the facilities are one to four stories high, 42% are five to eight stories in height, while the remaining 4% are over nine stories and usually of recent construction. With respect to multistory hospitals, several will have to be evacuated if heavily damaged, even though they are not subject to total collapse. Others will have to be evacuated pending inspection by qualified engineers to determine whether their structural integrity has been compromised beyond acceptable levels.

Local major hospital resources will be diminished as a result of building damage, deaths, injuries, loss of medical supplies, loss of utility services, and damage to vertical circulation systems. Combinations of various damage patterns affecting the hospital resources would occur in each of the postulated earthquakes assumed for this study. The problem types may be divided into the following four categories:

1. Life losses and injuries in hospitals,
2. Physical damage to hospitals,
3. Loss of medical supplies in hospitals, and
4. Loss of hospital use.

TABLE 15

INVENTORY BY COUNTY OF MAJOR HOSPITALS BY CONSTRUCTION DATE OF OLDEST PART OF BUILDING

County	Construction Date of Oldest Part		
	Pre-1933	1933-1960	1960-1970
Alameda	8	8	6
Contra Costa	3	3	2
Marin	2	1	-
Napa	2	1	-
San Francisco	11	7	4
San Mateo	3	3	3
Santa Clara	3	4	5
Solano	1	-	2
Sonoma	1	2	-
Totals	34 (40%)	29 (34%)	22 (26%)

TABLE 16

INVENTORY BY COUNTY OF MAJOR HOSPITAL STORY HEIGHTS

County	Number of Stories			
	1-4	5-8	9-13	14 and Over
Alameda	13	7	2	-
Contra Costa	6	2	-	-
Marin	2	1	-	-
Napa	2	1	-	-
San Francisco	6	16	-	-
San Mateo	5	3	1	-
Santa Clara	7	5	-	-
Solano	2	1	-	-
Sonoma	3	-	-	-
Totals	46 (54%)	36 (42%)	3 (4%)	0

Life Losses and Injuries in Hospitals

The 9 counties of the San Francisco Bay Area have 85 major hospitals accommodating approximately 36,300 beds with a current occupancy rate of about 90%. Table 18 lists the distribution of these beds by county and also gives a current total value of the facilities of about $1,271,000,000. Based on the bed occupancy rate, location and physical characteristics of the hospital building, the total number of deaths and injuries to occupants and personnel in the building were computed for the six earthquakes for three assumed times of day: 2:00 p.m., 4:30 p.m., and 2:30 a.m.

Percentile casualty distribution (death and significant injury) among patients, staff, visitors and outpatients, and doctors would be the same, generally speaking, for the two earthquakes occurring in the afternoon; for planning purposes, these numerical values will be considered equal. During the afternoon hours, the greatest percentage of casualties would be among the hospital staff. However, with the reduced numbers of staff, visitors and doctors present in the early morning hours, the percentile casualty distribution among the occupants of the hospital building would differ considerably with the majority of casualties being among the patients. Table 19 lists the projected percentile casualty distributions for the three times of day assumed for the occurrence of the postulated earthquakes.

Figure 3 shows the upper credible limit for the total life loss and injuries within hospitals in the 9 San Francisco Bay Area counties. This graphic illustration of the number of casualties indicates that the Hayward fault is potentially more hazardous than is the San Andreas fault. While a daytime earthquake of magnitude 7 on the San Andreas fault results in the potential of approximately 230 deaths, an earthquake of equal magnitude on the Hayward fault has a potential projection of 700 deaths. Similarly for potential injuries, the Hayward fault outweighs the San Andreas fault.

Tables 20 and 21 show the distribution of the deaths and injuries by county as well as by the time of day. Figure 4 is the casualty projections for doctors, patients, and staff in comparison to visitors and outpatients in the

TABLE 17

INVENTORY BY COUNTIES OF MAJOR HOSPITAL CONSTRUCTION TYPES

County	Construction Type: Concrete	Steel	Brick	Wood	Mixed
Alameda	16	1	1	3	1
Contra Costa	3	1	0	4	0
Marin	1	0	0	1	1
Napa	1	1	0	0	1
San Francisco	13	3	3	0	3
San Mateo	7	1	0	0	1
Santa Clara	8	1	1	0	2
Solano	1	1	0	1	0
Sonoma	2	0	0	0	1
Totals	52	9	5	10	9
Percentile	(61%)	(11%)	(5%)	(12%)	(11%)

TABLE 18

DISTRIBUTION OF MAJOR HOSPITAL BEDS BY COUNTY

County	Total Number of Beds	Total Present Value
Alameda	6,107	$ 213,700,000
Contra Costa	1,912	66,900,000
Marin	594	20,800,000
Napa	3,702	129,600,000
San Francisco	8,270	289,500,000
San Mateo	3,466	121,500,000
Santa Clara	6,720	235,200,000
Solano	444	15,500,000
Sonoma	3,912	136,900,000
Totals	35,127	$1,229,400,000

Note: Different authorities list different bed counts.

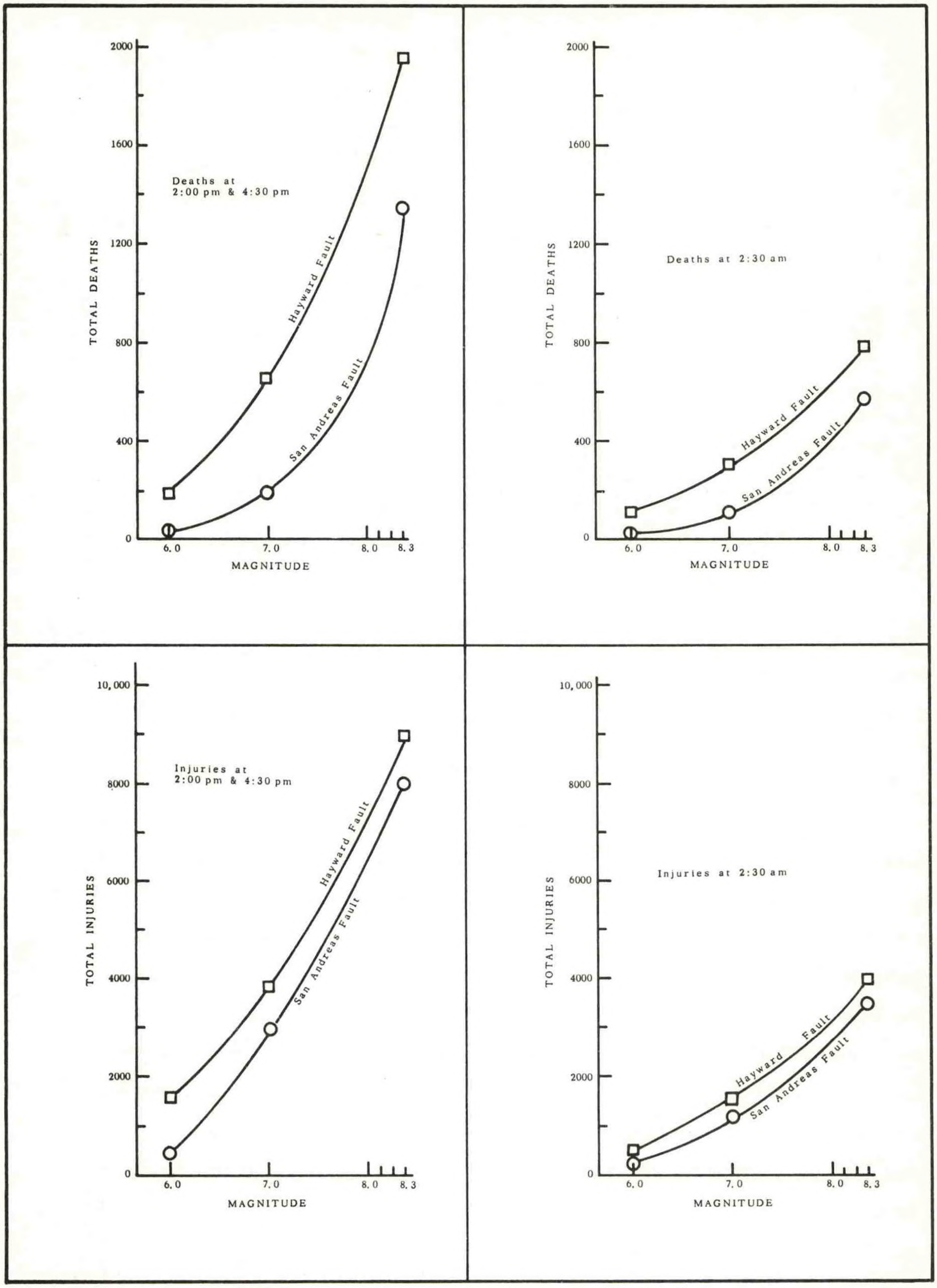


FIGURE 3. Deaths and injuries in hospitals.

TABLE 19

PERCENTILE CASUALTY DISTRIBUTIONS

Category	Time of Day: 2:00 p.m. & 4:30 p.m.	Time of Day: 2:30 a.m.
Patients	30%	70%
Staff	62%	$27\frac{1}{2}$%
Visitors & Outpatients	$6\frac{1}{2}$%	$\frac{1}{2}$%
Doctors	$1\frac{1}{2}$%	2%
	100%	100%

Percentages given above are applied to the totals given in Table 20 to obtain values shown in Figure 4.

hospitals for the 6 postulated earthquakes and the three times of day assumed for this study.

Physical Damage to Major Hospitals

As may be seen in Figure 2 which indicates the location and distribution of the major medical hospitals in the study area, 8 hospitals are located on or immediately adjacent to the Hayward fault. Accordingly, ground ruptures may be anticipated through several of these sites even during a moderate earthquake and particularly during one with a 7 or greater magnitude on the Hayward fault. As would be expected, therefore, Alameda County will be hard hit by movement on the Hayward fault as compared with comparable movement on the San Andreas fault. Conversely, San Francisco and San Mateo counties, while subject to major damage from strong earthquakes on the San Andreas fault, would experience a much more moderate influence from shocks along the Hayward fault. Santa Clara County, located between the two faults, would be subjected to major damage from major earthquakes on either fault.

TABLE 20

TOTAL DEATHS IN HOSPITALS

County	San Andreas Fault						Hayward Fault					
	2:00 p.m. or 4:30 p.m.			2:30 a.m.			2:00 p.m. or 4:30 p.m.			2:30 a.m.		
	8.3	7	6	8.3	7	6	8.3	7	6	8.3	7	6
Alameda	28	7	-	11	3	-	974	603	240	410	253	100
Contra Costa	-	-	-	-	-	-	39	14	-	17	6	-
Marin	3	1	-	1	1	-	2	3	-	1	1	-
Napa	20	1	-	9	1	-	19	3	-	8	1	-
San Francisco	555	79	-	233	33	-	19	-	-	8	-	-
San Mateo	160	65	10	67	27	4	39	-	-	17	-	-
Santa Clara	463	61	-	194	25	-	507	56	-	212	24	-
Solano	11	-	-	5	-	-	273	21	-	114	9	-
Sonoma	80	16	-	34	7	-	78	-	-	32	-	-
Totals	1,320	230	10	554	97	4	1,950	700	240	819	294	100

TABLE 21

INJURIES IN HOSPITALS

County	San Andreas Fault						Hayward Fault					
	2:00 p. m. or 4:30 p. m.			2:30 a. m.			2:00 p. m. or 4:30 p. m.			2:30 a. m.		
	8. 3	7	6	8. 3	7	6	8. 3	7	6	8. 3	7	6
Alameda	494	216	-	208	90	-	3,995	2,523	1,638	1,678	1,068	390
Contra Costa	142	-	-	59	-	-	544	179	-	228	75	-
Marin	67	27	-	28	11	-	27	18	-	11	8	-
Napa	142	46	-	59	19	-	153	46	-	64	21	-
San Francisco	2,874	1,024	175	1,208	431	74	272	-	-	114	-	-
San Mateo	1,071	620	123	448	260	51	361	64	-	152	26	-
Santa Clara	2,874	700	49	1,208	295	21	3,178	606	-	1,335	246	-
Solano	42	-	-	18	-	-	117	61	12	49	25	3
Sonoma	494	67	3	208	28	1	453	53	-	191	22	-
Totals	8,200	2,700	350	3,444	1,134	147	9,100	3,550	1,650	3,822	1,491	393

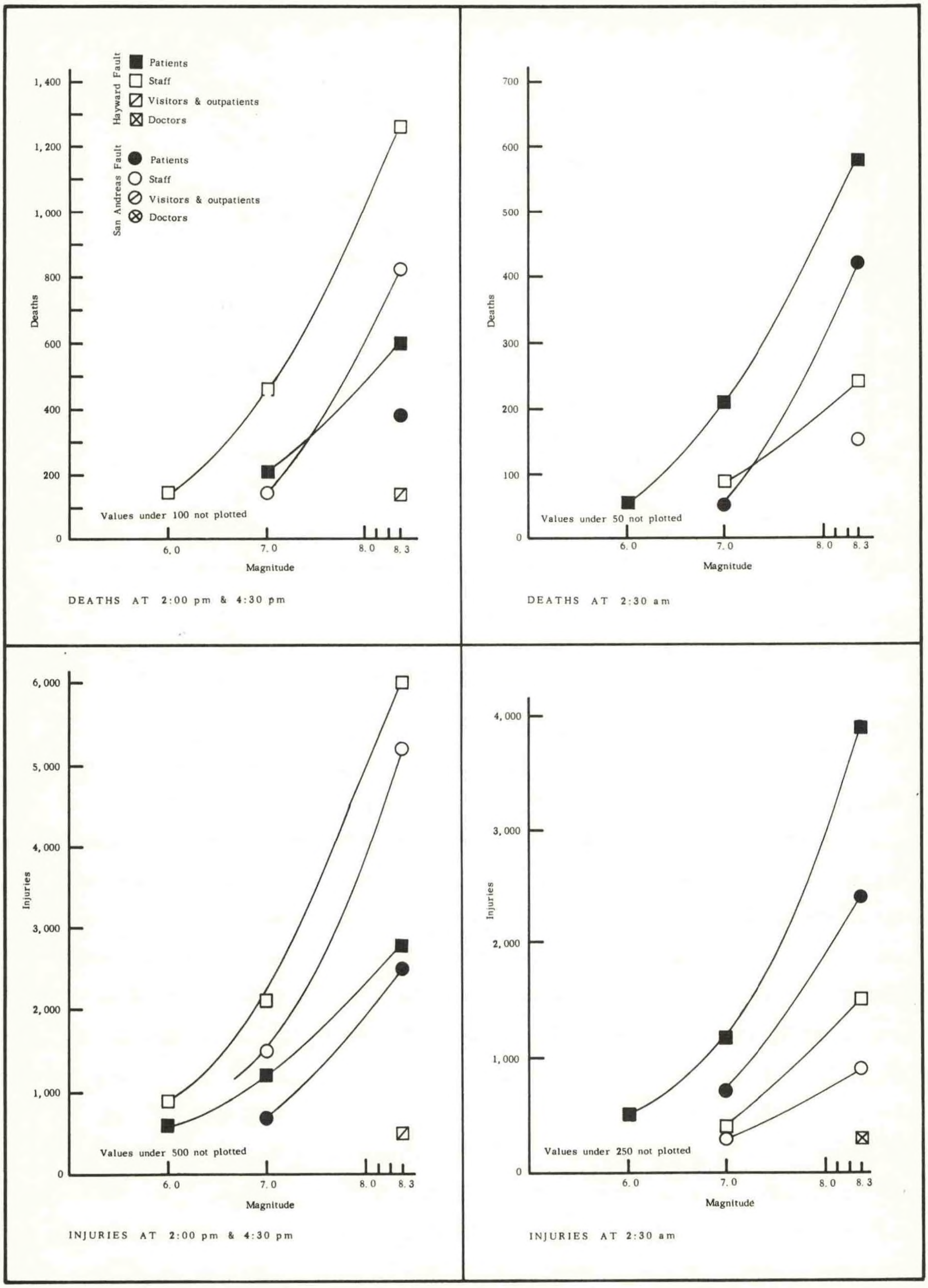


FIGURE 4. Total casualties (deaths and injuries) among patients, staff, visitors, and outpatients.

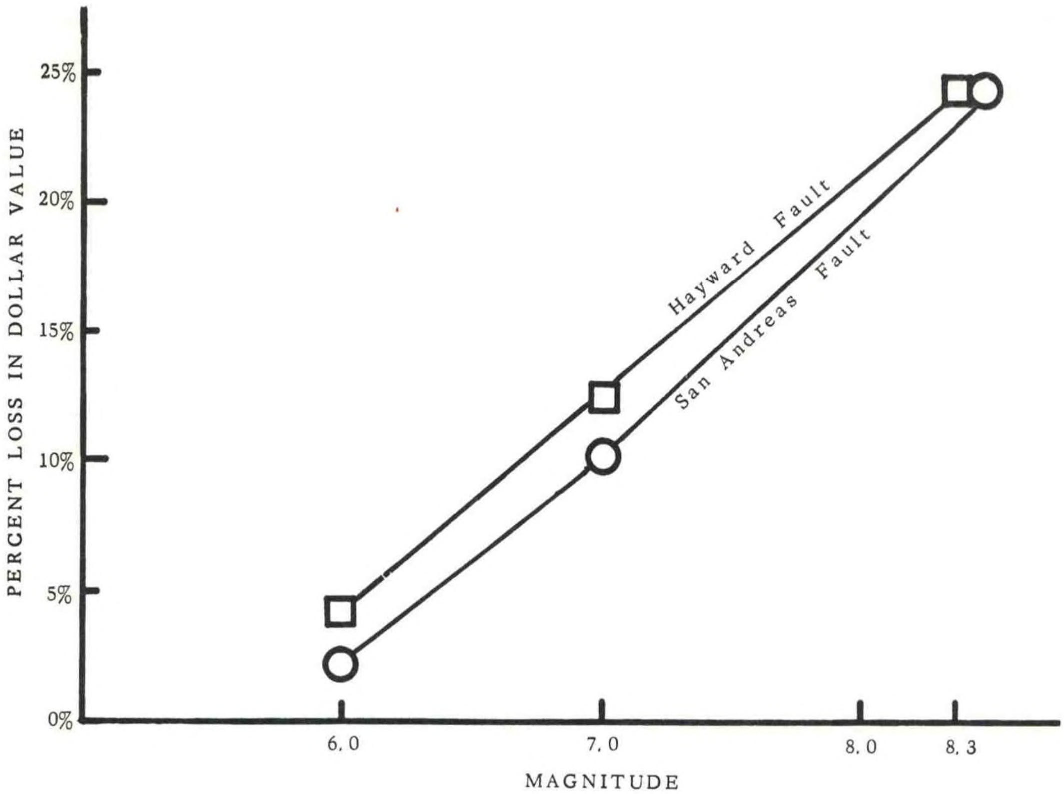


FIGURE 5. Hospital damage, in percent of replacement value.

The total $1,229,400,000 investment in hospital construction in the 9 county study area can be damaged up to about 25% of its replacement value during an 8.3 magnitude shock on either the San Andreas or Hayward fault; see Figure 5. It can also be calculated that an 8.3 magnitude earthquake on the San Andreas fault could potentially result in a $27,575,000 loss to hospital construction in San Francisco County while producing a corresponding $3,740,000 loss in Alameda County. Similarly, an 8.3 magnitude earthquake on the San Andreas fault may result in a total of $317,750,000 loss projection for all of the major hospitals located in the entire 9 San Francisco Bay Area counties.

Figure 6 shows bed loss in percent of total beds available as a function of magnitude. The actual estimated bed loss by county is shown in Table 22. On the San Andreas fault, earthquake losses vary from about 2% due to a 6 magnitude earthquake to about 50% loss for an 8.3 magnitude earthquake, while on the Hayward fault the variation extends from about 9% loss from a 6 magnitude shock to about 48% loss from an 8.3 magnitude shock. The expected damage patterns for

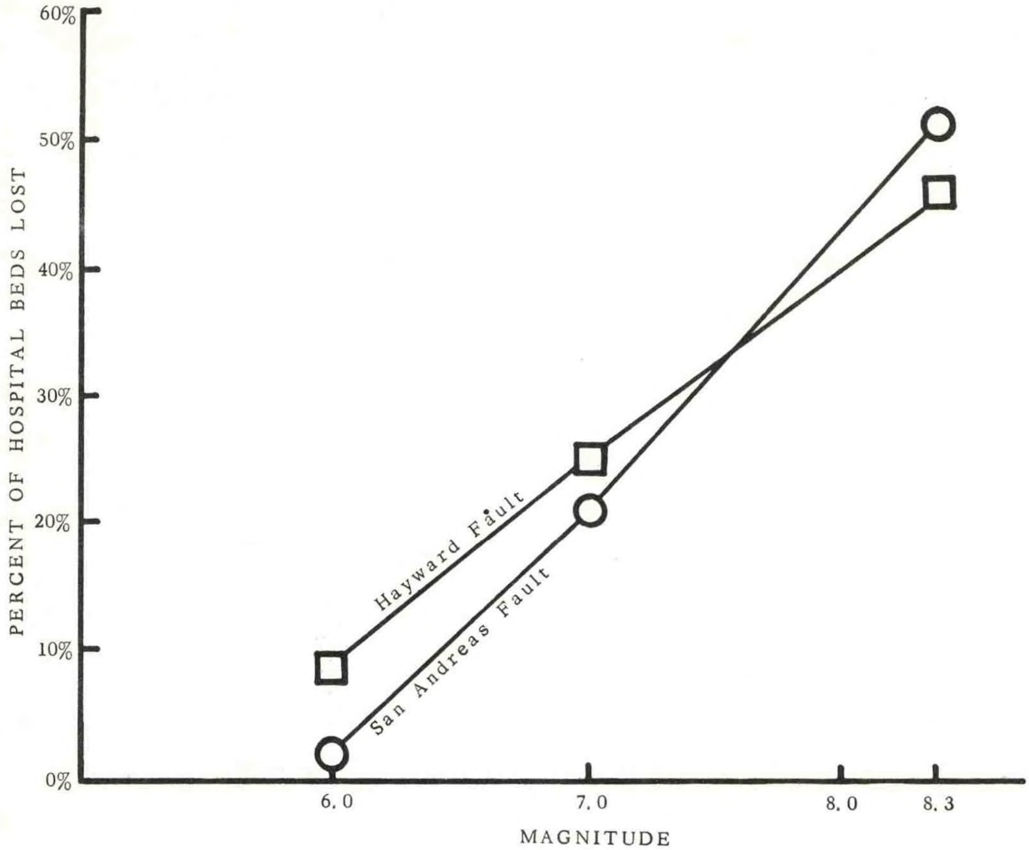


FIGURE 6. Loss of hospital beds, in percent.

TABLE 22

HOSPITAL BED LOSS

	San Andreas Fault			Hayward Fault		
	8.3	7	6	8.3	7	6
Alameda	1,265	240	12	5,006	4,780	3,141
Contra Costa	127	-	-	1,130	427	-
Marin	380	292	-	323	170	-
Napa	597	436	2	646	427	-
San Francisco	5,970	947	-	404	-	-
San Mateo	2,713	2,259	583	1,130	256	-
Santa Clara	4,527	2,039	-	5,006	1,878	-
Solano	90	-	-	161	85	20
Sonoma	2,351	1,093	-	2,423	513	-
Total	18,020	7,306	597	16,229	8,536	3,161

the two faults reverse themselves due to the fact that a smaller earthquake of lesser magnitude on the Hayward fault will damage more buildings due to their proximity to the fault than an earthquake of the same magnitude on the San Andreas fault. However, in a major earthquake the opposite is true since the East Bay has considerably fewer hospitals subject to damage as compared to San Francisco, for example, which has a larger number of hospitals related to the San Andreas fault.

Loss of Medical Supplies

The losses of medical supplies stored in a hospital building is a function of two variables: (1) loss of supplies stored in fragile containers falling from their shelves and/or equipment falling off counter tops, and (2) building collapse on supplies and equipment rendering them useless.

Reliable loss data from 30 hospitals subjected to the 1971 San Fernando earthquake proved to be invaluable to this study. Data was also used from the experiences documented as a result of the 1969 Santa Rosa shock. While admittedly these two earthquakes were limited to the extent of area affected and very little loss was reported, a larger earthquake of the magnitudes predicted for the San Francisco Bay Area will have a larger proportional loss of specific supplies, particularly liquid type drugs and chemicals stored on shelves in fragile containers.

By relating magnitudes and dollar loss to hospital supplies and equipment, the conceivable upper limit percentile dollar losses would be in the following ranges:

Magnitude 8.3	60 to 70% loss
Magnitude 7.0	20 to 30% loss
Magnitude 6.0	1 to 3% loss

Health Manpower

Health manpower problems at hospitals have been discussed in a previous section of this report; see particularly Figure 4. There are the additional problems of deaths and injuries to health manpower away from the hospitals as well as their transportation problems.

The estimate of the maximum number of deaths per 100,000 of health manpower away from hospitals is based on the data developed in Section 4 of this report, and the results are given in Table 23. Serious injuries are expected to number about 4 times those for deaths.

Health manpower endeavoring to return to their places of employment, or commute after the disaster, pose special problems. The following discussion of the transportation problems will emphasize problems for physicians and surgeons, but the general findings are applicable to all types of health manpower.

DATA COLLECTION

The main source of health manpower information available for this section was found to be the Department of Consumer Affairs, State of California, through which the Board of Medical Examiners issues its yearly "Directory" listing data on health manpower resources. Working with the latest "Directory" (1970) it was possible to determine the location and distribution of all professional medical personnel on a county basis. The total number of medical manpower resources is listed in Table 14 for the following professions: physicians and surgeons, podiatrists, veternarians, and registered nurses. Figure 7 shows the location and distribution of the residences of physicians and surgeons in each county.

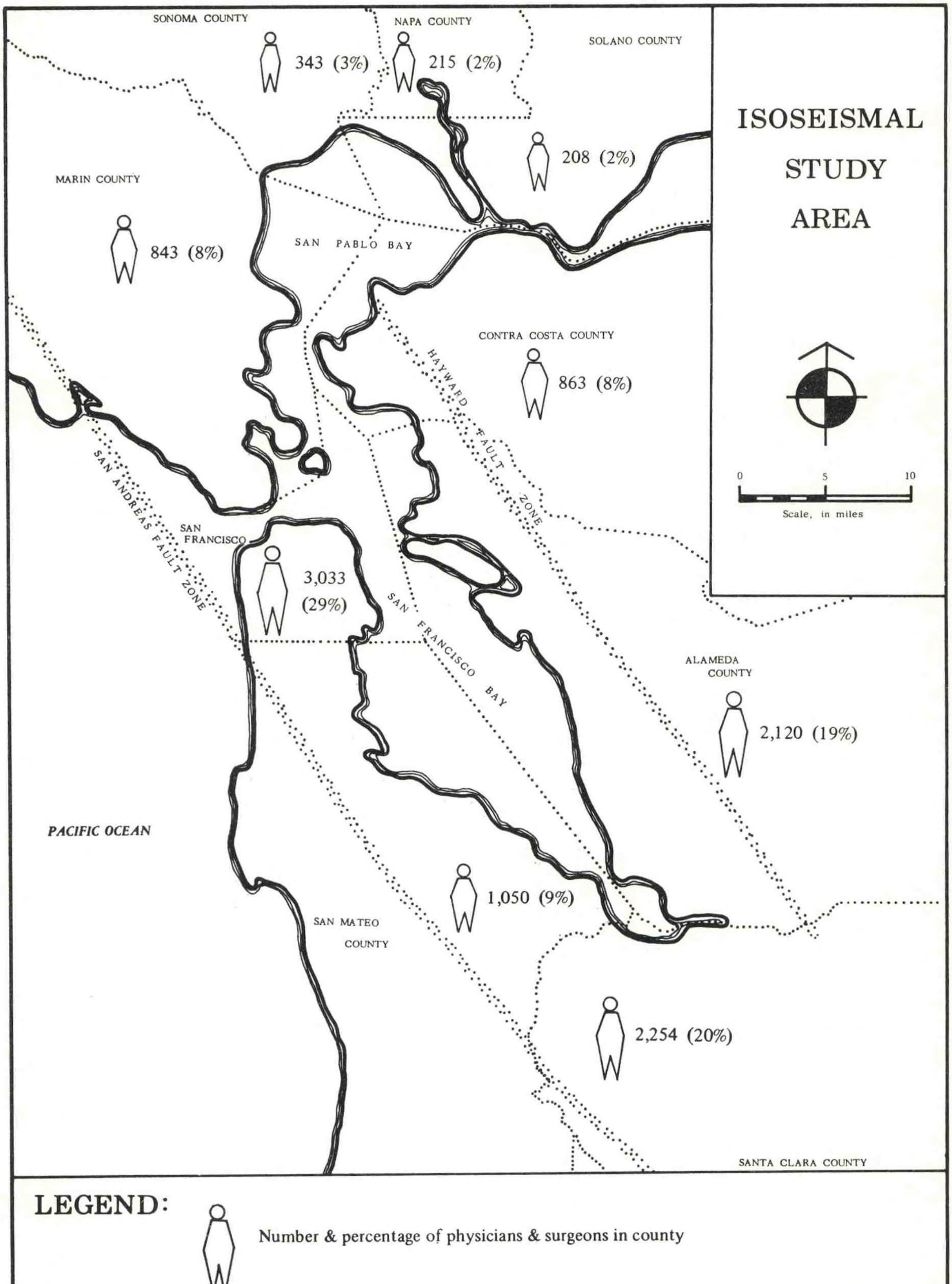


FIGURE 7. Residence of physicians and surgeons by county.

ANALYSIS

As standard procedure after a disaster, medical specialists and personnel are expected to immediately report to the hospital to which they are attached. If for any reason they are unable to reach their hospital, it is then expected that they will report to the nearest hospital available to them. In this regard, it is important to correlate the locations of the major hospitals with respect to major transportation arterials and medical manpower resources.

The Bureau of Emergency Medical Planning of the State of California, Department of Public Health, has a "command center" in the City of Berkeley. In dealing with emergencies, this center stands ready to respond to resource problems regarding medical care and public health. On a standby basis, equipment and manpower can be flown in from cooperative out-of-state agencies located in Arizona, Colorado, Texas, or Utah.

Table 24 gives the percentages of the population by county with respect to urban centers and rural areas for each county. Percentages of medical manpower resources in regard to residence would not in all probability differ from the general population figures given in this table.

The difficulty or ease with which the medical personnel will be able to reach their hospital stations will depend on the condition of ground transportation. The San Francisco Bay Area is unusual in this respect because of 3 special linkages which serve as keys to successful traffic flow through the area. These special links are: (a). Bridges, (b). System of Freeways, and (c). The almost completed BART facilities.

Considering the number of working hours in a week, it is more than likely that the medical manpower will be home or other than at their places of employment when the postulated earthquake strikes. Under these circumstances, some medical personnel will not be available due to damage to transportation routes. This availability problem will be significantly increased when the bridges and/or their approaches are damaged since some medical personnel use them for commuting.

TABLE 23

DEATHS TO HEALTH MANPOWER
Deaths at non-hospital locations

Fault	Magnitude	Deaths/100,000 of Health Manpower
San Andreas	8. 3	200
	7	40
	6	2
Hayward	8. 3	100
	7	30
	6	10

Example of usage: Physician deaths at non-hospital locations for a magnitude 8. 3 shock on the San Andreas fault would be: (200/100, 000) x 10, 938 = 22 deaths.

TABLE 24

TOTAL POPULATION STATISTICS FOR NINE BAY AREA COUNTIES

County	Total Population	% of Total	Population by % Urban	Rural
Alameda	1,073,184	23. 0	99. 0	1. 0
Contra Costa	558,389	12. 0	93. 6	6. 4
Marin	206,038	4. 3	92. 4	7. 6
Napa	79,140	1. 7	58. 0	42. 0
San Francisco	715,674	16. 0	100. 0	0. 0
San Mateo	556,234	12. 0	98. 2	1. 8
Santa Clara	1,064,714	23. 0	97. 5	2. 5
Solano	169,941	4. 3	93. 0	7. 0
Sonoma	204,885	3. 7	58. 7	41. 3
Totals	4,628,199	100. 0		

Source: 1970 Census

It was assumed for the purposes of this report that the residence and commuting habits of the medical manpower did not differ significantly from that of the general public. On these premises, use can be made of studies prepared by the Bay Area Transportation Study Commission and from other sources. These sources indicate that about 7.3% of the working population of the study area use one of the following bridges: Golden Gate, San Francisco-Oakland Bay, San Mateo, or Dumbarton. (All of which are subject to strong shaking from a great earthquake on the San Andreas fault.) A total of 6.2% of the working population use the San Francisco-Oakland Bay, San Mateo, Dumbarton, Carquinez, or Richmond-San Rafael Bridges; all of which are subject to heavy shaking in the event of a major earthquake on the Hayward fault.

Possibilities exist for earthquake damage to one or more of the following bridges and/or their approaches: San Francisco-Oakland Bay Bridge, Richmond-San Rafael Bridge, Golden Gate Bridge, Carquinez Straits Bridge, San Mateo Bridge, and the Dumbarton Bridge.

In addition to the bridge problem, blocked streets due to fallen overpasses, building debris, landslides, etc. will present difficulties, but these will not be so severe that alternate routes cannot be used in the vast majority of the cases. It seems reasonable to assume that the problems of bringing in injured to hospitals and to other centers will take even longer than that required for the uninjured medical personnel to arrive. It should be expected that much of the freeway system will be partially closed in specific areas due to the effects from fault displacement, local subsidence, lurch cracking, or landslides; further details are discussed in the section on Transportation.

Table 25 is a summary of transportation problems for medical personnel. The percentages for bridge related problems consider that a number of the 10,938 physicians and surgeons (as of 1970) would be able to find alternate routes around or over the Bay in the event that bridges were closed, even temporarily. The "other problems" in Table 25 presume wet season conditions so that earthquake induced landslide problems would be common.

TABLE 25

TRANSPORTATION PROBLEMS AND THEIR EFFECTS ON MEDICAL PERSONNEL

Personnel assumed to be away from hospital or place of employment

Fault	Earthquake Magnitude	Personnel Absence *Bridge Closure	Personnel Absence **Other Problems	Physician and Surgeon Absence *Bridge Closure	Physician and Surgeon Absence **Other Problems
San Andreas	8.3	6%	2%	650	220
	7	3%	1%	330	110
	6	0%	0%	0	0
Hayward	8.3	5%	3%	550	330
	7	2½%	2%	275	220
	6	0%	0%	0	0

*Absence for 1 or more days.

**Absence for 1 or more hours, but not more than 8 hours. Due to failure of rapid transit system, landslide, fallen overpasses, etc.

Note: The figures in this table apply to uninjured personnel; total absence figures must include injuries and deaths.

Medical Supplies

Supplying hospitals is normally achieved through shipments from the drug wholesalers and hospital supply houses located in the San Francisco Bay Area. If the buildings of these medical supply companies were damaged or destroyed, supplies would then have to be sought elsewhere in the outlying areas or brought in from out-of-state. Damaged transportation routes can also effectively reduce the supply to hospitals.

DATA COLLECTION

Data for this section were obtained directly from the records of the Office of Emergency Preparedness which has information regarding wholesale drug and surgical supply houses, including retail suppliers. Information was also made available for this study through the offices of county pharmaceutical associations, the American Red Cross, and county medical associations in California and the San Francisco Bay Area.

The locations of the surgical supply and wholesale drug houses were documented, tabulated and related to the nine counties of the San Francisco Bay Area as given below and shown in Figure 8.

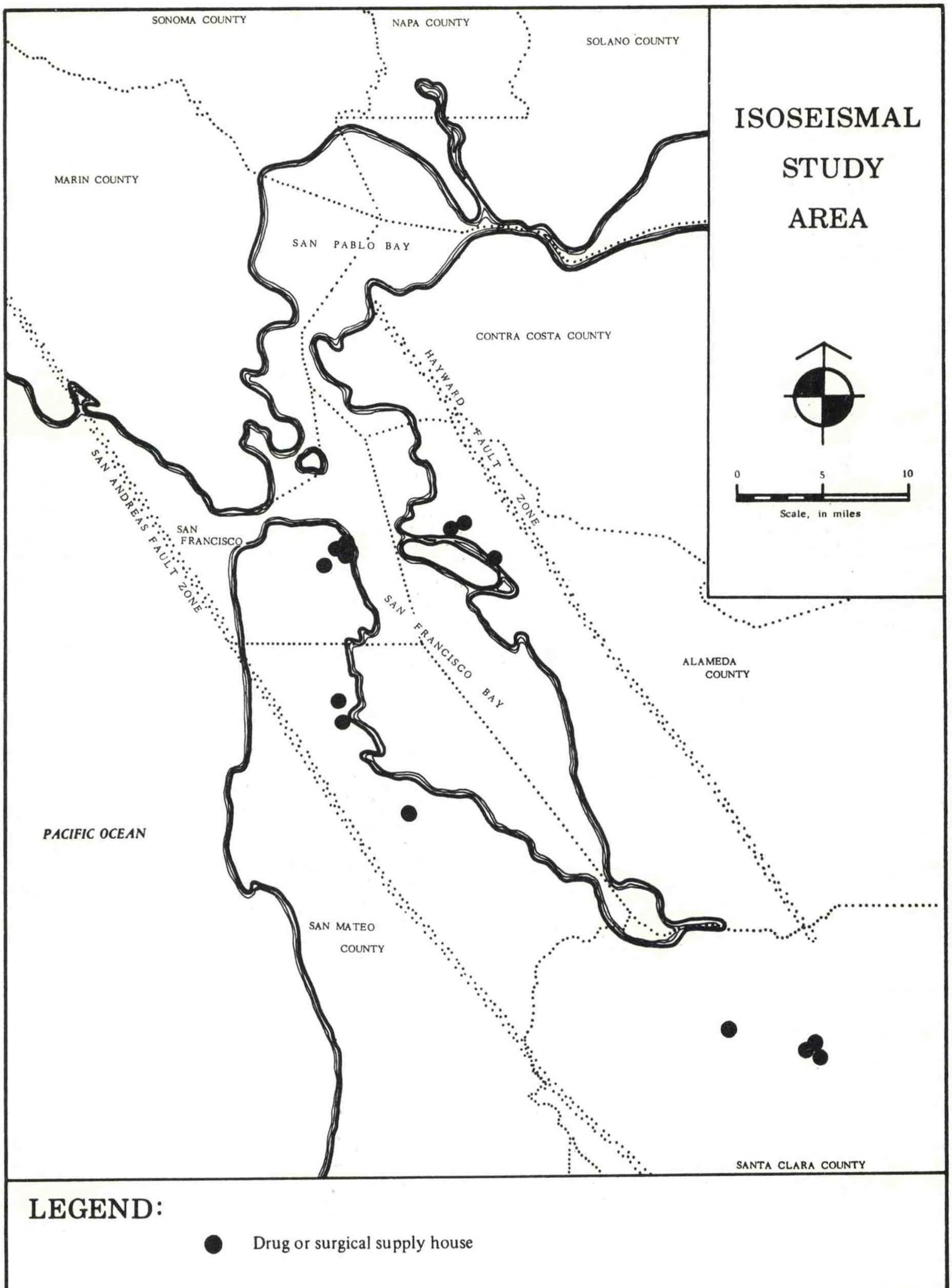


FIGURE 8. Drug and surgical supply houses.

Drug Wholesalers:	
Coffin-Reddington Co.	Oakland, Alameda
McKesson & Robbins, Inc.	Oakland, Alameda
McKesson & Robbins, Inc.	San Francisco, S.F.
Coffin-Reddington Co.	San Jose, Santa Clara
McKesson & Robbins, Inc.	Santa Clara, Santa Clara
Coffin-Reddington Co.	So. San Francisco, San Mateo
Independent Wholesale Drug Co.	San Francisco, S.F.
Aid Wholesale Drug Co.	San Jose, Santa Clara
Rx Specialties, Inc.	San Mateo, San Mateo
Surgical supply houses:	
Bischoff's	Oakland, Alameda
Bischoff's Surgical H.	San Jose, Santa Clara
T. E. E. Heard Co.	San Francisco, S.F.
A.S. Aloe Co.	S. San Francisco, San Mateo
American Hospital Supply Corp.	San Francisco, S.F.

In addition to the medical supply wholesalers, there are located in the Bay Area several pharmaceutical manufacturing firms which, in times of emergencies, can "by-pass" the wholesaler and execute "drop shipments" directly to the hospital or disaster area. A partial listing of these manufacturers include the following:

Name	Location--City & County
Cutter Laboratories, Inc.	Berkeley, Alameda
Parke Davis & Company	Menlo Park, San Mateo
Chas. Pfizer & Co. Inc.	San Francisco, S.F.
American Cyanamid Co.	Oakland, Alameda
CIBA Pharmaceutical Co.	Millbrae, San Mateo
Eli Lilly & Co.	San Francisco, S.F.
Hoffman-LaRoche Inc.	San Leandro, Alameda
Upjohn Co.	Menlo Park, San Mateo

Finally, data were received on 135 retail drug locations from a list provided by the Office of Emergency Preparedness.

ANALYSIS

The losses to medical supplies for hospitals and for direct public use may be considered as the losses to supplies stocked by wholesale and by retail facilities. For the purposes of this section of the report, retail medical supplies will be limited to those contained in pharmacies while wholesale supplies will be restricted to those contained in the 9 drug wholesaler locations and 5 surgical supply houses in the San Francisco Bay Area.

The losses of medical supplies requires the analysis of two factors: (1) loss as the result of drugs falling from their shelves, and (2) building collapse on drug stocks (or damaged to the extent that use and occupancy of the facilities is seriously restricted).

After the 1971 San Fernando earthquake, data were compiled on the pharmacy losses at 90 locations throughout the metropolitan Los Angeles area. The data included the dollar loss to prescription shelf stock and its percentage of total shelf stock value. Additionally, information was obtained on the length of time that each pharmacy was closed. These data provided the basis for the analysis made in this section of the report.

Retail Medical Supplies

Reliable loss data from 90 pharmacies experiencing the 1971 San Fernando shock, provided the information listed below. These losses include the results of rare instances of building damage to drug stocks plus the usual losses from falling from shelves.

1. Relationship between Modified Mercalli intensity and dollar loss to drug stocks:

Modified Mercalli IX	23% loss to drug stock
Modified Mercalli VIII	12% loss to drug stock
Modified Mercalli VII	7% loss to drug stock

2. Average length of time that pharmacy was closed when building damage or collapse was not a significant factor:

Modified Mercalli IX	3.7 hours
Modified Mercalli VIII and under	2 hours

The 90 locations in the metropolitan Los Angeles area provided an excellent sample size in view of the 135 pharmacies listed by the Office of Emergency Preparedness for the San Francisco study area.

The data listed above can be directly extrapolated to the San Francisco Bay Area for use in areas having the same Modified Mercalli intensities. This is based on the reasonable assumption that the average construction for drug stores will not differ significantly between the San Francisco and Los Angeles metropolitan areas. The obvious exceptions will be the congested areas of downtown San Francisco with its many multistory buildings in contrast to the usual 1 and 2 story buildings commonly found in the high intensity areas of San Fernando Valley.

In the analysis summarized by Table 26, drug stock losses for intensities greater than IX are influenced by the estimated number of building collapses since the stocks are already damaged by having fallen to the floor.

The 1971 San Fernando shock occurred before pharmacies were open and personnel had opportunities to take care of personal problems before reporting for work. In many cases, the delay in opening pharmacies located in the lower intensity zones appeared to be a function of general confusion and the delays of personnel arrival as well as the cleaning up of fallen shelf stock. It was noted that several downtown stores had opening delays in terms of hours even though reported stock losses were zero and the buildings were not damaged.

Wholesale Drug and Surgical Supply Houses

The records of the Office of Emergency Preparedness list 9 drug wholesale and 5 surgical supply houses in the study area. Of these 14 locations, construction information was available on 11 structures. The results of the study of these 11 structures were extrapolated to the entire 14 locations.

None of the aforementioned structures is located in or near a known active fault zone. Three buildings are located in structurally poor ground areas where differential soil movements during earthquakes may occur, thereby usually intensifying building damage. Two buildings, 3 stories and 7 stories respectively, are of unreinforced brick with sand-lime mortar; these two structures, located in a congested area of San Francisco, are of a class of construction which suffers severe damage and partial collapse on earthquakes having magnitudes of 8.3. At least three structures are of one story reinforced concrete tilt-up construction;

TABLE 26

DAMAGE TO PHARMACY STOCKS OF MEDICAL SUPPLIES

Fault	Earthquake Magnitude	Percent of Stock Lost in Specified Counties: San Francisco San Mateo	Santa Clara	Contra Costa Alameda	Marin	Napa Solano Sonoma
San Andreas	8.3	20%	12%	10%	10%	5%
	7	15%	10%	7%	7%	2%
	6	10%	7%	2%	2%	-
Hayward	8.3	12%	20%	25%	20%	15%
	7	7%	10%	20%	15%	10%
	6	2%	5%	10%	2%	-

TABLE 27

LOSSES TO WHOLESALE DRUG AND TO SURGICAL SUPPLY HOUSES

Earthquake Magnitude	Percent of Stock Lost
8.3	25%
7	15%
6	5%

Note: The above figures apply to postulated earthquakes on either the San Andreas or Hayward fault.

in the 1971 San Fernando shock this type of construction had approximately 20% building loss in the highest intensity areas (IX) and partial roof collapse was common.

San Andreas and Hayward Faults--
Expected Damage Patterns

Comparing an 8.3 magnitude earthquake on the San Andreas fault with the same magnitude shock on the Hayward fault, the intensity relationship with respect to building locations are as follows:

Modified Mercalli Intensity	San Andreas 8.3 magnitude	Hayward 8.3 magnitude
IX	8 locations	10 locations
VIII	6 locations	4 locations

It is apparent from the foregoing that the Hayward fault is the more crucial of the two if all other factors are equal. On the other hand, the earthquake resistance is poorer in buildings located near the San Andreas fault. In this case, the factors of intensity and construction quality are reasonably offsetting with respect to damage to the drug and surgical supplies, and thus no differentiation has been made between the two faults.

A majority of the buildings will have some damage in the event of an 8.3 magnitude shock, and some will have partial roof collapse. More extensive damage can be expected to the two brick structures in San Francisco. However, it is anticipated that much of the medical supplies can be salvaged from these damaged and unsafe locations depending, in part, on the season of the year. (During heavy rains, labels come loose and cartons are destroyed by rainwater.)

Table 27 is a summary of expected losses to wholesale drug and surgical supplies. The table assumes no losses due to inclement weather; it is reasonable to increase the listed losses by 20% over those shown in Table 27 if inclement weather is assumed for planning (i. e., 25% becomes 30%, etc.).

Bloodbanks

INTRODUCTION

Blood banks obviously play a major role in the event of a disaster which results in thousands of casualties, many of which will require blood. The capability of local blood banks to adequately supply disaster needs in these cases are of course, quite insufficient, and nationwide resources may be required.

However, the discussion in this report is limited to the potential damage to the 7 San Francisco Bay Area blood banks (Table 28), 6 of which are located within the isoseismal area shown on Figure 9. A total of 24 blood banks exist in California, and therefore the study area contains about 30% of those in California.

The blood banks located in the San Francisco Bay Area are typical of the medical facilities where blood is drawn and processed for later use. After processing, part of the supply is kept at the blood bank itself and the rest of it stored at the various member hospitals. According to an official at one of the blood banks inspected, at least 33% of the blood supply is kept at the blood center in order to handle an emergency. Blood is stored according to type in plastic bags (1 pint) which are set in cartons and stored on shelves in a refrigerator.

DATA COLLECTION

Authoritative information concerning the blood banks in the study area was received from the Managing Director of the Irwin Memorial Blood Bank in San Francisco. Reference has also been made to the American Association of Blood Banks in Chicago. Individual staff administrators of the various

TABLE 28

BLOOD BANKS WITH REGISTERED CAPACITIES

County	Blood Bank No.	Blood Unit Capacity **** In	Blood Unit Capacity **** Out
Alameda	1	347	786
Contra Costa	0*	0*	0*
Marin	1	-**	-**
Napa	0	0	0
San Francisco	1	450	675
San Mateo	1	916***	0
Santa Clara	1	300	0
Solano	1	-**	-**
Sonoma	1	150	200
Totals	7	2,163	1,661

*Alameda/Contra Costa Counties: blood bank in Oakland serves both counties.

**Blood units forwarded to Irwin Memorial Blood Bank in San Francisco for storage.

***Peninsula Memorial Blood Bank in San Mateo has a disaster capacity of 2,000 units.

**** "In" denotes capacity on bloodbank premises; "out" denotes storage capacity elsewhere.

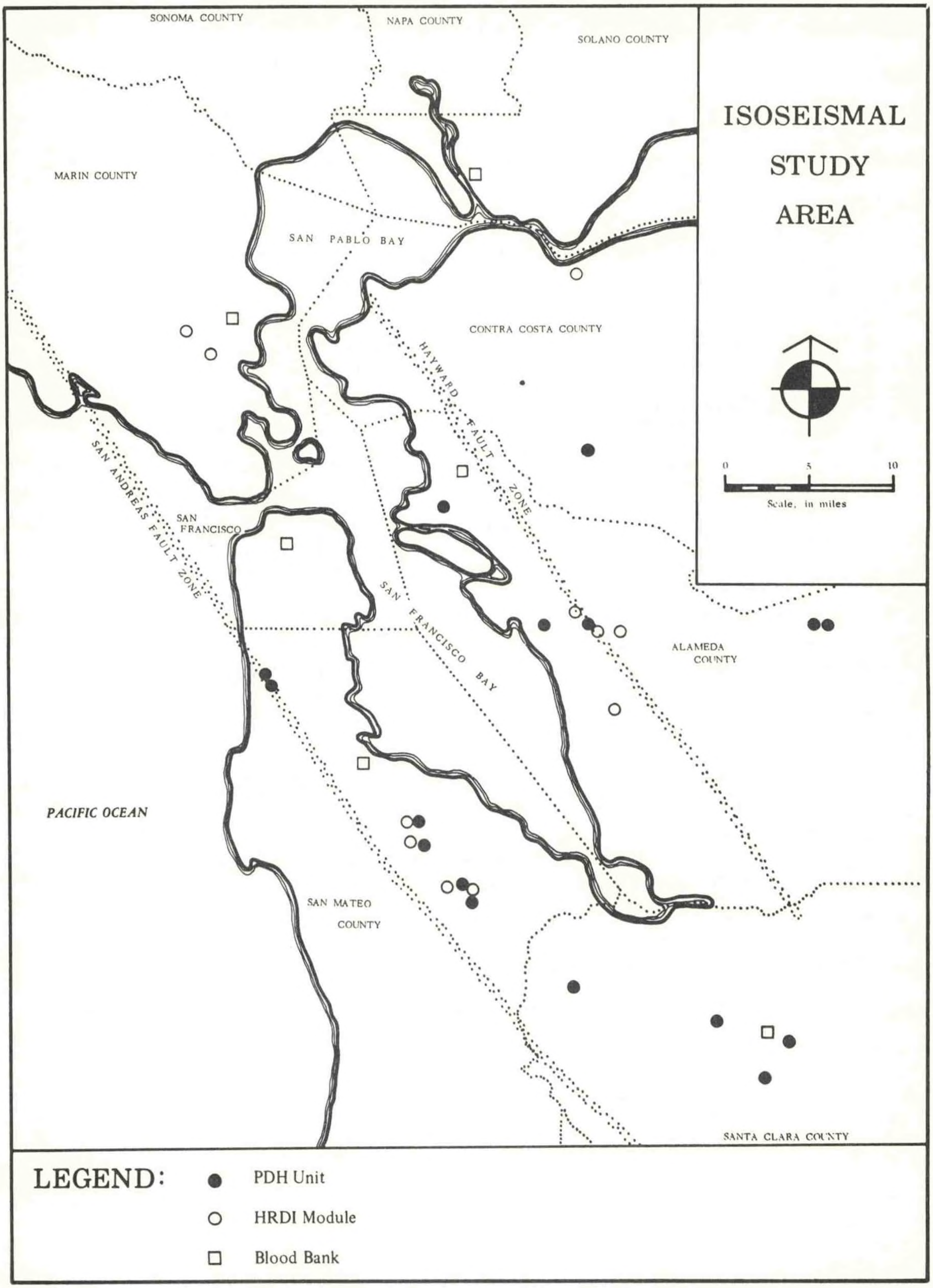


FIGURE 9. PDH Units, HRID Modules, and blood banks. Locations are approximate with respect to fault zones; see text.

blood banks in the subject area were also generous with their time and information.

Direct and individual field inspection was made of each of the seven (7) blood banks located in the study area. Each bank was individually reviewed for the following information:

Equipment & supplies	Capacity in blood units
Storage methods used	Construction type
Year built	Size of building
Foundation type	Type of lateral bracing
Number of stories	Accessibility for Mobile Units
Cost of building	Emergency (auxiliary) generators
Refrigeration capability	Emergency plans & systems

Rosters of the blood banks and drawing stations located in the study area were made available through publications of the American Association of Blood Banks (AABB) and the offices of the American Red Cross in San Francisco.

Representative examples of individual blood bank capabilities according to the standards used under the AABB disaster plan were reviewed for pertinent data. Accessibility patterns of circulation for the mobile units were carefully diagramed and documented. Representative inventory lists of non-expendable equipment, surplus supplies and critical apparatus were reviewed and noted for relevancy to the study.

All blood banks have emergency generators for supplying electric power which is vital to keep the refrigeration units in operation, thereby preserving blood supply in storage in the event of normal electric power failure. Additionally, the mobile units can be used for refrigerated storage for substantial quantities of blood units (750 blood units for a large mobile unit and 369 blood units for a small mobile unit).

ANALYSIS

All buildings were constructed in recent years, and therefore were probably designed to be earthquake resistive in keeping with the then prevailing building code requirements. While these code requirements have changed and construction techniques have improved, it is probable that these structures reasonably conform to today's practices. The exception is a wood frame structure which appears to be inherently earthquake resistive. All blood banks were field inspected, with several of them inspected by more than one person.

On a statistical basis, it is probable that none of the structure will collapse in the greatest postulated earthquake. However, substantial building damage will likely occur to some of them, requiring at least temporary closure until inspected and possibly braced. Damage to unanchored equipment on tables and shelves will be substantial where intensities are high since the equipment will fall to the floor, and in many cases it will become inoperable. The stored blood in plastic containers will fall from shelves and some loss is inevitable.

The building analysis was derived from information compiled specifically for this study, plus proprietary information from insurance sources, plus the consultant's personal knowledge on some of the specific structures. The degree of life hazard and property damage was determined as a function of the isoseismal maps in keeping with the known earthquake resistance of each class of structural system.

Loss of refrigerant due to the loss of electric power from regular sources as well as from standby generating equipment failure is to be expected in at least several instances in the largest postulated shocks. Experience in the 1971 San Fernando earthquake and in the 1964 Alaskan earthquake show that standby power equipment may be knocked off its anchored mountings or other failures may occur, such as loss of fuel due to broken fuel lines. In these cases, the mobile units must be used to the limits of their capacities.

In order to obtain a measure of demands made on blood banks immediately after the occurrence of a natural disaster, a statistical review of blood bank data in Los Angeles and Orange Counties was conducted by the authors on the 1971 San Fernando earthquake. The American Red Cross supplies over 90% of blood units to the two counties. Interestingly enough, there was no noticeable increase in demand on American Red Cross inventory for the two days following the earthquake. In fact, in the case of the San Fernando earthquake, usage of blood units was down as there was an apparent lessening in the demand due to the reduced scheduling of major surgery in the larger hospitals located in the region.

Summary of Postulated Earthquakes

San Andreas Fault, Magnitude 8.3

In the event of a magnitude 8.3 earthquake on the San Andreas fault, it is reasonable to expect two blood banks being out of service for not less than 2 or 3 days due to real or apparent structural damage plus loss of equipment necessary to adequately function. For longer periods of time, it is assumed that alternate facilities will become operational. For planning purposes, these out of service facilities should be the Irwin Memorial Blood Bank in San Francisco and the Peninsula Memorial Blood Bank in Burlingame. With these two out of operation, normal blood bank facilities will cease on the San Francisco Peninsula during the crucial days immediately following the earthquake. It should be pointed out that the foregoing is not probable, but sufficiently possible that planning should be done on this basis.

The 5 other blood banks will probably remain in servicable condition, although damage will be extensive in the form of plaster cracks. Additionally, substantial amounts of vital equipment will fall to the floor (and thereby be damaged). Standby power will be out in at least one of these remaining 5 facilities. Shut-down time should be in terms of hours rather than days, with the time probably being in terms of clean-up time and brief inspection of the building for structural safety.

For planning purposes, it is reasonable to expect the total loss of available blood supplies at Irwin Blood Bank and in the Peninsula Memorial Blood Bank, except for the blood units stored in the refrigerated mobile units. Depending upon the time of day and the location of the mobile units, it may be possible to safely transfer blood units from the buildings to the mobile units, but this should not be counted on. It is reasonable to expect that 20% of the remaining stock of blood supplies in the remaining 5 blood banks will spoil due to falling from shocks, loss of refrigerant, or from other earthquake effects.

It is expected that casualties be minimal, and sufficient personnel will remain to fulfill the functions of the facility to the extent that the facility remains in service. Dollar losses to buildings (excluding equipment) is estimated at $300,000.

San Andreas Fault, Magnitude 7

The damage from a magnitude 7.0 shock will be substantially scaled down from that of a magnitude 8.3 shock. For planning purposes, one blood bank will be considered out of operation; the Peninsula Memorial in Burlingame which is closest to the San Andreas fault is a reasonable choice for the one being out of service. It is anticipated that all of the other 6 facilities will remain operational, although half may be shut down for hours while structural inspections are made and clean-up is in progress.

Except for the probable total loss of the blood units at the Peninsula Memorial facility, overall loss of blood stocks should not exceed 5% of the total available. No life loss in the buildings is expected. Dollar losses to buildings (excluding equipment) is estimated at $150,000.

San Andreas Fault, Magnitude 6

In recent years, it has become apparent that the intensity of shaking in the epicentral region of a moderate earthquake may not be very much less than that experienced in a great earthquake, except that the duration of shaking may be longer in a great earthquake, and the size of the heaviest shaken area will be larger in a great shock.

For the case in point, a magnitude 6.0 earthquake centered on the San Andreas fault west of the Peninsula Memorial Blood Bank in Burlingame will cause damage to this facility similar to that of a magnitude 7.0 shock. The Peninsula Memorial Blood Bank is expected to be out of service. Elsewhere, however, building damage will be less and of little concern for this study. Loss of blood stocks will be limited to that at the Peninsula Memorial plus 5% of that at Irwin Memorial and Four County Red Cross.

Hayward Fault, Magnitudes 8.3, 7 and 6

The geographic distribution of blood banks in the heaviest shaken areas is such that the damage patterns resulting from earthquakes on the San Andreas fault will be nearly "opposite hand" to those from same magnitude shocks on the Hayward fault. The Alameda-Contra Costa Blood Bank can be considered to be the counterpart of Peninsula Memorial Blood Bank for damage planning purposes. The Marin Blood Center can be considered as the counterpart of the Irwin Memorial facility. The damage pattern to the Four County Red Cross, however, is expected to be heavier for earthquakes originating on the Hayward fault than those originating on the San Andreas fault.

Overall building damage, total blood unit loss, and overall loss of capacity to serve public needs will be somewhat greater for earthquakes on the Hayward fault than for comparable shocks on the San Andreas fault.

Hospital Reserve Disaster Inventory (HRDI) Modules

In addition to the Packaged Disaster Hospital (PDH) units provided by State and Federal Government agencies, other medical supplies in module form known as Hospital Reserve Disaster Inventory Modules (HRDI) have been pre-positioned and stockpiled in existing hospital buildings. The concept of the HRDI Module is based on a 30-days' supply of emergency medical resources for each bed unit, i.e. a 50-bed HRDI Module represents 1500 patient days of care. Since some of the medical supplies stockpiled in an HRDI Module have an expiration date limitation, they must be periodically inspected and cycled.

DATA COLLECTION

Information and specific material regarding inventory on HRDI Modules were received from the Division of Emergency Health Services, DHEW (Region IX, San Francisco) and from the Bureau of Emergency Medical Services (Department of Public Health, State of California).

As these HRDI Modules are located in hospital buildings which were previously field inspected, it was not necessary to conduct further building inspections. However, field inspections of two representative HRDI Modules were conducted in order to document storage methods.

The 15 HRDI Modules in the 9 county study area are listed in Table 29 with a summary of data regarding the bed capacities of each. Figure 9 shows their geographic distribution. It is important to notice that no HRDI Modules have been pre-positioned in San Francisco and Solano Counties.

TABLE 29

INVENTORY OF HRDI MODULES

County	HRDI Module No.	HRDI Module Total Bed Cap.
Alameda	4	450
Contra Costa	2	500
Marin	2	200
Napa	1	150
San Francisco	0	0
San Mateo	4	400
Santa Clara	1	100
Solano	0	0
Sonoma	1	50
Totals	15	1,850

Sources:

Division of Emergency Health Services, DHEW (Region IX, San Francisco).

Bureau of Emergency Medical Services, Department of Public Health, State of California, Berkeley.

ANALYSIS

The damage and other problems at the hospitals which house the Hospital Reserve Disaster Inventory Modules (HRDI) are discussed in the section of this report on "Hospitals." It is a high probability that most hospitals in the heaviest shaken areas of great earthquakes will function at a low capacity, and not at all in some cases.

Information developed after the 1971 San Fernando earthquake indicates that one HRDI Module was used following the shock. Tetanus toxoid, flashlight batteries and alcohol were the only supplies used. Although all of the supplies (100%) were reuseable following the earthquake, virtually all supplies were displaced from the original locations and generally all supplies were thrown off their storage shelves by the main shock.

The modules are packaged for shipping and long term storage, and the damage from falling off the shelves will be within reasonable limits. However, field inspections showed that these modules were often stored in out-of-the-way places; the day-to-day supplies are normally placed on the easily accessible shelving and other locations.

The Fairmont Hospital in San Leandro is on the Hayward fault, and the HRDI Modules located there will be needed at this hospital in any major shock on the Hayward fault. The merits of placing the modules right in the Hayward fault zone, and not near thereto, is not part of this study.

San Andreas and Hayward Faults--
Expected Damage Patterns

Table 30 gives the reasonable upper limit for damage or other use impairment to HRDI Modules. The effects of landslide as well as faulting are included in the analyses. Building collapse or damage to the point where HRDI Modules cannot be extracted from a structure is not expected to be the usual case, and this is reflected in the tabulated data. (The new multistory Olive View Hospital in San Fernando may be cited as a case in point; the 1971 earthquake damage rendered the hospital useless, but if the HRDI Modules had been in it, it is quite probable that the units would have been saved.)

The geographic distribution of the HRDI Modules has a significant effect on the values given in Table 30. For one example, the two sites for modules in Contra Costa County are located in the eastern portion of the county, away from the Hayward and San Andreas faults. On the other hand, the 4 sites for HRDI Modules in Alameda County are on or adjacent to the Hayward fault.

It is quite evident from Table 30 that earthquakes on the Hayward fault are more destructive to HRDI Modules than will be similar magnitude shocks on the San Andreas fault.

TABLE 30

HOSPITAL RESERVE DISASTER INVENTORY MODULES

County	Current Inventory (Beds)	Beds Available After Earthquake					
		San Andreas Fault			Hayward Fault		
		8.3	7	6	8.3	7	6
Alameda	450	400	450	450	50	50	100
Contra Costa	500	500	500	500	450	500	500
Napa	150	150	150	150	100	150	150
San Mateo	400	200	250	300	350	400	400
Santa Clara	100	50	60	75	50	60	75
Sonoma	50	50	50	50	50	50	50
Marin	200	150	175	200	100	150	200
San Francisco	0	0	0	0	0	0	0
Solano	0	0	0	0	0	0	0
Totals	1,850	1,500	1,635	1,725	1,150	1,350	1,475

Packaged Disaster Hospitals (PDH)

Medical supplies and equipment have been stockpiled and pre-positioned by State and Federal Government agencies to help communities meet their responsibilities in providing medical care during emergency situations following disasters. There are two types of these supplies: Austere Medical Stockpiles for community shelter needs and the Packaged Disaster Hospital Unit (PDH). The PDH Units (formerly called Civil Defense Emergency Hospitals) were pre-positioned several years ago, some placed as far back as 1960. They contain emergency supplies and equipment necessary to set up a 200-bed temporary disaster hospital in a school, or buildings adjacent to hospitals, or hotels or other suitable structures. Each is equipped with enough supplies to keep it in operation for a 30-day period.

DATA COLLECTION

The pre-packaged PDH Units, with a 30-day operational capability, contain approximately 660 boxes, weigh about 45,000 pounds, and require approximately 7500 cubic feet (1200 square feet) of general storage space: 50 cubic feet flammable storage, 1050 cubic feet heated storage, and 6400 cubic feet of general storage. These are large units and require sizable moving vans or trucks to move them along the highway. It is estimated that it will take up to six hours to load, transport, uncrate, and setup one PDH Unit. Further information may be obtained from Establishing the Package Disaster Hospital, Health Mobilization Series, Public Health Service Publication No. 1071-F-1, Revised Dec. 1964.

Other data sources were the Division of Emergency Health Services, DHEW (Region IX, in San Francisco) and the Department of Public Health, Bureau of Emergency Medical Services of the State of California.

One of the problems connected with a PDH unit is that it may not reach its destination due to damaged freeways, overpasses, or local streets which may also be blocked by fallen debris, building collapse, or other causes resulting from an earthquake. Consequently in collecting data it was necessary to determine and diagram accessibility patterns of circulation to and from the building in which the unit was housed. This was done during a field inspection of each PDH unit on the master list. Additionally, the building in which the PDH Unit was housed was field inspected for the following information:

Construction type	Date of last equipment check
Number of stories	Type of facility
Year built	Location & types of exits
Type of lateral bracing	Foundation type
Identification number	Geologic hazards
Storage methods	unusual characteristics

The PDH Units in the study area are listed in Table 31. In 7 cases, two PDH Units are being stored in the same building, while the remaining 21 cases have one unit per building. The locations of the 12 PDH Units within the isoseismal study area are shown in Figure 9. (Note: three units were in the process of being completely removed or transferred to another site at the time that this report was being prepared and are therefore not included.) Additional back-up data to Table 31 include building outline diagrams obtained from field inspection, from drawings, or from other reliable sources. Except for the PDH Unit stored by the State in the City of Vacaville, all of the other sites and buildings housing the units were field inspected, with some inspected by more than one person at different periods. As shown in Table 31, the 35 PDH Units which are located in the study area have a total bed capacity of 7,000 beds. It should be noted that no PDH Units have been pre-positioned in two counties: Marin and San Francisco.

All the PDH Units now pre-positioned at the various sites surveyed in the study area are not identical. Differences existed depending on the year in which the unit was packaged. The actual contents which were packaged in the many and various boxes and crates comprising the PDH Unit were not inspected as that

TABLE 31

PACKAGE DISASTER HOSPITAL (PDH) UNITS

County	Total Number of Units		Total Bed
	State Units	Federal Units	Capacity
Alameda	0	6	1,200
Contra Costa	0	2	400
Marin	0	0	0
Napa	2	6	1,600
San Francisco	0	0.	0
San Mateo	1	5	1,200
Santa Clara	1	5	1,200
Solano	1	0	200
Sonoma	0	6	1,200
Totals	5	30	7,000

Sources:

Division of Emergency Health Services, DHEW (Region IX, San Francisco.)

Bureau of Emergency Medical Services, Department of Public Health, State of California, Berkeley.

was beyond the scope of this study.

ANALYSIS

For evaluation purposes, data was collected on the use of PDH Units after the 1971 San Fernando earthquake. One known unit was used. Originally located in the Corporation Yard of the City of San Fernando, it was moved to the YWCA facility in San Fernando where 285 patients were treated in the two days following the earthquake.

The geographic distribution of these packaged hospitals (Figure 9) is mostly good from an earthquake standpoint in that many locations are out of the highly built-up areas, reducing problems from streets being blocked-off by collapsed buildings and problems from fire.

Of the 26 field inspected locations for which construction information on the building housing the PDH Units was available, 9 structures are of wood frame construction or of all steel construction; these types are inherently highly earthquake resistant. Not only is the collapse possibility remote, but if it did occur, the damage to the packaged hospital materials within the building is quite unlikely. In other words, these units will be available after an earthquake as long as they are not in a landslide area or subject to fire following earthquake.

Six structures were constructed prior to the 1930's, and therefore they include minimal earthquake design if any. Fortunately, several are of wood frame construction, and these are not hazardous to the packaged hospital units within them. Three structures, however, apparently are potential collapse hazards even in moderate local shocks:

Veterans Hospital, Livermore, reportedly built in 1924.

College of Notre Dame, Belmont, reportedly built in 1865.

Warehouse, San Jose, reportedly built in 1900.

The Veterans Hospital in Livermore appears to have a reinforced concrete frame with tile panel walls, apparently of similar construction to that found in the collapsed Veterans Administration Hospital in the 1971 San Fernando shock. The other two are non-reinforced brick; this construction type performs poorly in even a moderate shock.*

Several special problems exist. The PDH Unit at the Fairmont Hospital in Oakland is located in the Hayward fault zone. Ground ruptures are to be expected through the hospital site in even moderate earthquakes on the Hayward fault and, while not necessarily going through the building actually housing the PDH Unit, the general chaos at this location will not be helpful. (However, it may be argued that the PDH is located where undoubtedly the need will be great, and the propriety of this site selection is left to others.) The Fairmont Hospital also will have an access problem in that freeway structures will probably be down, thereby isolating the hospital from its surrounding community except for usage of obscure alternate routes.

Access and egress can be problems at two sites due to landsliding; Canyon Hospital in San Mateo County and Guadelupe College in Santa Clara County are two cases in point. Landsliding, of course, is greatly influenced by the season of the year, and is much more likely to occur during the winter and spring months, which comprise the rainy season, than at other times.

In the discussion that follows on the various postulated earthquakes, access to and the transporting of PDH Units are considered paramount. For example, a wood frame structure may incur damage to the extent that it becomes non-functional (as sliding off its foundation), but the PDH Unit within it still could be readily recovered, salvaged and used. The collapse of a brick wall, however, could destroy the unit beyond use. Roads must be open. Repeating, the following summary is based on the capability of retrieving the unit from its building and additionally being able to transport it to a chosen site.

Summary of Postulated Earthquakes

San Andreas Fault--Expected Damage Pattern

For planning purposes, in the event of a magnitude 8.3 shock, three units will be considered destroyed as indicated in Table 32. Two most likely sites for this problem are the College of Notre Dame in San Mateo County and the San Jose

*Note added in press: The bed capacity at the Livermore facility has been recently changed from 350 to 190 to reduce the earthquake hazard.

TABLE 32

DAMAGE SUMMARY TO PACKAGE DISASTER HOSPITALS

Postulated Earthquake	Inoperative Units
San Andreas fault:	
M = 8.3	3*
M = 7	2
M = 6	1
Hayward fault	
M = 8.3	4**
M = 7	3
M = 6	2

*College of Notre Dame (Belmont), warehouse (San Jose), plus one unspecified location on the San Francisco peninsula.

**Fairmont Hospital (Oakland), warehouse (San Jose), Veterans Administration Hospital (Livermore), plus one unspecified location in the Oakland area of Alameda County.

warehouse location in Santa Clara County. Four other locations on the San Francisco peninsula will have substantial building damage, some to the extent that the structures will become non-functional, but it is reasonable to expect that no more than one of these will be so badly damaged as to preclude the removal of the PDH Units.

For planning purposes in the event of a magnitude 7 or 6 shock, the damage has been scaled down as indicated in Table 32.

Hayward Fault--Expected Damage Pattern

For planning purposes, in the event of a magnitude 8.3 shock, four units will be considered destroyed as indicated in Table 32, with the most likely locations being the Fairmont Hospital, and the Veterans Administration Hospital (Livermore) in Alameda County, San Jose warehouse in Santa Clara County, plus one unspecified location in the Oakland area of Alameda County. A total of 12 buildings can reasonably be expected to have significant structural damage and many of these will become non-functional, but the PDH Units will be available for transfer to another site.

For planning purposes in the event of a magnitude 7 or 6 shake, the damage has been scaled down as indicated in Table 32.

Clinical Laboratories

DATA COLLECTION

As all clinical laboratories are licensed by the State of California for certification purposes, the main source of data was the Laboratory Field Services, Department of Public Health, State of California in Berkeley. Additional information was also obtained through the help of the Disaster Medical Care Planning Division of the Alameda-Contra Costa Medical Association.

A physical "on site" inspection was made of all the clinical laboratories and related facilities in the 3 counties of Alameda, San Francisco, and Santa Clara. This sampling of laboratories resulted in a comparative study of practices in the most heavily populated areas (San Francisco) with those having lesser population concentrations. The field inspections obtained the following information on the buildings in which the clinical laboratories are located:

Location	Number of stories
Year built	Area (sq. ft.)
Type of construction	Accessibility
Identification number	

The field survey of Alameda, San Francisco, and Santa Clara covered 63% of all the laboratories in the 9 counties of the San Francisco Bay Area. The number and distribution by county of the laboratories are given in Table 33 and Figure 10. Tables 34 and 35 give a summary of data on construction types and construction dates of the clinical laboratories included in the 3 county survey.

TABLE 33

CLINICAL LABORATORIES

County	Total Number	In Hospital	Non-Hospital
Alameda	64	28	36
Contra Costa	35	11	24
Marin	21	7	14
Napa	7	3	4
San Francisco	77	23	54
San Mateo	34	8	26
Santa Clara	68	18	50
Solano	6	6	0
Sonoma	21	11	10
Totals	333	115	218

Source: Laboratory Field Services, Department of Public Health, State of California.

TABLE 34

CLINICAL LABORATORIES BY CONSTRUCTION TYPE

County	Type of Construction						Total
	Wood Frame	Brick	Concrete	Steel	Mixed	Stone	
Alameda	17	6	29	1	11	0	64
	25%	9%	47%	2%	17%	0%	100%
San Francisco	14	7	41	3	6	6	77
	18%	9%	53%	5%	8%	8%	100%
Santa Clara	28	6	19	11	4	0	68
	41%	9%	28%	16%	6%	0%	100%

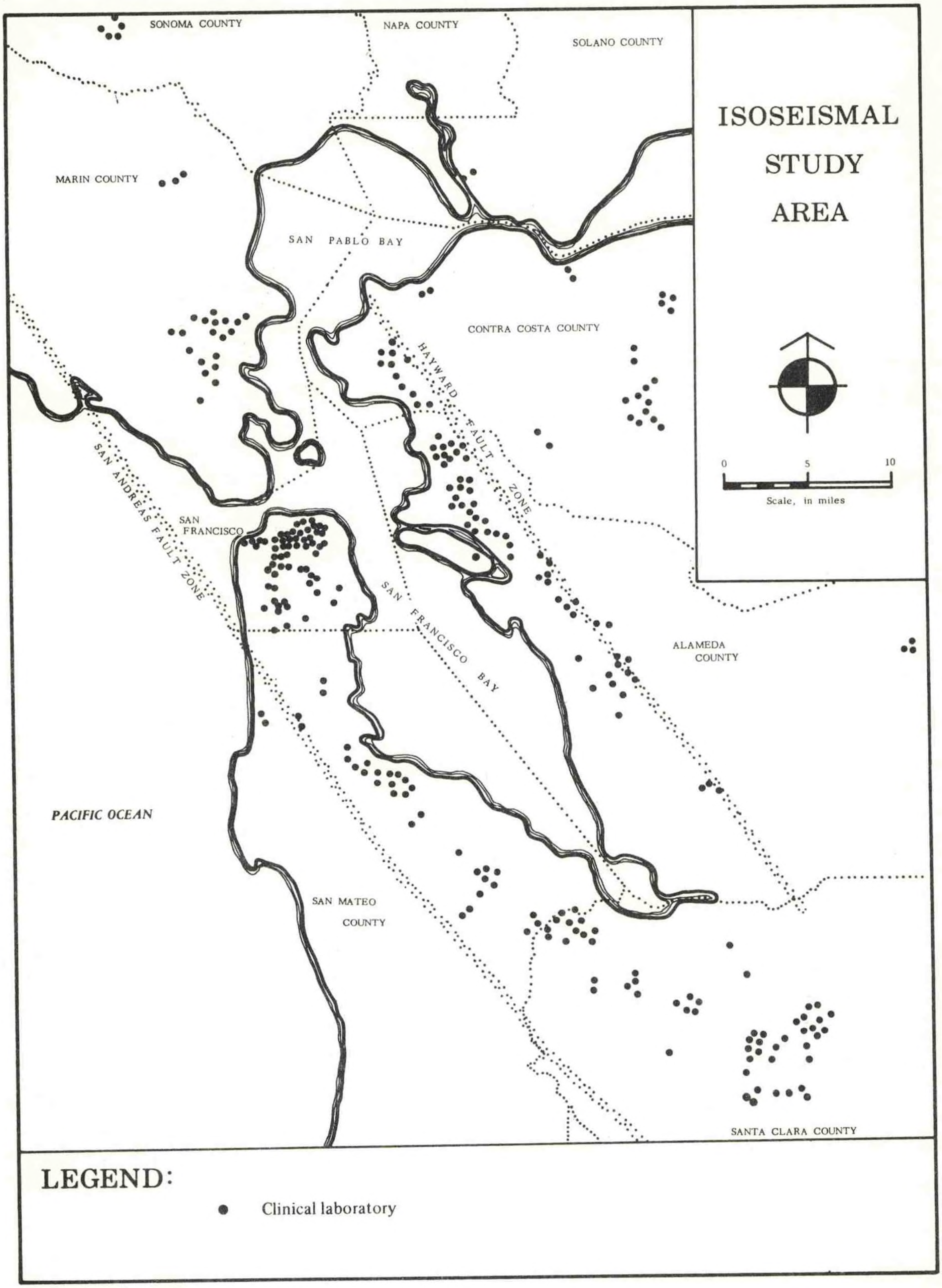


FIGURE 10. Clinical laboratories. Locations are approximate with respect to fault zones.

ANALYSIS

For the analysis purposes of this study, clinical laboratories are divided into those which are located in hospitals and those which are located elsewhere serving the adjacent neighborhood through doctors' offices located in the area.

The problems of a clinical laboratory located in a hospital will be greatly affected by the overall earthquake performance of that hospital in addition to whatever happens within the laboratory. For example, a structurally damaged hospital requiring evacuation will have a non-functioning clinical laboratory should one exist within the structure. Thus, the expected performance of the 115 clinical laboratories located in hospitals must be largely based on the discussion of "Hospitals" found elsewhere in this report except that the discussion on damage to equipment in the cases of building survival applies in both cases.

All buildings which contain clinical laboratories and which remain in safe functioning condition will have certain common problems to the laboratory equipment and supplies. In Intensity IX areas, microscopes and other equipment will fall from benches, chemicals will be thrown to the floor, and extensive laboratory glassware damage is to be expected. Electric power will be generally out in Intensity IX areas, thereby leading to the spoilage of refrigerated stocks if power remains out for any lengthy period of time. Lower earthquake intensities will cause fewer problems, but the loss to equipment and stock will remain a substantial problem even if power supplies do not.

The ability of clinical laboratories to function in areas experiencing intensities of IX or greater is serious. However, as long as some microscopes remain in a functioning condition, considerable vital work can continue, but at a significantly reduced pace and scale. For a large clinical laboratory with substantial amounts of labor saving devices, an Intensity IX event could reasonably result in as much as an 80% loss in output effectiveness even though the building remained sound and power was not lost. Smaller and less automated laboratories would not experience this efficiency loss due to the often more simplistic operations, but this will be partially offset by the lack of usable standby power.

TABLE 35

CLINICAL LABORATORIES BY YEAR OF CONSTRUCTION

County	Year of Construction Pre-1933	1933-50	1950-68	Post 1968	Total Buildings
Alameda	13 20%	1 2%	44 69%	6 9%	64 100%
San Francisco	35 45%	10 13%	25 34%	7 9%	77 100%
Santa Clara	5 7%	5 7%	51 76%	7 10%	68 100%

Note: In the case of several growth periods the date of the oldest still in use is listed.

San Andreas and Hayward Faults--
Expected Damage Patterns

Figure 10 shows the geographic distribution of clinical laboratories, including those which were field surveyed in order to obtain construction information and hazard data. Clearly from Figure 10, a major earthquake on the Hayward fault as compared to an equal magnitude shock on the San Andreas fault will result in more high intensity locations near the Hayward fault than near the San Andreas fault. An examination of the construction characteristics of the sampled laboratories shows no major geographical differences in expected building performance insofar as non-hospital locations are concerned. Exception is San Francisco where there are the factors of high-rise and congested areas; these two factors will slow the re-opening of laboratories, but not necessarily affect the damage therein.

Table 36 is a summary of expected damage resulting from the postulated earthquakes. It is evident that the Hayward fault poses the more significant threat than does the San Andreas fault for similar magnitude earthquakes. The percentages include the effects of building damage to non-hospital structures, including partial or total collapses in rare cases.

TABLE 36

FUNCTIONAL LOSS TO CLINICAL LABORATORIES
Non-Hospital Locations

		*Functional Loss, in Percent				
Fault	Earthquake Magnitude	San Francisco San Mateo	Santa Clara	Contra Costa Alameda	Marin	Napa Solano Sonoma
San Andreas	8.3	60%	40%	30%	40%	10%
	7	30%	20%	15%	20%	5%
	6	15%	5%	-	-	-
Hayward	8.3	30%	50%	70%	50%	30%
	7	15%	30%	40%	25%	15%
	6	-	15%	20%	5%	-

*Functional loss due to equipment and stock damage plus building damage, if any. (Equipment and stock losses will be somewhat less than the tabled values; for the purposes of this report, no differentiation will be made.)

Ambulance Services

In general, ambulance services are divided into two groups: those serving the public and those identified with "special services" provided by the American Red Cross, national guard units, military units, national park services, state hospital units, state colleges and universities, and private corporations.

In surface equipment (or ground equipment) used for ambulance services, the term "ambulance" includes any motor vehicle constructed, arranged and operated for the purpose of transporting ill, injured, infirm, or otherwise incapacitated persons. If the vehicle functions as an ambulance and is used to respond to emergency situations, the operator of the service must obtain an ambulance license and vehicle identification card. In accordance with the California Vehicle Code, the California State Highway Patrol is directed to adopt and enforce regulations governing the operation and equipment of all ambulances used for emergency services.

In air equipment used for ambulance services, the term "ambulance" applies to any aircraft, fixed-wing or helicopter, used to transport patients for immediate medical attention or for emergency evacuation purposes. Most of the aircraft carry an attendant and first aid equipment. Many of the operators and their aircraft are not exclusively involved in air ambulance work.

DATA COLLECTION

Identification and location of the ambulance services have been made through the use of the publication "Ambulance Survey Final Report" issued in 1969 by the Department of Public Health, State of California, in collaboration with the Business and Transportation Agency. Since the above mentioned report does not include the number of ambulances operated by each company, additional data was collected from the current roster of ambulance services compiled by the California State Highway Patrol. In the cases where data conflicted, the California State Highway Patrol records were accepted as final since they are maintained on a more current basis.

There are two important conditions which govern the serviceability of ambulance units during natural disasters. The first is the method used in parking the vehicle when it is not in use. The second is its vulnerability in the event of building collapse (either the building housing the vehicle or one adjacent to it). Accordingly the field inspection conducted of all the ambulance services in the three counties (San Francisco, Alameda, and Santa Clara) differs from those conducted for other building categories in that diverse sets of data had to be collected. The building in which the ambulance is garaged (or the systems used in parking the vehicles) was field inspected for the following information:

Number of vehicles	Type of construction of garage
Type of parking facilities	Age of building (garage)
Vehicle accessibility	Building materials (garage)
Type of garage structure	Vulnerability of adjacent bldgs.
Type of service	Number of stories (garage)
Number of vehicle exits	Location of service

Data collection concerned itself solely with general ambulance groups serving the public and those identified with the "special services" provided by specific and/or particular organizations such as the American Red Cross, military units, private corporations, colleges, etc. It did not include "rescue" services as operated by the fire department. Nor does it include data on "medicabs" or similar vehicular services designed for the "non-emergency" transportation of the infirm or handicapped. No "disaster" plans or emergency hospital services were included as part of this section of the report.

Air ambulance units were not field inspected. The majority of the air ambulance services are located at the following airfields in the study area: Oakland Airport, Buchanan Field, San Francisco Airport, Hayward Airport, Palo Alto Airport, and San Carlos Airport.

With respect to surface transport, the number and distribution of public service ambulance groups as well as the special service ambulance groups are given in Tables 37 and Figure 11. Field inspections of facilities in Alameda, San Francisco, Santa Clara counties obtained data on construction types, construction dates and methods of parking vehicles as shown in Tables 38, 39, and 40.

In the 1971 San Fernando shock, the Los Angeles City Fire Department and the Los Angeles County Fire Department used helicopter air ambulances to carry between 16 and 30 patients to emergency stations. In addition, the Los Angeles County Fire Department transported 41 physicians and official observers during the two days following the earthquake. Other air ambulance services were available for the emergency but were not used except for those of the Marine Corps Air Station in southern California which were used to transport observers and photographers.

ANALYSIS

Fortunately, data showed no significant variations in building age and building construction types between the sampled counties, and therefore the study area can be considered homogeneous for analysis purposes.

With respect to ambulance companies (and not to the number of vehicles), 35% of the companies park their vehicles outside of buildings. For these cases, the problem areas (or service impairments) are principally typified by building debris on the streets, landslides on roadway, and other roadway obstructions, with only rare direct damage to ambulances from buildings located at or near ambulance parking. Based on the field inspections, the 35% of the companies which park their vehicles out-of-doors will experience comparatively minimal service impairments.

The other 65% of the ambulance companies which park their vehicles indoor face the added problem of building collapse on the ambulances. The detailed survey of Alameda, Santa Clara, and San Francisco counties showed that 25 companies, or 71% of the total parking indoors, were housed in wood frame

TABLE 37

AMBULANCE SERVICE GROUPS

County	Public Groups		Special Service Groups	
	No. of Amb. Services	No. of Vehicles	No. of Amb. Services	No. of Vehicles
Alameda	15	58	8	21
Contra Costa	12	21	7	2
Marin	6	5	4	**
Napa	5	11	3	**
San Francisco	5	28	10	24
San Mateo	5	24	2	**
Santa Clara	13	44	8	12
Solano	9	11	2	**
Sonoma	12	15	3	**
Totals	82	217	47	59

**No available data.

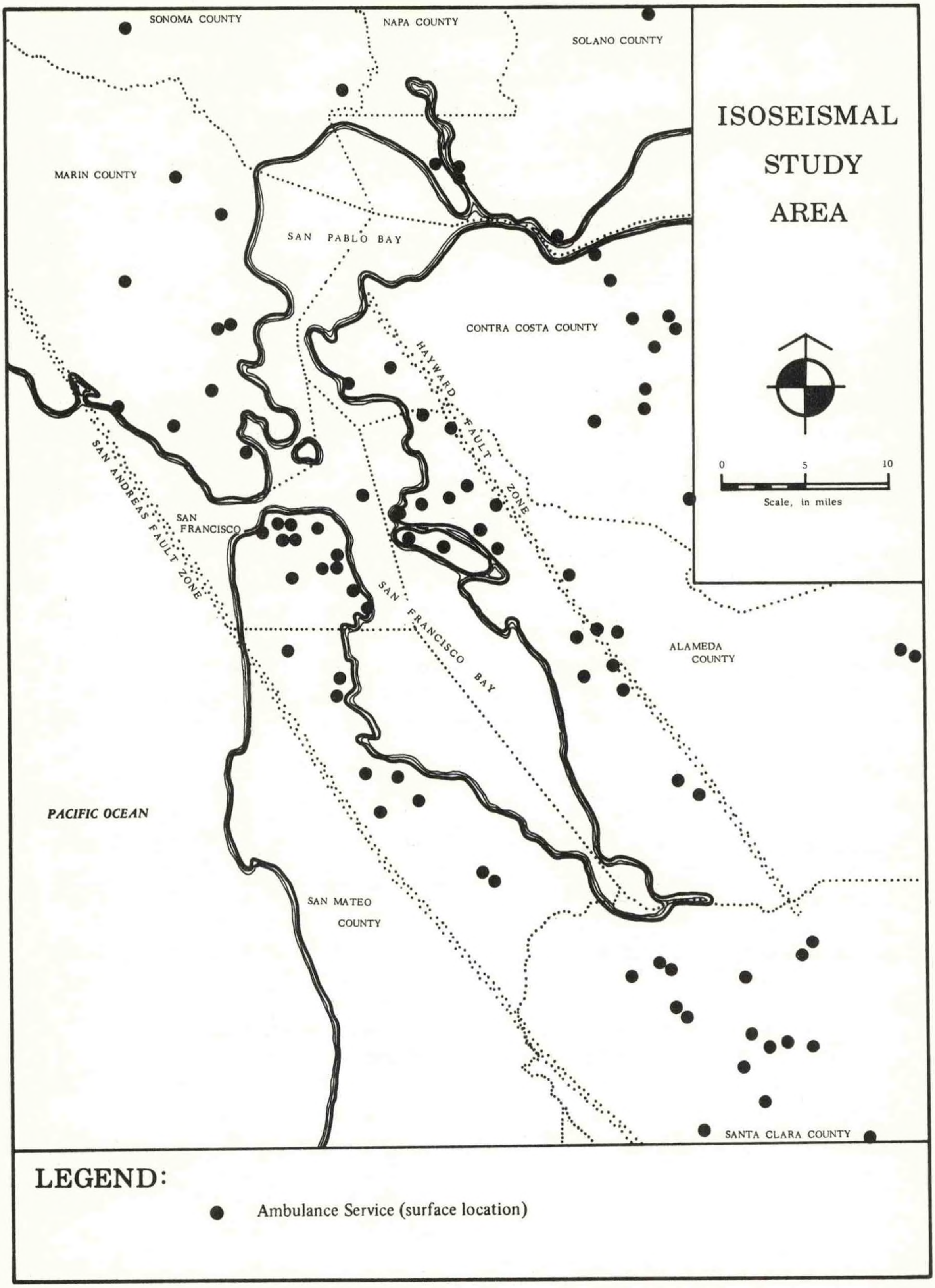


FIGURE 11. Ambulance services. Locations are <u>approximate</u> with respect to fault zones.

TABLE 38

CONSTRUCTION DATE FOR AMBULANCE SHELTER
Alameda, San Francisco, Santa Clara Counties

County	Construction Dates: Pre-1933 No.	%	1934-50 No.	%	1951-70 No.	%	Totals No.	%
Alameda								
Wood	2	12. 5	5	31. 3	2	12. 5	9	56. 3
Steel	0	00. 0	2	12. 5	1	6. 25	3	18. 7
Brick	1	6. 25	0	00. 0	1	6. 25	2	12. 5
Block	1	6. 25	0	00. 0	1	6. 25	2	12. 5
Sub-total	4	25. 00	7	43. 80	5	31. 25	16	100. 0
San Francisco								
Wood	2	25. 00	1	12. 5	1	12. 5	4	50. 0
Steel	0	0. 00	0	0. 00	1	12. 5	1	12. 5
Concrete	1	12. 5	1	12. 5	0	0. 00	2	25. 0
Brick	0	0. 00	0	0. 00	1	12. 5	1	12. 5
Sub-total	3	37. 50	2	25. 00	3	37. 50	8	100. 0
Santa Clara								
Wood	1	9. 1	3	27. 3	2	18. 1	6	54. 5
Concrete	0	0. 00	0	0. 00	3	27. 3	3	27. 3
Steel	0	0. 00	1	9. 1	1	9. 1	2	18. 2
Sub-total	1	9. 1	4	36. 4	6	54. 5	11	100. 0
Total all counties	8	22. 9	13	37. 1	14	40. 4	35	100. 0

Figures refer only to those companies which park their vehicles inside a structure.

TABLE 39

AMBULANCE PARKING
Alameda, San Francisco, Santa Clara Counties

	County							
	Alameda		San Francisco		Santa Clara		Totals	
	No.	%	No.	%	No.	%	No.	%
Park outside	7	30. 4	5	38. 5	7	38. 9	19	35. 2
Park inside	16	69. 6	8	61. 5	11	61. 1	35	64. 8

Figures refer to ambulance companies, not to vehicles.

TABLE 40

AMBULANCE HOUSING
Alameda, San Francisco, Santa Clara Counties

	County							
	Alameda		San Francisco		Santa Clara		Totals	
	No.	%	No.	%	No.	%	No.	%
Wood	9	56. 3	4	50. 0	6	54. 6	19	54. 3
Concrete	0	00. 0	2	25. 0	3	27. 3	5	14. 3
Steel	3	18. 7	1	12. 5	2	18. 1	6	17. 1
Brick	2	12. 5	1	12. 5	0	00. 0	3	8. 6
Hollow concrete block	2	12. 5	0	00. 0	0	00. 0	2	5. 7
Totals	16	100. 0	8	100. 0	11	100. 0	35	100. 0

structures or similarly inherently safe structures. The remaining companies are located in concrete or unit masonry structures which usually were constructed in recent years and thereby contained at least some degree of earthquake bracing. While many of these structures may be significantly damaged, it is likely that most of the vehicles can be removed from the building in a functioning condition. Structural collapse on ambulances, such as that which occurred at the Olive View Hospital in 1971, will occur again but the instances will be rare.

San Andreas and Hayward Faults--
Expected Damage Patterns

More ambulance facilities are located near the Hayward fault than the San Andreas fault. On the other hand, building congestion in San Francisco will be an offsetting impairment factor with respect to earthquakes on the San Andreas fault. As a result, the number of ambulance service impairments is expected to be about the same for similar magnitude earthquakes on either fault; of course, the concentration of impairments will be located close to the causative fault in each case.

In summary, the ambulance resources are expected to survive quite well as compared to the hospitals which they commonly serve. Numerically, the anticipated performance in various earthquakes is given in Table 41.

TABLE 41

AMBULANCE SERVICE IMPAIRMENT

Earthquake Magnitude	Ambulances Out of Service: Number of Vehicles	Ambulances Out of Service: Percent of Total
8.3	34	12%
7	6	2%
6	1	-

Note: This table applies to earthquakes on the San Andreas or Hayward faults. The impairments due to San Andreas fault earthquakes will be on the west side of the Bay and the impairments due to Hayward fault earthquakes will be on the east side of the Bay.

Nursing Homes

In terms of medical health facilities, nursing homes as a category include the following types:

Nursing homes
Convalescent hospitals
Retirement homes
Sanitariums
Rehabilitation hospitals

Not included in the nursing home category are the major hospitals and clinical laboratories referred to in other sections of this report. Also not included are day centers, intermediate care facilities, home health agencies, alcoholism hospitals, and long term mental facilities. Nursing homes differ from hospitals in that they do not generally contain all the complete facilities found in a major hospital facility, such as X-ray equipment, operating rooms, clinical laboratories, etc.

DATA COLLECTION

As all nursing homes must apply for certification and a license through the State, the main source of data was the Bureau of Health Facilities Licensing and Certification, Department of Public Health of the State of California. Additional detailed data on specific facilities was received from the administrative staff of various nursing homes in the area.

A three county survey was completed (Alameda, San Francisco, and San Mateo) in order to obtain the following information on the nursing homes:

Location	Year built
Type of facility	Type of construction
Number of stories	Total bed capacity

The summary results of this survey are given in Tables 42 and 43. Figure 12 shows the geographic distribution of all the nursing homes located in the isoseismal study area.

ANALYSIS

Nursing homes and the other similar occupancies discussed in the introductory paragraphs of this section consist of a type of medical resource which has a secondary role in the emergency responses required after a disasterous earthquake. On the other hand, the nursing home occupants do require some type of medical assistance or medically related assistance. Additionally, the patients usually lack the mobility possessed by the general population.

This study on damage to nursing homes has been approached on a more simplistic basis than that for hospitals for several reasons. A total of 84% of the nursing homes in the sampled counties were one story in height; a survey of the other less densely populated counties would probably increase this percentage for the entire nine county study area to about 90%. Since the large majority of the buildings are one story in height, elevator problems, stair damage, and ingress/egress problems will be reduced or eliminated compared to those at large hospitals.

A very large number of the one story nursing homes are of wood frame construction, and this type of construction is inherently earthquake resistive. The one story masonry nursing homes (wood roofs with walls of brick, hollow concrete block, or concrete) are usually of recent construction and, with their customary numerous wood stud partitions, are also not likely to collapse even if heavily damaged. A classic example was the performance of the Foothill Nursing Home which did not collapse in the 1971 San Fernando shock although the faulting went through the premises, and some ground breakage went through the building site itself.

With respect to modern one story nursing homes, the large majority will not have to be evacuated although many will sustain damage which will result in

TABLE 42

NURSING HOMES

County	Number of Facilities	Total Bed Capacity
Alameda	107	5,994
Contra Costa	36	2,707
Marin	14	1,192
Napa	12	717
San Francisco	33	2,286
San Mateo	30	2,421
Santa Clara	56	4,446
Solano	10	840
Sonoma	22	1,532
Total	320	22,135

Source: Department of Public Health, State of California, Bureau of Health Facilities, Licensing & Certification.

TABLE 43

NURSING HOMES, BY STORY HEIGHT

County	Number of Facilities: Story Heights			
	1 Story	2-4 Stories	5-8 Stories	Over 10 Stories
Alameda	102	2	1	2
San Francisco	19	12	2	0
San Mateo	23	7	0	0
Total	144 (84%)	21 (12%)	3 (2%)	2 (2%)

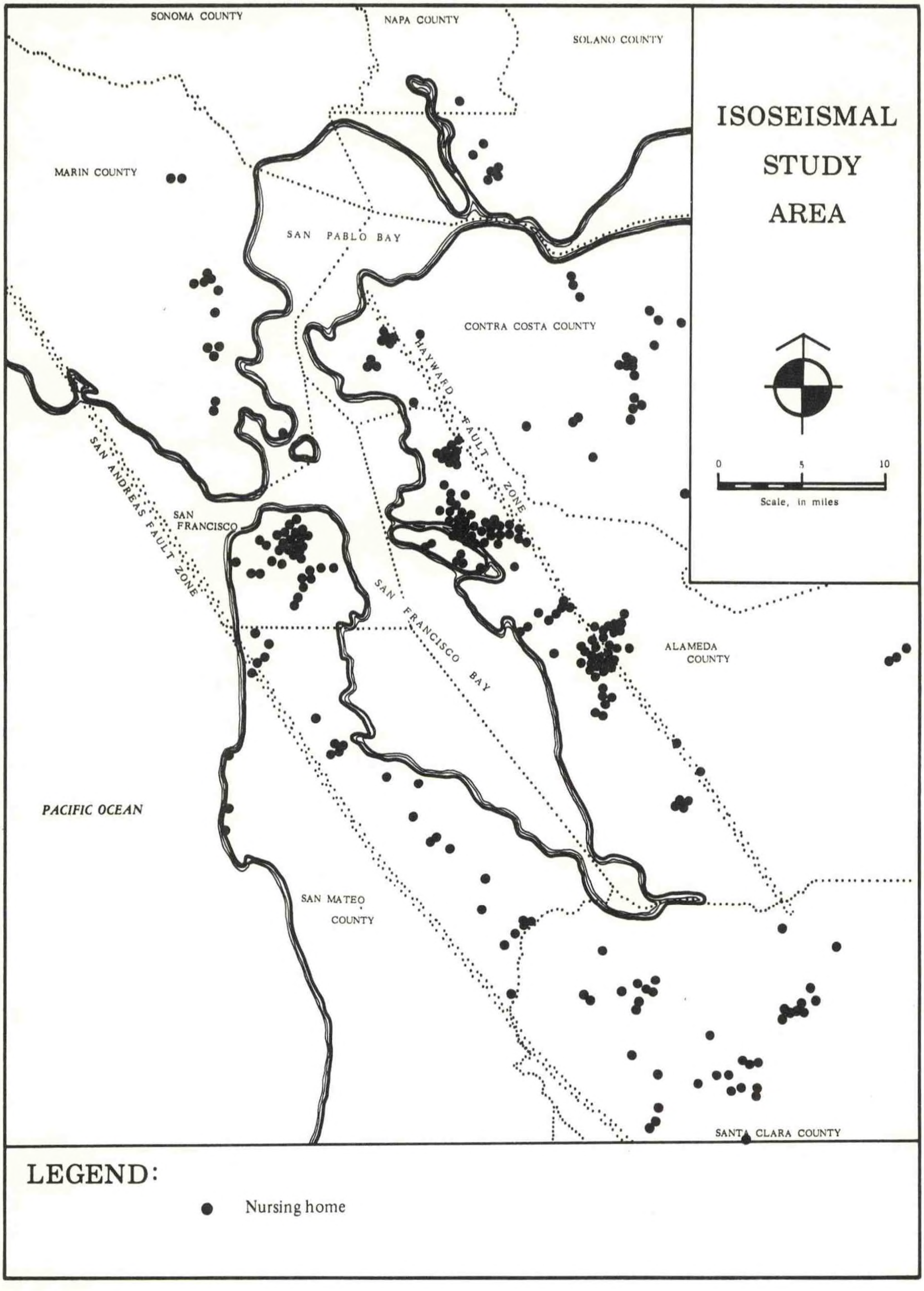


FIGURE 12. Nursing homes. Locations are approximate with respect to fault zones.

reduced functional capacities. This reduction in functional capacities will be due to the loss of utilities (gas, telephone, electricity, water, and sewerage) and due to internal damage in the form of overturned water heaters, supplies on the floor, and the like. In many cases, the decision to remain in operation under difficult circumstances or to transfer the patients elsewhere is expected to be more closely related to the functional impairments and the staffs' abilities to cope with these impairments rather than to structural safety.

The methodology used to evaluate the damage of all types to one story buildings was based on the known damage patterns to wood frame structures and on the known damage patterns to mixed construction (i.e., wood roofs with masonry walls of all types) determined after the 1971 San Fernando shock.

San Andreas and Hayward Faults-- Expected Damage Patterns

The percentage of one story nursing homes to be completely out of service for any reason is given in Table 44. It is evident that earthquakes centered on the Hayward fault are more hazardous than comparable magnitude ones on the San Andreas fault. It is also evident from the figures that a number of nursing homes are very close to the Hayward fault zone, and some of them are in this zone. Patient deaths and injuries, and health manpower losses have not been separately established, but are included in the overall deaths and injury estimates.

For the estimated 10% of nursing homes over 1 story in the entire study area, the losses should be about half way between the values given in Table 44 and those tabled in the section on "Hospitals."

TABLE 44

NURSING HOMES AND RELATED FACILITIES
One story structures which will be structurally unsafe. Functional impairments are not included.

		Unsafe Structures, In Percent, By Counties				
Fault	Earthquake Magnitude	San Francisco San Mateo	Santa Clara	Contra Costa Alameda	Marin	Napa Solano Sonoma
San Andreas	8. 3	15%	10%	2%	2%	-
	7	10%	5%	-	-	-
	6	5%	1%	-	-	-
Hayward	8. 3	2%	15%	20%	10%	2%
	7	2%	10%	15%	5%	-
	6	-	1%	5%	-	-

Section 4: Demands on Medical Resources

Deaths and Injuries, Excluding Dams

The following paragraphs consider only deaths and injuries from sources other than schools, hospitals, and dams, except that Table 50 summarizes all data other than those relating to dams.

Deaths and injuries resulting from the postulated earthquakes in the San Francisco Bay Area will be principally due to the failures of man-made facilities, such as dams and buildings. While earthquake induced landslides may cause life loss during the wet season, there is no possibility of the type of landslide which led to 25,000 to 30,000 deaths after the 1970 Peruvian earthquake. Tsunamis (seismic sea waves) have been a negligible problem in the study area and will probably never be a serious one; in contrast, almost 90% of the deaths in the 1964 Alaskan earthquake were attributed to tsunami effects.

DATA COLLECTION

The Historical Record

Table 2 in Section 2 of this report is a listing of earthquakes in the United States having relevance to this study. Excluded was the 1872 Owens Valley earthquake in which 23 persons were killed in Lone Pine, California, out of a population of 250 to 300; this exclusion was based on non-relevant construction, i.e., adobe and stone houses, usually without any kind of mortar. As has been discussed, foreign earthquakes normally have minimal relevance due to construction or other differences, and were therefore also excluded.

The back-up materials in the published literature to Table 2 are not as strong with respect to deaths and injury information as those for buildings and other property damage. Heart attack deaths may or may not be included, and the text leaves the matter unclear in most cases. Injuries leading to deaths may be included under injuries or under deaths. What constitutes the dividing line between "serious injury" and "injury" is rarely stated in reports, and the given data are often incomplete. Indeed, it is most likely that the original medical records were unclear in this matter. Whether or not emotional cases were included is usually not stated, although some of these cases will require medical attention.

Table 45 is a listing of deaths and injuries per 100,000 population for selected earthquakes. Earthquakes with life losses less than 8 were excluded from the listing, and the 1872 Owens Valley earthquake was omitted for reasons already stated. Quite possibly the cut-off figure should be much larger than 8 since the data for Tehachapi in the 1952 Kern County earthquake are so few as to be seriously questioned when used for extrapolation. The inclusion of the 1949 Puget Sound earthquake is also of little value for this particular study since Puget Sound earthquakes have much deeper focal depths than do those in northern California; as a result, the damage and life loss patterns are distinctly different. Similar variations apply for the Charleston shock of 1886. The effect of a single major collapse can strongly affect the losses per 100,000 population; see, for example, the variations in Table 45 upon inclusion of the deaths at the Veterans Administration Hospital from the 1971 San Fernando shock.

Table 45 is a useful guideline when used with judgment and in the context of the time of day, comparative construction, and appropriate Modified Mercalli intensities. It must be clearly understood that direct usage of this information is not possible without consideration of the foregoing qualifications. For one example, the unreinforced brick bearing wall buildings are slowly being phased out in the study area, although large numbers of them still exist; in other words, the situation is changing and is becoming less similar to 1906 conditions. On the other hand, the hazard from falling glass and broken precast concrete

TABLE 45

DEATH AND INJURY RATIOS
Selected United States Earthquakes

Earthquake	Date	Time of Occurrence	Deaths per 100,000 Population	Injuries per 100,000 Population
Charleston, S. C.	Aug. 31, 1886	9:51 p. m.	45 outright; 113 total	-
San Francisco, Calif.	April 18, 1906	5:12 a. m.	-	-
San Francisco			124	104 serious
Santa Rosa			116	69 serious
San Jose			80	38 serious
Santa Barbara, Calif.	June 29, 1925	6:42 a. m.	45	119
Long Beach, Calif.	March 10, 1933	5:54 p. m.	26	1,300
Imperial Valley, Calif.	May 18, 1940	8:37 p. m.	18	40 serious
Puget Sound, Wash.	April 13, 1949	11:56 p. m.	1	-
Kern County, Calif.	July 21, 1952	4:52 a. m.	-	-
Tehachapi			500	-
Bakersfield, Calif.	Aug. 22, 1952	3:41 p. m.	3	47
Alaska	March 27, 1964	5:36 p. m.	-	-
Anchorage			9	315
San Fernando, Calif.	Feb. 9, 1971	6:01 a. m.	see below	180 serious
Excl. Vet. Adm. Hosp.			12	-
Incl. Vet. Adm. Hosp.			64	-

masonry from the newer multistory buildings will cause deaths and injuries even though the buildings may be safe occupancies.

Building and Population Inventory

For realistic usage, the ratios calculated using the data given in Table 2 must be modified on the basis of a hazard evaluation of the construction types found in the study area. In turn, these modified ratios must be multiplied by the daytime as well as by the nighttime population in the areas being examined.

Data on selected multistory construction types by number of buildings, by total floor area, and by story height groupings were gathered for each of the areas shown in Figure 13. The selected construction types of multistory buildings were:

Concrete,
Steel frame,
Brick, and
Mixed construction.

The areas for which data were compiled corresponded to the Sanborn Map volumes used by the insurance industry. The summary of this compiled information is by city (not by areas within each city as shown in Figure 13) and is given in Table 46. It is clearly evident that San Francisco predominates in the number of multistory buildings, with Oakland being second, and the others having little effect on regional totals.

Table 47 is a listing of selected peak population figures based on the "Statistical Shelter Plan," 1970. The numerical values in Table 47 have been compiled in a manner which corresponds with the same areas (Figure 13) as those used for the detailed breakdown which supports the summary given in Table 46.

ANALYSIS

General Comments

There are several ways to approach the determination of the number of deaths and injuries caused by damage to or collapse of buildings. This determination will be greatly affected by the location of the inhabitants at the time of the

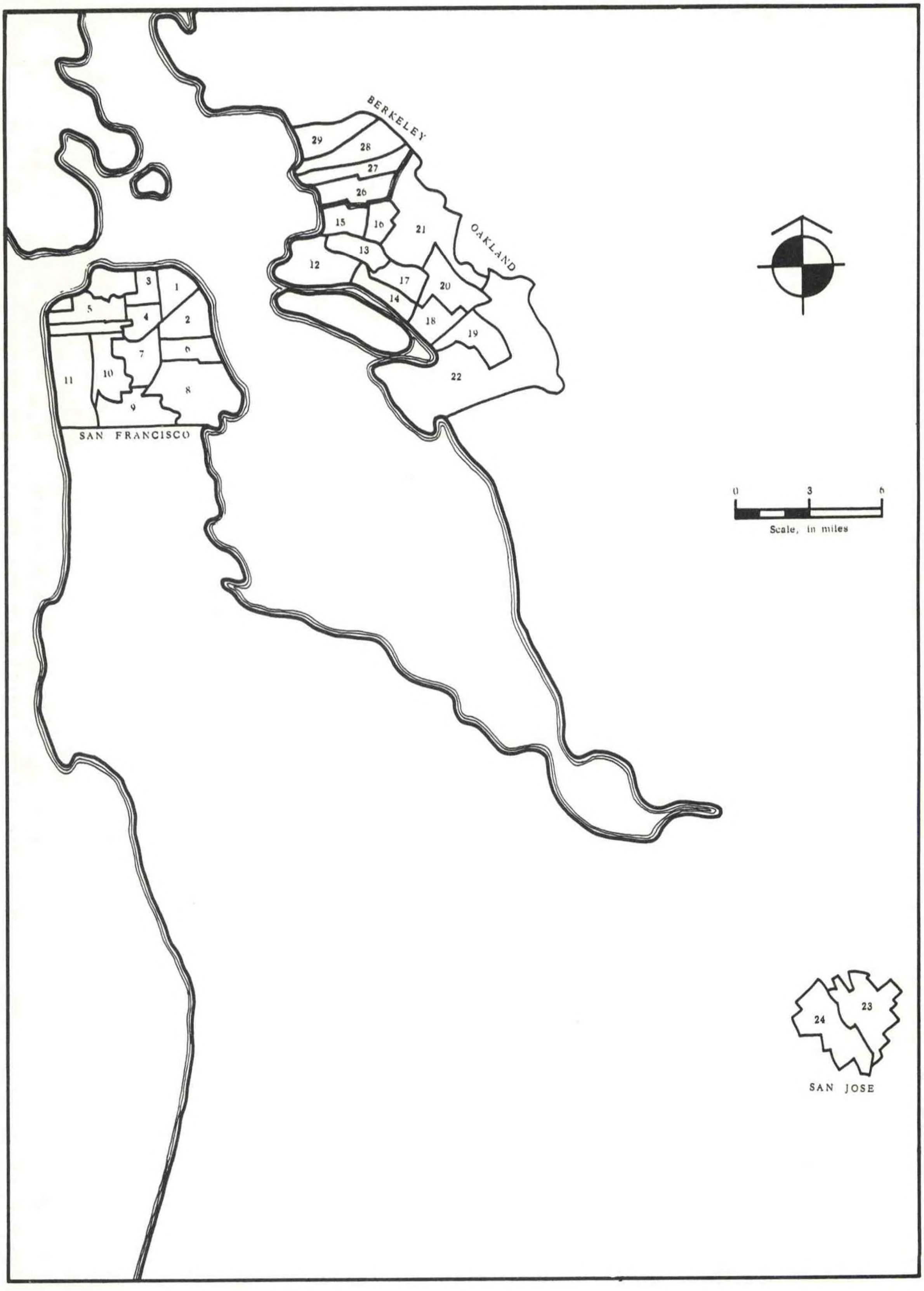


FIGURE 13. Multistory building study areas. See also Table 47.

TABLE 46

MULTISTORY BUILDING INVENTORY FOR SELECTED CONGESTED AREAS

Construction Material by Story Height	San Francisco Number of Buildings	San Francisco Floor Area (x1000)	Oakland Number of Buildings	Oakland Floor Area (x1000)	San Jose Number of Buildings	San Jose Floor Area (x1000)	Berkeley Number of Buildings	Berkeley Floor Area (x1000)	Palo Alto Number of Buildings	Palo Alto Floor Area (x1000)
Concrete:										
4-8 stories	627	28,550	74	6,218	35	2,478	41	3,152	14	965
9-13 stories	74	5,949	15	1,850	7	783	14	592	4	450
14-up stories	40	9,361	4	1,292	0	0	1	137	1	122
Steel frame:										
4-8 stories	399	19,932	47	3,108	6	213	13	613	1	53
9-13 stories	89	10,800	12	1,323	5	398	1	179	0	0
14-up stories	62	18,659	7	1,604	0	0	1	17	0	0
Brick:										
4-8 stories	132	14,181	38	1,324	0	0	11	350	2	112
9-13 stories	1	58	0	0	0	0	0	0	0	0
14-up stories	0	0	0	0	0	0	0	0	0	0
Mixed construction:										
4-8 stories	129	4,224	8	404	0	0	3	38	1	24
9-13 stories	1	79	0	0	0	0	0	0	0	0
14-up stories	0	0	0	0	0	0	0	0	0	0
Total	1,554		205		53		85		23	

Figures compiled from Sanborn Maps.
Areas in thousands of square feet.

TABLE 47

PEAK POPULATION FIGURES

City	Area Number*	Population	
		Peak Daytime	Peak Nightime
San Francisco	1	284,076	133,442
	2	169,997	35,481
	3	70,606	77,643
	4	74,266	86,612
	5	39,835	64,848
	6	49,109	41,502
	7	71,587	89,055
	8	89,773	88,552
	9	80,098	67,479
	10	32,803	47,527
	11	77,731	76,100
Oakland	12	82,375	41,908
	13	31,073	20,733
	14	87,515	25,221
	15	46,314	30,549
	16	26,822	24,372
	17	48,356	50,280
	18	28,599	26,647
	19	29,149	31,709
	20	26,226	42,518
	21	48,421	40,373
	22	70,722	78,919
San Jose	23	-	53,318
	24	-	28,930
	25	-	-
Berkeley/Albany	26	104,359	48,536
	27	25,945	41,823
	28	16,466	19,612
	29	16,777	23,383
Palo Alto	30	-	51,302

*See Figure 13; some boundaries inexact and not all areas mapped.

earthquake--at home, on the street, on the sidewalk, in schools, shopping, or at work. It will also be affected by the quality of the buildings they happen to be in or by the quality of the buildings adjacent to them in the event they are on the sidewalks or in the streets. In some cases, such as at 2:30 a.m., the majority of the population will be in relatively safe structures, normally being in one family wood frame homes or in small wood frame apartment buildings where experience has indicated little life loss or injury hazard exists. At other times, a large proportion will be on the streets or in buildings which are far more hazardous; this latter condition is much more difficult to evaluate. Serious damage to or collapse of a large building involves large numbers of people; one multistory building collapse will greatly affect the results if they are based solely on dwelling statistics.

The 1970 census states that there are 4,628,199 inhabitants in the entire study area. Additionally, the 1970 census gives the number of 1 unit dwellings and the number of "over 10" unit dwellings in those cities of over 2,500 population in the San Francisco-Oakland Urbanized Area. While some outlying cities are omitted through the use of these urbanized area data, the error is not significant in number and not otherwise significant since the outlying areas tend to have fewer earthquake problems. A summary of the pertinent urbanized area census data is given in Table 48.

As shown in Table 48, there are 1,036,891 dwelling units accounting for a population of 2,934,251 inhabitants in cities having a population of 2,500 or more in the urbanized area. From this we can conservatively determine the number of persons in the urbanized areas who live in one unit or in small structures; these are structures predominately of wood frame construction and for which considerable earthquake data exist. The 1,036,891 dwelling units (not buildings) are classified as follows from Table 48:

Single units	613,831
2 to 9 units	236,825
10 or more units	186,325
Total	1,036,891

TABLE 48

SELECTED POPULATION AND DWELLING DATA
Based on 1970 Census "Block
Statistics, San Francisco-Oakland, Calif. Urbanized Area"

	San Francisco	Oakland	Berkeley/Albany	**Cities of Over 2500 Population
Population	715,674	361,561	131,390	*** 2,934,251
1 unit dwellings	104,595	72,114	24,619	613,831
10 unit plus dwellings	87,729	28,313	9,929	186,325
Total	192,324	100,427	34,548	800,156
Owner occupied units	97,036	58,831	16,274	523,532
Rented units	198,138	80,000	32,479	513,449
Total	295,174	138,831	48,753	1,036,981
*2 to 9 unit dwellings	*102,850	* 38,404	* 14,205	* 236,825
1 person households	110,333	44,031	16,660	258,155

*Derived figure, being total units (owner plus rented) less (1 unit dwellings plus 10 or more unit dwellings).

**Cities of over 2,500 population in the urbanized areas of the study area. Does not include all 2,500 population cities in the study area.

***Total population of study area (which is larger than the urbanized area) was 4,628,199 in 1970.

From the foregoing, it can be determined that at least the following number of persons live in 1 unit dwellings that are inherently safe, as follows:

A. In cities in the urbanized areas and having 2,500 population or more:

$$\frac{613,831}{1,036,891} \times 2,934,251 = 1,737,000$$

(Probably on the low side because single units tend to have more than average number of occupants.)

B. In cities and areas with less than 2,500 population:

In suburban areas and in cities of less than 2,500 population, most live in single or small units:

(Total population) - (2,500 city population), or
4,628,199 - 2,934,000 = 1,694,000

A+B, or total population living in inherently safe dwelling units (normally wood frame) = 3,431,000

The number of persons in multiple living units is:

(4,628,199 total pop.) - (3,431,000 single units) = 1,197,000

The number of persons in 2 to 9 unit dwellings is:

$$\frac{236,825}{236,825 + 186,325} \times 1,197,000 = 670,000$$

The number of persons in 10 and over unit dwellings is:

1,197,000 - 670,000 = 525,000

Night Time Casualties (2:30 a.m.)

From previous earthquake experience shown in Table 45, it may be assumed for night hours that an 8.3 magnitude shock on either the Hayward or San Andreas fault will result in 12 deaths per 100,000 population for persons in wood frame structures. This ratio of 12/100,000 is the same as that of the heaviest shaken area of the 1971 San Fernando shock. Applying this ratio to all of the study area will lead to results which are on the high side, but probably not unduly so. For one reason, more older dwellings exist in the study area's high intensity regions than in the small area of highest intensity in San Fernando, resulting in heavier casualties. Also, the high population concentrations are close to the two faults. Additionally, the cities of San Francisco and Daly City have a specialized type of two story wood frame dwelling in which the front of the first story often has excessive openings and the first story also has few interior partitions; as a result, the first story of this type of dwelling is much weaker than the average of those in the San Fernando sample area. Landslide possibilities exist in the San Francisco Bay Area; for example, it is possible to lose several hundred lives through ocean fronting bluffs in Daly City sliding into the Pacific Ocean.

The remainder of the population which is not in wood frame structures at night will be in buildings of a higher hazard. Using appropriate factors for various proportions of the remaining 1,200,000 inhabitants, a total of 2,300 deaths for a magnitude 8.3 earthquake on either the San Andreas or the Hayward fault is reasonable for planning purposes. The breakdown for this estimated 2,300 life loss is given in Table 49. The death ratio is 50/100,000.

It will be noted that, while 8.3 magnitude earthquakes have approximately equal deaths on both faults, the smaller earthquakes indicate a greater hazard on the Hayward fault. This is reasonable when one stops to consider that, although the east side of the San Francisco Bay has a lower concentration of population, the Hayward fault has more apartment houses, institutions, etc. closer or on the fault trace than does the San Andreas.

Injury data are of considerably poorer quality than those for deaths. There is no consistent or adequate definition for "serious" injury with respect to Table 45, except for possibly the 1971 San Fernando experience. It will be assumed for planning purposes that a 4:1 ratio applies for "serious" injuries to deaths, with "serious" injuries being defined as those requiring hospitalization, however brief. For non-serious injuries, the ratio will be taken as 30 to 1.

TABLE 49

DEATHS AT 2:30 A. M. DUE TO 8. 3 MAGNITUDE EARTHQUAKE ON HAYWARD OR SAN ANDREAS FAULT

		Deaths
In wood frame structures: (3,431,000) x (12/100,000 San Fernando)		412
In 2 to 9 unit modern structures: (50% of 670,000) x (18/100,000)		60
In 2 to 9 unit older structures: (50% of 670,000) x (26/100,000 Long Beach)		87
In over 10 unit modern structures: (50% of 525,000) x (64/100,000 San Fernando)		168
In over 10 unit older structures: (50% of 525,000) x (500/100,000)		1,310
	Sub-total	2,037
Allowance for catastrophic landslide or collapse of high-rise apartment building		250
	Total	2,287
	Use	2,300

$$\text{Death ratio} = \frac{2,300}{4,628,199}$$

$$= 50/100,000$$

By using factors as determined during the study of hospitals (in this report), appropriate estimates for the number of deaths for magnitude 7 and 6 earthquakes were obtained. The results are given in Table 50.

Day Time Casualties (2:00 p.m.)

The life hazard problem is more complicated and less subject to reliable analysis for day time earthquakes than for those occurring at night. Many of the 4,600,000 persons in the study area will be at work in structures that are not as safe as their wood frame residences. The others will still be at home, in small shopping areas of not much greater hazard than their single family homes, in safe schools, in moderately safe industrial plants, in office buildings of various quality, and the like. Some will be on the streets in the more hazardous areas. At 2:00 p.m., the streets will not be as crowded as during the commuting hours.

Of the 4,600,000 total population in the study area, it is reasonable to estimate that 2,000,000 persons will have about the same general hazard as that of the night time population, or a death ratio of 50/100,000. On this basis, this segment of the population would be expected to have:

(2,000,000) x (50/100,000) = 1,000 deaths.

Another 2,000,000 persons could reasonably be expected to be subjected to a life hazard of about twice that of the 1933 Long Beach earthquake, and this leads to:

(200%) x (2,000,000) x (26/100,000) = 1,040 deaths.

The remainder of the population (600,000) would be largely concentrated in multistory downtown areas, in older unit masonry buildings, on freeway structures, and in other congested areas. Data on relative congestion are given in Tables 46 and 47. For example, Table 47 shows that the heaviest congested area of San Francisco (Area 1) has a peak day time population of 284,076, mostly in or about 1,100 structures which are 4 stories or higher. (Area 1 of San Francisco is bounded by San Francisco Bay, Market Street, and Van Ness Avenue.) Downtown Oakland has a peak day time population of 82,375 persons who are mostly in or about 205 structures which are four stories or higher. As a basis for

TABLE 50

DEATHS AND HOSPITALIZED INJURIES
Exclusive of dam failures

Fault	Magnitude	Time of Day	Deaths: Schools**	Deaths: Hospitals*	Deaths: Other Sources	Deaths: Total	Hospitalized Injuries: Schools**	Hospitalized Injuries: Hospitals***	Hospitalized Injuries: Other Sources	Hospitalized Injuries: Total
San Andreas	8.3	2:30 a.m.	0	550	2,300	2,850	0	1,600	9,200	10,800
		2:00 p.m.	2,100	1,320	6,040	9,460	5,800	4,000	24,600	34,400
		4:30 p.m.	200	1,320	8,840	10,360	600	4,000	35,760	40,360
	7	2:30 a.m.	0	100	400	500	0	300	1,600	1,900
		2:00 p.m.	350	230	1,060	1,640	1,300	700	4,200	6,200
		4:30 p.m.	40	230	1,720	1,990	100	700	10,880	11,680
	6	2:30 a.m.	0	5	20	25	0	20	80	100
		2:00 p.m.	10	10	60	80	50	30	240	320
		4:30 p.m.	0	10	90	100	0	30	360	390
Hayward	8.3	2:30 a.m.	0	820	2,300	3,120	0	2,400	9,200	11,600
		2:00 p.m.	1,900	1,950	3,350	7,200	8,700	6,000	13,800	28,500
		4:30 p.m.	200	1,950	4,500	6,650	900	6,000	18,000	24,900
	7	2:30 a.m.	0	300	740	1,040	0	900	2,960	3,860
		2:30 p.m.	1,400	700	1,100	3,200	3,400	2,100	4,400	9,900
		4:30 p.m.	100	700	1,440	2,240	300	2,100	5,760	8,160
	6	2:30 a.m.	0	100	230	330	0	300	920	1,220
		2:00 p.m.	140	240	350	730	560	700	1,400	2,600
		4:30 p.m.	10	240	450	700	50	700	1,800	2,550

*Numbers rounded off.
**Values given are 25% greater than totals of 4 counties given in Table 57.
***"Hospitalized" injuries rather than total injuries given in Table 21.

Note: The ratio of non-hospitalized injuries to deaths is 30:1 in all cases.

analysis, the death ratio in Anchorage in the 1964 Alaskan earthquake is used. Table 45 indicates that the ratio was 9/100,000 for this earthquake which occurred late in the day of Good Friday. Based on extensive building investigations made by the authors after the 1964 shock, it is reasonable to have had 100 deaths if the hour had been earlier and had the buildings under construction been completed. Metropolitan Anchorage had a population of 100,000 at the time of the earthquake, with about 50,000 within the city limits. If the population in homes, in schools, and in low wood frame buildings were discounted, then the downtown population at the time of the estimated 100 deaths is estimated to have been not more than about 20,000. This would give a death ratio of 500/100,000. Applying this to the study area:

(600,000) x (500/100,000) = 3,000 deaths.

Another approach may be used. Using the ratio of 3 major collapses in Anchorage per 20,000 downtown population would suggest:

$3 \times \frac{600,000}{20,000}$, or 90 equivalent collapses of structures in the congested regions of the study area.

A total of 90 building collapses at 40 deaths per collapse, as occurred in high-rise structures in the Caracas, Venezuela earthquake of 1967, would give 3,600 deaths--a not unreasonable check figure. (Most high-rise buildings in Caracas were of modern earthquake resistive types. Although designed for about half of San Francisco standards, the earthquake forces were perhaps half of those expected for maximum San Francisco conditions.)

The foregoing calculations do not include hazards from freeway collapses nor do they consider the special hazards due to falling ornamentation, parapets, curtain walls, and glass onto sidewalks and adjacent buildings.

In view of the miles of elevated freeway in San Francisco and Oakland, and in view of the hundreds of other freeway structures, deaths due to accident (driver panic) and freeway collapse has been estimated at 200.

According to Table 46, San Francisco has about 800 buildings, 4 stories and over, that are of brick and masonry construction, of mixed construction, and of structural steel frame construction. Virtually all of these will have some sort of heavy masonry facing, or brick, or brick veneer, or brick parapets. Many of these are of excellent construction, but it is reasonable to estimate that there are 800 buildings in congested areas which have this type of hazard. At 2:00 p.m., the streets will not be as crowded as at the lunch hour or as at the commuting hour. It is reasonable to estimate 1 person killed for each of the 800 buildings; this gives a total of 800 deaths.

Summarizing the foregoing, the deaths for a 2:00 p.m. earthquake in the event of an 8.3 magnitude earthquake on the San Andreas fault gives the following:

2,000,000 population with equivalent night time hazard: (2,000,000) x (50/100,000) =	1,000 deaths
2,000,000 population with twice the 1933 Long Beach hazard: (2,000,000) x 26/100,000) x (200%) =	1,040
600,000 population in congested areas: (600,000) x (500/100,000) =	3,000
Freeway collapses, driver panic, bridge approach damage	200
Parapet, ornamentation, glass, etc. falling from buildings	800
Total	6,040 deaths

When an 8.3 magnitude earthquake occurs on the Hayward fault, the most congested area (San Francisco) is farther from the source of energy than if this earthquake had occurred on the San Andreas fault. The resulting casualties in San Francisco will be less for the multistory building hazard and for the falling masonry and glass hazards. Table 47 shows that Oakland's peak daytime population in its downtown congested region is 82,375 in place of San Francisco's 284,076. One reasonable approach for the multistory building hazard and falling masonry hazard in Oakland is to reduce the San Francisco deaths by a factor of (82,375/284,076), or 29%. Summarizing, the resulting deaths for an 8.3 magnitude earthquake on the Hayward fault would be:

2,000,000 population with equivalent night time hazard: (2,000,000) x (50/100,000) =	1,000 deaths
2,000,000 population with twice the 1933 Long Beach hazard: (2,000,000) x (26/100,000) x (200%) =	1,040
Population in congested area: (3,000 deaths) x 29% =	870
Freeway collapses, driver panic, bridge approach damage	200
Parapet, ornamentation, glass, etc. falling from buildings (800) x 29% =	232
Total	3,342 deaths
Use	3,350 deaths

Reducing these figures for lesser earthquakes as before, the deaths and injuries are as given in Table 50 for earthquakes occurring at 2:00 p.m. on the San Andreas and Hayward faults.

Day Time Casualties (4:30 p.m.)

The deaths at 4:30 p.m. will be similar in number to those at 2:00 p.m., except that many of the 600,000 persons who were in offices and in other places of employment would now be on the streets. This effect can be approximated on a judgment basis by increasing the number of deaths and injuries on the freeways and due to falling objects from buildings.

On this basis, the total number of deaths for an 8.3 magnitude earthquake on the San Andreas fault at 4:30 p.m. would be:

2:00 p.m. deaths	6,040 deaths
Plus additional freeway	400
Plus additional falling debris	2,400
Total	8,840 deaths

In a similar manner, the total number of deaths for an 8.3 magnitude earthquake on the Hayward fault at 4:30 p.m. would be:

2:00 p.m. deaths	3,450 deaths
Plus additional freeway	400
Plus additional falling debris	696
Total	4,546 deaths
Use	4,500 deaths

Dams

A total of 226 dams exist in the nine county study area, distributed among the counties as shown in Table 51. Many of these dams are small, and their failures as a result of an earthquake would not be catastrophic. Additionally, the failure of some dams in Marin County would result in the flood waters drawing into Tomales Bay and the flood routes are not over highly populated area. However, the Marin failures would be critical from the standpoint of water supply, including fire protection for the heavily wooded residential areas.

Table 52 contains some of the characteristics of 14 dams selected for their importance with respect to fault location and downstream population. Some of these dams are shown in Figure 14, and their proximity to the San Andreas and Hayward faults is obvious.

Dams in many parts of the world have failed during earthquakes. In the United States, the earthen Sheffield Dam failed in the 1925 Santa Barbara earthquake. The earthen Hebgen Lake Dam was damaged but remained serviceable after the August 17, 1959 Montana earthquake, despite being overtopped several times and there being a major fault scarp less than 1,000 feet from the spillway. The partial failure of the Lower San Fernando Dam in the 1971 San Fernando earthquake required the evacuation of 80,000 downstream inhabitants.

On the other hand, several dams performed quite well in the 1906 San Francisco earthquake. The 95 foot high Pilarcitos Dam located less than 2 miles from the San Andreas fault had an earthen puddle core and was constructed in 1864-66; it was not damaged. In 1906, a seven foot right lateral offset on the San Andreas fault went through a knoll which formed an abutment for the two sections of the San Andreas Dam. This 93 foot high earthen puddle core dam was

TABLE 51

DAMS IN THE STUDY AREA

County	Number of Dams
Alameda	27
Contra Costa	22
Marin	11
Napa	44
San Francisco	7
San Mateo	20
Santa Clara	37
Solano	17
Sonoma	41
Total	226

Includes all dams 25 feet or more feet high which impound more than 15 acre-feet of water and dams more than 6 feet high which impound 50 or more acre-feet of water.

TABLE 52

CHARACTERISTICS OF SELECTED DAMS
Data from Bulletin No. 17-71, Dept. Water Resources, State of California

Dam	Storage (acre-feet)	Height (feet)	Crest Length (ft.)	Type	Year Completed	Remarks
Anderson	91,300	235	1,430	Earth & rock	1950	
Austrian	6,200	185	700	Earth	1950	Upstream from Lexington Dam
Briones	67,500	273	2,100	Earth	1964	Upstream from San Pablo Dam
Calaveras	100,000	210	1,200	Hydraulic fill	1925	Discharges through Niles Canyon
Chabot	12,600	135	450	Earth	1892	
Coyote	24,500	140	980	Earth & rock	1936	Upstream from Anderson Dam
Del Valle	77,100	222	880	Earth	1968	Discharges through Niles Canyon
James Turner	50,500	193	2,160	Earth	1964	Discharges through Niles Canyon
Lafayette	3,500	132	1,200	Earth	1929	
Lexington	21,430	205	810	Earth	1953	
Lower Crystal Spring	54,000	140	600	Gravity	1888	Survived 1906 earthquake
San Andreas	18,500	107	727	Earth	1870	Upstream from Lower Crystal Springs Dam
San Pablo	43,193	170	1,250	Hydraulic fill	1920	
Upper San Leandro	41,436	190	660	Hydraulic fill	1926	Upstream from Lake Chabot

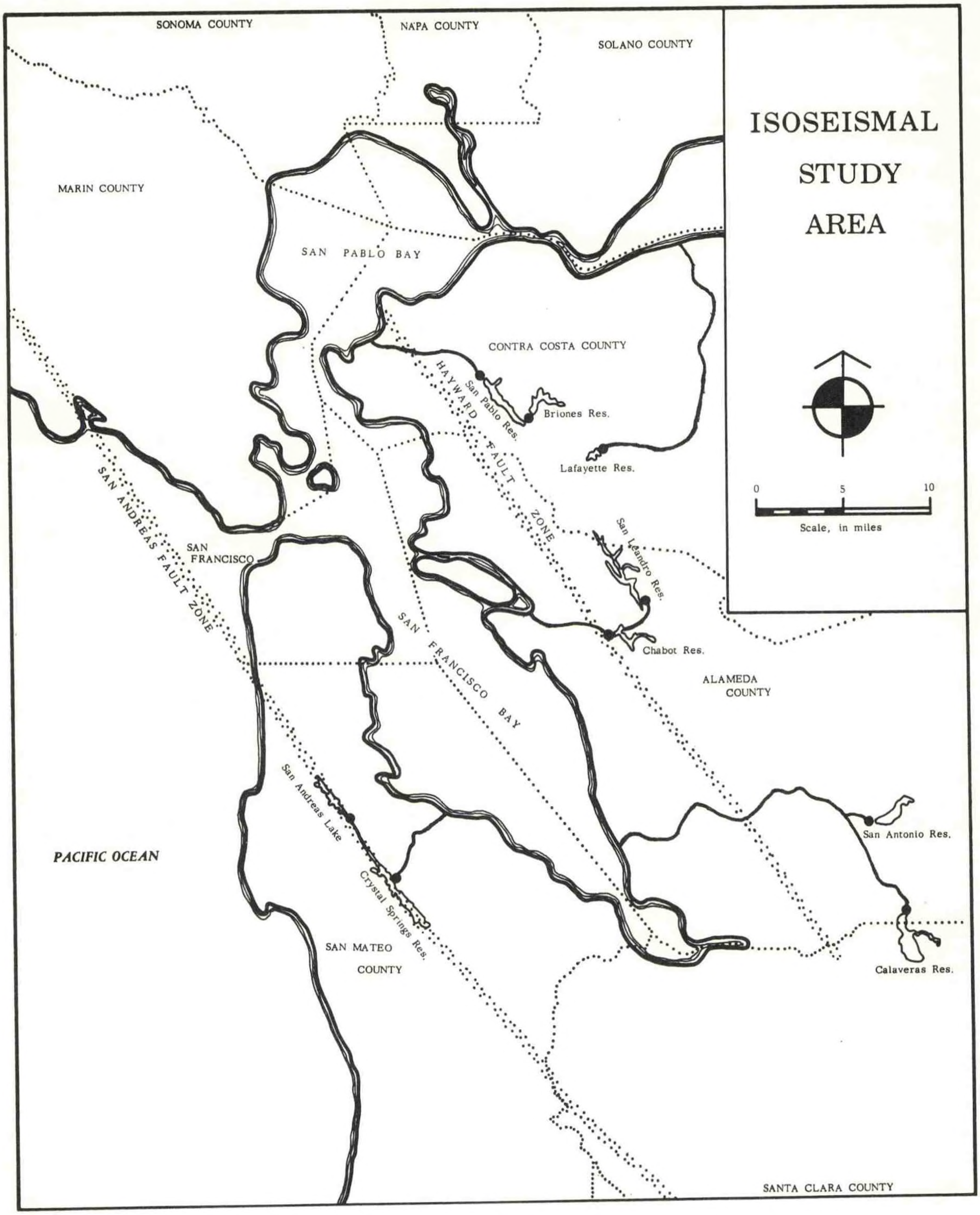


FIGURE 14. Dams and reservoirs. Locations are approximate with respect to fault zones.

constructed in 1868-70 and was uninjured. The Lower Crystal Spring Dam (Table 52) is a concrete dam and is located within a few hundred feet of the 1906 fault breakage; it survived the 1906 earthquake without injury.

The recency of the 1971 San Fernando experience has placed an excessive cloud over all earthen dams. However, it is clearly evident from studies made subsequent to the 1971 San Fernando earthquake that all hydraulic fill dams, such as the severely damaged Lower San Fernando Dam, must be held suspect until proven otherwise. The California Division of Safety of Dams is currently requiring all owners of hydraulic fill dams to re-evaluate the safety of their dams of this type.

The number of important dams is small compared to buildings in the study area. However, the rapid failure of any one of these important dams (listed in Table 52) would lead to catastrophic results to the downstream population. One possible conservative approach is to assume failure of all dams having even a small element of suspicion, and that the failure would occur in a catastrophic manner. (By "failure in a catastrophic manner" is meant failure in a very rapid and almost instantaneous manner, thereby not allowing downstream evacuation.) Under these extreme but credible assumptions, a magnitude 8.3 shock on either the San Andreas or Hayward fault would result in the failures of a half a dozen or more dams of those listed in Table 52. However, for the purposes of this report and in keeping with the known special hazard from hydraulic fill dams, only the hydraulic fill dams will be considered as being able to fail in a catastrophic, or near catastrophic manner. These are the Calaveras, San Pablo, and Upper San Leandro dams.* For planning purposes, leakage problems requiring the population evacuation below the dam will be considered for the Lower Crystal Springs Dam.

The consequence of error in assumptions is enormous. More lives can be lost from an unanticipated dam failure than from any other source. The

---

*At the present writing, these dams are being studied to determine if indeed they are hazardous. If they are hazardous, corrections are expected to be made. This postulated hazardous situation is a transient situation.

following paragraphs are a conservative approach, but even much greater damage and life loss is remotely possible.

EARTHQUAKES ON THE SAN ANDREAS FAULT

For planning purposes, an 8.3 magnitude shock will result in leaking of Lower Crystal Springs and Upper San Leandro dams, requiring evacuation downstream. Since upper San Leandro drains into Chabot, the population downstream from Chabot will also have to be evacuated.

A magnitude 7 earthquake will result in leakage to the Lower Crystal Springs Dam, again requiring evacuation.

A magnitude 6 earthquake will cause no significant damage to the major dams.

EARTHQUAKES ON THE HAYWARD FAULT

For planning purposes, 8.3 and 7 magnitude earthquakes will cause failure of the San Pablo and Upper San Leandro dams. Chabot Dam will be overtopped due to failure of Upper San Leandro; this manner of failure will lead to 75% of the "Estimated Probable Deaths" listed in Table 53 with the rest of the exposed population being homeless.

For planning purposes, a magnitude 6 earthquake will cause upper San Leandro Dam to have damage, requiring downstream evacuation.

GENERAL

The failure or significant leakage of a dam will cause many secondary effects. Streets, freeways, and rapid transit systems will be closed as will be schools, factories and airports. As a result, the major portion of the East Bay city complex will be largely isolated.

Clearly, the analysis of comparable magnitude earthquakes on the Hayward and San Andreas faults shows that the Hayward fault is the more hazardous by far.

TABLE 53

LIFE LOSS FROM DAM FAILURE

Dam	Maximum Possible Individuals Exposed		Maximum Possible Deaths		Estimated Probable Deaths	
	Day	Night	Day	Night	Day	Night
Lafayette	95,000	91,000	11,000	7,000	7,000	5,000
San Pablo, or Briones and San Pablo	49,000	51,000	29,000	30,000	20,000	25,000
Upper San Leandro and Chabot	86,000	109,000	50,000	52,000	30,000	35,000
Lower Crystal Springs	61,000	57,000	30,000	31,000	20,000	25,000
Calaveras, James Turner, and Del Valle	125,000	136,000	30,000	34,000	20,000	24,000
Only Calaveras	35,000	40,000	8,000	7,000	5,000	5,500
Only Del Valle	21,000	24,000	15,000	19,000	10,000	13,000
Lexington	*	72,000	*	20,000	*	15,000
Anderson and Coyote	*	18,000	*	5,000	*	3,000

*Not available

NOTE: The figures represent the worst conditions as they may currently exist, assuming unsafe dams. All of these dams are (or will be) re-evaluated for safety, and appropriate corrections will be made if unsafe.

Section 5: Effects on Immediate and Vital Public Needs

Public Structures

For planning purposes for this study, public structures are defined as those buildings under the jurisdiction of government at one of four levels: city, county, state, and federal. Only major public buildings considered vital after an earthquake were surveyed. Wherever possible, the following data were collected:

Location	Area or size (sq. ft.)
Year built	Original or replacement cost
Type of construction	Type of materials
Number of stories	Foundation type
Type of facility	Name of building
Soil conditions	Emergency power facilities

The respective offices of the City Architect were contacted for data regarding the cities of Oakland and San Francisco. In the case of the city of San Jose, the office of the City Engineer supplied the information required for this study. The respective county offices of the six counties surveyed provided the required data (counties of Alameda, Marin, Napa, San Mateo, Sonoma, and Solano). Data on Federally owned buildings were made available through the General Services Agency, San Francisco.

ANALYSIS

Federally Owned Buildings

The detailed information which has been gathered from Federal sources pertains only to the larger Federally owned buildings, thereby excluding military, leased, and small Federally owned structures. (The analysis of military structures is beyond the scope of this report, and leased building data could not be developed in the time available.) As a result, this analysis includes only a few of the many post offices, being mainly the principal one in the larger cities.

Data on the 67 Federally owned major buildings in the study area that were reviewed for this report included none of the construction types which are generally most heavily damaged in earthquakes, such as unreinforced brick. A summary breakdown by county is listed in Table 54 and plotted in Figure 15. Most buildings are relatively modern, and not less than 90% of them are estimated to be earthquake resistive by design or inherently earthquake resistive by choice of materials. Only a few are of reinforced concrete frame construction which predates 1920; concrete in these older buildings is often of poor quality. The taller multistory Federally owned buildings are of steel frame construction, with apparently the tallest reinforced concrete building being an 8 story structure built in 1943 at 390 Main Street in San Francisco.

In recent years, high-rise construction has generated considerable public concern regarding its collapse potential in earthquakes. However, a review of the 1906 experience discussed in Section 2 of this report will show that of the 17 multistory steel frame structures in existence in 1906, none collapsed and the damage was usually non-structural in nature. With this background, one may view the following listing of Federally owned multistory buildings (excluding military) in San Francisco from a comparative standpoint:

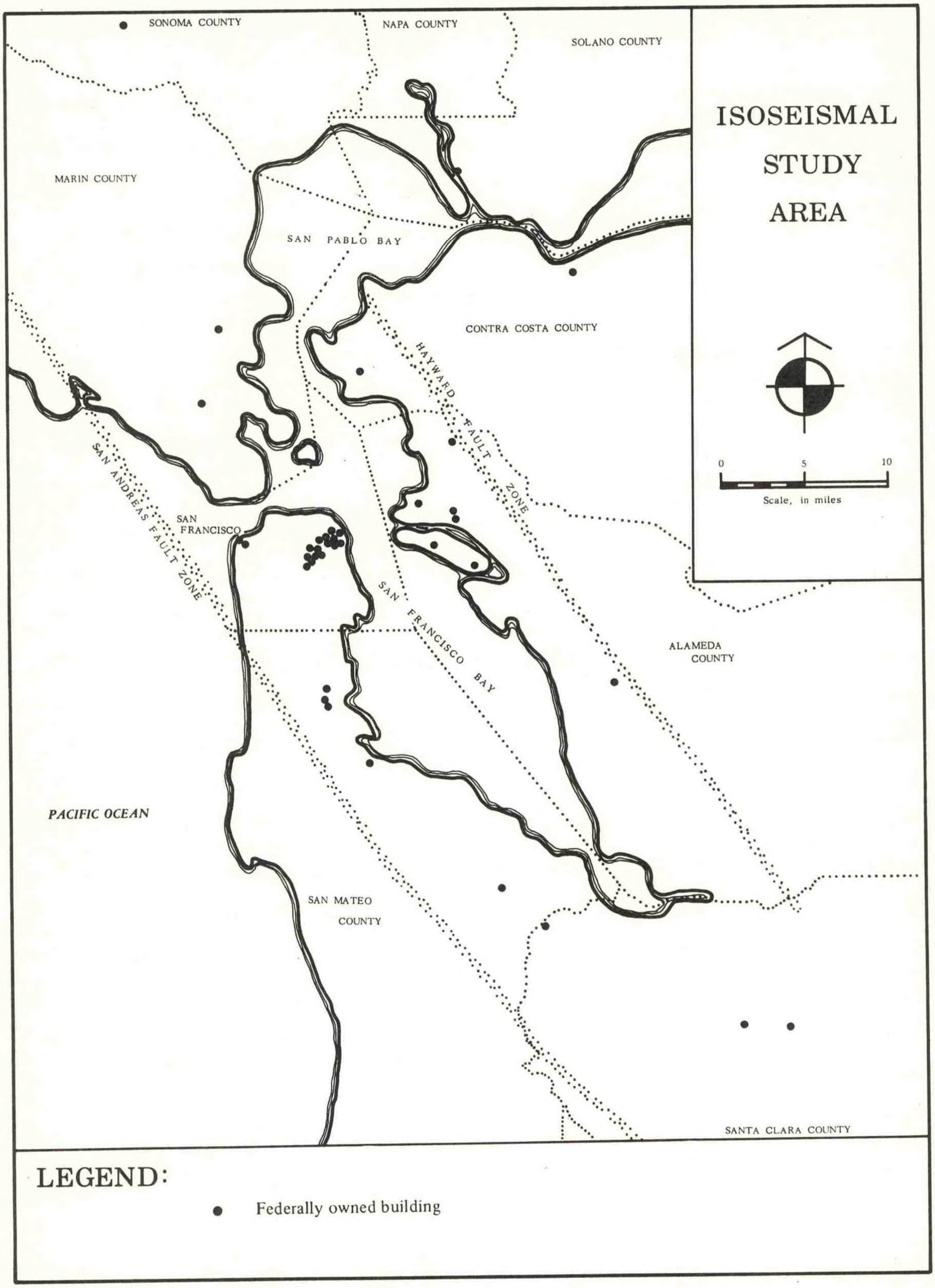


FIGURE 15. Major Federally owned buildings. Locations are approximate with respect to fault zones.

TABLE 54

FEDERALLY OWNED BUILDINGS

County	Total Number* of Buildings	Total Number with Emergency Power
Alameda	25	-
Contra Costa	2	-
Marin	2	-
Napa	2	-
San Francisco	16	7
San Mateo	8	-
Santa Clara	3	-
Solano	1	-
Sonoma	8	2
Total	67	9

*Includes U. S. Post Office buildings.

Stories	Year Built	Structural frame
4	1874	steel
4	1940	concrete
5	1893	steel
5	1925	concrete
5	1931	concrete
6	1911	steel
7	1936	steel
7	1937	steel
8	1943	concrete
12	1926	steel
16	1944	steel
22	1964	steel
29	1927	steel

From General Services Administration records. Other sources give somewhat different story heights and dates of construction; this is believed to be largely due to differences in definitions.

In the foregoing list, it will be noted that two of these buildings predate the 1906 shock, and their performance in 1906 is worth reviewing in summary form.

The 4 story building constructed in 1874 is the Old Mint Building located at Fifth and Mission Streets in San Francisco. This building "was not damaged to any appreciable extent by the earthquake" (USGS Bull. #324, p. 42). This reference goes on to state that "one of the interior walls was weakened by a break in a sewer which ran under it, and one of the chimneys was cracked at the top." Subsequent fire damage was slight.

The 5 story structure built in 1893 was (and remains) a post office building. Himmelwright in "The San Francisco Earthquake and Fire" states regarding the 1906 earthquake effects to this building as follows:

> The front of the north side has extensive earthquake cracks, the granite facing of the east front is cracked loose from the backing and is temporarily braced at several places. The southeast corner is racked and a window head has one ring stone of the arch out and others loose. At the southwest corner, the ground settled about 2

ft. at the building line and about 5 ft. at the curb, and entire surface from the building line moving about 5 ft. to the south. This distorted the sidewalk and steps of the two entrances, there being cracks in the joints of the cement sidewalk slabs 8" wide. It was necessary to place two temporary wooden steps of about 8" rise from the sidewalk in its settled position to that portion of the steps which remain approximately at the original height. (page 192.)

The damage represented about 15 percent of the building value (USGS, Bull. #324, p. 103), part of which was due to nearby blasting.

Earthquakes on the San Andreas fault--Expected Damage Patterns

For planning purposes, a magnitude 8.3 shock is expected to close down all Federally owned multistory buildings in San Francisco for 1 day, 90% for 2 days, and 50% for over one week. This closure will be due to the lack of utilities, lack of operable elevators, opening delays due to inspections to determine the extent of structural damage (if any), and the inability of employees to commute to these multistory buildings which are mostly located in the highest congested area of San Francisco. Federal offices in leased buildings in San Francisco will experience similar problems. The delays in reopening are expected to be longer in buildings over 10 stories than those under 10 stories. On the San Francisco Peninsula, one of the two Federally owned buildings in Menlo Park is expected to be structurally damaged and will be closed for an indefinite period of time.

For planning purposes, a magnitude 7 shock is expected to close down all Federally owned multistory buildings in San Francisco for 1 day, 50% for 2 days, and 10% for over 1 week.

For planning purposes, a magnitude 6 shock is expected to close down 20% of all Federally owned multistory buildings for 1 day, and 10% for 2 or more days.

Earthquakes on the Hayward fault--Expected Damage Patterns

For planning purposes, a magnitude 8.3 shock is expected to cause sufficient damage to indefinitely close the Alameda Post Office (built 1914), Berkeley

Post Office (built 1915), and Richmond Post Office (built 1939). The 10 story Federal Building in Oakland, built in 1920, is expected to be closed for over 1 week. In San Francisco, all Federally owned multistory buildings are expected to be closed for 1 day, 70% for 2 days, and 20% for over one week.

For planning purposes, a magnitude 7 shock is expected to indefinitely close the Berkeley and Richmond Post Offices. The 10 story Federal Building in Oakland is expected to be closed for 1 week. In San Francisco, all Federally owned multistory buildings are expected to be closed for 1 day and 20% for 2 or more days.

For planning purposes, a magnitude 6 shock is expected to indefinitely close the Berkeley Post Office. No major disruptions elsewhere are expected to occur to the Federally owned non-military structures.

County Buildings

No field inspections were made of any of the county facilities, except for those located in the Hayward fault zone in Alameda County. Some counties found it impractical to list all of their structures, and many of them had little or no information on the construction characteristics of their buildings. The effort required to compile the information from non-county sources in many cities, or the field inspection of all buildings, precluded the gathering of complete data. However, some additional specific information was available to authors at a few locations due to the authors' involvement as consultants or in other capacities in previous years. Lastly, some data were available through studies made by several of the authors after the 1969 Santa Rosa earthquakes; these shocks significantly affected one of the Sonoma County Center's buildings. (See, for example, "The Santa Rosa, California, Earthquakes of October 1, 1969," by Steinbrugge, et al.)

As a result, data are incomplete and some counties are not represented, as follows:

Alameda	32 buildings
Marin	22 buildings
Napa	8 buildings
San Francisco	See "Cities" section
Sonoma	19 buildings
Solano	43 buildings

Most of the county buildings have been constructed in recent years, and are therefore earthquake resistive to one degree or another. Some exceptions as to older buildings are as follows:

Napa County Court House at Napa, 1856-78 (per cornerstone)

Solano County Court House at Fairfield, 1910

Earthquakes on the San Andreas fault--Expected Damage Patterns

The incompleteness and uneveness of the data requires more generalized statements than those made in the analysis of other types of occupancies.

However, for planning purposes for a magnitude 8.3 earthquake, the county court house and the principal office building in San Francisco, San Mateo, and Santa Clara counties will be considered damaged (structural, utilities, elevators) to the point that only emergency personnel will use them for one week; they will not collapse. Damage to the Marin Civic Center will be so heavy as to require the use of alternate facilities. One of the Sonoma County buildings at their complex in Santa Rosa will be significantly damaged, requiring evacuation for one week. A total of 20% of the other county buildings in the counties of San Mateo, San Francisco, Marin, and Santa Clara will be out of service for 1 week due to the loss of utilities, access difficulties (freeway structures down), and damage to buildings.

Lesser magnitude earthquakes will not pose significant problems.

Earthquakes on the Hayward fault--Expected Damage Patterns

In the event of a magnitude 8.3 or 7 shock, the facilities located in the Hayward fault zone in the vicinity of the Fairmont Hospital will have to be abandoned, including the County's Emergency Operating Center at this location. Also for planning purposes the Alameda County Court House and the Welfare Building (both in Oakland) will be out of operation for 1 week due to damage to the building, loss of utilities, and loss of elevators. The 10 story Alco Park building will be damaged to the point that operations will have to be transferred elsewhere. The Marin Civic Center in San Rafael will be closed for 1 week as will the largest

Santa Clara County office building. A total of 20% of the other county buildings in Alameda, Contra Costa, Marin, and Santa Clara counties will be out of service for 1 week. Damage will occur to buildings in other counties, but it is not expected to result in disruptions which can't be handled by local authorities.

A magnitude 6 earthquake will not pose major problems.

City Buildings

The earthquake related problems are generally more severe in the larger cities than in the smaller ones. Therefore, this report is limited to the cities in the study area with largest populations, being San Francisco, Oakland, and San Jose. Additionally, only certain types of facilities are covered, being police, fire, hospitals (included in section on "Hospitals"), and major city occupied structures. Corporation yards, recreation and park structures, libraries, and similar structures have not been included although undeniably some of them, such as corporation yards, play important roles.

Admittedly, some cities have special problems such as the City of Hayward where the Hayward fault runs through the central business district and through its police station. Fremont, with its city hall located on an "island" in the Hayward fault zone, may find its city hall useless due to sheared utilities and communication lines where they cross the fault.

In the event of emergency safe churches can and do become places of refuge even though they are not public property in the usual sense of the phrase.

City Halls and Major City Occupied Structures

The city halls of San Francisco and Oakland are older monumental type structures, constructed in 1915 and 1914 respectively. Each has a steel frame and each will not collapse in a major shock, although non-structural damage probably will be spectacular. In the 1957 earthquake, very minor damage was reported to the Oakland City Hall; no information on damage to San Francisco's City Hall is on record. The 4 story San Jose City Hall, built in 1958, was designed to be earthquake resistive. Other major structures for which data were obtained include:

Oakland: Hall of Justice (1963)

San Francisco: Civic Auditorium (1914, 1961), Brooks Hall (1957) Opera House (1932, 1967), and Veterans Building (1932, 1967)

San Jose: Police Administration Building (1969), Health Building (1957), and Communications Center (1959)

All of the foregoing structures are either of earthquake resistive design or have inherently strong bracing systems sufficient to resist collapse. While collapse is not expected, severe non-structural damage is likely to a majority of them in the largest expected earthquakes.

Fire Stations

Fire Stations are distributed throughout San Francisco, Oakland, and San Jose as shown in Figure 16; fire stations in the other areas were not mapped. The number of stations in the selected cities are as follows:

San Francisco	44 stations
Oakland	27 stations
San Jose	25 stations
	96 stations

Construction information was obtained on all of the foregoing.

In San Francisco, the large majority of all fire stations have been built or strengthened since 1950, and they are therefore earthquake resistive to one degree or another. The majority of the stations are listed as being of "fireproof" construction, with this normally referring to materials such as heavy mass concrete and/or structural steel. On the other hand, over 50% of the fire stations in Oakland are of wood frame construction, although perhaps 2 can be listed as being of fire resistive construction. The vast majority of Oakland's fire stations are known to have been designed to be earthquake resistive or are of inherently earthquake resistive wood frame construction. However, apparently three stations are located in or immediately adjacent to the Hayward fault zone. San Jose fire stations are also mostly new, with about 50% being of wood frame construction and the others of mixed construction. All, or virtually all, of San Jose's stations are earthquake resistive to one degree or another.

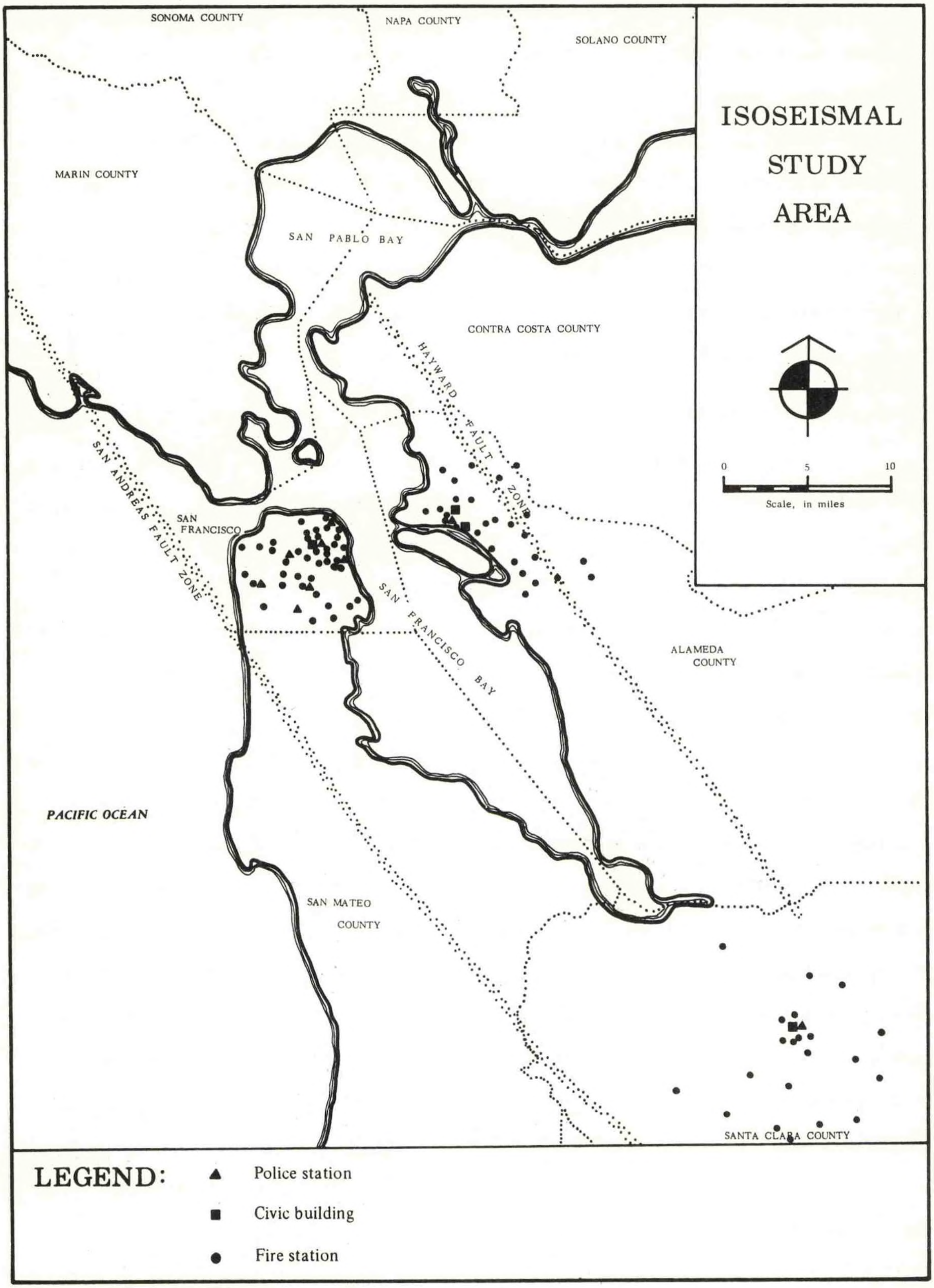


FIGURE 16. City buildings in San Francisco, Oakland, and San Jose. Buildings in other cities are not shown. Locations are approximate with respect to fault zones.

The overall high degree of earthquake resistance of the fire stations does not mean that they all automatically will be functional after the postulated earthquakes. Some fire engines will not be able to move from the station due to fallen buildings in front of the fire station or immediately adjacent thereto; this problem is expected to be particularly severe in the congested areas of San Francisco and Oakland. Some stations will receive direct damage, rendering equipment within the buildings inoperable. Fire station doors too often will jam due to slight racking of the fire station structure, with the building remaining safe. Communication facilities may be out or disrupted.

Earthquakes on the San Andreas fault--Expected Damage Patterns

For planning purposes, the San Francisco City Hall will not be in serviceable condition after an 8.3 magnitude earthquake, but it will not collapse. Damage will be extensive to all public buildings in San Francisco's Civic Center; for planning purposes, the remaining city structures at the Civic Center will remain safe although with disrupted utilities. Lesser magnitude earthquakes will cause extensive damage to the City's buildings in the Civic Center, but all will be able to function.

For planning purposes, 10 fire stations (about 25% of the total) in San Francisco will receive significant earthquake damage, be affected by neighboring building damage or have stuck doors, etc. in the event of an 8.3 magnitude earthquake. In 6 of the 10 trouble instances, the fire equipment will be on the streets and in the clear of the station within 15 minutes. In essence, the fire department will be able to place 90% of its equipment and manpower on the streets and in a clear position within 15 minutes, and the majority of it immediately after the shock. However, this does not imply 90% effectiveness in fire fighting due to fallen freeway structures, poor communications, water line disruptions, and similar problems discussed elsewhere in this report.

The other Peninsula cities, including San Jose, will have fewer fire station problems in an 8.3 magnitude earthquake.

Magnitude 7 and 6 earthquakes are not expected to pose major problems to fire stations and equipment located therein.

Earthquakes on the Hayward fault--Expected Damage Patterns

For planning purposes, the city halls of Oakland, Berkeley, Richmond, San Leandro, and Fremont will be damaged to the extent that they will not function and/or will be unsafe except for emergency use.

For planning purposes, 5 fire stations in Oakland will receive significant damage in the event of an 8.3 magnitude earthquake. Additionally, two stations in or adjacent to the Hayward fault zone will be completely out of operation and the equipment therein rendered useless. As in the case of San Francisco, overall effectiveness of the fire department equipment and manpower will be 90% or more within 15 minutes after the shock. However, this does not imply 90% effectiveness in fire fighting due to fallen freeway structures which may well isolate the hill areas east of the fault, poor communications, water line disruptions, and similar problems discussed elsewhere in this report.

The other East Bay cities, including San Jose, will have fewer fire station problems in an 8.3 magnitude earthquake.

Magnitude 7 and 6 earthquakes are not expected to pose major problems to fire stations and equipment located therein.

State Buildings

Information on the construction characteristics and location of State of California buildings was not developed due to the time requirements of this study and inability of the state authorities to provide the necessary information within the time constraints of this report.

Communications

Communications may take many forms: printed or written, verbal, or visual, among others. Some are emergency in nature (such as fire and police calls) while on the far end of the spectrum, others (as some magazines) may be weeks late and still fulfill their missions.

Emphasis in this report has been given to the communication types which are vital to emergency services and to minimal maintenance of community life in the days immediately after the disaster. Therefore greatest emphasis has been given to radio, TV, and telephone communications. However, some attention must be given to the other means of communication. It is obvious that post office facilities will be severely damaged when located in older non-earthquake resistive structures which are in the high intensity zones. Additionally, it is obvious that post office facilities located in the congested areas of San Francisco, for example, may be inoperative while the region is sealed off for damage evaluation. Newspapers are important in that they give the public much of the detail which can't be carried by radio or TV. Electric power outages, misalignment of sophisticated printing equipment or direct damage to it, and commuting problems for city employees will cause delays in the publishing process. It is reasonable to assume for planning purposes that newspapers will have to rely on presses located outside of Oakland and San Francisco for one week.

DATA COLLECTION

Due to the regional nature of commercial communication systems, data were collected from several sources rather than from one central agency. Among those consulted for information were:

Pacific Telephone Company
U.S. Department of Commerce
Federal Communication Commission
San Francisco Bay Conservation and
Development Commission (BCDC)

Use was also made of the BCDC publication "Public Facilities and Utilities in and Around San Francisco Bay," June 1967 edition. For detailed information on telecommunication systems, the "Television Fact Book," 1971-72 edition, was used where applicable.

Data were collected which permitted the plotting of the locations of commercial radio stations, radio and telecommunication towers, and radio-telegraph fields within the 9 San Francisco Bay Area County study area. Additionally, in the case of the transmitting or receiving towers, the following information was obtained:

Height in feet above ground level
Height in feet above sea level
Height in feet above the average adjacent terrain

Figure 17 shows the major commercial and television stations located in the isoseismal study area. There are approximately 58 major commercial radio stations, not including the small, local broadcasting stations which have a limited range and public function, in the subject study area. Several of these stations share and use a common transmitter tower. These transmitting towers are situated either atop transmitter buildings, on the ground adjacent to the buildings, in the Bay itself, or on an adjacent hilltop sufficiently elevated to avoid obstructions. The towers range in height from about 140 feet to over 500 feet, while their elevation above sea-level may be considerably higher depending where they are placed. For example, one of the towers located atop San Bruno Mountain in San Mateo County rises to an elevation over 1,400 feet above sea level, while one tower atop Peak Loma Prieta in the San Jose area reaches a height of over 4,000 feet above sea level.

Western Union, which operates most of the local telegraph service, makes extensive use of Pacific Telephone facilities and cables, but also utilizes

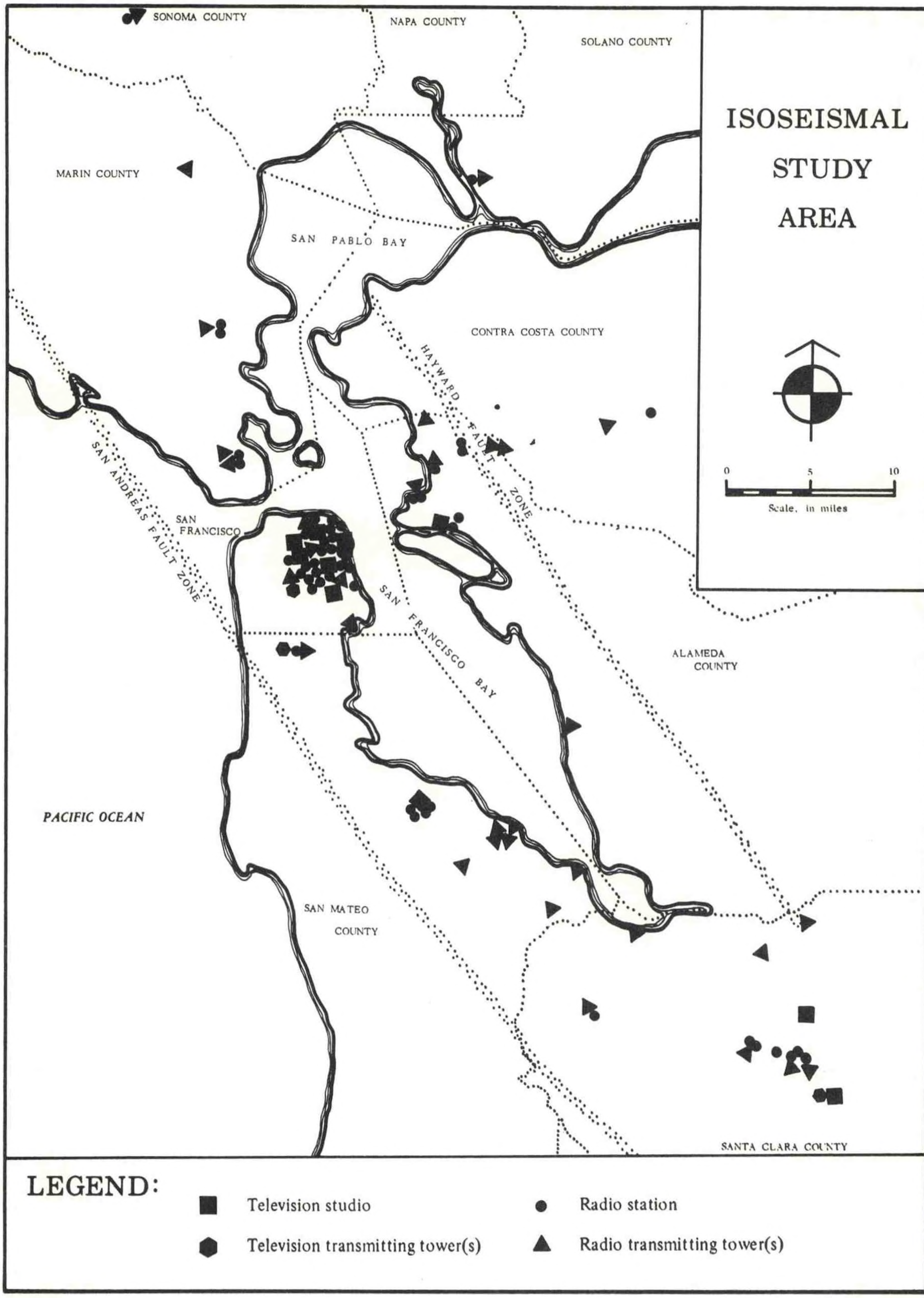


FIGURE 17. Radio and TV.

two cables between San Francisco and Oakland and two other cables across the Carquinez Strait between Port Costa, Contra Costa County, and Benicia, Solano County.

ANALYSIS

Radio and TV

Damage to radio and TV facilities may be divided into that which occurs to the studio building and its equipment, to the lines from the studio to the tower, and to tower and appurtenant structures and facilities.

The geographic distribution of radio and TV towers is shown in Figure 17. It is apparent that the radio towers are generally located along the Bay and this usually suggests areas of structurally poor ground. (This siting of radio towers near the Bay is to make use of the favorable properties of salt water on radio transmission.) The siting of TV towers is normally on top of mountains in order to obtain best line-of-sight benefits for high frequency transmission. As a result, foundation conditions for TV towers are often superior to those for radio towers.

Radio and TV towers have certain problems in addition to foundation conditions. The structural design standards are not as conservative as those for buildings, reportedly on the basis that life safety is not involved in the event of tower failure. Towers on the salt flats will have corrosive problems compared to the metals in the mountain-top tower. Tower maintenance is difficult; for example, it is difficult to repaint and otherwise service a high and often swaying tower. Ceramic insulators used in both guyed and unguyed towers are strong and reliable for non-impact loading conditions, but they may fail in a brittle manner under impact loads such as those which can be expected during earthquakes. Standby power is not always braced to resist earthquake forces.

With respect to past experience, radio towers survived quite well in the March 22, 1957 San Francisco shock which had a magnitude of 5.3. The 1964 Alaskan earthquake resulted in stations being off the air due to power failures rather than due to equipment or structural failures; however, most facilities were far from the epicenter and center of energy release. The April 13, 1949 Puget Sound earthquake resulted in the buckling of a freestanding radio tower in Seattle.

In the high intensity areas of a great earthquake, the too often unanchored equipment in buildings will shift and/or overturn, and other equipment will fall from shelves. A number of buildings containing the major radio and TV studios have been field inspected; significant building damage is anticipated but virtually all are expected to remain standing.

Public Radio and TV: San Andreas and Hayward Faults--
Expected Damage Patterns

In an 8.3 magnitude earthquake on the San Andreas fault, all radio and TV facilities are expected to be out of operation in San Francisco and San Mateo counties for 24 hours due to in-house problems, and/or power supply problems, and/or transmission line problems. Elsewhere in the study area, 1/3 of the facilities are also expected to be out of service for 24 hours. After 24 hours, 50% of the entire study area facilities are expected to be in operation.

In an 8.3 magnitude earthquake on the Hayward fault, all radio and TV facilities in the East Bay Cities west of the Berkeley hills and those in Santa Clara County are expected to be out of service. Two-thirds of the facilities located on the San Francisco Peninsula are expected to be out of service. Elsewhere in the study area, 75% of the facilities are expected to remain in operation. After 24 hours, 50% of the entire study area facilities are expected to be in operation.

Special Radio and TV: San Andreas and Hayward Faults--
Expected Damage Patterns

Fire, police, hospital, public utility and other special service communication requirements were not field inspected, except when incidental to the inspection of those facilities for other purposes.

The problems described for the public radio and TV facilities also apply in a general way to these facilities. Even though emergency service communications may be redundant to varying degrees due to multiple frequency and alternate base stations, experience has proved that, at best, a considerable number of unanticipated trouble sources will no doubt manifest themselves. Those services relying upon a single radio frequency must expect to experience overloading to a near impossible degree. However, in view of the large amount of mobile transmitting and receiving equipment, makeshift facilities are possible. Therefore, reliance must be placed on the management ability of those in charge of each special communication facility to make best use of mobile equipment should his base station be inoperative.

Any overall emergency planning should consider the transmitting and receiving capabilities of taxis as well as those of ham operators, and also the problems incident to their use.

Telephone Systems

Detailed information on telephone trunk lines, central stations, microwave facilities, etc. were not available for study, and the paragraphs which follow are based on incomplete knowledge of telephone construction practices and facility locations.

In general, the buildings are carefully designed, and more conservatively so than are conventional structures. It is expected that the newer exchange buildings usually will survive. In most cases they will remain safe even though some equipment in them may be damaged.

Experience has indicated that telephonic equipment in the San Francisco Bay Area will survive much better than the experience in San Fernando would indicate since much of the service in the study area is provided by another company with different equipment support practices. However, local service will be seriously affected due primarily to underground cabling practices. Overloading of circuits will be a major problem as it has been in previous earthquakes. Electrical problems may knock out some stations using the latest electronic switch gear. At least one local neighborhood station is located in the Hayward fault zone.

Submarine cables cross the Bay. Underwater cables have broken due to underwater soil flows in other earthquakes, and this possibility exists. Microwave stations were not evaluated due to lack of data.

Based on available information, it is anticipated that 50% of the telephone system will be out of service in the counties of San Francisco, San Mateo, Santa Clara and Marin for an indefinite period of time due to equipment damage in the event of a magnitude 8.3 shock on the San Andreas fault. An 8.3 magnitude shock on the Hayward fault will place out of service 60% of the telephone system in the counties of Contra Costa, Alameda, Santa Clara, and Marin. Magnitude 7 shocks may be expected to place out of service 30% of the systems in their respective areas, but 6 magnitude shocks will not create major problems.

Even without damage to the system, the lines will be overloaded and for all practical purposes it will be useless for telephoning in emergency situations. The problem, of course, is common in many disasters. Line-load limit control was not evaluated due to lack of data.

No multi-hospital communication network currently exists.

Transportation

This section of the report deals with all types of major transportation facilities considered vital to the efficient functioning of a community. Accordingly, the following transportation systems were investigated as representing both surface and air facilities:

- Major railroads
- Major highways, freeways, and bridges
- Mass public transportation
- Major airports
- Port facilities

DATA COLLECTION

The San Francisco Bay Area is serviced by three major railroad lines: Southern Pacific, Atcheson, Topeka and Santa Fe, and Western Pacific. Detailed information was obtained on tunnels, bridges, and routes from two of the systems. The locations of the principal railroad lines were plotted against the fault maps published by the United States Geological Survey (USGS). Information obtained from two of the railroad companies on the tunnels and bridges under their jurisdiction was as follows:

Bridge and/or tunnel number	Year built (age)
Location	Height (top of arch)
Type of construction	Area (sq. ft.)
Length	Materials of construction

Field inspection of the lines, tunnels, and bridges was not necessary due to the abundance of and the specifically detailed material received from the railroads.

Data on highways, freeways, and critical overpasses and bridges in all of the 9 San Francisco Bay Area counties was received from the California State Highway Division. Information regarding soil or geological conditions adjacent to the major overpasses was made available through the Bridge Department of the State Highway Division. In collecting data on overpasses, a complete list and detailed description of all major overpasses and bridges was obtained which included such information as follows:

Location	Type of piers
Type of construction	Bridge identification number
Year built (age)	What facility is crossed
Length and width	Foundation type

All major highway and freeway routes were plotted against USGS fault maps.

Detailed information was received from the design engineers for the Bay Area Rapid Transit System (BART) through its headquarters in the City of Oakland. Use was made of a major report entitled, "Composite Report - Bay Area Rapid Transit - May 1962," as prepared by the General Engineering Consultants for the transportation facility. The rapid transit routes were mapped for their relationship to the fault lines in the study area. Attention was given to identifying the portions of the system which are: (a). Underground, (b). Elevated, and (c). Surface. Detailed field inspections of the system were not attempted.

All airports were field inspected for the following information with particular emphasis placed on the collection of the following data in regard to the air control tower and the public spaces:

Year built	Type of construction
Location	Materials of construction
Number of stories	Size of buildings (sq. ft.)
Soil conditions	Access to freeways
Layout of runways	Passenger traffic statistics

The location of the airport sites were related to the two faults and the original boundary line of the bay marshlands.

ANALYSIS

Railroads

The network of railroad lines in the study area has changed and expanded since the 1906 earthquake, with the present location of main lines as shown in Figure 18. Bridges and trestles have been replaced and improved, and some main lines have been relocated or built since then. However, the changes are not so great that they will preclude the use of experience gained from the 1906 earthquake.

Earthquakes on the San Andreas fault--Expected Damage Patterns

The damage patterns from the 1906 shock will therefore be used as the model for a magnitude 8.3 event on the San Andreas fault. The following is quoted from the "Trans. Am. Soc. C.E., Vol. 59, pp. 214/215 (1907) as it relates to the 1906 disaster:

> Embankments. These settled more or less where they crossed marshes or were underlaid by soft strata. In one instance (across a tule marsh) the settlement was as much as 11 ft., while in another case (miles from the fault) a settlement of only 6 in. was accompanied by a horizontal displacement of 3 ft.
>
> Trestles. The damage to trestles was small, except on the North Shore Railroad, 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 down stream. These trestles were across soft ground, and near the fault-line. [Present authors' note: this line no longer exists.]
>
> Bridges. Draw-bridges . . . 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.
>
> A steel draw-bridge, over Petaluma Creek, was open at the time of the earthquake, and was thrown off its center 2 ft. to the east and

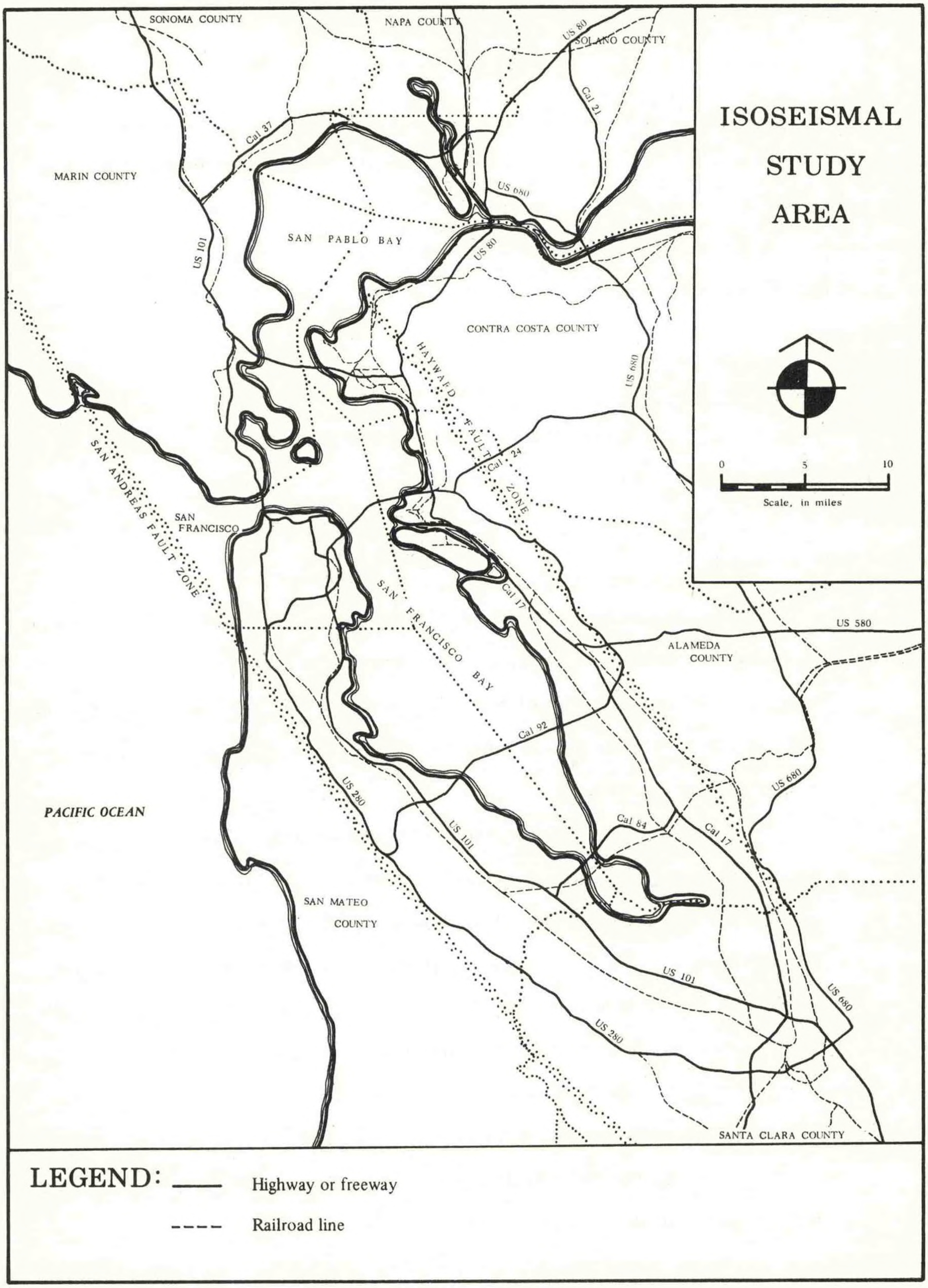


FIGURE 18. Major highway and freeway route, and railroads. Locations are approximate with respect to fault zones.

continuation of quotation:

> 1 ft. to the north. It was a 220-ft. span, and on four iron cylinders, filled with concrete, on pile foundations.
>
> Fixed spans, with a few exceptions, were not affected seriously. Where affected it was by a movement of the piers or abutments relatively to each other.
>
> 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.
>
> The new tunnels being constructed by the Southern Pacific Railroad on the Bay Shore line, in the southern part of San Francisco, were not injured at all.
>
> Overturned Cars, etc. At Chittenden Station, . . . three standing box-cars, two of them loaded, were turned over.

(end of quotation)

More detailed information may be found in the same reference on pages 258/262.

Additionally, it should be pointed out that in 1906 the Southern Pacific's main coastal line to Los Angeles from San Francisco crossed the San Andreas fault at the Pajaro River near Watsonville. The 1906 faulting went through the bridge site, badly damaging the bridge. The bridge has since been rebuilt at the same site, and its failure is anticipated in the event of an 8.3 magnitude shock.

Damage is expected to be heaviest in the structurally poor ground areas (Figure 23). The experience gained from the Alaskan earthquake is excellent in this regard, and reference should be made to the "Effects of the Earthquake of March 27, 1964, on the Alaska Railroad" by McCulloch and Bonilla (USGS Prof. Paper 545-D, 1970).

In summary, an 8.3 magnitude earthquake will result in damage somewhat less than that which occurred in 1906, in turn resulting in service being out for an indefinite period.

Earthquakes with magnitudes of 7.0 and 6.0 on the San Andreas fault are anticipated to develop similar problems to those occurring in an 8.3 magnitude shock, except that the damage will essentially be confined to the rail lines on the west side of the Bay.

Earthquakes on the Hayward fault--Expected Damage Patterns

Earthquakes having magnitudes of 8.3 and 7.0 are expected to offset the rail lines where they cross the Hayward fault. These offsets may be spectacular, but in a comparative sense, these lines can be quickly repaired since they cross the fault in locations of level terrain. The example of the 1952 Kern County earthquake where the faulting went through tunnels is not relevant; the long time delay in reopening this line is therefore not pertinent.

However, the damage to fills and the damage at and to bridges and trestles are expected to be more widespread as will be landsliding, and therefore more serious than that for a comparable earthquake on the San Andreas fault. For planning purposes in the event of an 8.3 shock, all east-west routes are expected to be closed for an indefinite period of time. A magnitude 7.0 shock is expected to close the east-west routes for a week, but allow the coastal route to remain functional.

Highways, Freeways, and Bridges

Principal damage to the highway, freeway, and Bay bridge systems may be placed into one of 3 categories: (1) earth failure due to landslide or to structurally poor ground movements, (2) overpass damage, and (3) damage to bridges which cross the Bay.

Should the postulated earthquake occur during the wet season of the year, landslides will be extensive in the high intensity areas. While hundreds of landslides may occur with respect to the highway and freeway systems, the serious slides will be those in the hill areas where their physical volume will preclude quick bulldozer removal of the slide material or the rapid construction of a bypass; additionally, alternate routes are often not available due to the topography. Southern Marin County is particularly vulnerable from this standpoint. To a somewhat lesser extent, Alameda and Contra Costa Counties are also vulnerable. In addition to the damage to the main arterials, large residential hillside regions in the study areas can reasonably be expected to be isolated for days, with the same landslides destroying the utilities going to the isolated areas. Obviously, these problems are possibilities and not probabilities since the wet season is only a small fraction of the year.

During earthquakes, man-made highway embankments and deep fills often settle with respect to the nearby rock or firmer soils. (This relative movement is called "differential settlement.") When these differential settlements occur at approaches to bridges and overcrossings, the pavements on the well placed deep fills may settle in terms of inches as compared to the surface of the bridge deck. These usually are aggravated nuisance problems which can be quickly repaired, although these problems will slow up traffic or stop it until repairs are made.

However, problems which are much more serious from a long term standpoint relate to the potential stability of certain major engineered fills. For one example, the miles of US 101 south of Candlestick Point in San Francisco to San Bruno may be cited; major land slips or movements are distinctly possible in heavy ground motion, and major stretches of this freeway can be under water or badly damaged due to soil movements. Additionally, the hydraulic fills used to construct miles of freeways along the east shore of the Bay in Alameda County may liquefy during heavy shaking, with long sections becoming totally impassable. Other less spectacular problems relating to the location of poor ground may be identified by comparing the freeway system (Figure 18) with the areas of structurally poor ground around the Bay (Figure 23).

The structural integrity of the many overpasses and similar structures throughout the study area (Figure 19) has come into sharp focus as a result of the 1971 San Fernando earthquake. In the San Fernando shock, freeway interchange and overpass structures were severely damaged, and many of them collapsed. This damage was confined to a relatively narrow zone on the upper plate of the fault which had left lateral thrust movement (i.e., in this case, almost all damage on the north side of the surface faulting). It is not yet clear if this zone

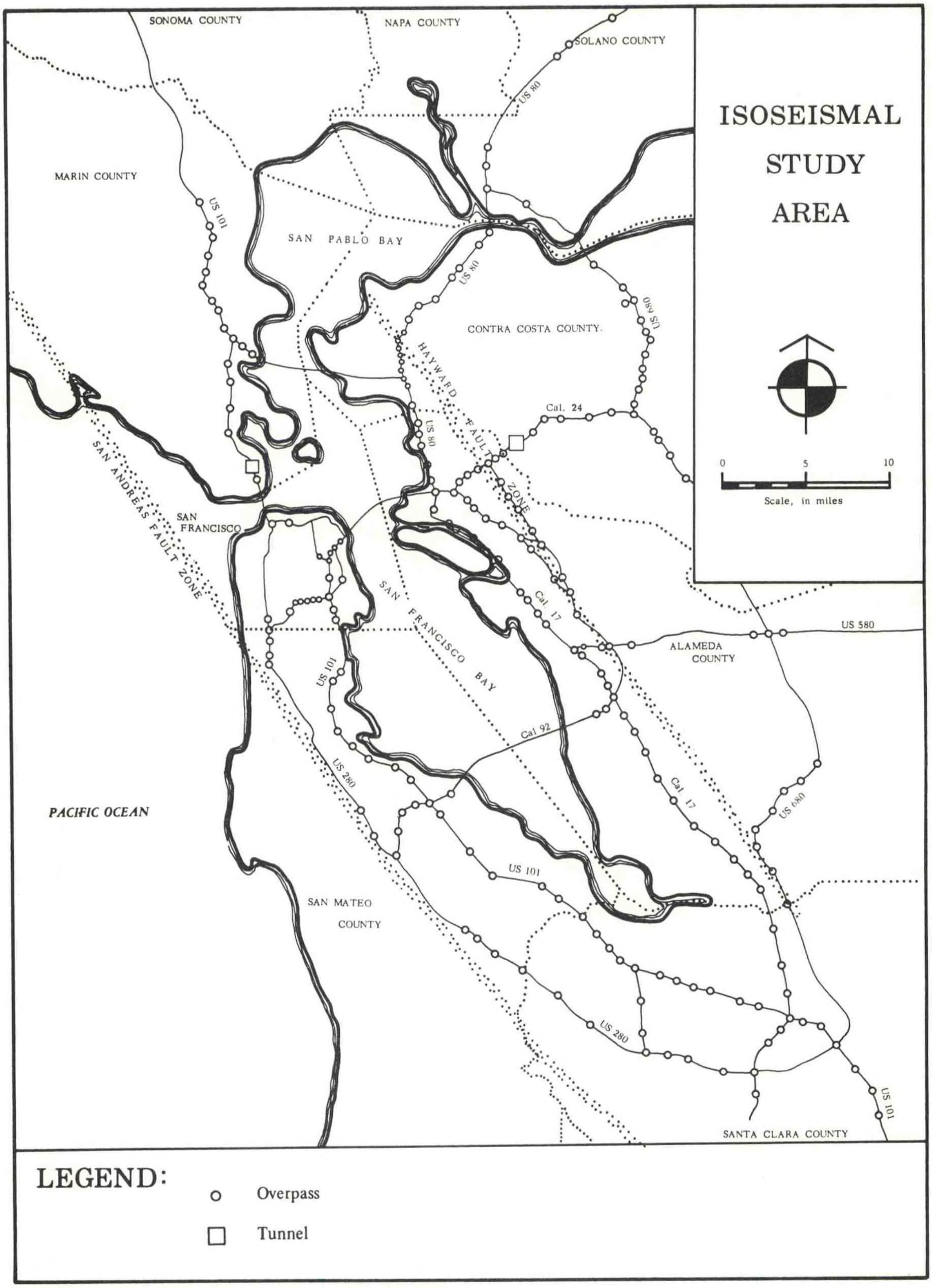


FIGURE 19. Overpasses on major freeway routes. Locations are approximate with respect to fault zones.

of intensified freeway damage was partially related to permanent changes in the length of the ground surface or entirely due to ground vibration. However, it was clearly evident that many of the design details and lateral force design standards will require major modifications since the existing standards were patently inadequate. The 1971 San Fernando earthquake experience provides a reasonable basis for evaluating the probable performance of freeway structures in the study area.

The bridges which cross the Bay pose special problems. The number of bridges are few (Figure 18) and thus statistically oriented statements are not satisfactory. The design and construction of all bridges was the best that the state of the art of earthquake engineering permitted at the times when they were built. However, there has been substantial progress in earthquake engineering in recent years, and undoubtedly the design would be different if prepared today. Lastly, no high intensity earthquake experience exists to back up the theoretical bases for their designs; the 1957 San Francisco shock was of low intensity at all bridges in the study area. Additionally, the Tacoma Narrows Bridge in the Puget Sound area has only experienced moderate shaking.

Easier to evaluate are the approach problems for the specific bridges, and these turn out to be as critical as those of the bridge for the first few weeks. The earth fills in the east approaches of the Bay Bridge appear to be subject to extensive slippage and differential settlements from strong ground motion, and the failure of these approach fills would effectively put the bridge out of operation for many days. Failure of the elevated interchange structures east of the Toll Plaza of the Bay Bridge would materially reduce the bridge's capability. In a similar fashion, the elevated approach structures on the west end of the Bay Bridge are also subject to failure based on San Fernando experience. The total collapse of the Bay Bridge in the heaviest shaking can be discounted. Yerba Buena Island effectively divides the bridge into 2 structures from an earthquake standpoint. The center span anchorage on the west (suspension) side will tend to further isolate damage. Whether it be direct damage to the Bay Bridge itself or failure of the approach fills and/or structures, for planning purposes the Bay Bridge is very vulnerable in major earthquakes.

Similar problems exist for the San Mateo Bridge and Dumbarton Bridge, but the seriousness of the problems is somewhat less than for the Bay Bridge. The miles of trestle allow for quicker temporary repair, although the ship channel areas remain more vulnerable.

The Golden Gate Bridge approaches on the north side are vulnerable to major landslides, particularly in the wet season, and virtually complete halt to bridge traffic is possible from landslides. The safety of the bridge was questioned in a storm of controversy when it was constructed, and this will probably not be fully resolved to the satisfaction of many until the "moment of truth" comes in a great shock.

Earthquakes on the San Andreas fault--Expected Damage Patterns

With respect to Figure 19, one-fourth of the freeway structures in the counties of Marin, San Francisco, San Mateo, and Santa Clara will be impassible, or virtually so in the event of an 8.3 magnitude shock. Surface faulting will disrupt freeways in the Daly City-San Bruno-Pacifica region, and Pacifica and other coastal cities will be isolated. Effectively, then, the freeway system will be out of operation in these counties until temporary bypasses are provided around fallen or unsafe structures. US 101 between Candlestick Point and San Bruno will be out of service due to land failure. The Golden Gate Bridge, Bay Bridge, and San Mateo Bridge will be out of operation for indefinite periods due to direct damage to the bridge structures and/or approach problems. The approach problems are the more likely of the two, but are the less serious from a time duration standpoint. The highways and roadways not requiring overpasses, etc. are expected to remain sufficiently intact to provide adequate transportation facilities, although time delays will be great in some areas. Assuming wet weather, 75% of southern Marin County will be isolated due to landslides and ground failures to freeways, highways, and city streets. A few hillside residential areas near the San Andreas fault will be isolated due to landslide, but these are not expected to be major problems.

For planning purposes, a 7.0 magnitude shock will cause the failure of

5% of the overpasses. Bay bridges are expected to survive, but the approach damage will restrict the effective capacity to 50% for all bridges.

Earthquakes on the Hayward fault--Expected Damage Patterns

All of the Warren Freeway and much of the MacArthur Freeway is in (or closely adjacent to) the Hayward fault (Figure 19), and damage is expected to be excessive in a magnitude 8.3 earthquake. As a result, residential areas east of these freeways will be isolated. The San Francisco and Peninsula freeway systems probably will survive quite well in the event of an 8.3 magnitude shock on the Hayward fault; however, trucked supplies from eastern areas to the San Francisco and Peninsula cities will be subject to substantial delivery delays due to the disruption of normal transportation routes.

For planning purposes in the event of an 8.3 magnitude shock on the Hayward fault, 50% of the freeway structures within 10 miles of either side of the fault will be out of service immediately after the earthquake. The Eastshore Freeway (Interstate 80) will be out of service for an indefinite period of time in Oakland, Emeryville, and Berkeley due to ground failures. Freeway pavements will be offset by horizontal fault movement, but required repairs are expected to be easily accomplished.

The Caldecott Tunnels on State Route 24 will remain servicable, but the highway will be out due to landslides on the assumption of wet season conditions. U.S. 50 near Castro Valley will be out due to landslides. Most other routes will also be out. Effectively, then, the communities of Martinez, Concord, Walnut Creek, Pleasanton, and others east of the Berkeley Hills will be isolated from Oakland, Berkeley, etc. for a day or two.

For planning purposes, the Richmond-San Rafael Bridge, the Bay Bridge, and the San Mateo Bridge will be out of service for an indefinite period of time in the event of an 8.3 magnitude shock.

Transportation routes to and from the city of Alameda will be essentially closed down for 24 hours, and then partially restored. The tubes under the estuary will be considered to be out of service for an indefinite period of time.

A magnitude 7.0 shock will cause similar damage along the Warren and MacArthur freeways since it makes little difference if an elevated structure is offset by 3 feet of faulting or by 6 feet of faulting--damage is serious in either case. Therefore, consequential effects will remain the same, i.e., isolated residential areas to the east.

General Comments

While the freeway system is expected to be seriously damaged in 8.3 magnitude shocks, experience has shown that alternate routes are quickly developed by those needing to travel locally. While local transportation delays will be long and quite troublesome, most of the confusion is expected to be over in several days.

However, the postulated damage to the bridges which cross the Bay and/or bridge approaches poses a much greater and significant problem since practical alternate routes do not exist other than driving around the Bay--and this is hardly feasible.

In the first two days after an 8.3 magnitude shock on the Hayward fault, US 101 south of San Jose should be considered as being available for service while all east-west and northern major highways will be considered closed. A comparable shock on the San Andreas fault will create substantially fewer problems.

Mass Public Transportation

Public transportation via air, rail, bus, and private automobiles is covered in other sections of this report. However, the rapid transit system (Bay Area Rapid Transit District, hereafter referred to as BART) is nearly complete and almost ready for partial operation at this writing, and the potential importance of this system requires that attention be given to it.

Figure 20 shows the location of the rail facilities which belong to the BART system, including elevated lines, surface lines, tunnel lines, and the line in the tube under the Bay.

The seismic hazards to the BART system have been competently studied and major efforts have been taken to reduce the hazards. Special research was conducted on the seismic stability of the Bay muds in which the underwater tube has been constructed. Records from small earthquakes and their effects on Bay

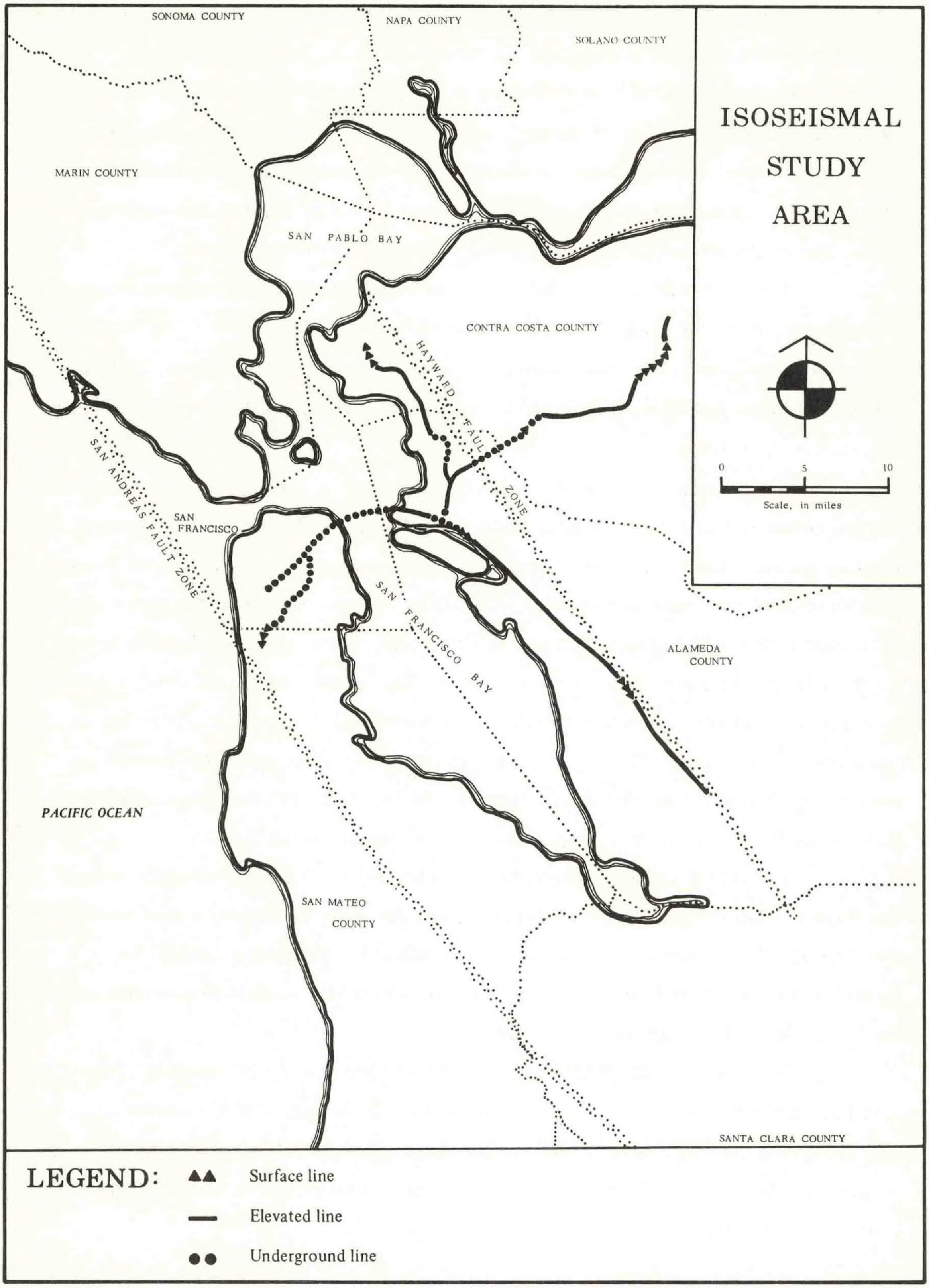


FIGURE 20. Bay Area Rapid Transit System (BART). Locations are <u>approximate</u> with respect to fault zones.

muds were extrapolated manyfold. The quality of design and construction have been superior from a seismic standpoint; the tube beneath the Bay represents a carefully and conservatively designed project. It is believed that the procedures used followed the best state of the art, and no improvements are being suggested. On the other hand, a much more comfortable feeling would exist if recorded strong motion data were in existence which would reliably quantify the motions which Bay muds will experience in a great earthquake of long duration.

The underwater tube, then, must be considered as a carefully conceived experiment, but only time will tell if experience confirms theory. Therefore for planning purposes, the tube under the Bay will be considered out of service for an indefinite period of time in the event of a magnitude 8.3 earthquake on the Hayward or San Andreas fault.

Many miles of elevated track are supported by precast concrete beams in turn supported by poured-in-place concrete columns. There are some similarities between the probable earthquake performance of the elevated rapid transit structures and the freeway structure performance in the San Fernando shock, but BART structure will perform better. Additionally, many miles of elevated track go through areas of structurally poor ground. Therefore, it is quite reasonable to expect a number of elevated structures damaged or down, albeit a very small percentage of the total. This type of disruption is expected in the San Francisco area for an 8.3 magnitude shock on the San Andreas fault and throughout the East Bay Cities for an 8.3 or 7.0 magnitude shock on the Hayward fault.

The BART tunnel through the Berkeley Hills in Oakland crosses through the Hayward fault. The BART system contains special provisions to accomodate some fault offset to the tunnel, but it is reasonable for planning purposes to consider the tunnel shattered and completely blocked off for faulting accompanying an 8.3, 7.0, or 6.0 magnitude earthquake.

In summary, the BART system will be closed down on the side of the Bay having the 8.3 or 7.0 magnitude earthquake. However, a 6.0 magnitude earthquake on the San Andreas fault would not cause major damage, while the same magnitude shock on the Hayward fault would cause disruptions in the East Bay portions of the system.

Airports

Within the study area there are 10 public and 4 military airports, distributed geographically as shown in Figure 21.

The 1957 San Francisco earthquake had a magnitude of 5.3 and caused only minor nuisance damage at the San Francisco airport; the airport is located on structurally poor ground about 10 miles southeast of the epicentral region of the 1957 shock. Slowly occurring differential settlements around buildings were accentuated by the earthquake, and a number of underground pipelines broke as a result. Some minor structural damage occurred to several buildings, but no runway damage is known to the authors.

The great Alaskan earthquake of 1964, with its 8.4 magnitude, provides a reasonable guideline for experience data from a great shock. A total of 13 airports were found to have had runway or taxiway damage out of 64 airports which were inspected. 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 the Anchorage International Airport required the use of radios in a grounded plane for air traffic control.

Runways remained functional at airports in the San Fernando Valley after the 1971 San Fernando shock.

The foregoing incomplete experience record is rather reassuring with respect to the most important function of an airport, namely, to allow airplanes to land and to take off with people and goods.

Earthquake damage to airports can be divided into (A) damage to buildings and structures and into (B) damage to runways and taxiways. Damage to structures, in turn, can be subdivided into (a) damage to structures vital to the operational aspects such as control towers, fuel tanks and similar features and (b) damage to the less important service structures. While detailed information was obtained on the construction of a large number of airport buildings and it is reasonable to expect serious structural damage to some of the buildings, the emphasis of the following paragraphs is on the damage to runways and taxiways. In other words,

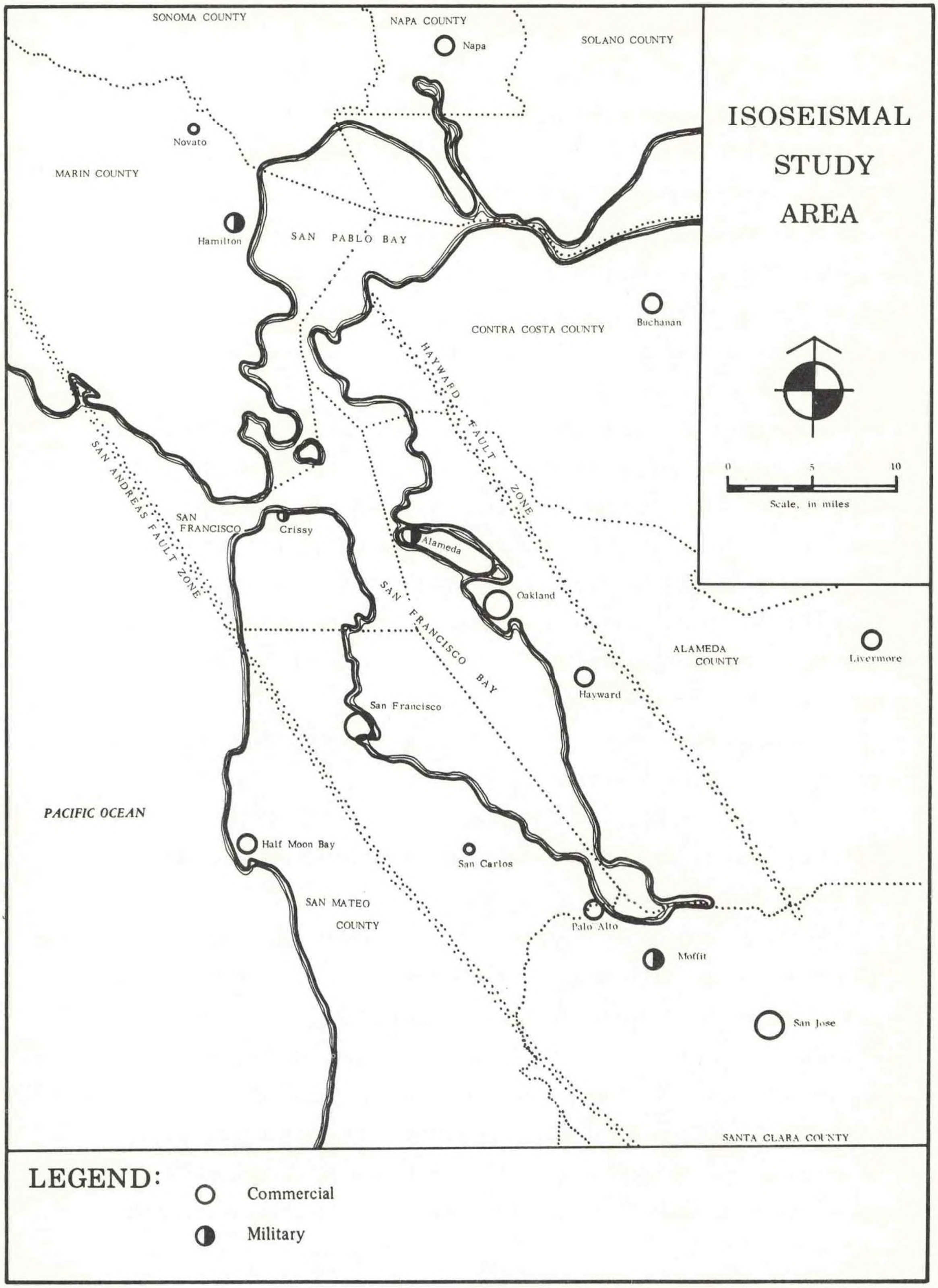


FIGURE 21. Airports.

we are relying on the ability of airports to remain functional after a disaster despite inconveniences and trusting to the leadership abilities of control tower management to find alternate and non-standard methods of communication.

San Francisco International Airport, Oakland International Airport, and Alameda Naval Airbase Airport are in regions of structurally poor ground (Bay mud areas), and Hamilton Air Force Base Airport soils are open to some question from a structural standpoint. In the event of high intensities at these four airports, the runways will be considered to be badly broken for planning purposes even though experience does not fully confirm this. The runways on the other airports are expected to remain in operation, or become operational again in hours.

Earthquakes on the San Andreas fault--Expected Damage Patterns

For planning purposes, a magnitude 8.3 shock will close down the San Francisco International Airport, Oakland International Airport, Alameda Naval Airbase Airport, and Hamilton Air Force Base Airport. The non-operational period is expected to be in terms of weeks for the first mentioned airport, and with the others down for not longer than a week. Practical land access will not exist to San Francisco airport due to freeway and highway damage which will effectively isolate the airport and nearby facilities.

A 7.0 magnitude earthquake is expected to close down only the San Francisco International Airport for several days, while a 6.0 magnitude shock is expected to leave all runways operational within hours at most.

Earthquakes on the Hayward fault--Expected Damage Patterns

For planning purposes, a magnitude 8.3 shock will close down the San Francisco International Airport, Oakland International Airport, Alameda Naval Airbase Airport, and Hamilton Air Force Base Airport. The non-operational period is expected to be in terms of weeks for Oakland International Airport and for the Alameda Naval Airbase Airports, with less than a week for the other two. Practical land access will be severely restricted to the Oakland and Alameda airports due to freeway and roadway damage.

A 7.0 magnitude earthquake is expected to close down only the Oakland

International Airport and the Alameda Airbase Airport for several days, while a 6.0 magnitude shock is expected to delay operations for not more than a few hours.

Staging Areas

The undamaged airports are all potential staging areas. For conservative planning, Travis Air Force Base will be available. Undoubtedly, smaller ones such as Buchannon Field in Contra Costa County will also be usable.

Port Facilities

The docks, cranes, and other components which comprise the port facilities for the metropolitan San Francisco area are extensive and found throughout the study area with, however, major concentrations of facilities in San Francisco and Oakland.

Extensive port facilities existed in San Francisco at the time of the 1906 earthquake. The earthquake performance of the pile supported docks along San Francisco's waterfront was excellent, although the soil in some fills nearby settled in terms of feet. Pile supported docks have generally performed well in earthquakes; the major exceptions in the 1964 Alaskan earthquake were due to submarine landslides and similar conditions which do not exist in the post facilities of the study area.

On the other hand, quay wall facilities have not performed comparatively well. (Quay wall facilities are docks which consist of waterfront walls with earthen fills behind them.) One quay wall failed in the Puget Sound earthquake of April 29, 1965; large walls failed in Puerto Montt (Chile) in 1960, in Tokyo in 1923, in Niigata in 1964, and in many other shocks. These failures have generally been attributed to the liquefaction of the soils behind the quay walls, forcing the walls outward due to the liquefied soil pressures.

The majority of the docks in the study area are pile supported. Overall, the port facilities are not expected to be greatly affected insofar as the pile supported docks are concerned. However, cranes will be thrown off their rails in many cases. Pipelines from storage tanks to docks may be ruptured where they cross poor ground areas in the vicinity of docks. Restricted access to docks due to the failure of approach fills and nearby freeways will be more common than significant damage to the pile supported docks.

Earthquakes on the San Andreas fault--Expected Damage Patterns

In the event of an 8.3 magnitude shock, the damage to port facilities on the San Francisco peninsula will be principally due to the derailment of cranes, damage to approach streets located in the structurally poor ground areas, and damage to quay walls. The overall effect is not expected to impair the efficiency of the study area port facilities by more than 15%. Lesser magnitude earthquakes will have substantially lesser effects. Access to ports due to collapsed freeway structures and land failures is expected to be more serious than damage to docks.

Earthquakes on the Hayward fault--Expected Damage Patterns

In the event of an 8.3 magnitude shock, the damage to the port facilities will be principally derived from quay wall dock failure and the derailment of cranes, including those for containerized cargoes. This damage will be principally distributed throughout the western half of Alameda and Contra Costa counties. The north end of the Hayward fault at San Pablo Bay passes close to waterfront located oil refineries in Richmond and Rodeo. Damage is expected to the refineries and their storage tanks, and to a lesser extent to their port facilities. The possibility of rupture to oil tanks and their dikes is reasonable in a few cases, thereby allowing oil to escape to the Bay. (This hazard has not been fully evaluated since it is beyond the scope of this study.)

The army and navy installations clustered in Oakland and Alameda are in regions of structurally poor ground and on questionable man-made fills. It is reasonable to expect serious soil displacements in these areas, and these facilities can be expected to be out of service immediately after the earthquake.

Except as stated above, the overall effects of an 8.3 magnitude earthquake is not expected to impair the facilities of the study area port facilities by more than 15%. San Francisco facilities are expected to remain operational. Restricted access to docks due to the failure of approved fills and nearby freeways will be more common than significant damage to the pile supported docks.

A 7.0 magnitude earthquake probably will not impair the overall port facilities by more than 10%, but the possibility of oil leakage as described above is expected to remain largely unchanged.

Public Utilities

DATA COLLECTION

The principal sources of data were:

Pacific Gas & Electric Company
San Francisco Public Utilities Commission
San Francisco Water Department
East Bay Municipal Utility District
San Francisco Municipal Sewage System
Regional Water Quality Control Board

Data were obtained which permitted the mapping of the locations of:

(a). Electric power generating plants and transmission routes,
(b). Natural gas terminals and transmission lines,
(c). Fresh water supply pipelines and aqueducts,
(d). Sewage treatment plants and outfalls, and
(e). Petroleum pipelines.

General information on public utilities was available on a regional basis through the Bay Conservation and Development Commission (BCDC) in its publication, "Public Facilities and Utilities in and Around the San Francisco Bay," June 1967. Specific back-up data was received through interviews with individual staff representatives of the various public utility companies in the area, and detailed maps and written reports were made available by them.

The Pacific Gas and Electric Company (PG&E), as the principal distributor of electric energy in the area, provides electric power for an area that includes the 9 San Francisco Bay Area counties. PG&E has a total of 80 generating plants in California; 66 are hydroelectric and 14 are steam-electric. Of the 14 steam-electric plants operated by PG&E, six are located on the shores of San Francisco Bay and three others supply power primarily to the industries where they are located in the interior.

The San Francisco Bay Area draws its domestic fresh water supply from several sources within and outside the study area. Local resources serve mostly the North Bay area while the other areas generally rely on supplies imported from elsewhere. The two largest of water supply agencies are the San Francisco Water Department and the East Bay Municipal Utility District. Approximately 4/5 of the San Francisco Water Department supply comes from the Tuolumne River watershed in Yosemite National Park; this is part of the Hetch Hetchy aqueduct system.

There are 66 major sewage treatment plants in the San Francisco Bay Area, and San Francisco Bay itself is the recipient of the treated sewage produced by more than 80% of the total 9 county area. These treatment plants, as of 1967, served an estimated 3.7 million people as well as the many major industries located in the area. The largest single plant in the San Francisco Bay Area is operated by the East Bay Municipal Utility District near the city of Oakland close to the Oakland-San Francisco Bay Bridge approaches. The plant serves an estimated 610,000 people and a considerable amount of industry.

Natural gas is supplied to central and northern California by the Pacific Gas and Electric Company (PG&E).

ANALYSIS

Public utility systems, whether publicly or privately owned, generally are designed and operated in a manner intended to allow the systems to remain in a functioning condition after a disaster. This has been particularly true of the public utilities in the study area of this report. In the case of the Pacific Gas and Electric Company (among others), the corporation designs their installations to meet a static earthquake force which is twice that required by building codes and they have done this for decades. For another example, two Hetch-Hetchy water supply aqueducts (constructed in 1925 and 1935, being respectively 60-inch and 66-inch diameter lines) where they cross the Hayward fault in the City of Fremont were constructed with pairs of expansion joints. In recent years, the East Bay Municipal

Utility District has placed additional storage reservoirs on both sides of the Hayward fault with at least a partial view towards minimizing the effects of pipe breakage as a result of earthquake effects. Many other examples of similar advanced planning can be cited.

However, earthquake forces and their effects are still imperfectly known. Additionally, certain geologic hazards can, at best, be only minimized. Utilities must cross earthquake faults. Facilities must sometimes be located in structurally poor ground areas such as in potential landslide regions and on liquefiable sands placed over San Francisco Bay muds.

Southern California utilities generally follow the same earthquake resistive practices as do those in northern California. However, the moderate earthquake of February 9, 1971 in San Fernando caused serious disruption to utility facilities which required weeks to partially ameliorate despite no significant supply or manpower problems. For one example, the City of San Fernando did not have a temporarily completed above ground water system until 11 days after the shock. Electric power was out for days in some areas. The telephone system was out over a wide area due to equipment collapse in a central station.*

Experience from the 1971 San Fernando shock and from other earthquakes has shown that the superior earthquake resistive precautions which are practiced by the public utilities do substantially reduce the earthquake hazard, but certainly do not eliminate it.

In some instances, the paragraphs that follow will be limited to generalized problem types for the entire area, and often not specify the "out of service" time. The "down" time for a particular location for a particular utility will be a function of not only the utility's resources, but the priorities established by government. In an 8.3 magnitude earthquake, the extent of the damage will create manpower and supply demands, along with their support facilities, which will vastly surpass the 1971 San Fernando earthquake demands.

---

*See, for example, pp. 80/91, "San Fernando Earthquake, February 9, 1971," Pacific Fire Rating Bureau (1971).

Water Supply

The discussion of earthquakes on the San Andreas fault is limited to the Hetch-Hetchy water system which supplies San Francisco and a number of municipal utilities in San Mateo, Santa Clara and Alameda counties. Water is obtained from the Sierra Nevada Mountains and from the Santa Cruz Mountains. The principal local storage is the San Andreas reservoir and the Crystal Springs reservoir, both located on the San Francisco Peninsula (Figure 22). Water from these two reservoirs, both on the San Andreas fault, is transmitted to San Francisco through 5 aqueducts to moderate size reservoirs and water tanks in that city.

Figure 22 shows the location of the Hetch-Hetchy aqueducts and the two reservoirs with respect to the San Andreas fault in San Mateo County. It will be noted that the aqueducts cross the Hayward fault, but not the San Andreas fault.

The 1906 San Francisco earthquake, with its 8.3 magnitude shock, is an excellent guide to expected future performance since most of the present facilities follow the routes in existence in 1906. Additionally, the present dams and reservoirs excellently survived the 1906 disaster. (Problems relating to the major storage dams are discussed in the section relating to dams.)

Magnitude 8.3 on the San Andreas Fault--Expected Damage Pattern

The Hetch-Hetchy aqueducts can be reasonably expected to deliver water to the Peninsula reservoirs, and these reservoirs can be expected to remain intact. Quickly repairable damage is likely where one conduit enters an underwater crossing of San Francisco Bay. For planning purposes, half of the aqueduct supply from the San Andreas and Crystal Springs reservoirs should be assumed to be out of service for a week; however, as in 1906, the storage reservoirs located in San Francisco will function. Indeed, the performance of the San Francisco water system in an 8.3 magnitude shock is expected to be substantially better than the 1906 experience.

Distribution system damage and water outages within San Francisco will be heavily accentuated in the structurally poor ground areas which border the Bay in an irregular fashion (Figure 23), just as occurred in 1906. Detailed maps

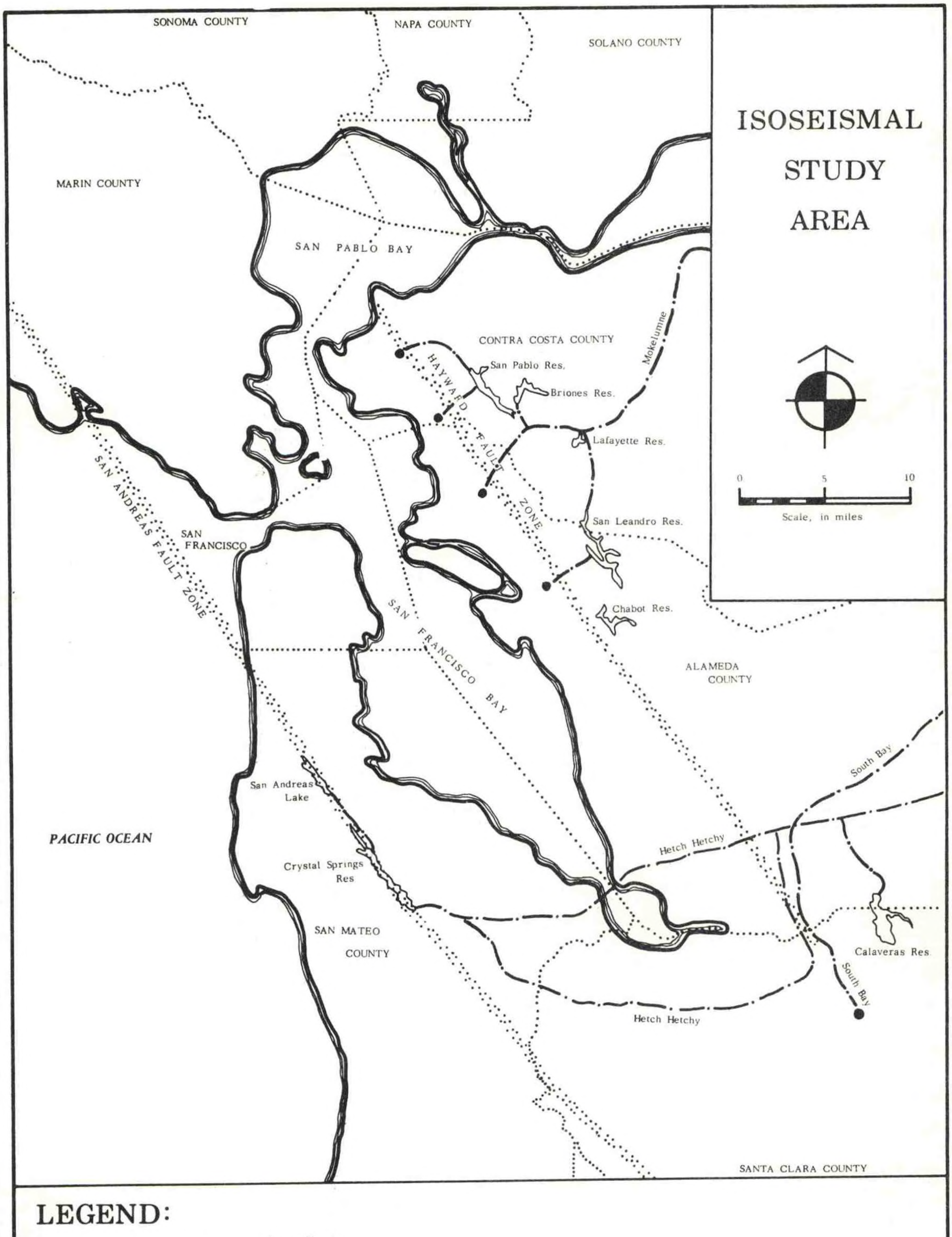


FIGURE 22. Some major aqueducts and reservoirs. Locations are approximate with respect to fault zones.

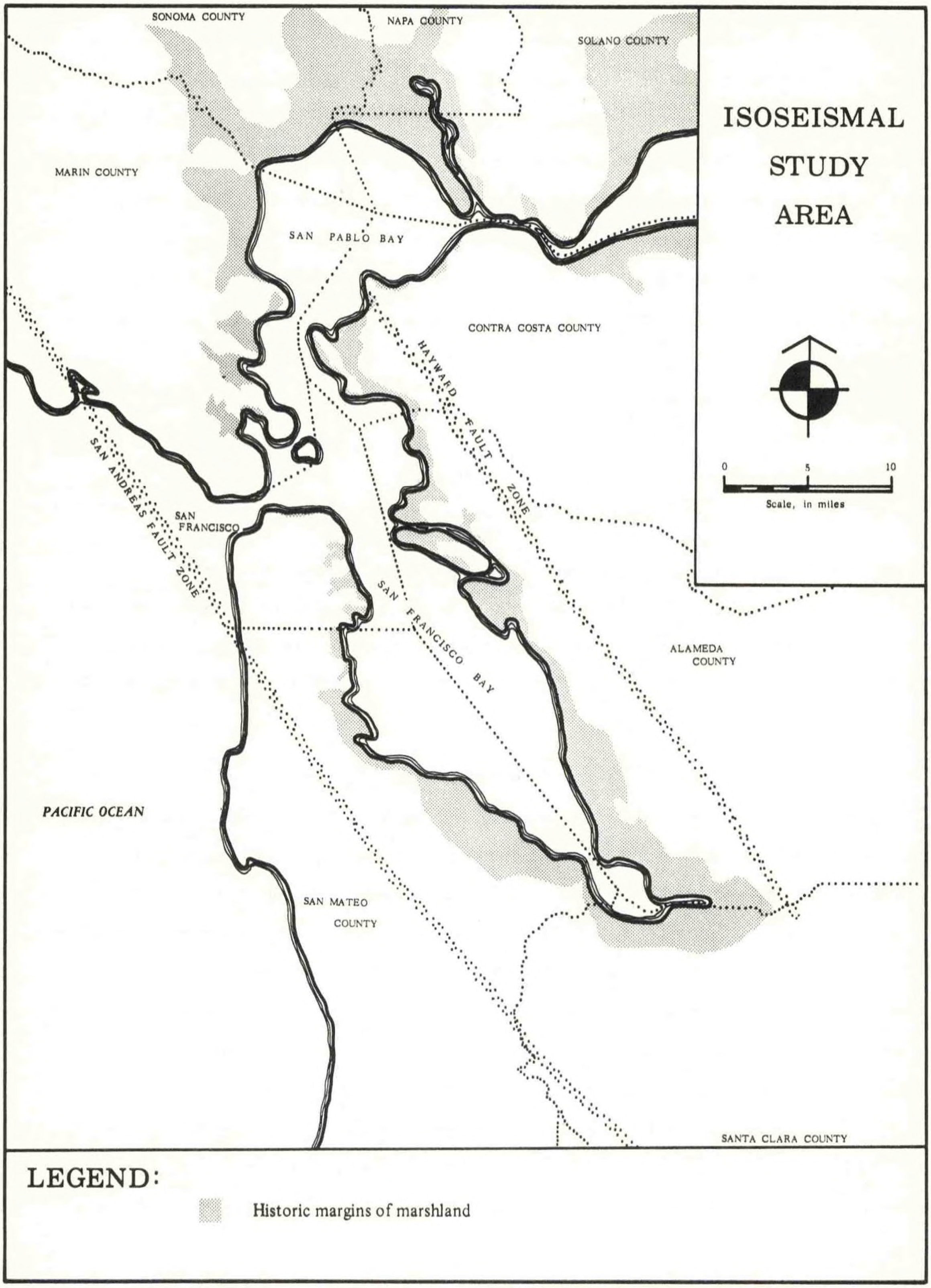


FIGURE 23. Historic margins of Bay marshlands.

of the expected problem areas are shown in the various references to this report and the maps need not be repeated here. However, the anticipated good use of improved valving systems is expected to substantially reduce the loss of water due to broken mains. Similar water outages can be expected along all of the industrial and residential regions within the poor ground areas along the Bay from San Francisco to San Jose (Figure 23). 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, and accessability. For scenario purposes, 90% of the water outages in these poor ground areas should be restored within 3 weeks by above ground piping similar to that which was used in San Fernando.

Damage to facilities in counties other than San Francisco, Santa Clara, San Mateo, and Marin is expected to be nominal.

Magnitude 7 and 6 on the San Andreas fault--Expected Damage Pattern

The damage from these postulated earthquakes will be substantially less, and may be more of nuisance than a major problem, except for the structurally poor ground areas along the west shores of San Francisco Bay where outages will be common.

Earthquakes on the Hayward fault--Expected Damage Pattern

The discussion of earthquakes on the Hayward fault is limited to the East Bay Municipal Utility District (EBMUD) system which supplies all built-up areas in Oakland and the neighboring communities in Alameda and Contra Costa counties. The water supply comes from the Sierra Nevada Mountains, is stored in reservoirs which are located east of the Hayward fault, and is then transmitted to the bulk of the distribution system through 4 conduits which cross the Hayward fault (Figure 22). Two conduits are tunnels where they cross the fault and two are near ground level. Creep on the Hayward fault has offset one tunnel by over 6 inches.

It is evident that any significant length of movement on the Hayward fault will disrupt many or all aqueducts (Figure 22). It is reasonable to assume for planning purposes that all aqueducts will fail or be badly ruptured in the magnitude

8.3 and 7.0 shocks. Some may still be able to transmit small amounts of water. However, for scenario purposes, the water supplied by conduits will be assumed to be reduced to 5% for 24 hours, then to 20% of capacity after 24 hours. In the magnitude 6.0 shock, all lines will be assumed to function at 80% of capacity.

The situation for most of the area served by EBMUD is much more critical than that for San Francisco in the event of similar magnitude shocks on the San Andreas fault. This is because the Hayward faulting will isolate the main EBMUD storage areas from its main distribution system; this problem is evident from an examination of Figure 22. In addition to the loss of water supply due to ruptured aqueducts, many distribution lines cross the fault, and these will also be ruptured. Therefore, the hillside areas of Oakland, Berkeley, Richmond, El Cerrito, and San Leandro will be in double jeopardy. To counter this, major efforts have been made by EBMUD to increase their storage capacity west of the fault and within their distribution system. However, a reasonable approach for scenario purposes is to assume that the hillside areas east of the fault of the aforementioned cities will be without water, some immediately and others within several days when their local storage reservoir runs dry.

By comparison, San Francisco and the Peninsula communities are fortunate with respect to a major Hayward fault earthquake since these cities will have large water supplies available in the San Andreas and Crystal Springs reservoirs, and this storage represents an adequate supply until the fault ruptured aqueducts are repaired. However, no cross connection exists to allow the use of this water by EBMUD.

Accentuated damage to the distribution system will occur in the structurally poor ground areas of the East Bay (Figure 23), but only nuisance damage in similar poor ground areas across the bay is expected.

Some local reservoirs throughout the distribution area will also be damaged. Some of the older and larger earthen reservoirs could fail and this result in lives lost as well as property damage.

Due to geological and geographic conditions beyond the control of the water utilities serving the East Bay cities and not due to bad planning, the water supply systems are expected to be severely crippled in a great earthquake and full permanent restoration of service could reasonably take half a year. The foregoing had included the possibility of storage dam failure which is discussed elsewhere.

Natural Gas

Earthquakes on the San Andreas fault--Expected Damage Pattern

For planning purposes, an 8.3 magnitude shock on the San Andreas fault probably will not cause excessive damage to the natural gas system, although localized outages will require extensive repair periods. No transmission lines will be sheared or ruptured by faulting (Figure 24). However, the transmission lines do pass through potentially unstable ground regions along San Francisco Bay. For planning purposes, the transmission line skirting the west side of the Bay is estimated to be out of service due to ground failure. Distribution system breaks will follow the damage patterns of the water distribution system discussed in previous paragraphs.

Lesser magnitude earthquakes are expected to cause damage only to the distribution system, similar to patterns to be found in the water distribution system.

Large gas holders (cylindrical steel gas containers which dominate the local skyline) have performed very well in earthquakes despite their large and massive appearance. However, for the purpose of scenarios, one such holder should be considered out of service in San Francisco in the event of a magnitude 8.3 shock on the San Andreas fault. No significant down time is to be anticipated for lesser shocks on the San Andreas fault.

Earthquakes on the Hayward fault--Expected Damage Pattern

Figure 24 shows that numerous gas transmission lines cross the Hayward fault. All lines are expected to fail due to the significant fault movements expected in 8.3 and 7.0 magnitude earthquakes. Two are expected to fail in a magnitude 6.0 shock.

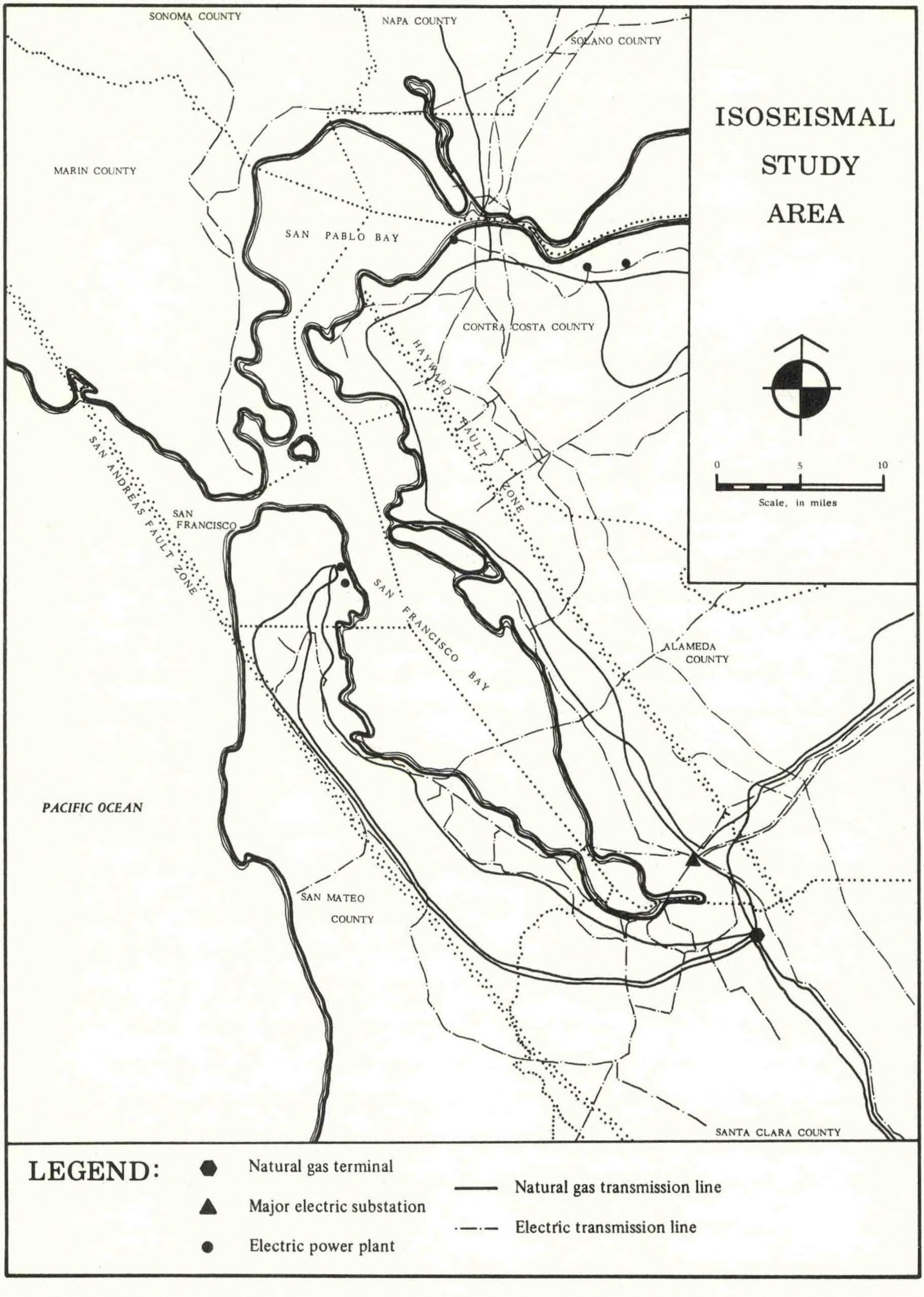


FIGURE 24. Major natural gas and electric power transmission facilities. Locations are approximate with respect to fault zones.

Distribution system damage will follow that of the water distribution system. Dwelling and other facilities on the east side of the fault in the communities of Oakland, Berkeley, Richmond, El Cerrito, Hayward, and San Leandro will be without service for extended periods of time.

One gas holder is expected to be out of service in Oakland in the event of a magnitude 8.3 shock on the Hayward fault. No significant down time is anticipated for lesser shocks on the Hayward fault.

Electric Power

Electric power facilities will be damaged and power failure will be general throughout the study area for a magnitude 8.3 shock on either fault. For scenario purposes, an 8.3 magnitude earthquake on the San Andreas fault will require the use of all standby power facilities throughout San Francisco, San Mateo and Santa Clara counties, and 50% of standby power facilities in Marin, Contra Costa, and Alameda counties. For a similar shock on the Hayward fault, all standby power will be required for the East Bay cities and Santa Clara county.

Sufficient damage will occur to power generating facilities in the San Francisco and Moss Landing sites to require shut-down. Other major generating facilities are expected to remain operational. Transmission lines bringing power from outside of the study area will tangle, resulting in relatively short duration power failures (Figure 24). Despite their good anchorages to power poles, to rails, and the like, many hundreds of transformers will be knocked out, and some will burn as they have in other earthquakes. Switchgear damage will result in serious power outages. Failures of porcelain insulators will additionally result in significant numbers of power failures. Some electrical facilities, such as that located in the Hayward fault zone where State Highway 24 intersects it, will be completely out of service if a major earthquake occurs on the Hayward fault.

It is difficult to give reliable outage time estimates. The Pacific Gas and Electric System is well engineered from an earthquake standpoint, has substantial reserves of manpower and material, and has responded well to previous earthquake disasters. However, 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 blackout a few years ago in the northeastern states.

It is reasonable for planning purposes to consider 50% of the service connections in the study area to be without power for 24 hours after a magnitude 8.3 shock on either the San Andreas or Hayward faults. In the congested portions of San Francisco and Oakland, the power outage should be considered at 100% for 24 hours, and thereafter at 75% for an additional 24 hours. Magnitude 7 shocks are estimated to create only half of the problems of 8.3 shocks. Magnitude 6 shocks are not expected to create major problems.

Sewage

Collection Systems

Sewerage systems are, of course, found throughout the populated areas. The flow in the various independent systems is generally by gravity to a treatment plant, and then by outfall sewer to the Bay. Exceptions are several smaller jurisdictions which have oxidation ponds and therefore their discharge does not go into the Bay. A few pumping plants exist, and power failures will cause some comparatively minor problems with raw sewage disposal.

It is of value to review the 1906 earthquake experience with respect to the sewers in San Francisco. The following is quoted from "Trans. Am. Soc. C. E.," Vol. 59:214 (1907):

> In the rocky portions of San Francisco the sewers were not affected. In portions where the rock was overlaid with sand, there were no permanent displacements except where the original ground supported a fill; in such areas settlements occurred, and the sewers were destroyed. In filled-in tidal areas, marsh-lands and swamps there was considerable movement in a number of places (the greatest near 16th St.

and Valencia St., where the settlement was 5 ft. and lateral movement 6 ft.) and in all such disturbed areas the sewers were destroyed.

Surface faulting is only a comparatively minor problem on the San Andreas fault. Principally affected will be Daly City and the nearby communities built in and near the San Andreas fault zone. On the other hand, major ground breakage on the Hayward fault is likely to result in the rupture of hundreds if not thousands of lines throughout the cities of Oakland, Hayward, San Leandro, Richmond, Berkeley, among others. The locations of the fault caused ruptures in the collection systems will be in a narrow zone for each fault.

Elsewhere, damage will be mainly a function of the soil conditions, and the damage patterns will follow those of the water distribution systems. See Figure 23 for the location of poor ground areas around San Francisco Bay. During the wet season, landslides will substantially increase the sewer system damage in localized hillside areas, but these are not expected to be major problems.

Experience from landslides has shown that the sewer line breaks can be dug out and the sewerage allowed to flow in open cuts in fault zones if necessary. This raw sewerage may be a health hazard, but this should not be an insurmountable problem.

For planning purposes, the damage patterns previously given for water distribution systems also apply here, except that the outage time can be substantially less. From a practical standpoint, the sanitary sewer collection lines will not require significant use until the adjacent water distribution systems are restored.

Treatment Plants and Sewer Outfalls

Figure 25 shows the locations of treatment plants and their outfall sewers. Earthquake faulting is a minor problem compared to structurally poor ground (compare Figure 25 with that showing the areas of poor ground, Figure 23).

In earthquakes, the sloshing of liquids in tanks and other containers has often damaged baffles and other equipment, and in some cases reinforced concrete

9~

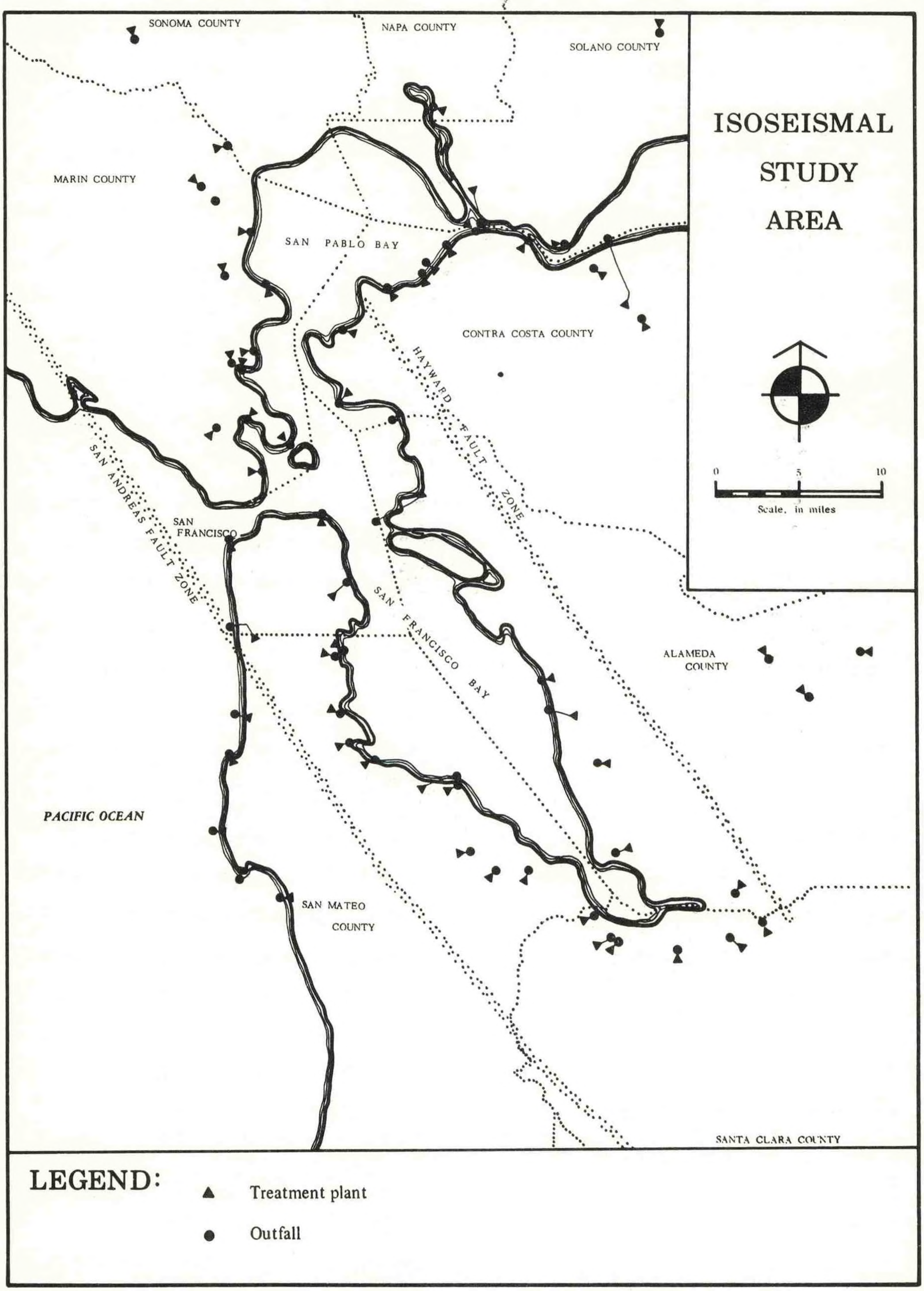


FIGURE 25. Sewage treatment plants and outfalls.

has failed. Equipment, panel boards, chlorine tanks, etc. are often poorly anchored and will topple in some cases. In poor ground areas, the treatment plant structures may be on piling while the pipe lines may not be. Differential settlements can, and have, caused pipe line damage where these lines enter or leave structures. For any one of the foregoing reasons, the immediate solution is to bypass the treatment plant, thereby discharging the raw sewage into the Bay.

For planning purposes in the event of an 8.3 magnitude earthquake on the Hayward fault, two-thirds of the raw sewage produced in Alameda, Contra Costa, and Santa Clara counties will be assumed to be discharged into the Bay.

For planning purposes in the event of an 8.3 magnitude earthquake on the San Andreas fault, two-thirds of the raw sewage produced in San Francisco, San Mateo, and Santa Clara counties will be assumed to be discharged into the Bay.

Lesser magnitude earthquakes are not expected to create major problems.

Petroleum Pipelines

From the standpoint of the San Andreas fault, there are no petroleum lines across this fault, and accordingly no problem exists. However, all major products and service lines servicing the San Francisco Bay Area cross the Hayward fault. These would all be cut by any major amount of displacement from magnitude 6 up to 8.3. A magnitude 6 earthquake with minor fault displacement on the Hayward fault would result in only about 50 percent of the pipelines being affected. However, after a major earthquake with 5 to 20 feet of fault displacement, all of the lines would be affected.

There are other complicating factors related to petroleum pipelines. In so far as it is known, none of these pipelines have automatic shut-off valves. If the rupture occurs during the height of the dry season in the Berkeley Hills and other surrounding areas, fire could be a very serious problem. This could also be wide spread during the rainy season, should the petroleum ignite as it is washed downstream rapidly with storm waters into the sewers.

Figure 26 shows the location and geographic distribution of the major petroleum pipelines in the study area. Many of these pipelines cross structurally poor ground found in the marshland regions encircling the shorelines of the San Francisco Bay.

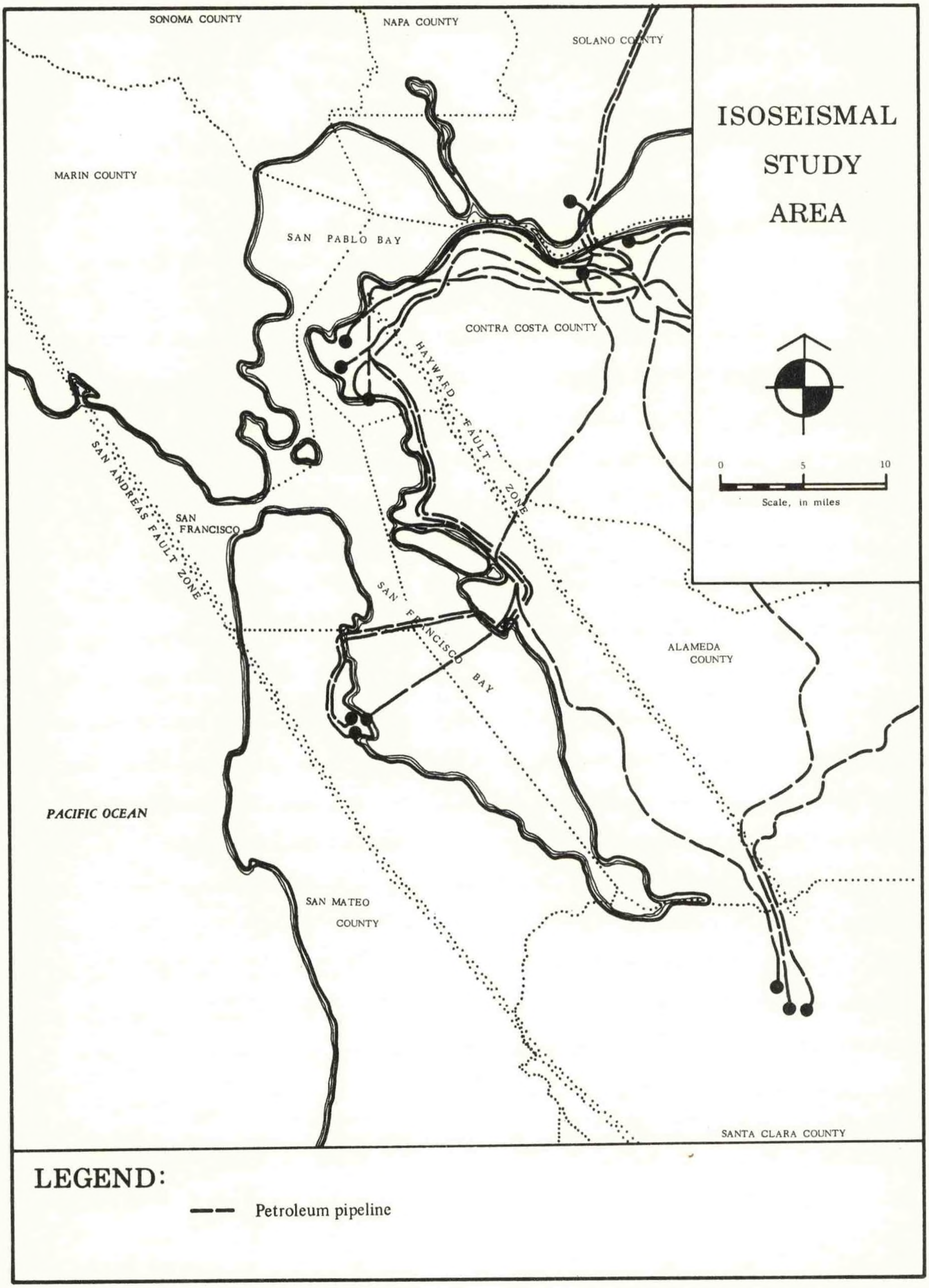


FIGURE 26. Major petroleum pipelines. Locations are approximate with respect to fault zones.

Schools

School buildings tend to be uniformly distributed throughout the populated areas and, if they remain in safe condition after an earthquake, they can and usually have provided the basis for mass shelter and feeding. This section of the report, then, deals with both the potential deaths and injuries to the student population and the availability of schools for mass housing and feeding after an earthquake.

Public schools in California have been given special legislative attention with respect to earthquake safety since the 1933 Long Beach earthquake. Had the 1933 Long Beach shock occurred during the school hours, the potential life loss and injury would have been appalling. As a result, the California Legislature passed a bill, known as the Field Act, which made a high degree of earthquake bracing mandatory for new public school buildings. It is important to recognize that the law did not include existing schools, private schools, and the University of California. Additionally, it did not prohibit the building of schools in earthquake active fault zones, although this deficiency has been recently corrected. However, the Field Act schools built in fault zones, such as the Hayward fault, still exist. While private schools and the University of California have, in general, built their new buildings in reasonable conformance to the technical provisions which supplement the Field Act, their older non-earthquake resistive buildings have been allowed to remain as is the case for public schools. (An older building, strengthened to meet the Field Act, is considered a Field Act structure.)

DATA COLLECTION

There exists a wealth of published data on school buildings. Principal among these sources were the following publications:

1. "Structurally Unsafe School Buildings," California State Department of Education, January 1971.
2. "Relative Earthquake Hazards of the Pre-Field Act School Buildings Within the San Francisco Unified School District," H. J. Degenkolb and Associates, et al., 1971.
3. "Oakland Unified School District, Estimated Cost for Replacement or Reconstruction of Non-Conforming School Buildings," Fisher, Friel, and McClure, December 1970.
4. "Statistical Abstract, Four County Bay Area Community Shelter Plan," Wilbur Smith & Assoc., May 1970.

The above mentioned reports supplied vital information which was sufficient for the analysis purposes of this report. Accordingly, no additional data were collected nor was it found to be necessary to conduct further field inspections of the various school buildings in the study area.

The Wilbur Smith report provided the name of the school, its student and teacher population, and its census tract location. Based on the consultants' knowledge of each school, the schools were classified as: 1) Public "Field Act" School, 2) Public "Pre-Field Act School, 3) Private School, or 4) College and University. The enrollment for each classification of schools was correlated with the Modified Mercalli Intensity for each specific earthquake by means of the census tract location of each school.

ANALYSIS AND SUMMARY OF POSTULATED EARTHQUAKES

The California State Department of Education released in January of 1971 the report "Structurally Unsafe School Buildings." Table 55 extracted from this report, lists the number of structurally unsafe buildings in the study area. Considering the location of the San Andreas and Hayward faults, the earthquake intensity distributions, the number of unsafe buildings, and mass feeding/housing requirements, this report has given its emphasis to the four counties of Alameda,

TABLE 55

STRUCTURALLY UNSAFE BUILDINGS

County	Number of Buildings
Alameda	60
Contra Costa	0*
Marin	3
Napa	8
San Francisco	84
San Mateo	2
Santa Clara	28
Solano	18
Sonoma	16

*One school district did not respond.

The "number of buildings" is a greater value than the "number of schools" since a school may have one or more buildings. There may also be confusion between buildings used for classes and those used for administrative purposes.

TABLE 56

FOUR COUNTY SCHOOL ENROLLMENT

County	School Type: Public "Field Act"	Public "Pre-Field Act"	Private	College & University
Alameda	231,578	31,101	18,803	38,839
Contra Costa	152,468	0	6,755	885
San Francisco	50,244	42,717	25,647	42,682
San Mateo	133,889	0	10,762	1,056
Totals	568,179	73,818	61,967	83,462

Above figures based on "Statistical Abstract, Four County Bay Area Community Shelter Plan", Wilbur Smith & Assoc., May 1970 and other sources.

The number of classrooms may be roughly approximated by dividing the enrollment figures by 30.

Contra Costa, San Francisco, and San Mateo. There will be losses in other counties, particularly in Santa Clara, but these losses are not expected to be as critical as those in the four specified counties.

Table 56 shows the enrollment distribution in the four counties by school type with particular attention paid to the Field Act and Pre-Field Act school enrollments. It is evident from those figures that about 90% of the students are in safe structures. While the remaining 10% may be in unsafe structures, some of these will be so far away from either the Hayward or the San Andreas faults as to be largely unaffected by the postulated earthquake.

The geographic distribution of the earthquake hazardous Pre-Field Act schools is quite uneven in the study area. The newer cities and the suburbs in general have few earthquake hazardous buildings, and many have none since these areas have experienced substantial development since 1933. The principal problem areas with respect to hazardous school structures are the long established cities of San Francisco and Oakland. Some details on the earthquake hazard problems to specific schools in these two cities, and the costs to repair these schools, may be found in the previously cited reports.

A Pre-Field Act school is a legally unsafe structure, but this statement by no means defines the degree of hazard or "unsafeness." Non-reinforced brick masonry bearing wall structures having sand-lime mortar are extremely vulnerable, but such structures have been largely replaced or strengthened. On the other hand, Pre-Field Act reinforced concrete structures will perform much better as a class than will non-reinforced brick masonry structures, and comparatively few collapses or severe damage are to be expected in the highest intensity areas of San Francisco and Oakland.

Unfortunately, a special problem exists with respect to schools in earthquake active fault zones. A total of 31 schools (including the University of California in Berkeley) are in or closely adjacent to the Hayward fault zone. A few of these 31 schools have structures across the fault trace and will be sheared by faulting in an earthquake. The total enrollment population of these 31 schools is

47,752, with 28,863 being at the University of California in Berkeley. In contrast, it appears that only one school is in the San Andreas fault zone, and it has an enrollment of 398.

As has been stated in previous paragraphs, the principal hazard areas are in the cities of San Francisco and Oakland. In San Francisco, 62 out of 197 schools (or 1/3) do not comply with the Field Act, and they are unsafe to one degree or another. In Oakland, 32 schools out of 90 schools (again, 1/3) don't comply with the Field Act, and are also unsafe to one degree or another. Serious damage and partial collapse of 25% of the Pre-Field Act schools is reasonable in the greatest postulated earthquakes. Three or four partial collapses, trapping hundreds of students, is a reasonable possibility.

The analysis results of the foregoing are given in Table 57. While the number of deaths and injuries may seem large to some, it must be remembered that the total collapse of even one Pre-Field Act school of multistory reinforced concrete construction can lead to life losses of several hundred.

TABLE 57

SCHOOLS

Deaths, injuries, and classroom outage in 4 counties

		County											
		Alameda			Contra Costa			San Francisco			San Mateo		
Fault	Richter Magni-tude	Deaths	Injuries	Class-room Outage	Deaths	Injuries	Class-room Outage	Deaths	Injuries	Class-room Outage	Deaths	Injuries	Class-room Outage
San Andreas	8.3	0	20	1%	0	20	1%	1,500	4,000	33%	200	600	10%
	7	0	*	**	0	*	**	250	750	10%	50	300	2%
	6	0	0	0%	0	0	0%	*	25	2%	0	10	1%
Hayward	8.3	1,000	3,000	20%	500	1,500	10%	0	20	1%	0	20	1%
	7	750	2,500	15%	400	1,200	8%	0	*	**	0	*	**
	6	100	400	2%	10	50	1%	0	0	0%	0	0	0%

"Injuries" are defined as those requiring hospitalization.

"Classroom Outage" is defined as damage to the extent that the classroom can not function.

*Several

**Negligible

Mercantile, Industrial, and Warehousing

DATA COLLECTION

Among others, the following reports were collected as source data for this section of the study:

1. "Controlled Trends" Zonal Forecasts 1965-1990, issued March 1971, Bay Area Transportation Study Commission. (For all 9 counties.)
2. Area Manpower Review, issued February 1972, Department of Human Resources Development, State of California. (For Alameda, Contra Costa, Marin, San Mateo, and San Francisco counties.)
3. Estimated Average Annual Employment by Industry, "INFO" issued May 1971, Santa Clara County Planning Department. For Santa Clara County.
4. Options for Oakland, issued December 1969, City Planning Department of Oakland. (Jobs in manufacturing, wholesale trade, and retail trade, by standard industrial classification for all 9 counties.)

Working with the various land use maps which were collected, the basic regions in the San Francisco Bay Area related to mercantile and industrial activities were mapped in their context to the Hayward and San Andreas faults. Manpower figures were tabulated and documented for each type of industry and retail and/or commercial trade. No field inspections of the building structures in this category were made, and it was found to be unnecessary to collect additional data other than that found in published reports.

Mercantile, industrial, and warehousing structures along with related types of facilities are so varied in construction types, in earthquake resistive properties, and in geographic distribution that it is impractical to list and to discuss damage patterns to them except in the general terms of isoseismal maps.

Figures 27 and 28 show the principal locations of these types of facilities.

ANALYSIS AND SUMMARY OF POSTULATED EARTHQUAKES

While no detailed evaluations of mercantile, industrial, and warehousing structures are practical, certain common types of problems to particular occupancies can be looked at. Figure 27 shows the locations of the principal mercantile areas, including shopping centers, in the isoseismal study area. By no means are all important locations shown on the map. Damage within the long established downtown mercantile areas of San Francisco, Oakland, Berkeley, Richmond, Hayward, Palo Alto, among others will be much heavier than those in the newer shopping centers located in the suburbs. Shopping habits will change after a disastrous earthquake and its customary aftershocks. The heavier than average life loss and injuries in the older shopping areas in the event of an earthquake during the shopping hours will, if past experience can be relied upon, influence the shoppers to take their patronage to the less damaged mercantile areas, inferred to be safer. This change may be permanent for some persons, and months long for others. It is probably not viable for San Franciscans to change their shopping habits to any great extent; however, many suburb shoppers will avoid San Francisco due to the above average damage expected there in the event of a major shock on the San Andreas fault. Oakland and the other East Bay cities will experience similar problems for major earthquakes on the Hayward fault. It should be added that the Hayward fault runs through the central shopping area of the City of Hayward, and one major shopping center in Oakland is also on the Hayward fault. As a result, a significant down turn in business in the central core of the larger cities in the study area is expected, causing unemployment if the workers choose to continue to reside close to their places of employment.

Food warehousing, including cold storage and cannery storage, is frequently located in one story structures having wood roofs and reinforced concrete walls. These reinforced concrete walls are of a type known as "tilt-up," in which the usually 6-inch thick wall is constructed in a horizontal position, then picked-up

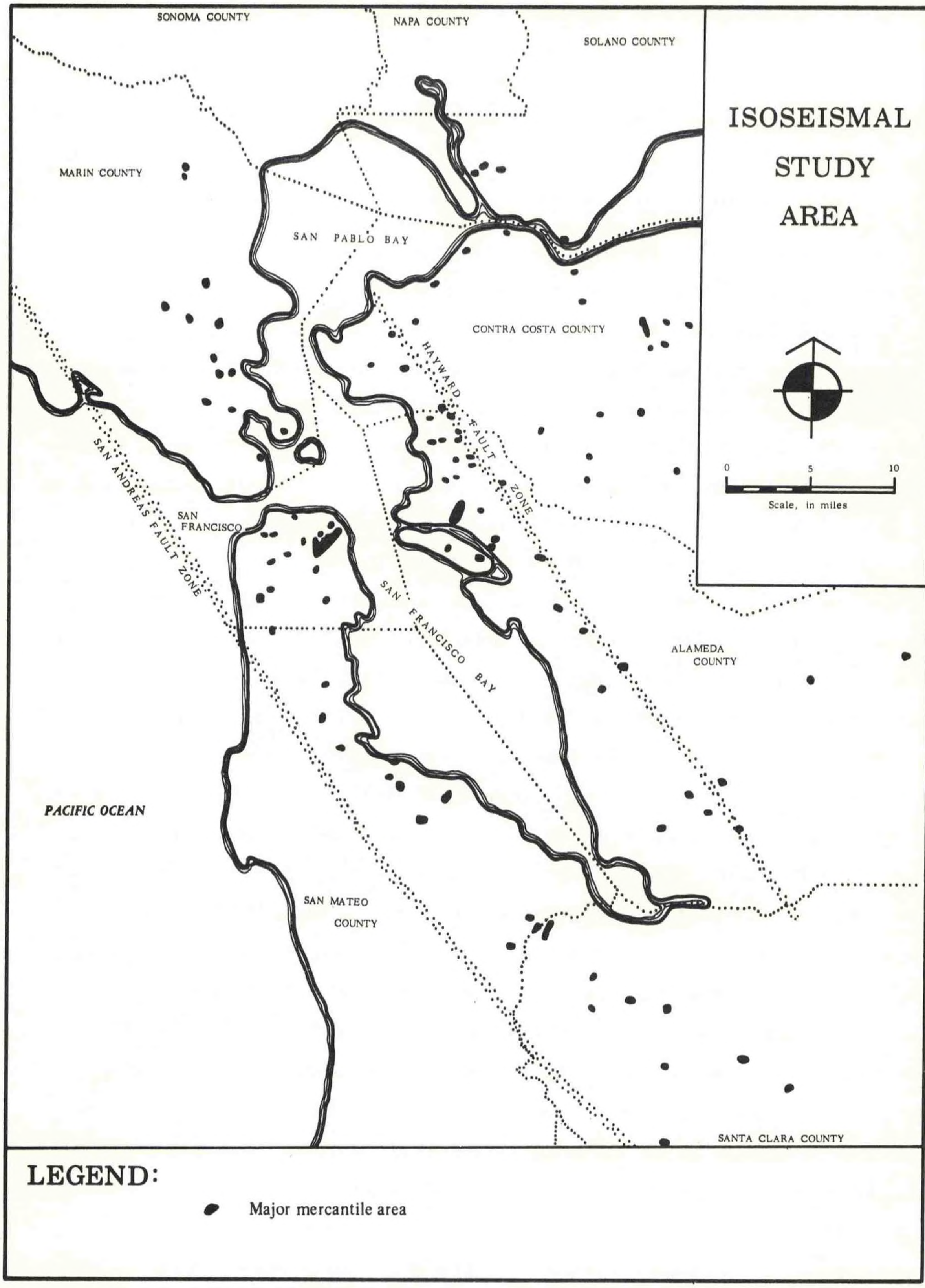


FIGURE 27. Major mercantile areas.

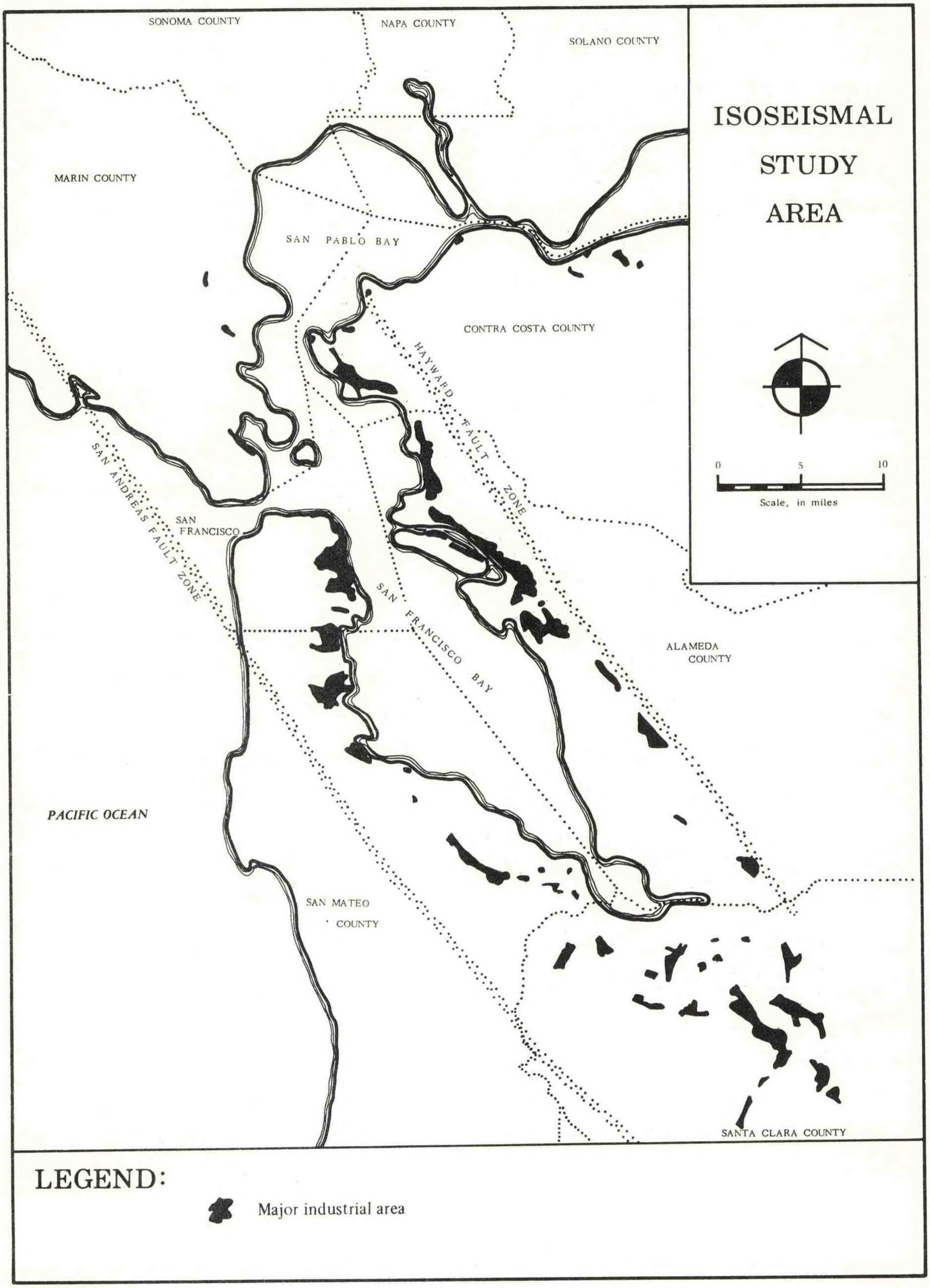


FIGURE 28. Major industrial areas.

("tilted-up") by a crane and placed in its final vertical position, and lastly tied to its adjoining tilt-up wall panels by poured-in-place reinforced concrete columns (pilasters) located between the panels. In the 1971 San Fernando earthquake, this type of construction in the heaviest hit areas experienced building damage which averaged almost 20% of the cash value of the building. Similar buildings with reinforced hollow concrete block or reinforced brick had a similar experience record. Contents within the structures which commonly lost part of their roofs were damaged, but no experience figures exist with respect to foodstuffs.

Refrigerated warehouses present the most serious problems from a food loss standpoint. Damage to the building can also rupture the insulation; a partial roof failure is expected to be a frequent problem in the hardest shaken areas. This kind of building damage, compounded with the loss of electric power for possibly days and the resulting loss of refrigeration, is expected to cause serious foodstuff losses at some locations.

Based on past earthquake experience, it is probable that no more than 15% of the foodstuffs in non-retail locations within the study area will be so greatly damaged as to be unusable. This damage will be due to falling stock, building damage, or other causes. As an example of another cause of damage, rainwater (or water from fire protection sprinkler systems) can destroy paper cartons containing foodstuffs or loosen labels making content identification difficult.

Contents within certain types of building occupancies are particularly prone to damage. Chemical laboratories and electronic facilities will have all movable stock on shelves, benches, and assembly lines fall if located in the high intensity area. There is the false notion among many plant managers that heavy equipment resting on floors is safe due to the equipment's large mass; the reverse is too often true. There are many examples of heavy equipment such as lathes overturning or shifting in terms of feet.

Computer units are often supported on false floors and are not properly anchored to these floors. Cables between units normally have a small amount of slack. Computers located in the upper stories of high-rise buildings will be more heavily shaken than those on or near the first story due to motion amplification with height. Computers located on these upper floors are expected to move until cable slack is gone, then overturn and/or damage the cables. In the high intensity areas of a great shock, computer facilities in upper stories of buildings may be out of service for indefinite periods. Tape libraries will be scattered about the floors, but damage to the tapes will be not more than if the tapes had been dropped during handling.

Homeless

DATA COLLECTION

The prevalent type of construction of the single family dwellings found in the San Francisco Bay Area is wood frame. The number of masonry construction single family dwelling types are relatively few in proportion and therefore, in the interests of the planning purposes of this report, were not surveyed or documented.

The principal source of data on dwelling statistics was found to be the "1970 Census of Population" report as issued through the U.S. Bureau of the Census. The most densely populated areas are shown in Figure 29.

Since dwellings may be damaged by many causes, during the earthquake or during the immediate post-earthquake period (fire, landslide, dam failure, etc.), it was necessary to tabulate the following information:

Urban & rural population	Hill area population
Bay margins area population	Down-stream population of dams
Single family dwelling units	Multiple unit dwellings
Total population by county	Densely populated areas

Some of the more important compiled data are given in Tables 58, 59, and 60.

ANALYSIS

Single Family Dwellings

Data on the past performance of single family wood frame dwellings in earthquakes are summarized in Appendix A to "Studies in Seismicity and Earthquake Damage Statistics, 1969" (ESSA report to HUD, 1969). In addition, a

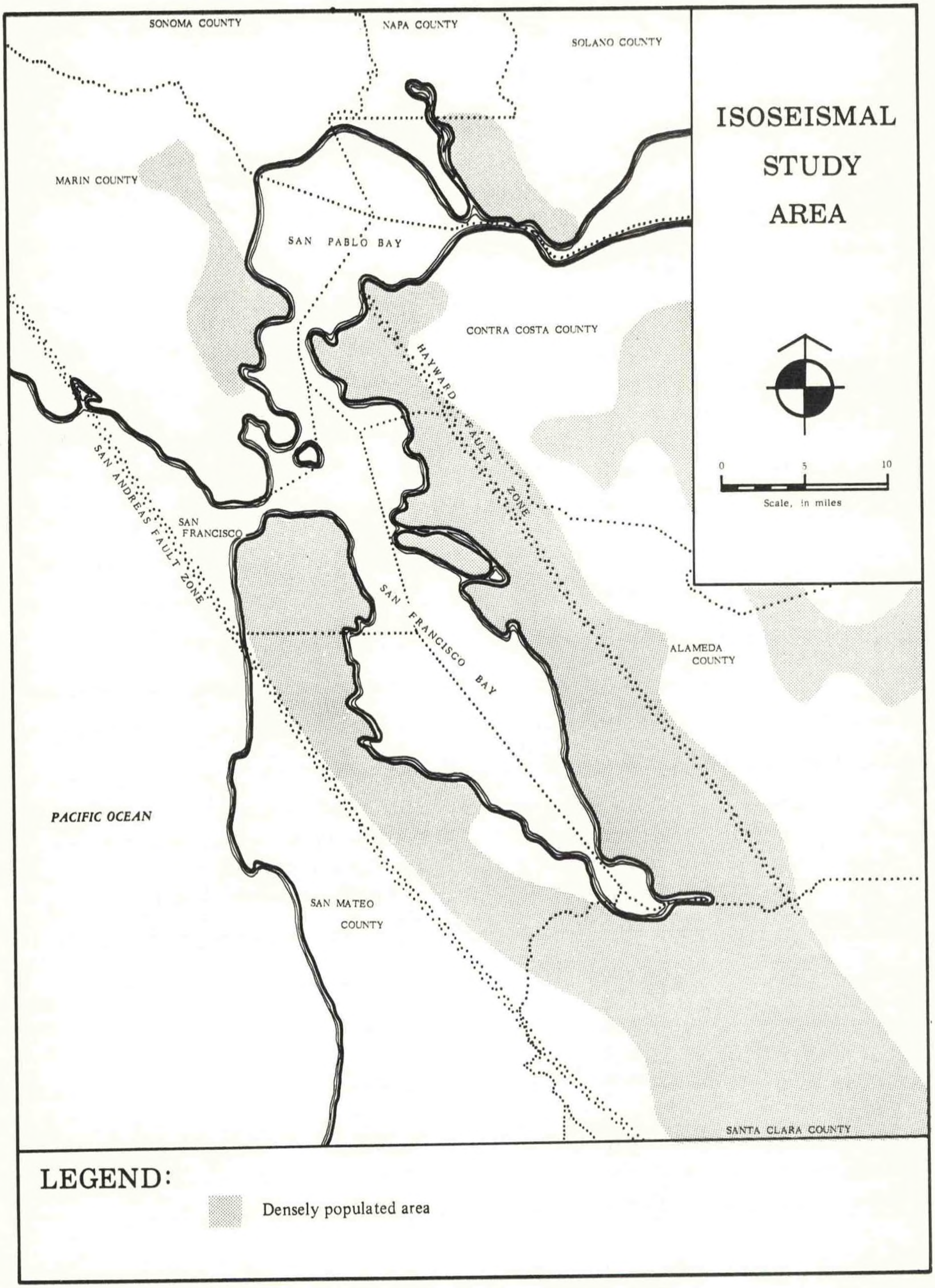


FIGURE 29. Densely populated areas.

TABLE 58

POPULATION STATISTICS

County	Total Population	% of Total Population	Location of Population by % Urban	Rural
Alameda	1,073,184	23.0	99.0	1.0
Contra Costa	558,389	12.0	93.6	6.4
Marin	206,038	4.3	92.4	7.6
Napa	79,140	1.7	58.0	42.0
San Francisco	715,674	16.0	100.0	0.0
San Mateo	556,234	12.0	98.2	1.8
Santa Clara	1,064,714	23.0	97.5	2.5
Solano	169,941	4.3	93.0	7.0
Sonoma	204,885	3.7	58.7	41.3
Total	4,628,199	100.0		

Source: 1970 Census Report

TABLE 59

INVENTORY OF DWELLING UNITS

County	Single Family Dwelling Units	Units in Multiple Dwellings	Mobile Homes or Trailers
Alameda	230,430	146,251	3,040
Contra Costa	138,638	36,290	3,384
Marin	51,801	18,397	504
Napa	21,416	3,914	1,451
San Francisco	104,595	205,427	342
San Mateo	135,330	52,888	1,950
Santa Clara	232,648	94,013	9,569
Solano	38,731	12,932	1,805
Sonoma	63,065	10,195	3,919

Source: 1970 Census Report

TABLE 60

BAY MARGINS AND HILL AREA POPULATION OF THREE COUNTIES

County	Population: Bay Margin Areas	Population: Hill Areas
Alameda	51,900 (4. 8%)	83,800 (7. 8%)
Contra Costa	9,850 (1. 7%)	144,900 (26. 0%)
Marin	9,800 (4. 8%)	172,460 (83. 5%)
Totals	71,550	401,160

Source: 1970 Census Report

detailed study on dwelling performance in the 1971 San Fernando shock may be found in "San Fernando Earthquake, February 9, 1971" (Pacific Fire Rating Bureau). These sources identify the dollar losses to wood frame dwellings but do not state at what damage level the houses were evacuated. Indeed, there probably was no consistent practice in this regard; in some earthquakes, social needs were sometimes confused with safety requirements when it came to building condemnations. For the purposes of this report, wood frame dwellings suffering 50% or greater loss are considered to be uninhabitable since the utilities are usually inoperative, doors won't open or close, and the buildings often have substantial structural damage. On this basis, the back-up data used from the cited San Fernando earthquake report may be summarized as:

1. For pre-1940 dwellings in Modified Mercalli IX zones, 2% of the wood frame dwellings had 50% loss or more.
2. For post-1940 dwellings in Modified Mercalli IX zones, 0.3% of the wood frame dwellings had 50% loss or greater.

In the 1933 Long Beach earthquake, 1% of the wood frame dwellings in the City of Compton had 50% loss or greater.

The data for the 1971 San Fernando earthquake and for the 1933 Long Beach earthquake provide good upper limits for the purpose of this study. Lower intensity values were determined by interpolation.

Multiple Unit Dwelling Structures

Multiple unit dwellings such as apartment houses vary in construction materials, depending mainly upon location. Multiple unit structures in San Francisco are often multistory and constructed of heavier mass materials such as concrete and steel; these heavier mass materials have often been associated with large life loss, particularly when they are of non-earthquake resistive unit masonry construction. Wood frame multiple units are more common in other counties. Additionally, there is a higher percentage of multiple unit structures in San Francisco than elsewhere as may be seen in the following partial listing of counties:

County	Percent of housing units in multiple unit structures
San Francisco	66%
Alameda	37%
Santa Clara	28%
Marin	25%
Contra Costa	20%
Napa	15%

Source: Derived from 1970 Census

Multistory structures are often subject to long period earthquake effects, i.e., the earth's gentle rocking motions from distant earthquakes may cause heavy damage due to quasi-resonance with these taller buildings.

Outside of San Francisco, multiple unit housing is a lesser percentage of the total than in San Francisco, lower in height, and more often of wood frame construction. As a result, the multiple unit housing outside of San Francisco will perform better than that in San Francisco.

SUMMARY OF POSTULATED EARTHQUAKES

San Andreas and Hayward Faults--Expected Damage Patterns

The calculations which derived the values shown in Table 61 include the comparative numbers of single family wood frame dwellings and multiunit structures of the various construction types. The geologic hazard factors of landslide and ground conditions were also included. Two separate sets of upper limit conditions were imposed on each of the 6 postulated earthquakes. First, the wet season was assumed and the damage due to ground shaking plus landslide were added together. The second set of conditions assumed the dry season, with the damage due to ground shaking added to the fire losses.

The estimated number of long term homeless in San Francisco is 19,500 in the event of fire following earthquake. This is in sharp contrast to the 225,000 persons left homeless after the 1906 San Francisco earthquake and fire. (The likelihood

TABLE 61

LONG TERM HOMELESS

Homeless due to potential dam failure must be added to these figures; see section on "Dams" for locations.

County	San Andreas Fault M = 8.3	San Andreas Fault M = 7	San Andreas Fault M = 6	Hayward Fault M = 8.3	Hayward Fault M = 7	Hayward Fault M = 6
Alameda						
Wet season	2,100	1,000	*	16,600	16,600	3,000
Dry season	2,100	1,000	*	25,900	25,900	2,600
Contra Costa						
Wet season	300	*	*	8,400	8,400	2,100
Dry season	300	*	*	10,500	10,500	1,400
Marin						
Wet season	1,400	*	*	3,800	3,500	*
Dry season	600	*	*	1,700	900	*
Napa						
Wet season	*	*	*	300	*	*
Dry season	*	*	*	300	*	*
San Francisco						
Wet season	16,500	6,100	900	7,100	4,700	*
Dry season	19,500	6,100	900	7,100	4,700	*
San Mateo						
Wet season	9,100	9,100	1,400	700	700	*
Dry season	9,600	9,100	1,400	700	700	*
Santa Clara						
Wet season	3,400	1,500	*	10,600	10,600	2,700
Dry season	3,900	1,500	*	10,600	10,600	2,700
Solano						
Wet season	*	*	*	300	*	*
Dry season	*	*	*	300	*	*
Sonoma						
Wet season	400	*	*	400	*	*
Dry season	400	*	*	400	*	*

*Negligible (less than 100)

of general conflagration following earthquake has been discussed in the section on "Fire Following Earthquake.")

Dead and injured are not included in Table 61 and the injured must be housed in addition to those listed in Table 61.

The number of persons evacuated below unsafe dams has not been included, but this figure must be included in the grand totals. The homeless below dams pose special problems due to the high concentration of homeless persons in a relatively small area, due to mass evacuation hampered by downed freeways, and due to the lack of nearby accommodations.

Based on procedures developed in "Studies in Seismicity and Earthquake Damage Statistics, 1969" (ESSA, Dept. of Commerce, 1969), the dollar losses in terms of repair costs to single family wood frame dwellings would be approximately:

San Andreas, 8.3	$1,240,000,000.
Hayward, 8.3	$1,400,000,000.

It is apparent that comparable magnitude earthquakes on the San Andreas and Hayward faults place the greatest problems in the areas adjacent to the Hayward fault.

Fire Following Earthquake

One of the greatest potential dangers to be faced during the period immediately following a major earthquake is the threat of fire which, if unchecked, could lead to a major conflagration under certain situations. The threat of a fire always exists following any earthquake, and this exists for all areas and building categories considered in this report.

The memory of the three day fire which followed the 1906 shock in San Francisco and accounted for 80% of the property loss in that city has dominated much of the thinking on the probable effects of the next great San Andreas earthquake. This thinking is also colored by the fact that over 100,000 persons were killed, injured, or missing in the 1923 Tokyo earthquake and fire.

DATA COLLECTION

Population counts were taken from the 1970 Census Report and correlated to census tract maps, in turn keyed to the salient environment features related to fire hazard. Data on fire stations were collected from three major local governments (Oakland, San Francisco, and San Jose) and their locations are shown in Figure 16.

ANALYSIS

Fires almost invariably occur after destructive earthquakes in the United States, but these have not been true conflagrations. (Fires which spread in an uncontrolled manner for long periods of time are defined as conflagrations for the purposes of this report.)

Conflagrations which follow earthquakes appear to require all of several unfavorable conditions before they can be considered as a reasonably possible occurrence. First, there must be a high density of combustible material. Obviously, wooden structures in close proximity to each other or facing each other across narrow streets provide one such possibility. Second, weather plays an important role. The hot dry winds in southern California have led to conflagrations in the brush areas, and large dollar losses have occurred to the dwellings and other properties in these brush areas. Life losses have been low. Tinder dry situations also occur in parts of the San Francisco Bay area during prolonged periods of dry weather and during other than dry seasons, portions of the area are frequently subjected to periods of high winds with 40 mph gusts not uncommon. Thirdly, the fire departments' operations at the fires might be crippled or otherwise restricted through the lack of water or other impairments.

Table 62 is a listing of fires following earthquake for selected United States earthquakes; the selections were limited to those shocks in which the construction had relevance to the San Francisco Bay area. The data often are not compatible; some refer only to fires requiring fire department response, some include fires put out by the occupants, and some include those which burned themselves out (as is sometimes the case for transformer fires). The number of reported fires, particularly for the 1906 San Francisco event, varies widely depending upon the source of information.

With respect to Table 62, it should be noted that conflagration occurred only in the case of the 1906 shock. Uncontrolled fires occurred at the Paloma Refinery in the 1952 earthquake and from oil storage in the 1964 Alaskan earthquake in cities other than Anchorage. Conflagration has been rare. It appears that the 1971 San Fernando earthquake caused many more fires than did the 1906 San Francisco shock, but most of these were small. Conflagration did not follow the San Fernando shock despite the loss of water in large areas, possibly due to the fact that the combustible material was thinly spread compared to that at the time of the 1906 San Francisco shock. Weather conditions were also favorable and helped check any spread of fire.

TABLE 62

FIRES FOLLOWING EARTHQUAKE
Selected United States Earthquakes

Earthquake	Date	Magnitude	Number of Reported Fires	Reference
San Francisco, Calif.	April 18, 1906	8.3	50 fires 3 hours after	N. B. F. U., 1906
Santa Barbara, Calif.	June 29, 1925	6.3	1 dwelling	B. F. U. P., 1925
Long Beach, Calif.	March 10, 1933	6.3	2 fires in Los Angeles, 11 to 15 in Long Beach	N. B. F. U., 1933
Imperial Valley, Calif.	May 18, 1940	7.1	4 (?) including Mexico	"The Insurance Journal", May 1940
Kern County, Calif.	July 21, 1952	7.7	Major refinery fire	B. S. S. A. 44:270
Bakersfield Calif.	Aug. 22, 1952	5.8	1 dwelling	B. F. U. P., private report, 1952
San Francisco, Calif.	March 22, 1957	5.3	1 at 2 story apartment	Calif. Div. Mines, Special Report 57
*Anchorage, Alaska	March 27, 1964	8.4	*4 "minor"	N. B. F. U. and P. F. R. B., 1964
San Fernando, Calif.	Feb. 9, 1971	6.4	109	Steinbrugge, et al "San Fernando E. Q.", P. F. R. B.

*Oil fires elsewhere in Alaska not included.

Abbreviations:

N. B. F. U.	National Board of Fire Underwriters
B. F. U. P.	Board of Fire Underwriters of the Pacific
P. F. R. B.	Pacific Fire Rating Bureau
B. S. S. A.	"Bull. Seism. Soc. Am."

There are types and degrees of emergency fire services currently available which were not available in 1906. In addition to the San Francisco and Oakland fireboats, the Coast Guard and Navy vessels stationed in the area are equipped for fire fighting, mainly pumping sea water. Merchant marine shipping also usually includes some degree of similar capability. Fire departments in the area are equipped with more hose, both in total lengths and in larger sizes. A certain amount of quick-coupling large diameter pipe is maintained in the area through the California State Office of Emergency Services. Although earthquake results might preclude availability of the Oakland fireboat (due to its berthing location), marine service and land forces could effect salt water supplies for fire fighting for perhaps up to one mile from waterfront locations.

There is, however, a possible deterrent to effective cooperation of fire departments whenever either San Francisco or Oakland is involved. Although hose-coupling adapters have been provided within the fire services, dissimilar sizes of hose and related couplings could create a problem if adapter demand exceeded supply.

The section of this report which discusses water systems has pointed out that the water supply to the East Bay Cities of Oakland, Berkeley, etc. must cross the Hayward fault in order to reach these cities. The water must then cross the fault again to reach the residential areas in the hills immediately east of the fault. While storage reservoirs exist east of the fault in these residential hill areas, the possibilities of reservoir failure and the certainty of water line ruptures leave a significant element of comparative unreliability to the water supply in these hill areas.

San Francisco no longer has the conflagration problem that was present in 1906. Strategically located valves in water mains can isolate potentially troublesome areas and thereby reduce the possibilities of uncontrolled water loss due to ruptured lines in poor ground areas. Cisterns which store substantial amounts of water have been placed in important areas. Lastly, an independent high pressure system, fed from numerous sources including the Bay, protects the congested area of San Francisco.

Fire department response will be delayed in the congested areas due to blocked streets, collapsed or otherwise impaired fire stations, and breakdown or overloading of equipment. Mobile fire fighting apparatus may be damaged by displacement within fire station apparatus rooms. These problems will allow fires to enlarge. The capability of the various fire departments to respond under these handicaps have not been fully evaluated.

In general, the fire service finds itself at time of area-wide disaster in an almost impossible situation. Because it is on a ready standby basis during normal day-by-day operations, all too many variations of related activity and emergency service planning by others are in the category of "the fire department can or will do that." Rescue may be cited as an example of life safety taking precedent over fire fighting; fires may go unattended while the fire forces effect rescue and search.

Summary of Postulated Earthquakes

San Andreas Fault--Expected Damage Patterns

In the event of an 8.3 magnitude shock, no general conflagration is expected in San Francisco, or elsewhere, similar to that which occurred in 1906. It is reasonable to plan for very large fires, some of which may be uncontrolled for hours. The largest of these are most likely to occur in the poor ground areas of San Francisco where damage to the water systems is expected.

For planning purposes, serious uncontrolled fires should be expected in the Western Addition, in the Mission District, and in the Marina. However, no more than a few city blocks are expected to be lost in any of these fires. As many as three high-rise structures may burn, but the fires will be restricted to these three high-rise buildings.

Also for planning purposes, San Jose, San Mateo and other larger cities on the Peninsula should each anticipate one major uncontrolled fire in the industrial areas and one in the residential areas. Mutual aid will not be available, except from a considerable distance. The problems of blocked freeways and broken water lines in the poor ground area will create impossible chores for some fire companies.

Principal life loss and burn injuries will occur when a fire spreads in a high-rise building during the working day. It is quite reasonable for several newer high-rise structures to have fires due to equipment problems in the mechanical floors which are often located in the middle stories. Should a fire start on the 20th story of a 40 story building when elevators and stairs are out due to earthquake, life loss in the upper stories could be in terms of hundreds of persons. It must be remembered that the earthquake will shatter many fire resistive enclosures around the elevators and stairs, allowing fire to progress from story to story where combustible material exists. This is a significant hazard in San Francisco with its many high-rise buildings. Life loss under these reasonably possible conditions could be in terms of several hundred persons.

Lesser magnitude shocks are not expected to cause major uncontrolled fires.

Hayward Fault--Expected Damage Patterns

In the event of an 8.3 magnitude shock on the Hayward fault, it will be assumed for planning purposes that the water system will be immediately unavailable for 15% of the residents living in hillside areas of the East Bay cities, particularly for those east of the fault. It will also be assumed that no additional water will flow across the fault due to pipe breakage, and that 30% will be out of water within 12 hours. Two major uncontrolled fires may occur in these water short areas--one in Oakland and one in Berkeley. In addition for planning purposes, Berkeley will have 1 uncontrolled fire, Oakland 3 uncontrolled fires (1 in the army/navy supply area), and Hayward 2 uncontrolled fires.

Life loss is expected to be minimal and persons requiring attention from serious burns are not expected to exceed 100.

The refineries in Richmond and Rodeo will sustain substantial damage leading to fires. Uncontrolled fires are less than a 50-50 possibility. However, for planning purposes, it will be assumed that the Richmond refinery will have a major uncontrolled fire.

A 7.0 magnitude shock on the Hayward fault is expected to cause similar fire problems to those of an 8.3 magnitude shock on the Hayward fault due to the disruption of the water system in a 7.0 magnitude shock.

General

It should be re-emphasized that uncontrolled fires are probable in the event of an 8.3 magnitude shock on either fault, or in a 7 magnitude shock on the Hayward fault. However, it is not reasonable to expect a conflagration in terms of 1906. The closest approximation to this would be a fire in the Oakland-Berkeley hills.

Selected Bibliography

Allen, C. R., et al. (1968). "The Borrego Mountain, California, Earthquake of 9 April 1968: A Preliminary Report." Bull. Seism. Soc. Am., 58:1183-1186.

American Society of Civil Engineers (1907). "The Effects of the San Francisco Earthquake of April 18, 1906 on Engineering Constructions," Trans. Am. Soc. Civil Engr., 59: 208-329.

Anonymous (June 1940). "Imperial Valley Earthquake," West. Constr. News.

Binder, R. W. (1952). "Engineering Aspects of the 1933 Long Beach Earthquake," Proc. Symp. on Earthquake and Blast Effects on Structures, 186-211.

Board of Fire Underwriters of the Pacific (1925). Notes of Interest to Underwriters on Earthquake Damage to City of Santa Barbara, California.

Chamber of Commerce of San Francisco (1906). Report of the Special Committee of the Board of Trustees of the Chamber of Commerce of San Francisco.

Cluff, L. S. and K. V. Steinbrugge (1966). "Hayward Fault Slippage in the Irvington-Niles Districts of Fremont, California," Bull. Seism. Soc. Am., 56:257-279.

Committee of Five (1906). Report of the Committee of Five to the Thirty-Five Companies on the San Francisco Conflagration.

Degenkolb, H. J. (1955). "Structural Observations of the Kern County Earthquake," Trans. Am. Soc. Civil Engr., 120:1280-1294.

Degenkolb, H. J. (1969). "An Engineer's Perspective on Geologic Hazards," in Geologic Hazards and Public Problems, Conference Proceedings. Office of Emergency Preparedness.

Degenkolb, H. J. (Committee member) (1951). "Lateral Forces of Earthquake and Wind," Trans. ASCE 117:716-780.

Degenkolb, H. J. (1960). "Earthquake Resistant Design of Small Buildings," Proc. II WCEE.

Degenkolb, H. J., R. D. Hanson (1969). "The July 29, 1967 Venezuela Earthquake Lessons," Proc. IV. WCEE.

Dewell, H. D., and B. Willis (1925). "Earthquake Damage to Buildings," Bull. Seism. Soc. Am., 15:282-301.

Duke, C. M., and D. J. Leeds (1959). "Soil Conditions and Damage in the Mexico Earthquake of July 28, 1957," Bull. Seism. Soc. Am., 49:179-191.

Dutton, C. E. (1887-1888). "The Charleston Earthquake of August 31, 1886," Ninth Annual Report, U. S. Geological Survey.

Edwards, H. H. (February, March, and April 1951). "Lessons in Structural Safety Learned from the 1949 North-west Earthquake," West. Construction.

Engle, H. M. (1936). "The Montana Earthquakes of October, 1935: Structural Lessons," Bull. Seism. Soc. Am., 26:99-109.

ESSA (1969). "Studies in Seismicity and Earthquake Damage, Statistics, 1969." "Summary and Recommendations" plus Appendix A and Appendix B.

Greely, A. W. (1906). Special Report of Maj. Gen. Adolphus W. Greely, U.S.A., Commanding the Pacific Division, on the Relief Operations Conducted by the Military Authorities of the United States at San Francisco and other Points.

Hanson, R. D., and H. J. Degenkolb (1969). The Venezuela Earthquake, July 29, 1967, American Iron & Steel Institute, New York.

Hershberger, J. (1956). "A Comparison of Earthquake Accelerations with Intensity Ratings," Bull. Seism. Soc. Am., 46:317-320.

Hiriart, M., and E. Rosenblueth (1958). Los Efectos del Terremoto del 28 de Julio y la Consiguiente Revision de los Criterios para el Diseño Sismico de Estructuras, Universidad Nacional Autonoma de Mexico, Escuela Nacional de Inginieria

Hollis, E. P. (1971). Bibliography of Earthquake Engineering, 3rd ed., Oakland, Calif.: Earthquake Engineering Research Institute.

Housner, G. W., and D. E. Hudson (1958). "The Port Hueneme Earthquake of March 18, 1957," Bull. Seism. Soc. Am., 48:163-168.

Hudson, D. E. editor (1971). Strong Motion Instrumental Data on the San Fernando Earthquake of Feb. 9, 1971. California Institute of Technology, Pasadena.

Inard, C. D. (1925). "Report of Engineering Committee on the Santa Barbara Earthquake," Bull. Seism. Soc. Am., 15:302-304.

Jennings, P. C., editor, (1971). Engineering Features of the San Fernando Earthquake, February 9, 1971. California Institute of Technology, Pasadena.

Lawson, A. C. et al. (1908). The California Earthquake of April 18, 1906. Report of the State Earthquake Commission, 2 vols. and atlas, Washington, D.C.: Carnegie Institution of Washington.

Los Angeles County Earthquake Commission (1971). San Fernando Earthquake, February 9, 1971.

Manson, M. (1907). Report of the Sub-Committee on Statistics to the Chairman and Committee on Reconstruction.

McAuliffe, J., Moll, K. (1965). "Secondary Ignitions in Nuclear Attack," Stanford Research Institute.

Miller, A. L. (1952). "Earthquake Lessons from the Pacific Northwest," Proc. Symp. on Earthquake and Blast Effects on Structures, 212-223.

National Board of Fire Underwriters (May 1906). The San Francisco Conflagration of April 1906, Special Report to the National Board of Fire Underwriters (by a) Committee of Twenty.

National Board of Fire Underwriters (1933). Report on the Southern California Earthquake of March 10, 1933.

National Board of Fire Underwriters and Pacific Fire Rating Bureau (1964). The Alaska Earthquake.

Oakeshott, G. B., ed. (1955). "Earthquakes in Kern County, California, During 1952," California Division of Mines, Bull. 171. (A collection of 34 papers.)

Oakeshott, G. B., ed. (1959). "San Francisco Earthquake of March 1957," California Division of Mines, Special Report 57.

Richter, C. F. (1958). Elementary Seismology, San Francisco: W. H. Freeman.

Richter, C. F. (1959). "Seismic Regionalization," Bull. Seism. Soc. Am., 49:123-162.

Schussler, H. (1906). The Water Supply of San Francisco, California, Before, During and After the Earthquake of April 18, 1906 and the Subsequent Conflagration.

Shannon & Wilson, Inc. (1964). Report on Anchorage Area Soil Studies, Alaska to U. S. Army Engineer District, Anchorage, Alaska.

Steinbrugge, K. V. (1970). Engineering Aspects of the Santa Rosa, California, Earthquakes, October 1, 1969, in "The Santa Rosa, California, Earthquakes of October 1, 1969." Environments Sciences Services Administration, U. S. Department of Commerce.

Steinbrugge, K. V., and V. R. Bush (1960). Earthquake Experience in North America, 1950-1959, Proceedings of the Second World Conference on Earthquake Engineering, I:381-396.

Steinbrugge, K. V., and V. R. Bush (1965). "Review of Earthquake Damage in Western United States, 1933-1964," in Earthquake Investigations in the Western United States, 1931-1964, pp. 223-256.

Steinbrugge, K. V. (Chairman) et al., (1970). "Task Force on Earthquake Hazard Reduction." Office of Science and Technology, Executive Office of the President.

Steinbrugge, K. V., V. R. Bush, and E. G. Zacher (1959). "Damage to Buildings and Other Structures During the Earthquake of March 22, 1957," in California Division of Mines Special Report 57, pp. 73-106.

Steinbrugge, K. V. and W. K. Cloud (1962). "Epicentral Intensities and Damage in the Hebgen Lake, Montana, Earthquake of August 17, 1959," Bull. Seism. Soc. Am., 52:181-234.

Steinbrugge, K. V. and D. F. Moran (1954). "An Engineering Study of the Southern California Earthquake of July 21, 1952 and Its Aftershocks," Bull. Seism. Soc. Am., 44:199-462.

Steinbrugge, K. V. and D. F. Moran (1956). "The Fallon-Stillwater Earthquakes of July 6, 1954, and August 23, 1954," Bull. Seism. Soc. Am., 46:15-33.

Steinbrugge, K. V., and D. F. Moran (1957a). "An Engineering Study of the Eureka, California, Earthquake of December 21, 1954," Bull. Seism. Soc. Am., 47:129-153.

Steinbrugge, K. V. and D. F. Moran (1957b). "Engineering Aspects of the Dixie Valley-Fairview Peak Earthquakes," Bull. Seism. Soc. Am., 47:335-348.

Steinbrugge, K. V., E. E. Schader, H. C. Bigglestone, and C. A. Weers (1971). San Fernando Earthquake, February 9, 1971. Pacific Fire Rating Bureau, San Francisco.

Steinbrugge, K. V., E. E. Schader, and D. F. Moran (in press). Building Damage in San Fernando Valley, California Division of Mines and Geology, Sacramento, Calif.

Steinbrugge, K. V., and E. E. Schader (in press). Earthquake Damage and Related Statistics, National Oceanic and Atmospheric Administration (volumes on the San Fernando earthquake).

Structural Engineers Association of California, (1968). Recommended Lateral Force Requirements and Commentary.

Tocher, D. (1960). Movement on Faults, Proceedings of the Second World Conference on Earthquake Engineering, I:551-564.

Ulrich, F. P. (1936). "Helena Earthquakes," Bull. Seism. Soc. Am., 26:323-339.

Ulrich, F. P. (1941a). "The Imperial Valley Earthquakes of 1940," Bull. Seism. Soc. Am., 31:13-31, map.

Ulrich, F. P. (October 1941b). "The Santa Barbara Earthquake," Building Standards Monthly.

U. S. Coast and Geodetic Survey (1964). Preliminary Report, Prince William Sound, Alaskan Earthquakes, March-April, 1964.

U. S. Coast and Geodetic Survey (1965a). Earthquake History of the United States, Part I, Washington, D. C.: U. S. Government Printing Office.

U. S. Coast and Geodetic Survey (1965b). Earthquake Investigations in the Western United States, 1934-1964, D. S. Carder, ed.

U. S. Coast and Geodetic Survey (1965c). The Puget Sound, Washington, Earthquake of April 29, 1965, Washington, D. C.: U. S. Government Printing Office.

U. S. Coast and Geodetic Survey (1966a). Earthquake History of the United States, Part II, Washington, D. C.: U. S. Government Printing Office.

U. S. Coast and Geodetic Survey (1966b). The Parkfield, California, Earthquake of June 27, 1966, Washington, D. C.: U. S. Government Printing Office.

U. S. Coast and Geodetic Survey. The Prince William Sound, Alaska, Earthquake of 1964 and Aftershocks, Washington, D. C.: Environmental Sciences Services Administration, U. S. Government Printing Office.

Vol. 1: Operational Phases of the USC and GS, Including Seismicity, 1966.
Vol. 2, Part A: Engineering Seismology, 1967.
Vol. 2, Part B: Seismology, 1969.
Vol. 2, Part C: Marine Geology, 1969.
Vol. 3: Geodesy and Photogrammetry, 1969.

U. S. Coast and Geodetic Survey (annual). United States Earthquakes, Washington, D. C.: U. S. Government Printing Office.

U. S. Geological Survey (1907). "The San Francisco Earthquake and Fire of April 18, 1906 and their Effects on Structures and Structural Materials by G. K. Gilbert, R. L. Humphry, J. S. Sewell and F. Soule," Bull. 324.

U. S. Geological Survey (1912). "The New Madrid Earthquake," by Myron L. Fuller, Bull. 494.

U. S. Geological Survey (1964-1968). "The Alaska Earthquake, March 27, 1964," Professional Papers 541, 542, 543, 544, 545, and 546.

U. S. Geological Survey (1964). Circular 491: Alaska's Good Friday Earthquake, March 27, 1964.

U. S. Geological Survey (1967). "The Parkfield- Cholame, California, Earthquakes of June-August 1966," Professional Paper 579.

U. S. Geological Survey and National Oceanic and Atmospheric Administration (1971). The San Fernando, California Earthquake of February 9, 1971. A preliminary report. U. S. G. S. Professional paper 733.

Wood, H. O. (1933). "Preliminary Report on the Long Beach Earthquake," Bull. Seism. Soc. Am., 23:43-56.

Wood, H. O., and F. Neumann, "Modified Mercalli Intensity Scale of 1931," Bull. Seism. Soc. Am., 21:277-283.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1973 O - 501-299