UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EXAMPLES OF THE USE OF GEOLOGIC AND SEISMOLOGIC INFORMATION FOR EARTHQUAKE-HAZARD REDUCTION IN SOUTHERN CALIFORNIA

by

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Open-file Report 83-82

1983

This report is preliminary and has not been reviewed
for conformity with U.S. Geological Survey editorial standards.

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ILLUSTRATIONS

EXAMPLES OF THE USE OF GEOLOGIC AND SEISMOLOGIC INFORMATION FOR EARTHQUAKE-HAZARD REDUCTION

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INTRODUCTION

There is much recent interest in earthquake hazard-reduction in California, for example, the creation of the Southern California Earthquake Preparedness Project (1981) which is making use of scientific information to develop prototypical emergency plans. The purpose of this report is to illustrate some of the range and types of applications of geologic and seismologic information used by planners and decisionmakers to reduce earthquake hazards in Southern California. Included among the users are State legislators, State agencies, county planning commissioners, county board supervisors, mayors, councilpersons, engineers, building inspectors, and real-estate sellers. The examples affect an entire State, a metropolitan region, a 2,740 square-mile (7,097 km^2) county, a city of almost 3 million people, and individual lots and acreages offered for sale. The selection of these five examples does not imply endorsement by the U.S. Geological Survey. Other examples by users such as schools, Federal regulatory agencies, private corporations, financial institutions, and individual homeowners can be cited.

Each example contains a summary of the problems or needs faced by the users, the Earth-science information used or available, the specific action taken, the methods and procedures used to carry out each action, and brief comments on the impact of each plan or decision and its adaptation for earthquake-hazard reduction by other users. The users applied the earth-science information available at the time; users can revise, update, or amend their plans and decisions as later or better information becomes available. Similar examples of the use of geologic and seismologic information are reported elsewhere (Kockelman, 1975, 1976, 1979; Kockelman and Brabb, 1978; Robinson and Spieker, eds., 1978; Blair and Spangle, 1979; and Brown and Kockelman, in press).

I gratefully acknowledge the many helpful comments of those who reviewed this report in draft form: James Kahle, Theodore Smith, and Earl Hart, geologists, California Division of Mines and Geology; Albert McCurdy, Deputy Director, Santa Barbara County Current Planning Division; David Doerner, geologist, Santa Barbara County Resource Management Department; James Gates and Guy Mancarti, bridge engineers, California Department of Transportation; Earl Schwartz, Chief, Conservation Bureau, Los Angeles Department of Building and Safety; Glenn Johnson and Victor Hernandez, Citywide Planning Division, Los Angeles City Planning Department; Rachel Gulliver Dunne, Vice-president, Los Angeles Board of Building and Safety Commissioners; William Spangle, William Spangle and

Associates; and Richard Andrews, Executive Director, California Seismic Safety Commission.

This report has been prepared for inclusion as a chapter in a U.S. Geological Survey professional paper on earthquake hazards in the Los Angeles region and is being released here in the open-file series for use and distribution at the International Earthquake Conference scheduled in February, 1983 in Los Angeles and at the Conference on Earthquake Research in Urban and Regional Planning scheduled by the American Planning Association in April, 1983 in Seattle..

ANTICIPATING DAMAGE TO CRITICAL FACILITIES*

For purposes of assessing the impact of a major future earthquake, scenarios are used. Although a scenario is usually thought of as a synopsis or outline of a play or movie, a scenario for an earthquake can be considered a synopsis or outline of a large seismic event and its severe impacts on an urban region. It is important to assess the effects of a future earthquake upon principal lifelines for emergency planning purposes. An analysis of readiness can then be used to provide planning insights, recommend further work, and serve as a basis for making or improving emergency preparedness, response, recovery, and reconstruction plans.

For example, property losses to buildings and their contents, deaths and injuries requiring hospitalization, and failure of critical and other facilities were estimated for a suite of seven postulated earthquakes in California including a magnitude 8.3 event on the southern San Andreas fault system in the Los Angeles-San Bernardino region by the Federal Emergency Management Agency (FEMA, 1980, p. 15-26). The FEMA and the California Office of Emergency Services then conducted an analysis of readiness and discussed Federal, State, and local responses (p. 27-32) and response planning (p. 43-51). In addition, the National Oceanic and Atmospheric Administration (Algermissen and others, 1973) made a study of earthquake losses in the Los Angeles area; Blume and others (1978) predicted damage to structures in southern California; and the U.S. Geological Survey (1981) presented detailed scenarios for the seven postulated earthquakes used by FEMA (1980) affecting major California population centers including the Los Angeles and San Diego metropolitan regions.

Many critical facilities, particularly lifelines, are vulnerable to the effects of earthquakes. For example, landslides and rockfalls can block highways and railways; surface fault ruptures can damage highways, runways, and railbeds or break sewer, water, or fuel pipelines causing pollution and fire hazards; strong shaking can cause transmission lines and overpass structures to fail interrupting power transmission, highway use, and railway use; and liquefaction and resulting ground failures can cause failure of bulkheads, piers, and quays thereby disrupting shipping.

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*The term "critical facilities" is used here to include:

(a) Lifelines such as major communication, utility, and transportation facilities and their connection to emergency facilities;
(b) Unique or large structures whose failure might be catastrophic, such as dams or buildings where explosive, toxic, and radioactive materials are stored or handled;
(c) High-occupancy buildings, such as schools, churches, hotels, offices, auditoriums, and stadiums; and
(d) Emergency facilities such as police and fire stations, hospitals, communications centers, and disaster-response centers.

A radio network may use a complex combination of telephone lines, microwave circuits, satellite interfaces, and underground cables. According to Davis and others (1982, p. 68), the failure of one link in this electronic "chain" can effectively disable a large portion of the system. Most of southern California's water supply arrives by way of three major aqueduct systems--Los Angeles Aqueduct from the eastern Sierra Nevada Mountains, the California Aqueduct from northern California, and the Colorado River Aqueduct. Both the Los Angeles and the Colorado River aqueducts cross the San Andreas fault; the California Aqueduct closely parallels the San Andreas fault for over 160 miles (100 km) and crosses the fault at four locations. See figure 3.

Information

Evernden and others (1981) have developed procedures for predicting intensities of any hypothetical earthquake at any location in the conterminous United States. Their computer model calculates the ground-shaking parameter of Rossi-Forel or modified Mercalli intensity on a grid of reference points throughout a region, employing equations which include the influence of distance from fault source, attenuation, and the geology of the area. They published a series of intensity maps for specific earthquakes, including a magnitude 8.3 event on the southern part of the San Andreas fault. Their work includes a map of southern California (1981, plate 1) showing 10 ground-condition units correlated to geologic units digitized on a 1/2 minute by 1/2 minute grid and 8 categories of predicted Rossi-Forel intensities for the occurrence of an event similar to the 1857 Fort Tejon earthquake.

Geologic information at a scale of 1:250,000 is available from the California Division of Mines and Geology (CDMG) "Geologic Atlas of California". Information on ground water and liquefaction is available from the USGS, CDMG and other sources, including Youd and others (1978), Fife and others (1978), and local and metropolitan water departments.

Decision

The CDMG, using an intensity map provided by the USGS, prepared a planning scenario for the Governor's Emergency Task Force on Earthquake Preparedness based on a repeat occurrence of the great Fort Tejon earthquake of January 9, 1857 (Davis and others, 1982). The map is based on the method described in the Evernden and others (1981) paper; the CDMG modified the map based on additional geologic information. Its scenario assumed that a magnitude 8.3 earthquake on the southern San Andreas fault would produce:

> 200 miles (320 km) of surface rupture from Cholame Valley in northern San Luis Obispo County to near San Bernardino,

Intense shaking continuing for at least 60 seconds throughout the planning area,

Slip on the fault, predominantly horizontal, reaching a maximum of 33 feet (10 m) within a zone generally less than 330 feet (100 m) wide,

No concurrent secondary movement on other faults, and

Aftershocks with occasional events in the magnitude 6-7 range continuing for several weeks.

Zones roughly paralleling the postulated surface rupture along the San Andreas fault are shown on a map (fig. 1) as isoseismal areas, that is, as areas within which the anticipated seismic intensities are comparable. Each zone is assigned an intensity rating based on the Rossi-Forel (R-F) scale. According to Davis and others (1982, p.34):

> Regionally, the isoseismal values diminish to intensity 7 or less (R-F) southward and westward across the Los Angeles Basin toward the coast at succesively greater distances from the fault. In the Long Beach and Huntington Beach areas, the Santa Clara Valley, and Ventura-Oxnard areas farther west, the groundwater-saturated substrates are considered to be intensity 8 (R-F) with ground failure potential.
>
> These regional patterns associated with the scenario event are of sufficient plausibility to form a credible basis for evaluation of general effects upon lifelines that service the greater Los Angeles area and adjacent communities.

Their map showing the distribution of seismic intensity (fig. 1) is intended for emergency planning purposes only and is based upon the following hypothetical chain of events: the specified earthquake occurs, various localities in the planning area experience a specific type of shaking or ground failure, and certain critical facilities undergo damage while others do not. Because the scenario is based upon the occurrence of a specific earthquake on the San Andreas fault, it is not valid for the assessment of possible damage produced by an earthquake on any other fault or by a different earthquake on the San Andreas fault (Davis and others, 1982, p. 23).

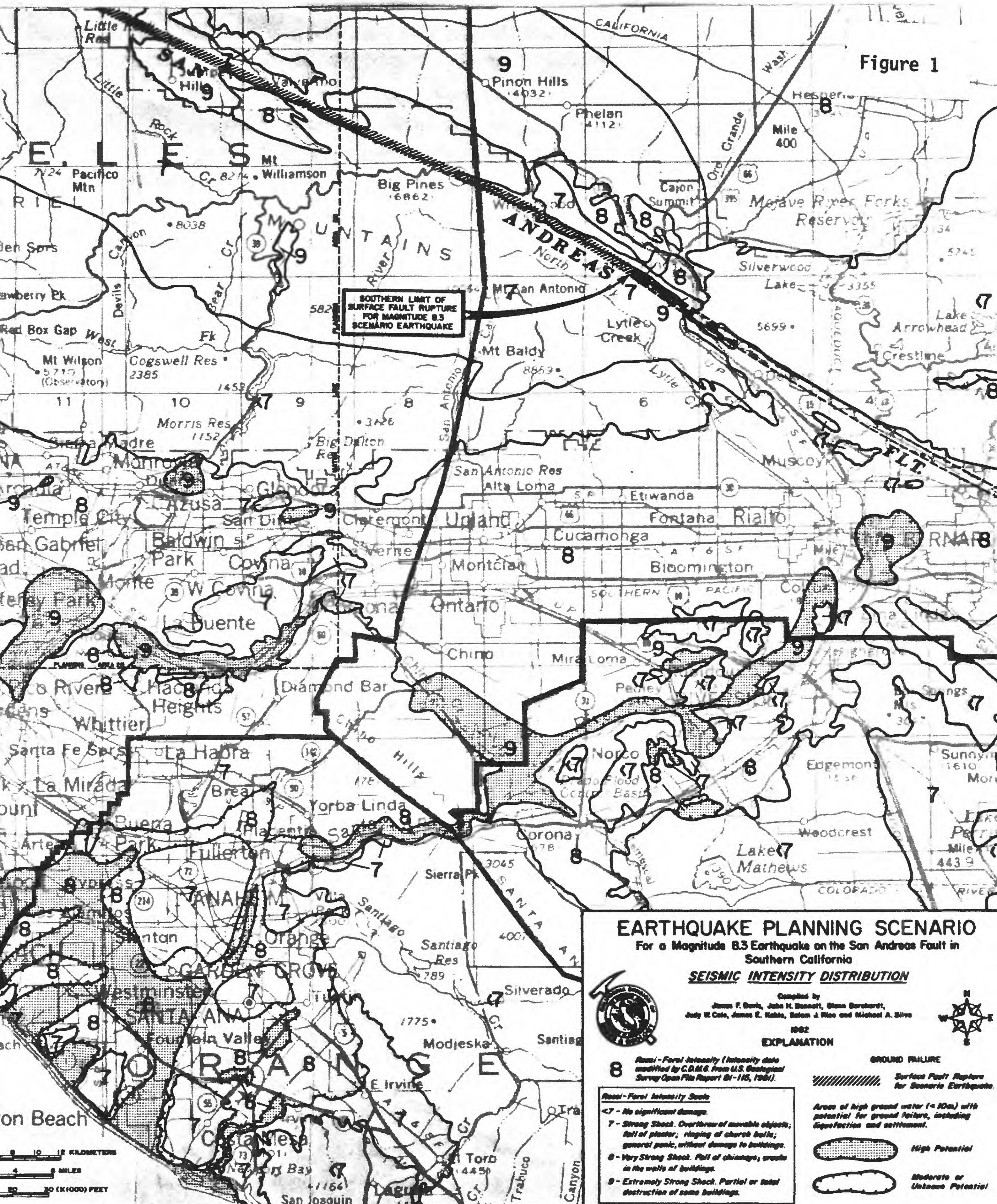
Application

Individual scenarios showing damage to critical facilities, specifically lifelines such as highways, airports, railroads, marine facilities, communication lines, water supply and waste disposal facilities, and electrical power, natural gas, and petroleum lines were developed by Davis and others (1982, p. 35-116) . The scenarios for

Figure 1. — Predicted seismic intensity distribution from a 1857-sized earthquake along the south-central San Andreas fault for part of the Los Angeles region. Compiled by Davis and others (1982) showing areas subject to surface fault rupture, liquefaction or other ground failure, and predicted intensity corresponding to the Rossi-Forel scale. Richter (1958, p. 651) alines the Rossi-Forel and modified Mercalli intensity scales as follows:

R-F	1	1-2	3	4-5	5-6	6-7	8-	8+ to 9-	9+	10
MM	I	II	III	IV	V	VI	VII	VIII	IX	X-XII

Figure 1


EARTHQUAKE PLANNING SCENARIO
For a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California
SEISMIC INTENSITY DISTRIBUTION
Compiled by
1982
EXPLANATION
8
Rossi-Forel Intensity (Intensity data modified by C.D.M.G. from U.S. Geological Survey Open File Report 81-115, 1981).
Rossi-Forel Intensity Scale
<7 - No significant damage.
7 - Strong Shock. Overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
8 - Very Strong Shock. Fall of chimneys; cracks in the walls of buildings.
9 - Extremely Strong Shock. Partial or total destruction of some buildings.
GROUND FAILURE
Surface Fault Rupture for Scenario Earthquake
Areas of high ground water (< 10m) with potential for ground failure, including liquefaction and settlement.
High Potential
Moderate or Unknown Potential
N
E
S
W
SOUTHERN LIMIT OF SURFACE FAULT RUPTURE FOR MAGNITUDE 8.3 SCENARIO EARTHQUAKE
SAN ANDREAS FLT.
MOUNTAINS
ORANGE
Pinon Hills
Phelan
Hesperia
Mile 400
Cajon Summit
Mojave River Forks Reservoir
Silverwood Lake
Lake Arrowhead
Crestline
Big Pines
Mt Williamson
Pacifico Mtn
Mt San Antonio
Mt Baldy
Lytle Creek
Mt Wilson
Cogswell Res
Red Box Gap
Morris Res
Big Dalton Res
San Antonio Res
Alta Loma
Etiwanda
Fontana
Rialto
Cucamonga
Upland
Claremont
Montclair
Bloomington
Ontario
Chino
Mira Loma
Muscoy
Monrovia
Azusa
Glendora
San Dimas
La Verne
Temple City
San Gabriel
Baldwin Park
Covina
W Covina
El Monte
La Puente
Hacienda Heights
Whittier
Diamond Bar
Chino Hills
Pedley
Norco
Prado Flood Control Basin
Edgemont
Sunnymead
Woodcrest
Lake Mathews
Corona
Santa Fe Springs
La Habra
La Mirada
Brea
Yorba Linda
Placentia
Buena Park
Fullerton
Anaheim
Orange
Garden Grove
Westminster
Santa Ana
Fountain Valley
Tustin
Villa Park
Santiago Res
Silverado
Modjeska
Sierra Pk
E Irvine
Costa Mesa
Newport Bay
San Joaquin Hills
El Toro
Mission Viejo
COLORADO RIVER
Ord Grande Wash
0 4 8 12 KILOMETERS
0 4 8 MILES
0 10 20 30 (X1000) FEET

lifelines are based upon evaluation of earthquake-engineering literature, comments by numerous engineers and other public-agency officials, and judgments by the authors. The reason for formulating the assessment of the effects of the earthquake upon lifelines was to interpret a regional pattern of ground shaking and ground failure (fig. 1) and to evaluate the resulting performance of lifeline segments throughout the Los Angeles region. For example, the communications map shows an assessment of telephone-systems performance following the postulated earthquake (fig. 2). Other maps, for example those for water supply and waste disposal facilities (fig. 3), show the location of, and estimates of damage to, the facilities. Most of the planning maps for the scenario contain notations which are explained in the text, for example, the notation "W12" on a Metropolitan Water District transmission pipeline shown on figure 3 reads:

> Water deliveries through the MWD Upper Feeder will be temporarily interrupted by pipe rupture where this major transmission line crosses the Santa Ana River.

According to Davis and others (1982, p. 9) most of the lifelines will sustain significant damage, and coping with it could require a major emergency-response effort. Each of the scenario maps are accompanied by a discussion of the general patterns of effects of the earthquake, for example:

> Interstate 5 from the San Joaquin Valley and Interstate 15 through Cajon Pass will be closed, leaving U.S. 101 along the coast as the only major viable route open from the north. Highway connections with San Diego will remain open (p. 37).
>
> Not all of the (telephone) systems in the greater Los Angeles region are set up to process emergency calls automatically on previously established priority bases. Thus overloading of equipment still in service could be very significant (p. 67).
>
> Two of the three major aqueduct systems that import water to southern California will be ruptured by displacement of the San Andreas fault, and supply will not be restored for a three- to six-month period (p. 85).

Each of the planning maps is accompanied by specific examples of anticipated damage, for example:

> In San Bernardino County, Interstate 15 will be closed by settlement of major fills and rockfalls in Cajon Canyon. Other freeway damage along Interstate 15E to the south, including major damage to the Interstate 15E/10 interchange will result in closure of this route south to Riverside and Interstate 10 to the east (p. 39).

> Norton Air Force Base near San Bernardino could experience some shaking of an intensity high enough to damage runways through the secondary effects of ground failure. Some damage could also occur to runways at Los Alamitos Armed Forces Reserve Center, but this may not be great enough to disrupt emergency operations (p. 51).

> The several hydroelectric-power plants located on the California and Los Angeles aqueducts in northwestern Los Angeles County and the Devil Canyon Power Plant near San Bernardino will be out of service for an extended period of time due to major damage to both of the aqueduct systems (p. 100).

Each of the planning maps for the scenario is also accompanied by planning needs, for example:

> Emergency planners need to identify major emergency routes that can be most readily opened immediately following the earthquake .... alternative emergency routes should be selected which are at grade, wide, not flanked by buildings which are likely to be damaged, and not likely to be obstructed by fallen powerlines or other obstructions (p. 40-41).

> Selection of air cargo delivery sites will influence the manner in which off-loaded personnel and supplies will be distributed by helicopters, highway, rail, or marine transport. Preferred airports need to be identified (p. 52).

> Plans should be developed to ensure gas availability for those users who have priority emergency responsibilities (p. 110).

Each of the planning maps is also accompanied by some recommendations for further work, for example:

> An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan (p. 83).

> Further analysis should be undertaken to confirm the tentative conclusion that up to 50 percent of the total power supply could be lost by this or a similar scenario earthquake and evaluate utility capabilities necessary to accomplish timely repairs to various damaged facilities (p. 104).

Figure 2. -- Impact of scenario earthquake on communications (telephone systems) for part of the Los Angeles region. Compiled by Davis and others (1982) showing the percent of telephone system effectiveness in four zones designated A, B, C, and D up to three days after the postulated earthquake.

Figure 2

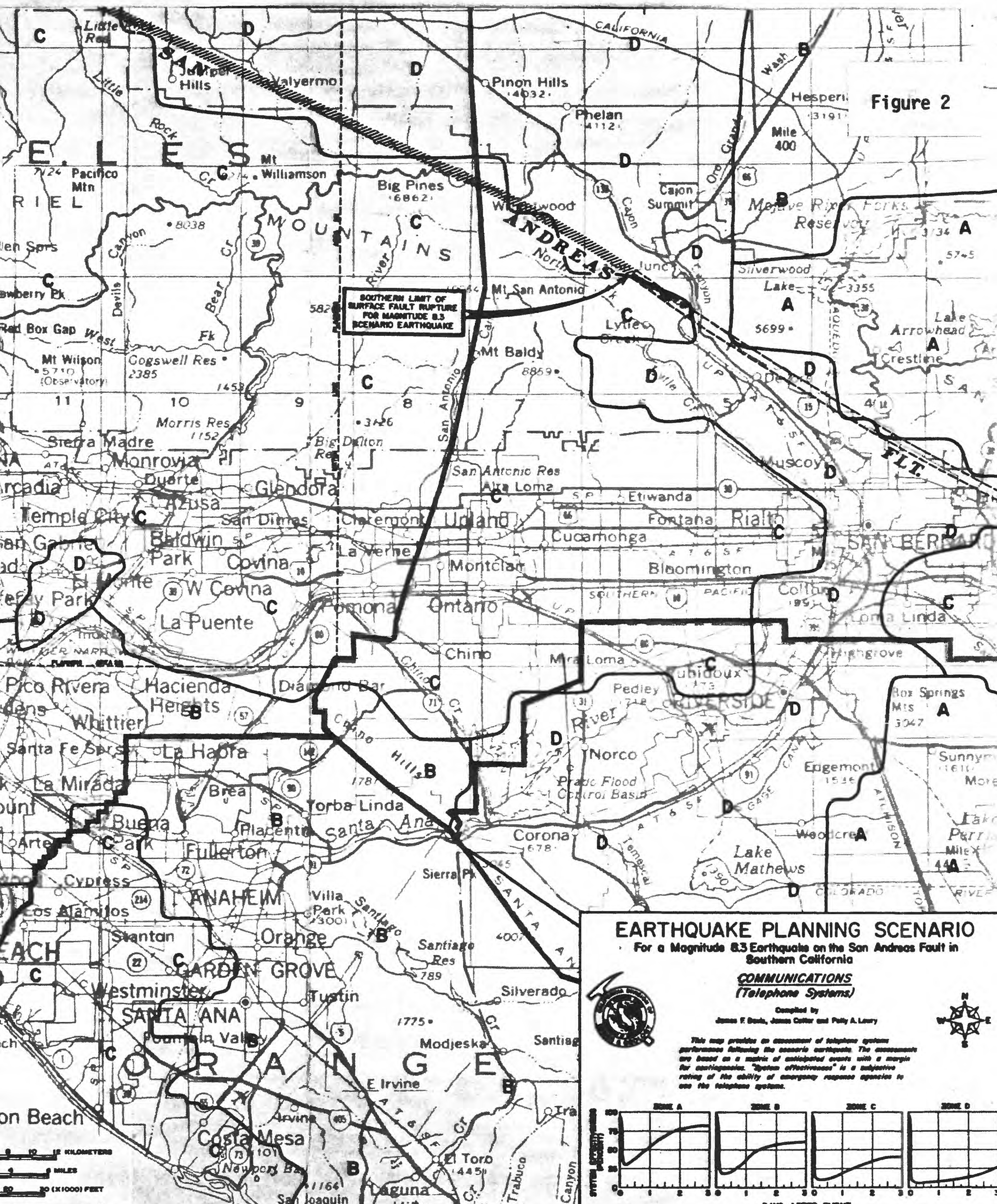
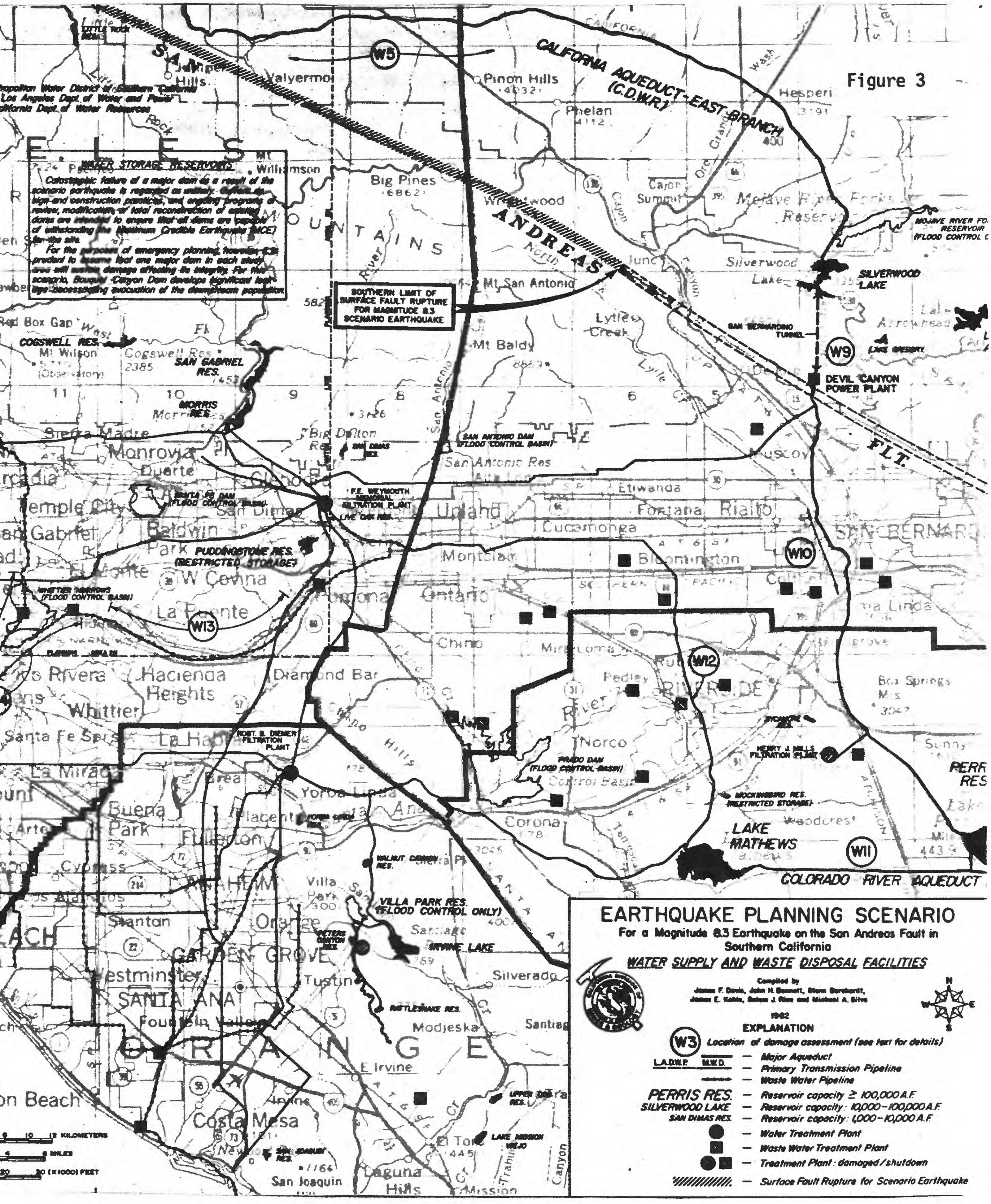

EARTHQUAKE PLANNING SCENARIO
For a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California
COMMUNICATIONS
(Telephone Systems)
Compiled by
This map provides an assessment of telephone systems performance following the scenario earthquake. The assessments are based on a matrix of anticipated events with a margin for contingencies. "System effectiveness" is a subjective rating of the ability of emergency response agencies to use the telephone systems.
ZONE A
ZONE B
ZONE C
ZONE D
DAYS AFTER EVENT
SOUTHERN LIMIT OF SURFACE FAULT RUPTURE FOR MAGNITUDE 8.3 SCENARIO EARTHQUAKE
SAN ANDREAS FLT.
MOUNTAINS
ORANGE
Pinon Hills
Phelan
Hesperia
Big Pines
Wrightwood
Cajon Summit
Mt San Antonio
Mt Baldy
Lake Arrowhead
Crestline
Silverwood Lake
Sierra Madre
Monrovia
Arcadia
Duarte
Azusa
Glendora
Temple City
Baldwin Park
San Dimas
Claremont
Upland
Etiwanda
Fontana
Rialto
Cucamonga
Covina
La Verne
Montclair
Bloomington
W Covina
La Puente
Pomona
Ontario
Colton
Loma Linda
Chino
Mira Loma
Rubidoux
Highgrove
Riverside
Pedley
Box Springs Mts
Pico Rivera
Hacienda Heights
Whittier
Diamond Bar
Santa Fe Sprs
La Habra
La Mirada
Brea
Yorba Linda
Norco
Edgemont
Buena Park
Placentia
Fullerton
Corona
Woodcrest
Lake Mathews
Cypress
Los Alamitos
ANAHEIM
Villa Park
Orange
Stanton
GARDEN GROVE
Westminster
Tustin
Silverado
SANTA ANA
Fountain Valley
Modjeska
E Irvine
Irvine
Costa Mesa
Newport Bay
El Toro
San Joaquin
Laguna Hills
Mission

Figure 3. -- Impact of scenario earthquake on water supply and waste disposal facilities for part of the Los Angeles region. Compiled by Davis and others (1982) showing the location of, and estimates of damage to, specific facilities -- aqueducts, pipelines, reservoirs, and treatment plants --from the postulated earthquake. The damage to specific facilities noted "W" and numbered on the map are explained in their text.

Figure 3



EARTHQUAKE PLANNING SCENARIO
For a Magnitude 8.3 Earthquake on the San Andreas Fault in Southern California
WATER SUPPLY AND WASTE DISPOSAL FACILITIES
Compiled by
James F. Davis, John H. Bennett, Glenn Borchardt, James E. Kahle, Salem J. Rice and Michael A. Silva
1982
EXPLANATION
W3 — Location of damage assessment (see text for details)
L.A.D.W.P. M.W.D. — Major Aqueduct
— Primary Transmission Pipeline
— Waste Water Pipeline
PERRIS RES. — Reservoir capacity ≥ 100,000 A.F.
SILVERWOOD LAKE — Reservoir capacity: 10,000–100,000 A.F.
SAN DIMAS RES. — Reservoir capacity: 1,000–10,000 A.F.
— Water Treatment Plant
— Waste Water Treatment Plant
— Treatment Plant: damaged/shutdown
— Surface Fault Rupture for Scenario Earthquake
WATER STORAGE RESERVOIRS
For the purposes of emergency planning, however, it is prudent to assume that one major dam in each study area will sustain damage affecting its integrity. For this scenario, Bouquet Canyon Dam develops significant leakage necessitating evacuation of the downstream population.
SOUTHERN LIMIT OF SURFACE FAULT RUPTURE FOR MAGNITUDE 8.3 SCENARIO EARTHQUAKE
CALIFORNIA AQUEDUCT-EAST BRANCH (C.D.W.R.)
COLORADO RIVER AQUEDUCT
SAN ANDREAS FLT.
SILVERWOOD LAKE
DEVIL CANYON POWER PLANT
SAN BERNARDINO TUNNEL
LAKE GREGORY
COGSWELL RES.
SAN GABRIEL RES.
MORRIS RES.
SAN DIMAS RES.
SAN ANTONIO DAM (FLOOD CONTROL BASIN)
F.E. WEYMOUTH FILTRATION PLANT
LIVE OAK RES.
PUDDINGSTONE RES. (RESTRICTED STORAGE)
WHITTIER NARROWS (FLOOD CONTROL BASIN)
ROBT. B. DIEMER FILTRATION PLANT
PRADO DAM (FLOOD CONTROL BASIN)
SYCAMORE RES.
HENRY J. MILLS FILTRATION PLANT
MOCKINGBIRD RES. (RESTRICTED STORAGE)
LAKE MATHEWS
WALNUT CANYON RES.
VILLA PARK RES. (FLOOD CONTROL ONLY)
PETERS CANYON RES.
IRVINE LAKE
RATTLESNAKE RES.
UPPER OSO RES.
LAKE MISSION VIEJO
SAN JOAQUIN RES.
W5
W9
W10
W11
W12
W13
Pinon Hills
Phelan
Big Pines
Wrightwood
Mt San Antonio
Mt Baldy
Upland
Ontario
Pomona
Chino
Fontana
Rialto
Riverside
Norco
Corona
Orange
Santa Ana
Garden Grove
Costa Mesa
Tustin
Fullerton
Whittier
La Puente
W Covina
Monrovia
Duarte
Arcadia
Temple City
ORANGE

> Plans for fire control should be developed for areas where these pipelines cross the San Andreas fault. Plans should also exist to ensure distribution of fuel supplies to airports selected for emergency activity and to other locations where fuel supplies for emergency response activities will be needed (p. 115).

Comments

Each planning map contains a caveat to users concerning the assessment of damage, as follows:

> The conclusions regarding the performance of facilities are hypothetical and not to be construed as site-specific engineering evaluations. For the most part, damage assessments are strongly influenced by the seismic intensity distribution map for this planning area. There is disagreement among investigators as to the most realistic model for predicting seismic intensity distribution. None have been fully tested and each would yield a different earthquake planning scenario. Facilities that are particularly sensitive to emergency response will require a detailed geotechnical study.
>
> The damage assessments are based upon this specific scenario. An earthquake of significantly different magnitude or epicentral location on this or any one of many other faults in the planning area will result in a markedly different pattern of damage.

It should be stressed that the lifeline damages anticipated in the scenario are presented for planning purposes only, and some may consider them overly pessimistic. However, it is important in emergency planning to consider the worst possibilities concerning disruption of lifelines after a major earthquake so as to be better able to prepare, respond, and recover.

ADOPTING SEISMIC SAFETY PLANS

The California State Legislature (1971) requires that each county prepare and adopt a comprehensive, long-term general plan for the physical development of the county. This general plan shall include:

> A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches.
>
> The seismic safety element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, ground shaking, ground failure, and seismically induced waves.

All counties in the Los Angeles region have prepared and adopted seismic safety plans -- Orange County Environmental Management Agency (1975), Los Angeles County Department of Regional Planning (1974), Riverside County Planning Department (1978), Santa Barbara County Planning Department (1979), San Bernadino County Planning Department (1979), San Diego County Environmental Development Agency (1975), and Ventura County Environmental Resources Agency (1974). Some of these counties have included hydrologic hazards, and geologic hazards other than seismic, in their plans as required by the California State Legislature (1971). Santa Barbara County's plan is presented here as an illustration of how a seismic safety plan is prepared and adopted.

Santa Barbara County lies in the Transverse Range and the southern Coast Range provinces. The county includes 2,740 square miles (7097 km^2) and four channel islands. Because of its excellent climate, Santa Barbara County has been experiencing a rapid growth in population. According to the Santa Barbara County Planning Department (1979, p. 14), the county is not yet so urbanized that planning is in the "too little and too late" category. The department's report states that:

> in the past, rapid population growth in California has pushed new urbanized development into geologically unfriendly terrain, where even minimal precautions were not observed because of ignorance of facts that were often readily available. Planning can avoid the areas least feasible for development from a geologic point of view.

For more than two centuries significant earthquakes have been felt or have caused damage in Santa Barbara County. Strong shaking and major damage from earthquakes occur an average of every 15 to 20 years.

Information

Much geologic and seismologic information is available and is referred to in the report by the Santa Barbara County Planning Department (1979, p. 181-190). For example, basic geologic maps have been prepared by Dibblee (1950, 1966, 1973) and Woodring and Bramlette (1950). Various USGS papers on ground-water supply -- Evenson and Miller (1963), Muir (1968), Upson (1951), and Worts (1951) -- were used to identify areas of possible liquefaction. A report on recency of faulting by Ziony and others (1973) is frequently referred to. A report by Hamilton and others (1969) on seismicity is cited. The discussions of seismic risk refer to methods for calculating recurrence intervals on the basis of long-term slip rates on the fault developed by Wallace (1970), Clark and others (1972), and Lamar and others (1973).

Decision

The county planning department used a consultative team headed by a firm of city and regional planners, Livingston and Associates, and a firm of consulting engineers and geologists, Moore and Taber. The county board of supervisors unanimously adopted the county seismic safety plan on January 22, 1979. The planning department and the investigative team were assisted by area advisory committees and others including the California Earth Science Corporation, Lindvall-Richter and Associates, and Drs. Robert M. Norris and Robert W. Webb of the University of California, Santa Barbara. The Santa Barbara County Planning Department (1979, p. 7) states that:

> The study consisted primarily of a thorough review of the general geology of Santa Barbara County and its compilation onto base maps, and an investigation of the main geologic and soil problems, with emphasis on those associated with faults and earthquakes. Specific geologic and soil problems that were considered, together with their effect on land use planning, were ground rupture, ground shaking, tsunamis and seiches, soil liquefaction, landslides and slope stability, expansive soils, soil creep, compressible and collapsible soils, high groundwater, erosion and shoreline regression, and subsidence.

For purposes of the study, the county was divided into four study areas based mainly on population patterns and potential development. According to the Santa Barbara County Planning Department (1979, p. 33), geologic, soil, and seismic factors "affect the suitability of land for various uses and ... should be considered, along with other factors, in land-use planning in order to eliminate or minimize their adverse effects...." The department also developed the following tabulation which provides a rough classification of factors to be considered in land-use planning:

> Critical
>
> Ground rupture from fault movement
> Tsunamis and seiches
> Liquefaction
>
> Sometimes Critical
>
> Ground shaking
> High ground water
> Subsidence (normally correctable with engineering)
> Slope stability and landslides
> Soil creep
>
> Less Critical
>
> Expansive soils
> Compressible - collapsible soils

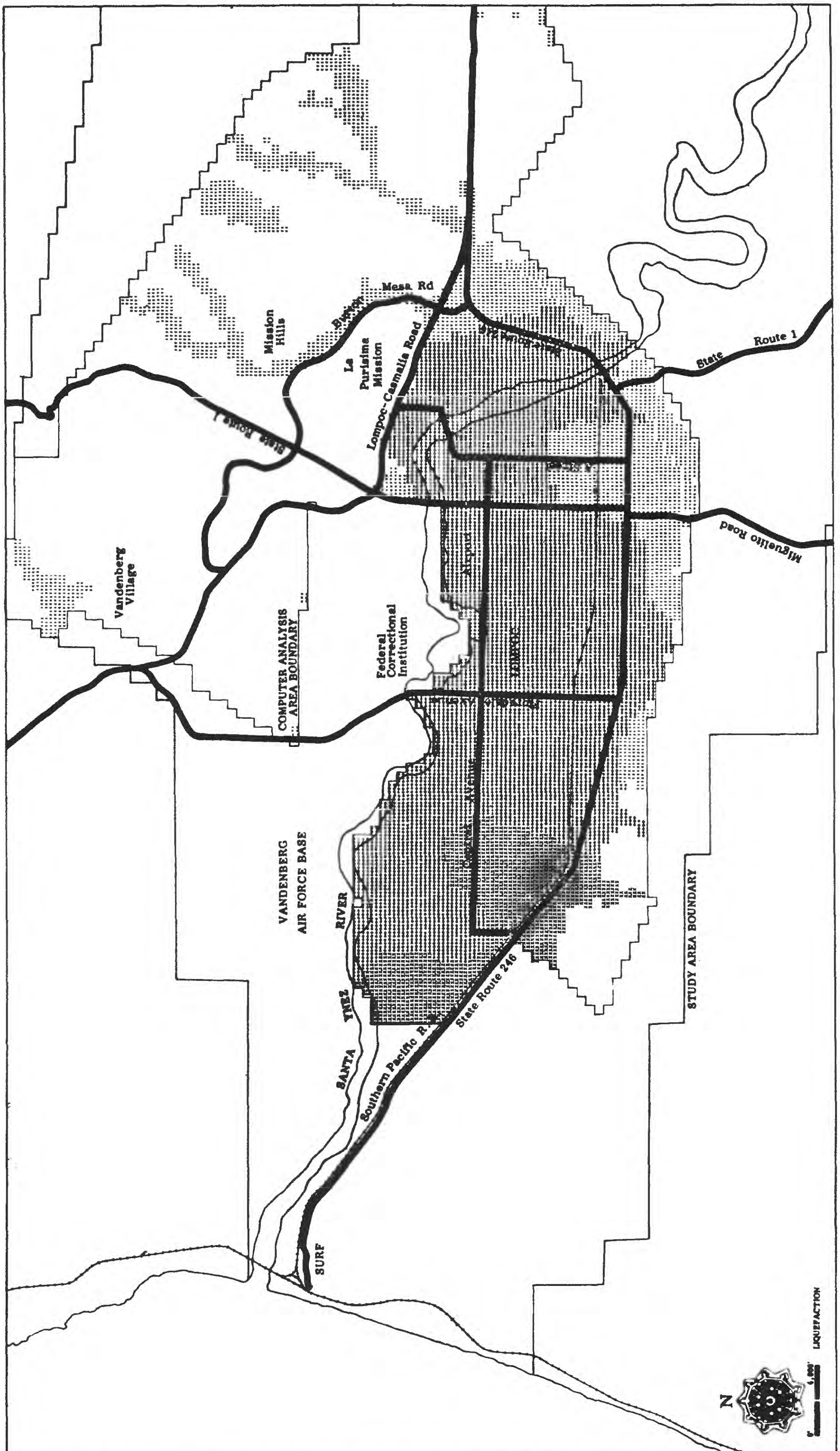
The county planning department (p. 33) concludes that:

> Ground rupture from fault offset and tsunamis and seiches are the only geologic problems for which there are no really feasible engineering solutions, and which could be considered as dominant factors in planning (assuming fairly frequent occurrence). Items lower on the list should also be taken into account during development, and probably should be given some consideration in planning land use or density.

The Seismic Safety and Safety Element prepared by the Santa Barbara County Planning Department (1979) includes a description of each geologic and seismologic hazard. For example, the fundamentals of engineering seismology including earthquake intensity, magnitude, frequency, recurrence intervals, and duration of shaking are discussed; general seismicity and a condensed earthquake history are presented; a three-zone seismo-tectonic map for each study area is shown; earthquake recurrence intervals for the San Andreas and Big Pine faults are estimated; forty-seven faults classified as either active, potentially active, or inactive are described; five major areas subject to inundation by future tsunamis are identified; areas subject to liquefaction are mapped (fig. 4); and areas subject to landsliding are identified and mapped.

Figure 4. -- Liquefaction susceptability for part of the Lompoc study area. Prepared by the Santa Barbara County Planning Department (1979) at an original scale of 1:96,000. The white areas and lighter pattern within the computer analysis area boundary indicate a low problem rating. The darker patterns indicate a moderate problem rating.

Figure 4


Mesa Rd
Mission Hills
La Purisima Mission
Lompoc-Casmalia Road
State Route 1
State Route 1
Miguelito Road
Vandenberg Village
Airport
Federal Correctional Institution
LOMPOC
COMPUTER ANALYSIS AREA BOUNDARY
VANDENBERG AIR FORCE BASE
SANTA YNEZ RIVER
Southern Pacific R.R.
State Route 246
STUDY AREA BOUNDARY
SURF
N
LIQUEFACTION

Application

Geologic and seismologic information were compiled and transferred to USGS 7½-degree quadrangle maps (topographic series) at a scale of 1 inch = 2,000 feet (1:24,000) for the four study areas. A reproducible mylar geologic map of the county at a scale of 1 inch = 8,000 feet (1:96,000) is on file at the county public works department. The geologic maps show the major bedrock units, surficial geologic units, faults, and folds.

The hazards were evaluated and rated according to their severity by applying geologic and engineering judgments. The areal extent and severity of the hazards were shown on the topographic base maps for the study areas. The data were then transferred to 5-acre-grid (2 ha) base maps and the ratings for the individual hazards were encoded to produce computerized maps. Each geologic hazard evaluated was given one of three ratings -- high, moderate, or none to low. (fig. 4).

The Santa Barbara Planning Department (1979) then assigned a composite number to give an overall indication of the difficulty of developing any particular area, based on known geologic hazards. The department devised a system for rating geologic hazards for a given area on both an individual and collective basis -- a system that could be performed by computer. The resulting cumulative value was designated the geologic problem index (GPI). The GPI values for the four study areas were obtained by multiplying each geologic hazard by a weighting factor that takes into account the seriousness of the hazard, the difficulty of alleviating it, and the frequency of occurrence. The GPI values were then divided into five categories, ranging from low through moderate to severe.

The GPI was calculated for each 5-acre (2 ha) cell in the computer analysis areas for each study area. The GPI was then assigned to the appropriate severity category and displayed on a computer-produced map (fig. 5). Thus these computer GPI maps reflect a summation of the ratings delineated on the geologic hazard maps (fig. 4).

Recommendations were then made by the Santa Barbara County Planning Department (1979) concerning land-use planning, subdivision procedures, grading codes, building codes, and land stability insurance. For example, the land-use planning section contains the following recommendation concerning areas designated severe on the GPI index:

> These areas should be given primary consideration for minimum development and use. They could be planned as natural areas, or for recreational or agricultural use. If development is permitted, it should generally be of low density.

One of the recommendations concerning subdivision procedures is that geologic reports should generally be required when the property contains or is near an active or potentially active fault or has a moderate to severe GPI.

In addition, the county planning department makes recommendations for future studies such as updating basic geologic maps, investigating potentially active faults, installing additional seismic instrumentation, and inventorying existing structures to determine their physical condition and location relative to potential geologic problems.

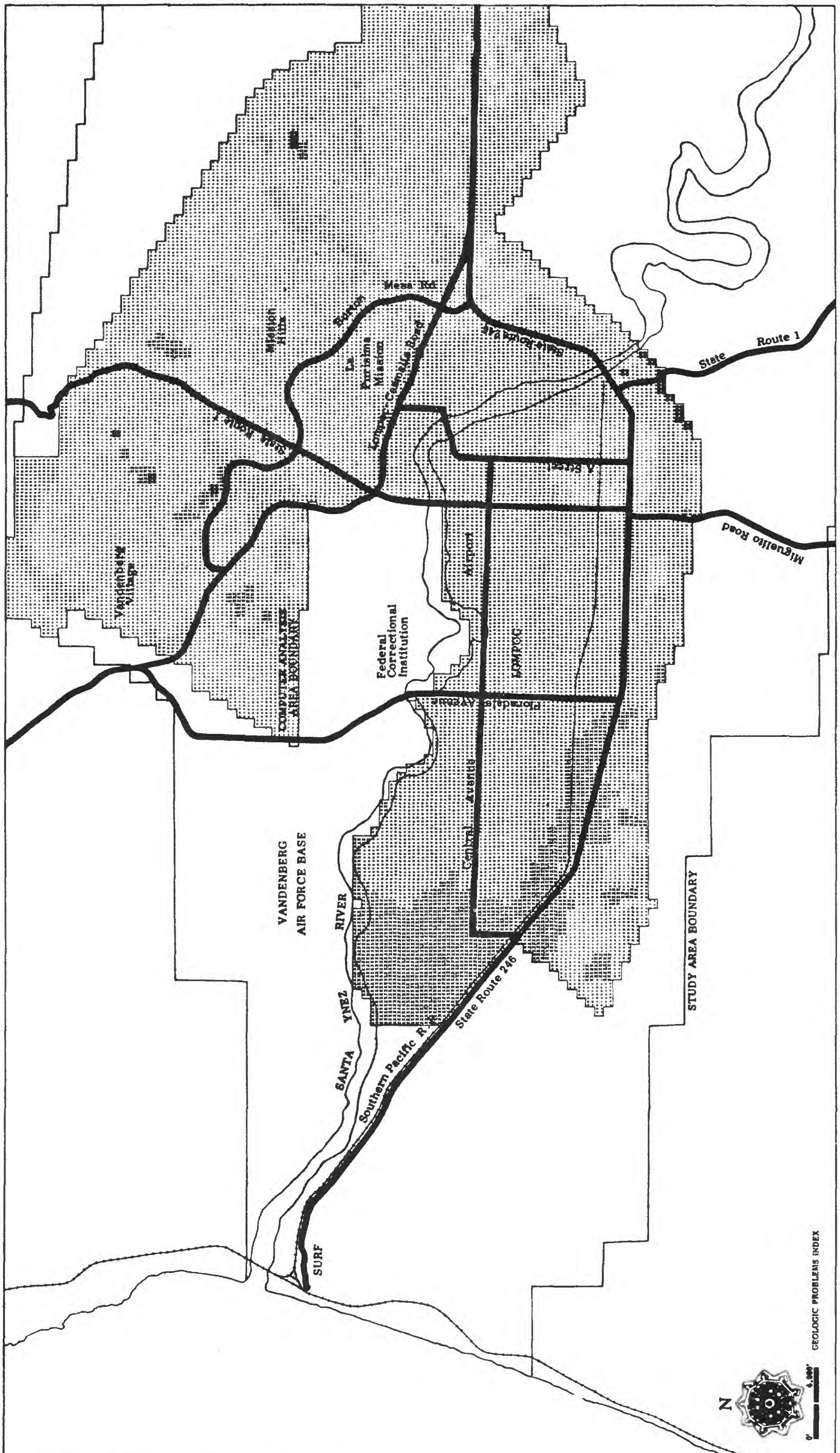
Comments

This example illustrates how a county planning department, assisted by planning, engineering, and geotechnical consultants compiled, evaluated, digitized, and rated a wide range of geologic and seismologic information. The Santa Barbara County Planning Department (1979, p. 138) concludes that the time and effort expended on developing the GPI system for the county has been well spent, and that:

> As a planning aid, it shows the range in occurrence and severity of geologic problems within the County, providing valuable input necessary to the development of an intelligent plan for land use. The individual problem rating maps can be used by developers and by the various governmental agencies responsible for their supervision and guidance as an index to the specific geologic problems that can be expected in a particular area.

Figure 5. -- Summary of geologic hazards in the Lompoc study area. Prepared by the Santa Barbara County Planning Department (1979) at an original scale of 1:96,000. The lighter patterns indicate low to moderate severity. The darker patterns indicate moderate to severe.

Figure 5



Mesa Rd.
Burton
Mission Hills
La Purisima Mission
Lompoc-Casmalia Road
State Route 1
Vandenberg Village
COMPUTER ANALYSIS AREA BOUNDARY
Federal Correctional Institution
Airport
LOMPOC
Central Avenue
Miguelito Road
VANDENBERG AIR FORCE BASE
SANTA YNEZ RIVER
Southern Pacific R.R.
State Route 246
SURF
STUDY AREA BOUNDARY
GEOLOGIC PROBLEMS INDEX
N

RETROFITTING HIGHWAY BRIDGES

The 1971 San Fernando earthquake represented a major turning point in the development of seismic design criteria for bridges. Gates (1976, p. 2301) a senior bridge engineer in the California Department of Transportation (CALTRANS), reports that prior to the earthquake very little bridge damage was caused directly by vibrational effects, however:

> After the 1971 San Fernando event ... we observed a significant amount of vibrational effects on bridge structures.... These effects were the result of very large vertical and horizontal ground accelerations, possibly exceeding 0.5g.... The total damage to highway bridges in San Fernando was about $6,500,000. The major damage, especially the vibrational damage, was concentrated within the narrow region close to and possibly within the causitive fault zone of the magnitude 6.6 event.

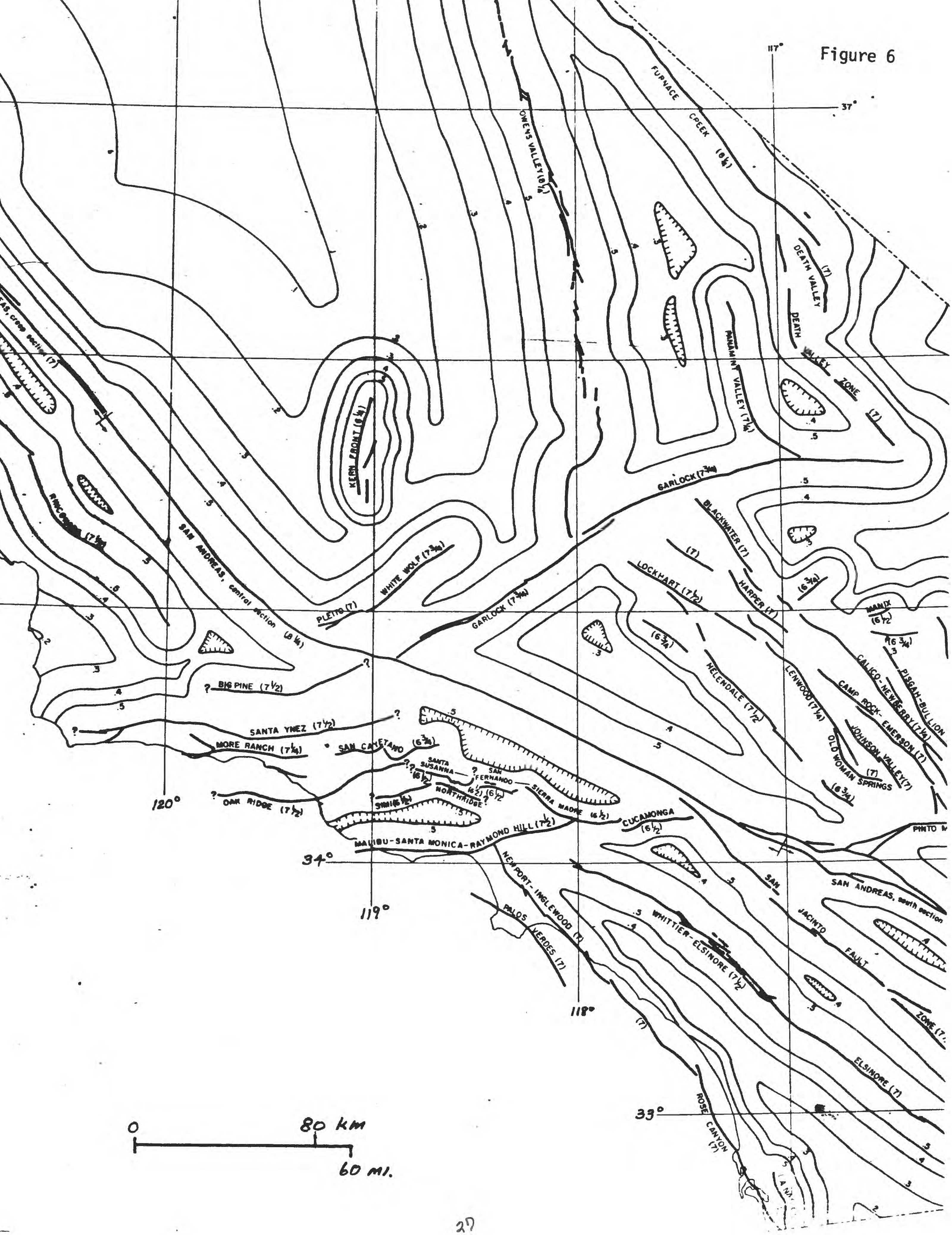
One of the problems is a design feature deliberately built into bridges and overpasses throughout the United States during the 1950's and 1960's to allow the structures to expand and contract with temperature changes. Bridge and overpass superstructures have traditionally been placed on the supporting piers and abutments without being attached to accomodate temperature movements; the weight of the roadbed is expected to hold them in place. The problem with this design feature was not realized until the 1971 earthquake. At that time, the ends of many bridges in the San Fernando Valley fell off the abutments or hinge seats upon which they sat. CALTRANS has identified 1,133 bridges throughout the State, out of approximately 13,000, which need retrofitting. CALTRANS is now focusing on the retrofitting of the unrestrained joints of these bridges (Gates, written commun., Dec. 1981).

Information

After the 1971 San Fernando earthquake, a map showing maximum credible ground acceleration on bedrock from future earthquakes in California was prepared by the California Division of Mines and Geology (Greensfelder, 1972). The method used assumed that faults known to have been active in Quaternary time would indicate the distribution of future earthquake epicenters (Greensfelder, 1973). According to Gates (1976) each of the selected faults was then assigned a maximum probable earthquake magnitude based on fault-rupture length data from Bonilla (1970). Using a set of curves relating peak ground acceleration, distance from fault rupture, and magnitude based on Schnabel and Seed (1972), peak ground acceleration values for bedrock sites were plotted for each fault. These values were then contoured to produce a map covering all of California, a portion of which is shown in

Figure 6. -- Maximum credible ground acceleration on bedrock from future earthquakes. Prepared by Greensfelder (1972) at an original scale of 1:2,000,000 showing potentially active faults and acceleration contours for part of southern California. Numbers next to the fault name indicate assumed maximum-magnitude earthquake for that fault. More recent studies, based on probabilistic estimates of expected shaking, are available. See Thenhaus and others (1980) and Algermissen and others (1982).

Figure 6



117°
37°
FURNACE CREEK (8¼)
OWENS VALLEY (8¼)
DEATH VALLEY (7)
DEATH VALLEY ZONE (7)
PANAMINT VALLEY (7½)
KERN FRONT (6¾)
GARLOCK (7¾)
WHITE WOLF (7¾)
PLEITO (7)
SAN ANDREAS, central section (8¼)
SAN ANDREAS, creep section (7)
RINCONADA (7½)
BLACKWATER (7)
LOCKHART (7½)
HARPER (7)
HELENDALE (7½)
LENWOOD (7¼)
MANIX (6½)
CALICO-NEWBERRY (7¼)
PISGAH-BULLION
CAMP ROCK-EMERSON (7)
JOHNSON VALLEY (7)
OLD WOMAN SPRINGS
BIG PINE (7½)
SANTA YNEZ (7½)
MORE RANCH (7¼)
SAN CAYETANO (6¾)
SANTA SUSANNA
SAN FERNANDO
NORTHRIDGE
SIERRA MADRE (6½)
OAK RIDGE (7½)
CUCAMONGA (6½)
MALIBU-SANTA MONICA-RAYMOND HILL (7½)
PINTO M
120°
34°
119°
SAN ANDREAS, south section
SAN JACINTO FAULT ZONE (7
NEWPORT-INGLEWOOD (7)
PALOS VERDES (7)
WHITTIER-ELSINORE (7½)
118°
ELSINORE (7)
33°
ROSE CANYON (7)
0
80 km
60 mi.

figure 6. Gates (1976) discusses how this map information is combined with soil data and used as a basis for the seismic design criteria for California's bridges.

More recently, probabilistic estimates of the levels of ground shaking have been made. For example, Thenhaus and others (1980) show earthquake shaking anticipated in California coastal and outer-continental-shelf areas on a series of six maps at a scale of 1:5,000,000. The maps show peak horizontal acceleration and peak horizontal velocity on rock having a 90 percent probability of not being exceeded in 10 years, 50 years, and 250 years; the respective return periods being approximately 100 years, 500 years, and 2,500 years. Algermissen and others (1982) show earthquake shaking anticipated for the contiguous United States on a series of six maps. The maps show maximum horizontal acceleration and horizontal velocity in rock with a 90 percent probability of not being exceeded in 10 years, 50 years, and 250 years. Hays (1980) has reviewed the current procedures for specifying the characteristics of ground motion needed for earthquake-resistant design.

Decision

One of the major conclusions drawn after the San Fernando earthquake was that deficiencies in details, especially at connections of major structural components, played a major role in all of the collapse failures of bridges. According to Gates (1976, p. 2302), the decision was then made to (1) develop rational design criteria which take site-dependent characteristics into consideration, (2) incorporate improved details into all bridges being designed and constructed, and (3) evaluate and determine priorities for upgrading the earthquake resistance of existing bridges. Two of the factors selected for inclusion in the design criteria were to consider the location of the site relative to active faults, and the effect of maximum credible earthquakes originating on individual active faults.

A CALTRANS bridge engineer (Mancarti, 1981, p. 1, 2), in discussing highway bridge retrofit, describes the types of restrainers -- steel cables, rods, hinges, and bearing support hardware -- used to tie bridge superstructures together as well as tie superstructures to substructures, and states that the main purpose is:

> to prevent spans from separating at hinges or falling off their bearing supports and to make structures seismically resistant to the extent that while they may sustain localized damage, they will not collapse catastrophically. It is also desirable that highway structures be rendered capable of carrying emergency traffic, with quickly performed temporary repairs so as to provide transportation lifelines for a stricken community immediately after a disaster.

The new designs for hinges have substantial cable restrainers, for example, multiple units of seven 3/4-inch cables that form a tendon inside a pipe (fig. 7A). These restrainers allow the bridges to move in small increments; the joints may open and close to the maximum amount needed to accomodate temperature changes normally ranging from 1 to 3 inches (25-76 mm). Pond in a bulletin of the California State Division of Highways (1972, p. 3), observes that when this movement has occurred, the restrainers are designed to limit further movement and prevent collapses such as occurred during the 1971 San Fernando earthquake.

Application

Since 1971, CALTRANS has been involved in retrofitting existing bridges. Their program began almost immediately after the 1971 San Fernando earthquake. The initial goal of the retrofitting program was to tie bridge superstructures together at hinges and bearings and to tie superstructures to substructures at bearing supports.

According to Mancarti (1981, p. 3), CALTRANS concentrated first on the hinges in the continuous structures and developed a fairly simple hinge restrainer unit for use in concrete box girder bridges (fig. 7A); and:

> Components were easily fabricated from standard, available hardware and our retrofit contractors quickly developed the knack of installing them in structures at a reasonable price.

This unit does not have high enough load capacity for certain superstructure configurations in highly seismic areas. As a result, CALTRANS developed a high-strength rod restrainer (fig. 7B). A unit with four symmetrically placed 1¼-inch (31.75 mm) high-strength rods is rated at 600,000 pounds (600 kips) design load. Units using one, two, or four rods have been successfully installed. They possess the additional advantage of requiring smaller size holes to be cored through existing concrete elements (Mancarti, 1981).

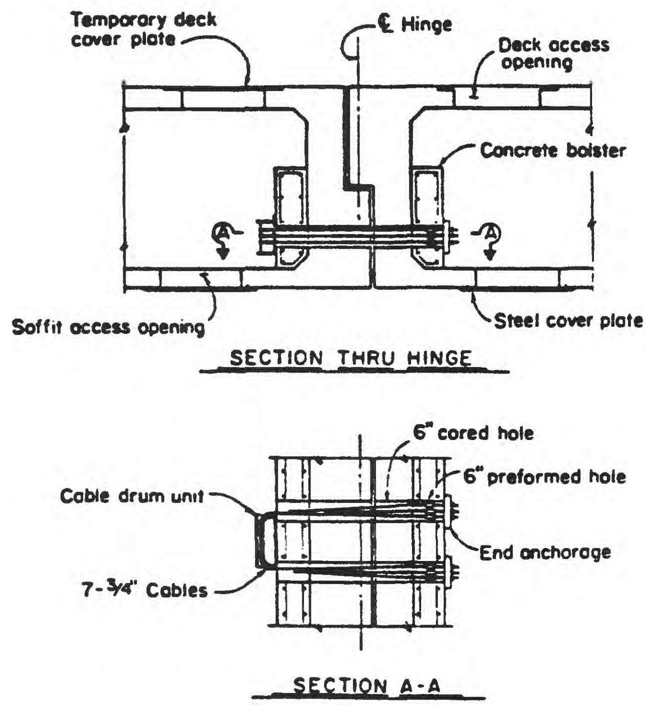
Selection of structures for retrofit is currently based on a priority system. Mancarti (1981) reports that the priority system:

> takes into account the bedrock acceleration at the structure site, the estimated cost to retrofit the structure, the cost of replacement in the event of loss, the ratio of the replacement cost to the retrofit cost, the length and availability of detours, and the average daily traffic on the main line as well as other factors which reflect the importance of the structure in the system.

This rating technique has been put on the CALTRANS' computer in conjunction with their ongoing program for structure replacement and improvement; it ranks the structures for inclusion in the annual State transportation improvement program. To date, over one-half of these structures have been retrofitted at a cost of $24 million. According to Gates (written commun., Dec. 1981) current budget allocation will permit completion of all bridges identified as deficient by 1990.

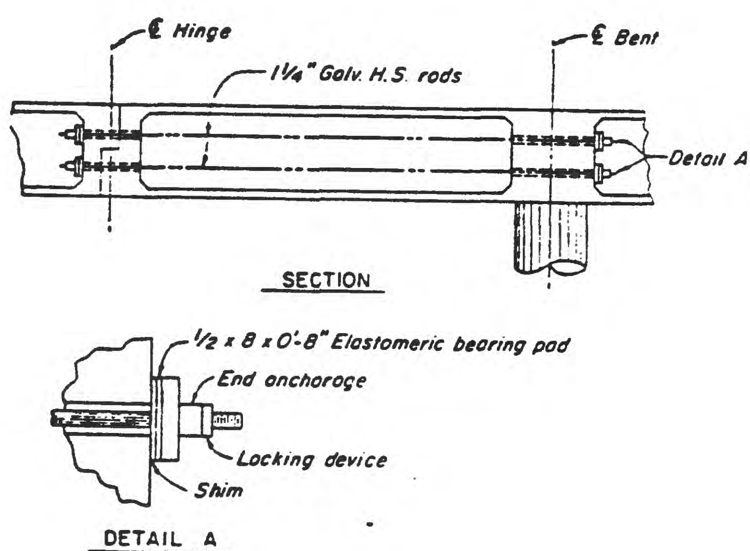
Figure 7. -- Hinge connections designed to make concrete highway bridges earthquake resistant (from Mancarti, 1981) showing cross sections and details for (A) cable restrainer and (B) high-strength rod restrainer.

Figure 7



Temporary deck cover plate
℄ Hinge
Deck access opening
Concrete bolster
Soffit access opening
Steel cover plate
SECTION THRU HINGE
6" cored hole
6" preformed hole
Cable drum unit
End anchorage
7-3/4" Cables
SECTION A-A

(A)



℄ Hinge
℄ Bent
1 1/4" Galv. H.S. rods
Detail A
SECTION
1/2 x 8 x 0'-8" Elastomeric bearing pad
End anchorage
Locking device
Shim
DETAIL A

(B)

Comments

The average CALTRANS retrofit project consists of the addition of steel restrainer cables at hinge and expansion joints to prevent spans from collapsing. The potential for collapse is minimized even if extensive damage occurs. The design criteria and priority system selected can be easily modified as estimates of likely shaking are refined and as new developments are made in earthquake engineering.

Gates (written commun., Dec. 1981) reports that the CALTRANS-designed details for restrainer units have evolved to the point where the systems are performing satisfactorily in the field, although none have been tested by a natural earthquake. CALTRANS' engineers warn that retrofitting will not keep an overpass bridge from collapsing if the fault rupture of a major earthquake is under or adjacent to the structure.

REGULATING DEVELOPMENT IN POTENTIAL SURFACE FAULT-RUPTURE AREAS

Many active fault zones underlie the Los Angeles region. The traces of these faults are likely to be the sites of significant displacement during future major earthquakes. It is difficult and costly to design and construct structures to withstand fault displacement. Even an inch or two (25-50 mm) of sudden fault movement can severely damage some buildings. The probability that an earthquake will destroy buildings and kill or injure people becomes significant where high-density urban development or critical facilities straddle active faults. Thus the dominent strategy for reducing the hazard from surface rupture is the avoidance of potential surface fault-rupture areas.

If new fault traces are discovered or new areas are designated as hazardous, existing structures may be determined to be unsafe. For example, many schools, hospitals, and other public and private developments have been built on or near the surface traces of previously unrecognized active faults. The 1971 San Fernando earthquake in southern California is a recent example of damage occurring to structures erected over an active fault whose trace was not generally recognized at the time of development. Much of the damage associated with fault rupture can be limited if construction on active faults is avoided. Utility lines and transportation facilities can be located, designed, and operated in such a way as to reduce outages and other disruptions. Some of the methods for using earth-science information and hazard mapping in land-use planning and regulations are discussed by Blair and Spangle (1979).

However, reconstruction commonly takes place in the same hazardous areas after an earthquake. For example, Youd and others (1978, p. 111) observed that after the San Fernando earthquake:

> buildings had been repaired, new buildings have been built, and a freeway interchange has been constructed across the trace of the 1971 fault rupture.

Information

In California, many potentially active and recently active faults have been identified and mapped at various scales. A preliminary map showing recency of faulting by Ziony and others (1974) shows the location of presently known or inferred faults in the coastal region of southern California and what is currently known about the recency of displacement along each fault. Maps by the USGS and the California Division of Mines and Geology (CDMG) are available chiefly at scales of 1:24,000 or smaller for many individual faults or fault-rupture zones. Examples include Sharp

(1967) on the San Jacinto fault zone, Sarna-Wojcicki and others (1976) on the Ventura fault, Barrows and others (1976) on the Palmdale segment of the San Andreas fault zone, and Weber (1977) on the Elsinore and Chino faults.

The trace of an active fault cannot always be seen at the surface. It may be concealed, and the geologist may have to approximate its location. Displacements do not always occur along a single fault trace; branching segments, braided, and en echelon faults may result in wide zones of disturbance (fig. 8). Therefore, regulatory measures for avoiding or reducing the hazards of fault rupture commonly require detailed geologic investigations to accurately identify and evaluate all the strands of the faults. Once located, specific regulations -- prohibiting certain uses or requiring specific buildings to be set back from the active strands -- can be applied.

Decision

In response to public concern and because of the availability of scientific information, the California State Legislature (1972) enacted the Alquist-Priolo Special Studies Zones Act. The act provides for public safety by restricting development near or over the surface traces of active faults. In addition, the act provides for: geologic reports, approval of projects by cities and counties, exemptions for altering and adding to existing structures, disclosure of hazards by sellers and their agents, and the charging of reasonable application fees.

In order to assist the cities and counties, the act requires the State Geologist to delineate Special Studies Zones that include all "potentially and recently active" traces of the San Andreas, Calaveras, Hayward, and San Jacinto faults and other faults he deems "sufficiently active and well-defined" as to constitute a potential hazard from surface fault rupture. For the purpose of the act, a fault is deemed "sufficiently active" if there is evidence of surface displacement along one or more of its segments or branches during the last 11,000 years; a fault is considered "well-defined" if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface (Hart, 1980, p. 5, 6).

The State Geologist initially delineated zones about one-quarter of a mile (400 m) wide. Currently, the zones delineated are about 400 to 600 feet (130-200 m) wide. Using the best information available, surface traces of well-known faults have been delineated on about 300 quadrangle maps (fig. 9). The Special Studies Zones are established by selecting turning points located at obvious features on either side of a mapped fault trace. The zone boundaries are drafted as straight lines connecting these points. Because fault traces vary, some having branching segments, curved or discontinuous traces, or wide areas of crushed rock, the zones are irregular and may exceed one-quarter of a mile (400 m) in width. Maps similar to figure 10 show faults, historical offsets and the year of their occurrence, displacement caused by creep, and lineaments seen on aerial photographs. Currently, the CDMG is evaluating those faults identified as "sufficiently active and

Figure 8

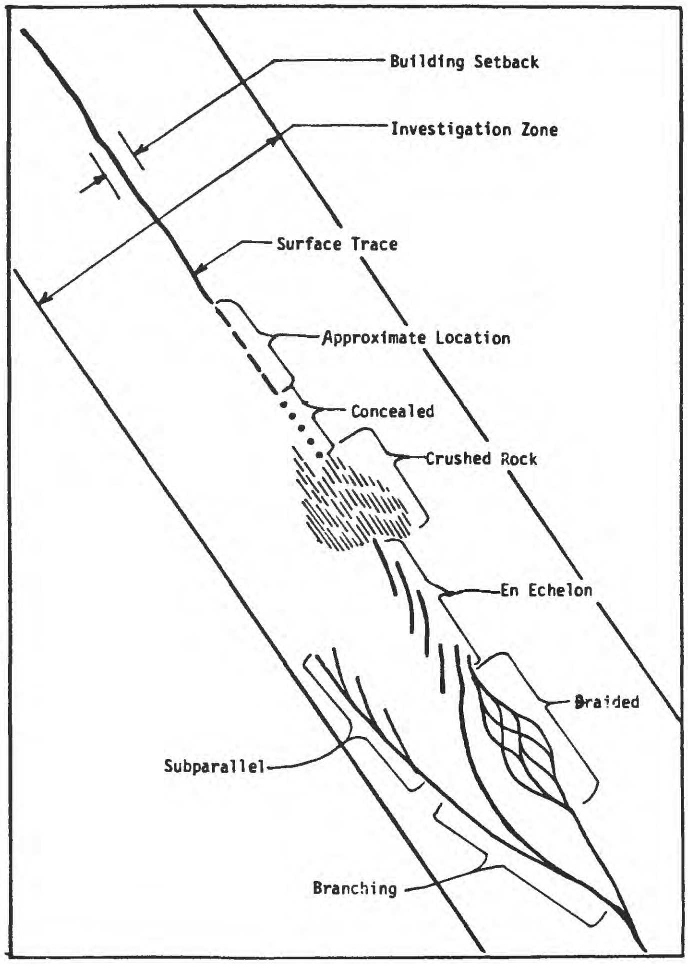


Figure 8. -- Diagram of hypothetical fault traces showing possible complexities of faulting, that demonstrate the necessity for detailed geologic investigations within a broad zone astride a known fault-rupture trace.

FIGURE 9

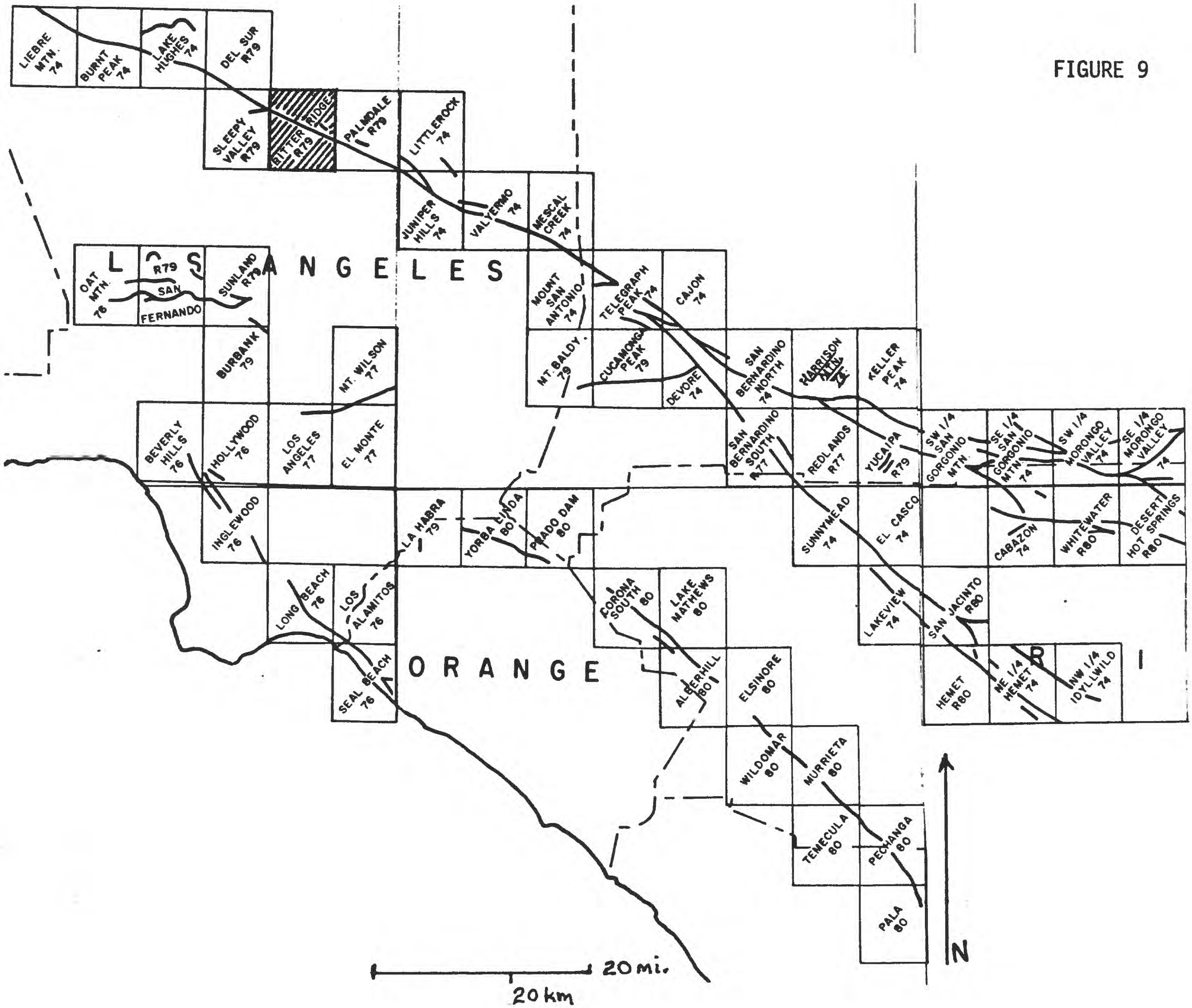


Figure 9. -- Part of the index to the Special Studies Zones maps showing faults zoned for special geologic studies (Hart, 1980). The official name of each quadrangle map and the year issued are indicated. Part of the cross-hatched quadrangle is shown as figure 10. Information about the availability of the maps and their updating can be obtained from the Fault Evaluation Program Supervisor, California Division of Mines and Geology, Room 1009, Ferry Building, San Francisco, CA 94111.

well-defined". The results, methods of evaluation, recommended zoning and zone revisions, and some of the problems encountered during the evaluation are summarized by Hart and others (1977, 1978, 1979).

Application

The State Geologist uses USGS 7½-minute quadrangle maps (topographic series) as the base for delineating the Special Studies Zones. Information is transferred from published and unpublished fault and geologic maps to the quadrangle maps. Each Special Studies Zones quadrangle map contains specific references to the source of the scientific information. For example, the geologic reports of Sarna-Wojcicki and others (1976) and Weber and others (1975) are cited as the references used to compile the Ventura fault data for the Saticoy and Ventura quadrangle maps. As of January 1, 1982, Special Studies Zones affect 25 counties and more than 70 cities in California; reproducible master copies of pertinent quadrangles have been provided each affected city and county.

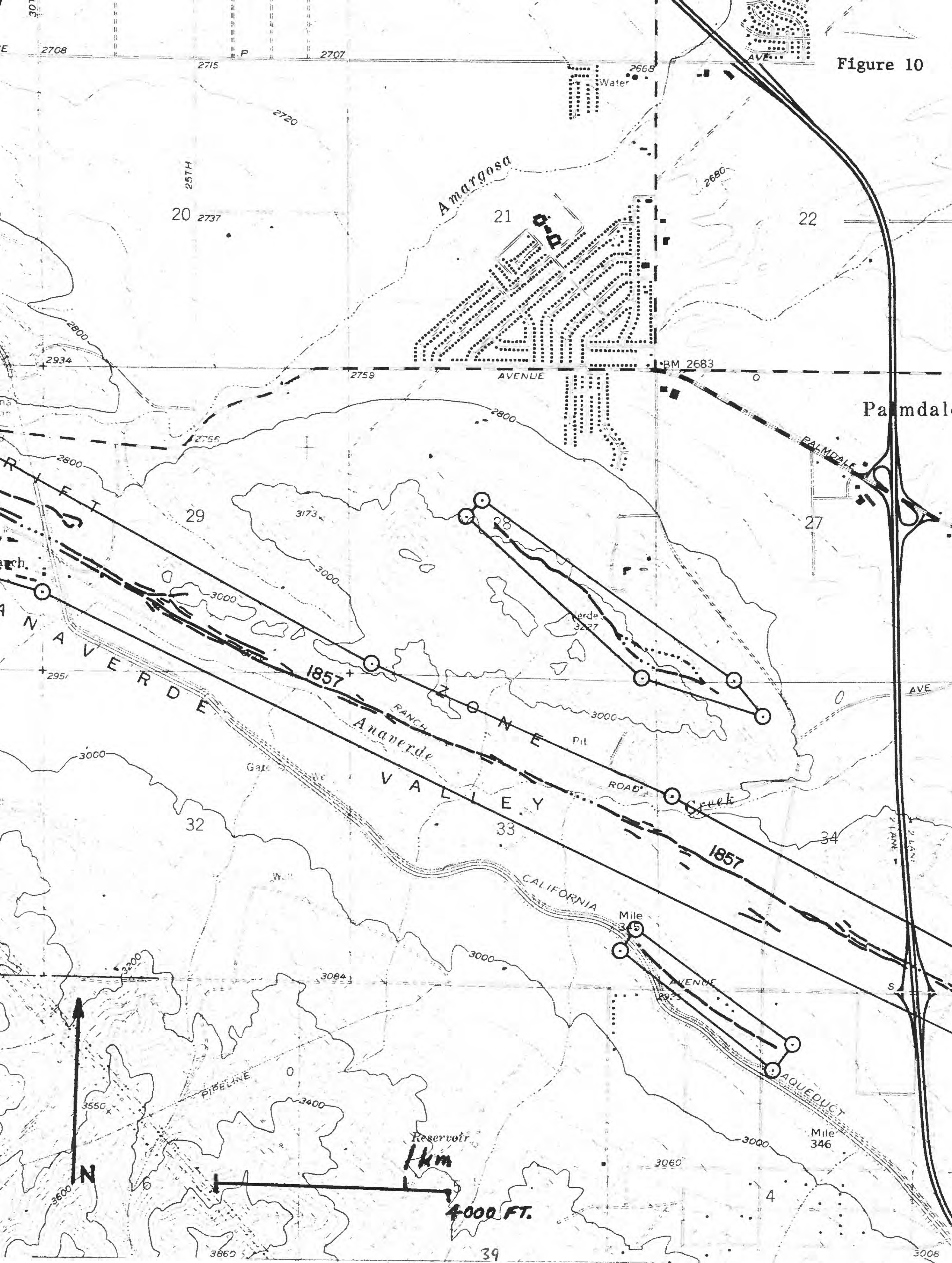
The California State Legislature (1972, sec. 2623) provides that cities and counties shall require, prior to the approval of a project in a Special Studies Zones, "a geologic report defining and delineating any hazard of surface fault rupture," and that approval shall be in accord with the policies and criteria established by the California Mining and Geology Board.

The California Mining and Geology Board (in Hart, 1980, app. B) has prepared and adopted specific and detailed criteria. The board's criteria prohibit specific development in Special Studies Zones until a geologist, registered in California and retained by each city or county, has evaluated the geologic report that must accompany the application for development. The fault information shown on a quadrangle map (fig.10) is not sufficient to meet the requirement for a "geologic report"; cities and counties must require that the developer retain a registered geologist to evaluate the sites within the Special Studies Zones to determine if a potential hazard from any fault exists. If a city or county finds that no undue hazard exists, the geologic report may be waived with the approval of the State Geologist. The California Division of Mines and Geology can provide information on the availability of: waiver forms, maps showing Special Studies Zones, guidelines for evaluating surface fault ruptures, indexes to the zone maps, and indexes to geologic reports within the zones.

The act and the criteria provide that cities and counties may establish more restrictive policies and criteria. One criterion initially adopted by the board provided that "No structure for human occupancy ... shall be ... placed across the trace of an active fault ...." The area within 50 feet (15 m) is assumed to be underlain by active branches of the fault until proved otherwise by an investigation by a geologist registered in California. In 1976, the California State Legislature (1972, sec. 2621.6(a)) amended the original act to exclude:

Figure 10. -- Part of the Ritter Ridge quadrangle map originally compiled at a scale of 1:24,000 by the California Division of Mines and Geology (1979) showing boundaries of the Special Studies Zone (lighter lines) along part of the San Andreas fault southwest of the City of Palmdale. Traces of potentially active faults are indicated by heavier lines where accurately located, by a long dash where approximately located, by a short dash where inferred, and by dots where concealed. Geologic reports that define the hazard of surface fault rupture are required prior to development within a Special Studies Zone.

Figure 10



Amargosa
Palmdale
RIFT ZONE
ANAVERDE VALLEY
Anaverde
1857
1857
AVENUE
PALMDALE
CALIFORNIA
AQUEDUCT
PIPELINE
Creek
ROAD
RANCH
Pit
Gate
Reservoir
1 km
4000 FT.
N
BM 2683
Water
Mile 345
Mile 346
20
21
22
27
28
29
32
33
34
4
5
6
39

> A single-family wood frame dwelling not exceeding two stories when such dwelling is not part of a development of four or more dwellings

and therefore removed such buildings from the board's criteria. However, some cities and counties retain the 50-foot (15 m) setback for all structures for human occupancy; others, like the Portola Valley Town Council (1973), require greater setbacks. The California Mining and Geology Board now "recommends" that a geologic report be required if the single-family dwelling lies on or within 100 feet (32 m) of the trace of an historically active or other known active fault.

The California Association of Realtors* (1977) published an instruction booklet on the legal obligations of Realtors* to disclose geologic hazards that relate to the use of real estate. The association (1981) provides, in its real-estate purchase contract form, a place for attaching information about Special Studies Zones. The California Association of Realtors (1978) has also prepared a disclosure form for Special Studies Zones which can be attached to the contract. The last paragraph of this form provides a place for entering the number of days a prospective buyer has, from the time of the seller's acceptance, to make further inquiries concerning the use of the property under the Special Studies Zones Act; and provides that where inquiry discloses conditions unsatisfactory to the buyer, the buyer may cancel the contract.

Comments

This example illustrates how earth science information can be used by State legislators, State geologists, city and county officials, consulting geologists, and real estate buyers to avoid the hazards of surface fault rupture. The act's provisions, the board's criteria, and local ordinances discourage the building of either public or private buildings over faults which may creep or move suddenly during a major earthquake. This method of providing for public safety can be adapted to other types of potential ground failure, such as landslides or liquefaction; and to other States where similar hazards exist and where adequate scientific information is available.

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*The word "Realtors" denotes members of the National Association of Real Estate Boards.

STRENGTHENING OR REMOVING OLD MASONRY BUILDINGS

Officials of the city of Los Angeles know that the city will be subjected to intense ground shaking in the event of a moderate or major earthquake. In the seismic safety plan adopted by the Los Angeles City Council as required by the California State Legislature (1971), the Los Angeles Department of City Planning (1974, p. 1) states that:

> Shaking causes the greatest amount of damage from earthquakes occurring in rather populous areas. It is estimated the majority of structural failure that has been caused by earthquakes results from: (1) shaking which damages the structure directly, (2) shaking which causes soil failure beneath the foundation of a structure, and (3) shaking which causes the soil beneath the foundation to densify and settle, thus causing the structure to fail.

The department noted that the ground shaking can result in loss of life, personal injuries, damage to property, and economic and social dislocations, but that most of this loss is preventable. Consequently, to keep the loss to a minimum, the Los Angeles Department of City Planning (1974) specified policies and programs regarding geologic evaluation, existing development, new development, critical facilities, emergency preparednesss, and post-disaster recovery.

The major earthquake-related problem faced by the city is the strengthening or removal of existing hazardous buildings. The policies adopted concerning existing development included the recommendations that:

> Buildings that do not meet requirements for seismic safety be strengthened or abated in an orderly manner.
>
> Priorities for seismic upgrading of existing buildings be based on hazard to life, type of occupancy, the location of the structure and the capability of the structure to withstand earthquake forces.

Some of the specific ways listed to implement the policies are:

> Give priority to pre-1934 unreinforced masonry structures, starting with structures which are most hazardous to life.
>
> Consider amending the Building Code to provide for a special rehabilitation code in evaluating existing pre-1934 unreinforced masonry structures on their ability to meet an acceptable degree of seismic safety.

> Consider enacting an ordinance to require building owners to conduct structural surveys and/or seek State or Federal funding to implement structural surveys for the identification of structures that do not meet lateral force requirements.

In 1976, the mayor of Los Angeles established a task force to "explore and evaluate the range of possible City responses to an earthquake prediction .... " Regarding unreinforced masonry buildings built before 1934, the Los Angeles City Task Force on Earthquake Prediction (Dunne, ed., 1978, p. 21) identified them as posing the greatest life hazard in an earthquake and recommended that "priorities for reinforcement, decreasing occupancy levels, or demolition should be established before we are confronted with a credible earthquake prediction."

A complete inventory of pre-1934 masonry buildings was conducted by specially trained city building inspectors in the earthquake safety division to document the nature and extent of the problem. The inventory was made available to building owners and other interested persons. There are at present approximately 8,000 pre-1934 unreinforced-masonry buildings in the city of Los Angeles (fig. 11). These buildings have been classified as follows:

	Number	Use
	4,108	Commercial
	2,393	Industrial
	811	Apartment
	268	Hotel
	134	Public
	162	Other
Total	7,876	

More than 80 percent of them are commercial and industrial buildings providing places of employment for an estimated 70,000 workers. About 14 percent are residential apartments and hotels containing nearly 46,000 units, housing perhaps 137,000 persons (Los Angeles City Planning Department, 1980, p. F-iii). They are vulnerable to total collapse or the shedding of the outside walls under moderate to strong ground shaking, thus presenting a substantial risk to their occupants and to passersby. The city planning department concludes:

> It is the consensus of seismic safety experts that these pre-1934 unreinforced masonry buildings represent the greatest single threat to life and limb in Los Angeles in the event of a major quake.

According to the Los Angeles City Planning Department (1979) the unreinforced masonry buildings constructed prior to 1934 have become more vulnerable to earthquake forces than when they were designed and built and that:

This fact was dramatically demonstrated during the Long Beach quake occurring in March of 1933 and the San Fernando Valley quake and aftershock of February and March of 1971. Earthquake resistance in buildings has deteriorated over the years due to factors such as: decreases in the strength of construction materials, fire damage, foundation settlement, alterations that have weakened structural elements and damage sustained in past earthquakes.

Information

Many estimates of potential ground shaking and its effects are available for the Los Angeles region, for example, maximum credible ground acceleration (see fig. 6) by Greensfelder (1972), earthquake losses by Algermissen and others (1973), seismic risk zones by the International Conference of Building Officials (1976, fig. 1, p. 149), probabilistic estimates of maximum horizontal ground motion by Thenhaus and others (1980), predicted intensities by Evernden and others (1981), and maximum horizontal acceleration and horizontal velocity by Algermissen and others (1982). Using Algermissen and others (1973) estimates for losses from a major earthquake in the Los Angeles area, and assuming that 70 percent of the losses would be within the Los Angeles city limits, the Los Angeles Earthquake Safety Study Committee estimated that without a program of structural improvement, there could be up to 8,500 deaths and 34,000 injured because of damage to unreinforced-masonry buildings.

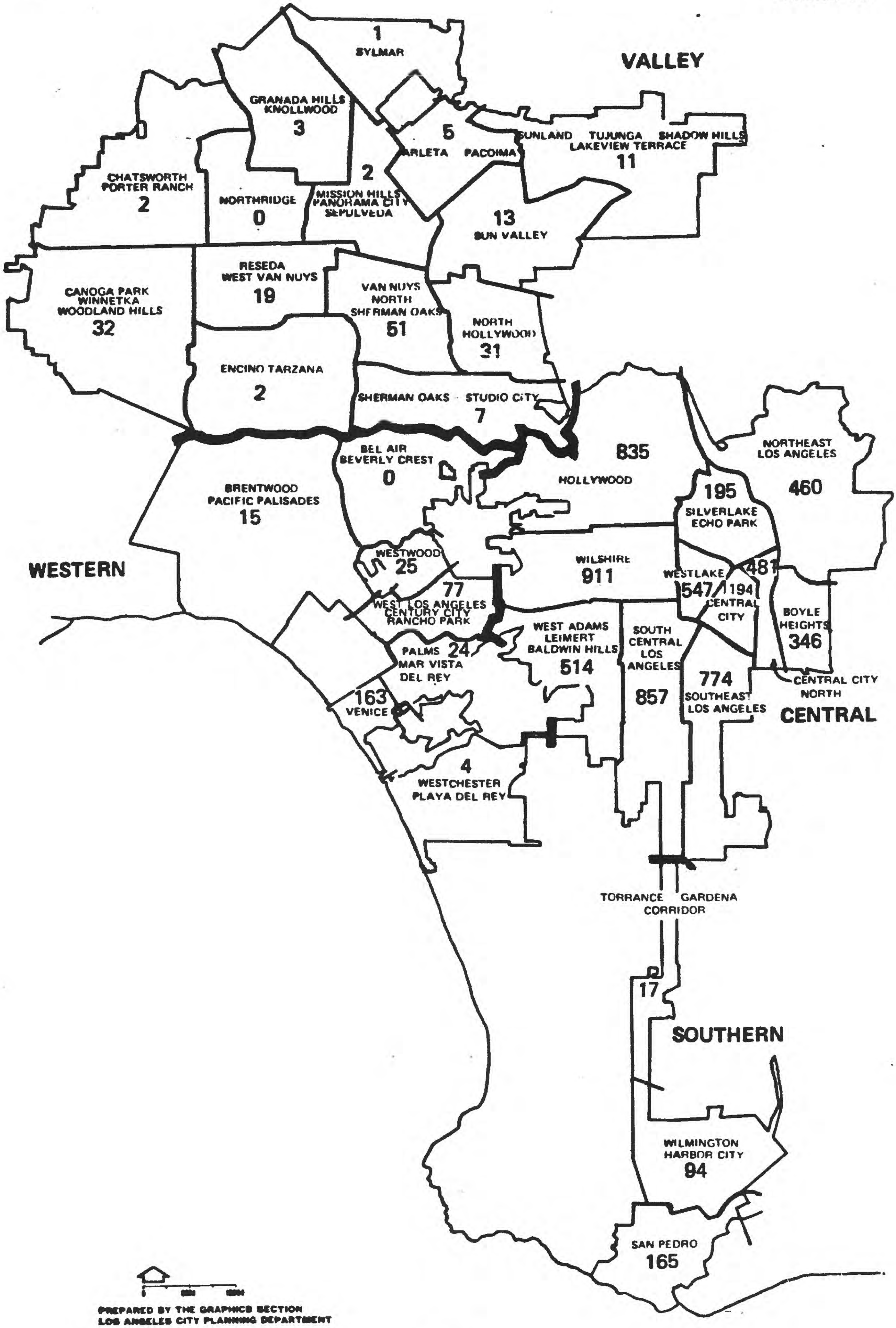
Decision

After two years of deliberation, an ordinance amending the city of Los Angeles building code was formulated by the Los Angeles Earthquake Safety Study Committee (1978) and submitted to the City Council in 1979. The ordinance would reduce earthquake hazards by requiring the strengthening or removal of pre-1934 buildings that have bearing walls of unreinforced masonry. The strengthening standards are not identical to those required for new construction but are especially adapted for the type of construction and typical weaknesses of these older buildings.

Because of the anticipated high cost of compliance, the Earthquake Safety Study Committee requested that a detailed cost study be prepared. The city council authorized and funded such a study, which was carried out by private consultants under contract to the Los Angeles Department of Building and Safety. This structural engineering cost study was prepared by Wheeler and Gray, Consulting Engineers, (in Los Angeles City Planning Department, 1979, Appendix G). They evaluated a 4-story apartment building, 2-story apartments over a 1-story industrial building, a 1-story warehouse, a 1-story warehouse with mezzanine, and a 2-story commercial and office building. According to the study (1979, p. 4), total

Figure 11. -- Number of unreinforced masonry buildings originally verified in the field for each census tract by the Los Angeles Department of Building and Safety (in Los Angeles City Planning Department, 1979) and shown here by community areas. Similar diagrams are available showing the number of dwelling units in apartment buildings or the number of guest rooms in hotels and motels. Unnumbered areas are outside the city's corporate limits.

FIGURE 11


VALLEY
1
SYLMAR
GRANADA HILLS
KNOLLWOOD
3
5
ARLETA
PACOIMA
SUNLAND
TUJUNGA
SHADOW HILLS
LAKEVIEW TERRACE
11
CHATSWORTH
PORTER RANCH
2
NORTHRIDGE
0
2
MISSION HILLS
PANORAMA CITY
SEPULVEDA
13
SUN VALLEY
RESEDA
WEST VAN NUYS
19
CANOGA PARK
WINNETKA
WOODLAND HILLS
32
VAN NUYS
NORTH
SHERMAN OAKS
51
NORTH
HOLLYWOOD
31
ENCINO TARZANA
2
SHERMAN OAKS - STUDIO CITY
7
BEL AIR
BEVERLY CREST
0
835
HOLLYWOOD
NORTHEAST
LOS ANGELES
460
BRENTWOOD
PACIFIC PALISADES
15
195
SILVERLAKE
ECHO PARK
WESTERN
WESTWOOD
25
WILSHIRE
911
WESTLAKE
547
481
194
CENTRAL
CITY
77
WEST LOS ANGELES
CENTURY CITY
RANCHO PARK
BOYLE
HEIGHTS
346
PALMS
MAR VISTA
DEL REY
24
WEST ADAMS
LEIMERT
BALDWIN HILLS
514
SOUTH
CENTRAL
LOS
ANGELES
857
774
SOUTHEAST
LOS ANGELES
CENTRAL CITY
NORTH
CENTRAL
163
VENICE
4
WESTCHESTER
PLAYA DEL REY
TORRANCE
GARDENA
CORRIDOR
17
SOUTHERN
WILMINGTON
HARBOR CITY
94
SAN PEDRO
165
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LOS ANGELES CITY PLANNING DEPARTMENT

compliance costs calculated for these five actual buildings ranged from $6.22 to $12.08 per square foot. The estimated cost of anchoring the walls to the floors and roof ranged from $1.00 to $1.60 per square foot.

Some of the advantages of the proposed ordinance, as noted by the Los Angeles City Planning Department (1980), were: the city's greatest single hazard to life would be substantially reduced, resulting in perhaps five-fold fewer casualties; buildings not worth repairing would eventually be demolished, possibly making the land available for more productive use; and the repair or demolition would provide work for members of the construction industry.

Some of the disadvantages of the proposed ordinance were: the city would lose some of its lowest-priced housing through demolition; temporary relocation of tenants will probably be necessary while the remedial work is carried on; rents in affected buildings would have to be increased to amortize the expense of the repair; and normal business would be interrupted during remedial construction causing severe hardship on many small businesses, and perhaps forcing lay-offs and closures.

Recommendations for mitigating some of the ordinance's adverse impacts were suggested. For example, adverse impacts on historic buildings might be reduced in the following ways:

Adverse Impacts	Recommended or Code-Required Mitigation Measures	Net Mitigated Adverse Impacts
Some buildings demolished under the proposed ordinance could have historical significance. Loss of irreplaceable cultural resources could result.	Proposed regulations have been prepared to incorporate the provisions of the State Historical Building Code ... into the ordinance. These provide alternative requirements for designated historical structures to facilitate their preservation.	Historic buildings will not be exempted from remedial measures, but the special provisions should make it unlikely that any would have to be demolished.

The alternative of upgrading buildings to current new building standards was considered in 1976 but not adopted by the city council. The alternative of no ordinance was considered and according to the Los Angeles City Planning Department (1980), this alternative:

> would tend to preserve the status quo, leaving any remedial measures to the discretion of building owners. It is

> considered unlikely that many would choose to make the necessary investment. The likely result would be heavy casualties and property damage in the event of a major earthquake.

The proposed ordinance was approved and adopted by an 11 to 3 note of the Los Angeles City Council on January 7, 1981 (fig. 12).

Application

The ordinance provides systematic procedures and standards for identifying and classifying buildings having unreinforced-masonry bearing walls -- the procedures and standards being based on the buildings' present use and occupancy. Priorities, time periods, and standards are also established under which these buildings are required to be structurally analyzed and anchored. Where analysis determines deficiencies, the ordinance requires that the buildings be strengthened or demolished. The ordinance applies to all buildings having bearing walls of unreinforced masonry which were constructed or under construction before October 6, 1933, or for which a building permit was issued prior to October 6, 1933, the effective date of the city's first seismic building code. The ordinance does not apply to detached 1- or 2-story single-family dwellings and detached apartment houses containing less than five dwelling units and used solely for residential purposes.

Affected buildings are classified according to type of function and occupancy as: essential, high-risk, medium-risk, and low-risk buildings (fig. 12, sec. 91.6803). The strengthening standards and time schedules for notification and compliance vary with the risk category. A structural analysis of each individual building is also required in order to determine the remedial measures necessary to meet the appropriate standards. A specific time schedule is provided (fig. 12, sec. 91.6805).

An alternative compliance schedule, intended to lessen the financial and social impacts of the ordinance, gives the building owner the option of performing a portion of the remedial work within one year of notification in exchange for a longer time in which to reach full compliance. The work to be performed within a year involves the anchoring of unreinforced masonry walls to the roof and to each floor of the building with bolts and washers. This procedure yields an immediate and substantial improvement in safety for perhaps one-fifth of the cost of full compliance (Los Angeles City Planning Department, 1979, p. 5). The compliance schedule, including the anchoring alternative, has the following features:

> All affected buildings are scheduled to be strengthened within 14 years.
>
> It will take at least four years to complete notification of all affected owners.

Figure 12. -- Part of the Los Angeles City Council (1981) earthquake-hazard reduction ordinance requiring owners of buildings having unreinforced masonry bearing walls constructed before 1934 to obtain a structural analysis. If the building does not meet the minimum standards, the owner is required to strengthen or remove it according to a specific time schedule.

Ordinance No. 154,807

An ordinance adding Division 68 of Article 1 of Chapter IX of the Los Angeles Municipal Code relative to earthquake hazard reduction in existing buildings.

Section 1. Article 1 of Chapter IX of the Los Angeles Municipal Code is hereby amended to add a Division 68 to read:

DIVISION 68 — EARTHQUAKE HAZARD REDUCTION IN EXISTING BUILDINGS

SEC. 91.6801. PURPOSE:

The purpose of this Division is to promote public safety and welfare by reducing the risk of death or injury that may result from the effects of earthquakes on unreinforced masonry bearing wall buildings constructed before 1934. Such buildings have been widely recognized for their sustaining of life hazardous damage as a result of partial or complete collapse during past moderate to strong earthquakes.

The provisions of this Division are minimum standards for structural seismic resistance established primarily to reduce the risk of life loss or injury and will not necessarily prevent loss of life or injury or prevent earthquake damage to an existing building which complies with these standards. This Division shall not require existing electrical, plumbing, mechanical or fire safety systems to be altered unless they constitute a hazard to life or property.

This Division provides systematic procedures and standards for identification and classification of unreinforced masonry bearing wall buildings based on their present use. Priorities, time periods and standards are also established under which these buildings are required to be structurally analyzed and anchored. Where the analysis determines deficiencies, this Division requires the building to be strengthened or demolished.

Portions of the State Historical Building Code (SHBC) established under Part 8, Title 24 of the California Administrative Code are included in this Division.

SEC. 91.6802. SCOPE:

The provisions of this Division shall apply to all builings constructed or under construction prior to October 6, 1933, or for which a building permit was issued prior to October 6, 1933, which on the effective date of this ordinance have unreinforced masonry bearing walls as defined herein.

EXCEPTION: This Division shall not apply to detached one or two story-family dwellings and detached apartment houses containing less than five dwelling units and used solely for residential purposes.

SEC. 91.6803. DEFINITIONS:

For purposes of this Division, the applicable definitions in Sections 91.2301 and 91.2305 of this Code and the following shall apply:

Essential Building: Any building housing a hospital or other medical facility having surgery or emergency treatment areas; fire or police stations; municipal government disaster operation and communication centers.

High Risk Building: Any building, not classified an essential building, having an occupant load as determined by Section 91.3301(d) of this Code of 100 occupants or more.

EXCEPTION: A high risk building shall not include the following:

1. Any building having exterior walls braced with masonry crosswalls or wood frame crosswalls spaced less than 40 feet apart in each story.
2. Any building used for its intended purpose, as determined by the Department, for less than 20 hours per week.

Historical Building: Any building designated as an historical building by an appropriate Federal, State or City jurisdiction.

Low Risk Building: Any building, not classified an essential building, having an occupant load as determined by Section 91.3301(d) of less than 20 occupants.

Medium Risk Building: Any building, not classified as a high risk building or an essential building, having an occupant load as determined by Section 91.3301(d) of 20 occupants or more.

Unreinforced Masonry Bearing Wall: A masonry wall having all of the following characteristics:

1. Provides the vertical support for a floor or roof.
2. The total superimposed load is over 100 pounds per linear foot.
3. The area of reinforcing steel is less than 50 percent of that required by Section 91.2418(e) of this Code.

SEC. 91.6804. RATING CLASSIFICATIONS:

The rating classifications as exhibited in Table No. 68-A are hereby established and each building within the scope of this Division shall be placed in one such rating classification by the Department. The total occupant load of the entire building as determined by Section 91.3301(d) shall be used to determine the rating classification.

TABLE NO. 68-A
RATING CLASSIFICATIONS

Type of Building	Classification
Essential Building	I
High Risk Building	II
Medium Risk Building	III
Low Risk Building	IV

SEC. 91.6805. GENERAL REQUIREMENTS:

The owner of each building within the scope of this Division shall cause a structural analysis to be made of the building by a civil or structural engineer or arthitect licensed by the State of California; and, iif the building does not meet the minimum earthquake standards specified in this Division, the owner shall cause it to be structurally altered to conform to such standards; or cause the building to be demolished.

The owner of a building within the scope of this Division shall comply with the requirements set forth above by submitting to the Department for review within the stated time limits:

a. Within 270 days after the service of the order, a structural analysis. Such analysis which is subject to approval by the Department, shall demonstrate that the building meets the minimum requirements of this Division; or

b. Within 270 days after the service of the order, the structural analysis and plans for the proposed structural alterations of the building necessary to comply to the minimum requirements of this Division; or

c. Within 120 days after service of the order, plans for the installation of wall anchors in accordance with the requirements specified in Section 91.6808(c); or

d. Within 270 days after the service of the order, plans for the demolition of the building.

After plans are submitted and approved by the Department, the owner shall obtain a building permit, commence and complete the required construction or demolition within the time limits set forth in No. Table 68-B. These time limits shall begin to run from the date the order is served in accordance with Section 91.6806(a) and (b).

TABLE NO. 68-B
TIME LIMITS FOR COMPLIANCE

Required Action By Owner	Obtain Building Permit Within	Commence Construction Within	Complete Construction Within
Complete Structural Alterations or Building Demolition	1 year	180 days*	3 years
Wall Anchor Installation	180 days	270 days	1 year

*Measured from date of building permit issuance.

Owners electing to comply with Item c of this Section are also required to comply with Items b or d of this Section provided, however, that the 270-day period provided for in such Items b and d and the time limits for obtaining a building permit, commencing construction and completing construction for complete structural alterations or building demolition set forth in Table No. 68-B shall be extended in accordance with Table No. 68-C. Each such extended time limit, except the time limit for commencing construction shall begin to run from the date the order is served in accordance with Section 91.6806 (b). The time limit for commencing construction shall commence to run from the date the building permit is issued.

TABLE NO. 68-C
EXTENSIONS OF TIME AND SERVICE PRIORITIES

Rating Classification	Occupant Load	Extension of Time if Wall Anchors are Installed	Minimum Time Periods for Service of Order
I (Highest Priority)	Any	1 year	0
II	100 or more	3 years	90 days
III	100 or more	5 years	1 year
	More than 50, but less than 100	6 years	2 years
	More than 19, but less than 51	6 years	3 years
IV (Lowest Priority)	Less than 20	7 years	4 years

SEC. 91.6806. ADMINISTRATION:

(a) Service of Order. The Department shall issue an order, as provided in Section 91.6806(b), to the owner of each building within the scope of this Division in accordance with the minimum time periods for service of such orders set forth in Table No. 68-C. The minimum time period for the service of such orders shall be measured from the effective date of this Division. The Department shall upon receipt of a written request from the owner, order a building to comply with this Division prior to the normal service date for such building set forth in this Section.

(b) Contents of Order. The order shall be written and shall be served either personally or by certified or registered mail upon the owner as shown on the last equalized assessment, and upon the person, if any, in apparent charge or control of the building. The order shall specify that the building has been determined by the Department to be within the scope of this Division and, therefore, is required to meet the minimum seismic standards of this Division. The order shall specify the rating classification of the building and shall be accompanied by a copy of Section 91.6805 which sets forth the owner's alternatives and time limits for compliance.

(c) Appeal From Order. The owner or person in charge or control of the building may appeal the Department's initial determination that the building is within the scope of this Division to the Board of Building and Safety Commissioners. Such appeal shall be filed with the Board within 60 days from the service date of the order described in Section 91.6806(b). Any such appeal shall be decided by the Board no later than 60 days after the date that the appeal is filed. Such appeal shall be made in writing upon appropriate forms provided therefor, by the Department and the grounds thereof shall be stated clearly and concisely. Each appeal shall be accompanied by a filing fee as set forth in Table 4-A of Section 98.0403 of the Los Angeles Municipal Code.

Appeals or requests for slight modifications from any other determinations, orders or actions by the Department pursuant to this Division, shall be made in accordance with the procedures established in Section 98.0403.

(d) Recordation. At the time that the Department serves the aforementioned order, the Superintendent of Building shall file with the Office of the County Recorder a certificate stating that the subject building is within the scope of Division 68 — Earthquake Hazard Reduction in Existing Buildings — of the Los Angeles Municipal Code. The certificate shall also state that the owner thereof has been ordered to structurally analyze the building and to structurally alter or demolish it where compliance with Division 68 is not exhibited.

If the building is either demolished, found not to be within the scope of this Division, or is structurally capable of resisting minimum seismic forces required by this Division as a result of structural alterations or an analysis, the Superintendent of Building shall file with the Office of the County Recorder a certificate terminating the status of the subject building as being classified within the scope of Division 68 — Earthquake Hazard Reduction in Existing Buildings — of the Los Angeles Municipal Code.

(e) Enforcement. If the owner or other person in charge or control of the subject building fails to comply with any order issued by the Department pursuant to this Division within any of the time limits set forth in Section 91.6805, the Superintendent of Building shall order that the entire building be vacated and that the building remain vacated until such order has been complied with. If compliance with such order has not been accomplished within 90 days after the date the building has been ordered vacated or such additional time as may have been granted by the Board and the Superintendent may order its demolition in accordance with the provisions of Section 91.0103(o) of this Code.

> Building owners have the option, after notification, of either anchoring all the building walls within one year; or strengthening the entire building within three years.
>
> If the walls are anchored within one year of notification, one to seven additional years (depending on the building risk classification), are allowed for full compliance.

In addition, the ordinance provides for service of orders, appeals, and enforcement. Various analyses and design factors, such as allowable stresses of construction materials, alternate materials, and minimum acceptable quality of existing unreinforced masonry walls, are specified. As of January 8, 1983, the Los Angeles Department of Building and Safety has issued 895 orders to owners to meet the minimum seismic standards. Over 200 of the projects are using the wall anchor alternative and are now in the automatic time extension period (Earl Schwartz, written comm.). A Los Angeles city councilman (Hal Bernson, written comm.) emphasizes that:

> this is a life safety rather than a property ordinance. That is, the level of seismic resistance that we provided in the ordinance does not necessarily guarantee than the structure will come though a major earthquake intact, or even usable. It is intended to assure that the structure will not collapse outright. This resulted from a compromise between optimum engineering goals and rehabilitation costs. Other cities may, and have, set their compromise at a different point.

Comments

According to the Los Angeles Earthquake Safety Study committee, compliance with the provisions of this ordinance could reduce the number of deaths within the Los Angeles city limits from 8,500 to 1,500 and the number of injured from 34,000 to 8,000 for a single future earthquake. It was estimated by the Los Angeles City Planning Department (1979, p. 4) that a major earthquake in the Los Angeles area will result in structural damage to about two-thirds of the old unreinforced masonry buildings. The implementation of the ordinance would reduce this structural damage to approximately one-fourth, saving an estimated $900 million in building costs. In addition, the Los Angeles Department of Building and Safety project coordinator for the cost study noted that the building owners actually receive a profit from demolition because of the high salvage value of used brick (1979, app. G).

CONCLUDING COMMENTS

The five examples presented in this report include anticipating damage to critical facilities; preparing, adopting, or implementing seismic safety studies, plans, and programs; retrofitting highway bridges; regulating development in areas subject to fault-rupture; and strengthening or removing unreinforced masonry buildings. The collective effect of these activities is to provide for greater public safety, health, and welfare of individuals and their communities.

The examples are typical of the problems faced by planners and decisionmakers and the actions they could take to reduce the effects of future earthquakes. Their innovative responses are based on the use of geologic and seismologic information to reduce earthquake hazards and property damage. Each plan or decision was influenced by many factors -- the nature of the geologic hazard; public concern; strong community interest; State enabling legislation; availability of scientific information; and the ability of geologists, engineers, planners, and lawyers to incorporate the information into a study, plan, program, or regulation.

The criteria and methods used in each of the examples can be of value to other urban regions where similar earthquake hazards exist and where adequate scientific information is available. The adaptation to, and adoption by, other jurisdictions and users depends on similarities in public awareness, enabling legislation, targeted issues, order of priorities, community interests, and abilities of the planners and decisionmakers.

Some of the geologic and seismologic information needed for prudent land use and general engineering design in the Los Angeles region is available but generally not at the level of detail and scale needed for general planning and decisionmaking. Even greater detail at larger scales ranging from 1:1,200 to 1:12,000 (1 inch = 100 feet to 1,000 feet) are needed for other purposes, including development planning, site investigations, ordinance administration, project review, and permit issuance. Public staffs and consulting firms can provide this information in greater detail and at larger scales.

Earthquake-hazard research is continuing, the information base is improving, the methods for evaluating hazards are being perfected, and new reduction techniques are being developed. Planners and decisionmakers need to recognize these facts and use the latest information, methods, and techniques. Planners and decisionmakers -- public or private -- cannot be expected to have the requisite training or experience to understand and use scientific information. Therefore, to enable nonscientists to use this information, it must be interpreted and transferred to maps. Such information includes recurrence intervals for major earthquakes, relative intensities of ground shaking, susceptibility to landsliding, locations of active faults, potential for liquefaction, and predicted geologic effects of postulated earthquakes.

Within the Los Angeles region, planners and decisionmakers -- public and private -- live and work in a complex environment. Moreover, the geologic environment is just one aspect of the planner's or decisionmaker's life and work. Other aspects include social, economic, political, and esthetic -- some of which are more apparent or more important to individual planners, decisionmakers, or their constituents.

Lasting Effectiveness

Even with adequate research, accurate information, useable products, effective communication, and proper use, the lasting effectiveness of earthquake-hazard reduction plans and decisions depend upon many other factors, including:

Continued awareness and interest by the public and their decisionmakers

Meticulous updating of hazard information and maps by geologists, seismologists, and geotechnical engineers

Careful revision of enabling legislation (if needed) by legislative bodies

Accurate site investigations by registered geologists or geotechnical engineers

Conscientious administration of regulations by inspectors

Consistent enforcement by government attorneys

Sustained support of inspection and enforcement officials by political leaders

Judicious adjustment of regulations by administrative-appeal bodies

Skillful advocacy by public officials (if challenged) and informed interpretation by the courts

Concern for individual, family, and community health, safety, and welfare by home buyers and real-estate developers

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