Technical Appendix to the Safety Element of the Los Angeles County General Plan

HAZARD REDUCTION in LOS ANGELES COUNTY

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OF THE

LOS ANGELES COUNTY GENERAL PLAN

HAZARD REDUCTION IN LOS ANGELES COUNTY

VOLUME 1

December, 1990

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FOREWORD AND ACKNOWLEDGEMENTS

The Safety Element is the end product of a major effort to update the Los Angeles County Safety Element which included the preparation of this technical report entitled Hazard Reduction in Los Angeles County. The report covers earthquake, landsliding, flood and fire hazards. It also addresses such issues as earthquake insurance, management of post-earthquake recovery, and seismic hazard overlay zoning. A review of State and Federal safety legislation, recent safety research, innovative safety programs, and existing County safety policies and programs provides the foundation for the implementation programs outlined in the Safety Element. The updating and evaluation of hazard information, which resulted in the preparation of eight 1 inch = 2 miles maps delineating potential hazards in the County, supported the technical evaluation of hazards identified in this report.

Many organizations contributed to Hazard Reduction in Los Angeles County and thus to the Safety Element. These contributions ranged from professional and constructive commentary to provision of valuable information. Among the agencies providing assistance were the United States Geological Survey, the California Division of Mines and Geology, the Earthquake Engineering Research Institute, the U.S. Army Corps of Engineers, the Southern California Earthquake Preparedness Project, the Bay Area Regional Earthquake Preparedness Project, the Business and Industry Council for Emergency Planning and Preparedness, the Governors Office of Emergency Services and the California Seismic Safety Commission.

The Los Angeles County Safety Element Technical Committee, which included representatives from the planning department of the City of Los Angeles, the University of Southern California, the California Division of Mines and Geology, the Southern California Gas Company and Caltrans, contributed significantly to the preparation of a revised Safety Element and this supporting technical report through knowledgeable review and comment.

Providing information and cogent discussion through interviews and meetings were representatives of many County agencies including the Department of Regional Planning, Chief Administrative Office, Public Works, Internal Services, Sheriff, Forester and Fire Warden, Health Services, Public Social Services and the Community Development Commission/Housing Authority. The County Sanitation Districts also provided input to the Element revision. These County agencies constituted the Safety Committee of the Los Angeles County General Plan Policy Review Board, which was established to provide advice on the revision of the Safety Element.

The County-wide Citizens' Planning Council (CCPC), particularly the CCPC Safety Committee, devoted approximately 25 meetings to the review and revision of the Safety Element and supporting materials. Essential information and valuable critiques were provided by Sedway Cooke Associates, Paul Sedway and Rod Jueng (previously with Sedway Cooke), and William Spangle of William Spangle and Associates, the principal subconsultants on this project.

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EXECUTIVE SUMMARY

A. INTRODUCTION

In April 1988, the County of Los Angeles contracted with the firm of Leighton and Associates to prepare a revised Safety Element of the General Plan, an evaluation of the environmental analysis requirements of the Element, and a supporting technical background report for the Safety Element. **Hazard Reduction in Los Angeles County** is the technical appendix (background report) for the Safety Element. Composed of two volumes, the report provides the foundation for the goals and policies set forth in the Element; and for the action programs related to the Element. The purpose of the report is to:

- Identify and describe safety hazards affecting the County;
- describe and analyze existing County safety programs, policies, and regulations;
- identify major safety needs, issues, and opportunities; and
- draw conclusions that may form the basis of Safety Element policies and action programs.

The report includes several technical appendices covering such subjects as safety law and technical descriptions of selected faults in the County.

The major chapters in Volume 1 are:

- The Seismic Environment of Los Angeles County
- Hazards Analysis
- Earthquake Vulnerability
- Management of Future Development
- Management of Existing Development
- Seismic Hazard Overlay Zone and Related Programs
- Post-Earthquake Recovery
- Research Needs and Opportunities

The report is supplemented with eight 1 inch = 2 mile maps or plates (in Volume 2). They include:

- Active and Potentially Active Faults and Historic Seismicity
- Engineering Geologic Materials
- Shallow Ground Water
- Liquefaction Susceptibility
- Landslide Inventory
- Flood and Inundation Hazards
- Wildland and Urban Fire Hazards
- Critical Facilities and Lifeline Systems

The report addresses earthquake, geologic, flood, fire and hazardous materials threats. Although hazard information is summarized for all of Los Angeles County, where readily available, the policies and programs of the Element apply primarily to unincorporated areas. Because the potential losses from a major earthquake are vastly greater than any other type of hazard addressed, the report deliberately emphasizes seismic hazards.

B. CHAPTER SUMMARIES

Seismic Environment of Los Angeles County

This chapter reviews fundamental aspects of the seismic and geologic setting of Los Angeles County. The geography of the County is described in terms of the diverse geomorphic terrains: the coastal lowlands, the mountain highlands, the Antelope Valley, and the Channel Islands and offshore area. Damage patterns from historical earthquakes are summarized, and the development of earthquake mitigation legislation is briefly reviewed.

Hazards Analysis

Earthquake, geologic, flood, fire and hazardous materials threats are described in this chapter. Nontechnical, but detailed explanations reference the data compiled in Plates 1 through 7. The chapter discusses the uses and limitations of the plates and provides an introduction to hazard management alternatives for landslide, flood, and fire hazards. As the primary hazard data base, this chapter provides the foundation upon which succeeding chapters build discussions of earthquake hazards and vulnerability of the urban environment. The hazards analysis chapter is subdivided into separate hazard sections:

- Seismic hazards;
- geologic hazards and landslide and slope instability;
- flood and inundation hazards; and
- wildland and urban fire hazards and hazardous materials.

Earthquake Vulnerability

An analysis of the vulnerability of Los Angeles County to earthquake damage, including analyses of Plates 7 and 8, is presented covering:

- Lifeline system facilities;
- critical facilities and infrastructure, including the vulnerability of hospitals, facilities storing hazardous materials, dams and freeway interchanges;
- potentially hazardous and high occupancy buildings;
- dependent care facilities;
- land use and development; and
- socioeconomic effects of earthquakes.

Management of Future Development

This discussion pertaining to management of future development includes a summary of existing County safety regulations, standards, and programs. Selected safety programs from other jurisdictions are described and conclusions are presented about needs and opportunities to improve safety programs. The chapter summarizes project evaluation and design practices; and reviews existing construction regulations, standards and enforcement.

HAZARD REDUCTION IN LOS ANGELES COUNTY

MANAGEMENT OF FUTURE DEVELOPMENT

Seismic
Geologic
Flood and Inundation
Fire and Hazardous Materials

MANAGEMENT OF EXISTING DEVELOPMENT
Inventory, Retrofit, and Abatement Programs
Disaster Response Planning and Assessment

SEISMIC HAZARDS OVERLAY ZONE:
Feasibility Analysis

COST-TRANSFERENCE DISINCENTIVES IN HAZARDOUS AREAS:
Feasibility Analysis

POST-EARTHQUAKE RECOVERY
Earthquake Insurance
Post-Disaster Recovery
and Reconstruction

Many of the findings derived in the hazard analysis chapter are elaborated on within the framework of existing State and County safety programs, and the County departments responsible for their implementation.

Management of Existing Development

An overview of current safety programs directed at abating hazards in existing development is presented in this chapter. Certain programs from areas outside Los Angeles County are summarized to provide future hazard management alternatives. Needs, issues, and opportunities are identified regarding the following:

- Critical facilities and infrastructure, including hospitals, dependent care facilities, lifeline systems, and dams and highway systems;
- potentially hazardous buildings and their rapid inventory through building screening techniques;
- emergency preparedness planning;
- increased use of microzonation hazard mapping for disaster response planning;
- utilization of compiled inventories of unreinforced masonry (URM) and other potentially hazardous buildings and infrastructure for disaster response planning and management;
- potential applications of earthquake early warning technology; and
- improved evacuation planning and preparedness.

Seismic Hazards Overlay Zone and Related Programs

The feasibility analysis of a seismic hazards overlay zone concept is in response to a recommendation in the County Five-Year Plan for Earthquake Preparedness (1987). Major issues and constraints are examined. The objectives of a zoning overlay are to increase public awareness of the risks of living in seismically hazardous areas; provide for special studies and investigations which will improve site design and planning as a means of reducing risk; identify mitigation measures which may be applied to reduce risks; and identify examples of land uses and activities which are most compatible with hazardous conditions. Active fault zones and liquefaction areas are the most feasible alternatives for applying the hazard zoning concept.

This chapter explores the feasibility of utilizing hazard impact mitigation fees, special study requirements, insurance requirements, and tax disincentives or incentives to guide incompatible development away from hazardous areas; or to encourage appropriate development. Although these measures are designed to guide inappropriate development away from hazardous areas, they also offer the advantage of providing for improved safety features early in the project review phase.

Post-Earthquake Recovery

This chapter commences with an examination of the earthquake insurance issue. Concerns for the private insurance industry's ability to cope with a catastrophic earthquake, the effects that such an event could have on County residents, and the need for and feasibility of Federal participation in an insurance program are examined. The issues and needs associated with rebuilding severely damaged areas are also reviewed. A draft post-earthquake reconstruction and recovery ordinance is presented, including a proposal for the development of a reconstruction authority.

Research Needs and Opportunities

Selected research needs and opportunities are summarized in the final chapter. They include:

- Research programs to improve knowledge of seismic, geologic, and other hazards, including establishment of a standardized hazard mapping program, a geotechnical and hazard information repository, and improved safety information processing capability;
- research that will lead to improved microzonation and disaster response planning and management, including mapping of potentially hazardous buildings and critical facilities, and developing a coordinated computer-based emergency management system; and
- applied early warning, hazard reduction, and disaster prediction research.

C. SUMMARY OF MAJOR FINDINGS

- Los Angeles County is located in a very dynamic tectonic environment featuring two active fault systems: The San Andreas system of transform faults, which includes such ruptures as the San Andreas, San Gabriel, Whittier, and the Newport-Inglewood; and a system of thrust faults associated with the Transverse Ranges featuring faults such as the Sierra Madre, San Fernando, and "blind thrusts" underlying the Los Angeles Basin.
- Approximately 50 onshore active and potentially active faults or principal fault segments are located wholly or partly in Los Angeles County. Some 21 of these are considered major active faults. In addition, there is an unknown number of buried thrust faults and several offshore faults, some of which could cause damaging earthquakes.
- Between 1800 and 1989, active fault systems in the Los Angeles region were responsible for approximately 54 damaging earthquakes, indicating the region as a whole experiences about one earthquake every four years.
- Since 1933, three very damaging earthquakes (Long Beach, San Fernando, and Whittier Narrows) have caused 181 deaths, several thousands of injuries, and significant damage to the Los Angeles metropolitan area. Strong shaking, fault rupture, and/or liquefaction have collapsed buildings and structures on the average of approximately once every 20 years.
- The most tenable earthquake forecast in the County is for a Magnitude 7.5 earthquake on the San Andreas fault. The risk is estimated to be about two percent per year, or a 30 percent probability before 2018 A.D. Earthquake recurrence cannot be reliably determined for the majority of faults in the County due to insufficient seismic and geologic data.
- There are five major Alquist-Priolo Special Study Zone (APSSZ) faults in Los Angeles County: the San Andreas, Newport-Inglewood, San Gabriel, Raymond, and San Fernando faults. These zones contain approximately 77 square miles, whereas other active faults shown on Plate 1 encompass roughly 45 square miles. Approximately 122 square miles, or less than three percent of the total County area, are included in these active fault zones. Around 70 square miles of APSSZ and other active fault zones are in unincorporated County territory, accounting for less than three percent of the unincorporated area.
- Plate 4 shows numerous potential liquefaction areas, including those located in the Harbor area, Marina del Rey, Walnut Valley/Whittier Narrows, southern San Fernando Valley, the flood plain of the Santa Clara River, along the San Andreas fault and low-lying areas in the Antelope Valley surrounding Rosamond Playa. Other localized high ground water conditions also make liquefaction possible where land use practices are actively recharging shallow and perched aquifers.

conditions also make liquefaction possible where land use practices are actively recharging shallow and perched aquifers.

- It is estimated that about 300,000 acres or about 11 percent of the total County area are in liquefiable areas ("L" on Plate 4). About 100,000 acres are in County areas or about six percent of all unincorporated territory. Some 20 freeway-to-freeway interchanges are located in or near liquefiable (L) areas depicted on Plate 4.
- While only limited areas of Los Angeles County are located in active or potentially active fault zones, or in liquefaction prone areas, all of the County, with its current population of 8.5 million people and millions of structures, is subject to various levels of ground shaking. The pattern of destructive shaking can be highly variable depending on the characteristics of a particular earthquake, its location relative to an urban center, and the nature of the earth materials through which it passes.
- Scenarios have been published for an 8+ Magnitude earthquake on the San Andreas fault in North Los Angeles County and a 7 Magnitude earthquake on the Newport-Inglewood fault in the Los Angeles Basin. According to the scenarios, the San Andreas event could possibly cause 12,000 to 55,000 casualties requiring hospital care and socioeconomic losses near $20 billion dollars. The Los Angeles Basin event could possibly cause 16,000 to 80,000 casualties requiring hospital care and up to $35 billion dollars in socioeconomic losses.
- A Federal Emergency Management Agency (FEMA) study forecasts as many as 22,000 persons permanently and 37,000 temporarily homeless in the aftermath of an 8+ Magnitude earthquake on the San Andreas fault.
- Residential development may account for nearly 70 percent of future damage sustained in an earthquake, yet due to high deductibles, homeowner disinterest, and the reluctance of insurance companies to market earthquake insurance, only about 10 to 20 percent of homeowners insure against earthquakes.
- A major earthquake in Los Angeles County could cause hundreds or thousands of landslides within minutes, blocking roads, severing utilities, and exposing the public to a far greater risk and inconvenience than a single nonseismic landslide.
- Low-lying coastal areas of Los Angeles County, notably the Harbor area and Marina del Rey, are at risk from potentially damaging tsunamis (Plate 6). The historic record indicates that southern California earthquakes in 1812 and 1927 caused tsunamis, however, little data exists to estimate the probability of future events.
- Los Angeles County has a vast array of critical facilities, which are exposed to the damaging effects of earthquakes. These include:
  - Hundreds of essential facilities, such as police stations, fire stations, hospitals, emergency operation centers, and communication/computer centers;
  - thousands of high-risk (hazardous) facilities using, storing, or transporting hazardous materials in storage tanks, containers, or pipelines;
  - more than 14,500 dependent care facilities, including nearly 600 health care facilities; over 11,000 day care centers, convalescent homes and mentally handicapped care facilities (721 are in unincorporated areas); jails housing thousands of prisoners; and some 2,800 public and private, secondary and elementary schools with a total enrollment of about 1.5 million;

- a vast network of lifeline systems, including aqueducts and trunk water distribution lines; freeways, arterial highways, transit lines and railways; natural gas, petroleum and chemical pipelines; sewage trunk lines; major storm drains and flood channels; and high voltage electrical transmission lines. Each class of lifeline includes hundreds or thousands of miles of vulnerable lines; and
- hundreds of high-rise buildings which are often vulnerable to nonstructural damage and disruption of supporting infrastructure.

- Unreinforced masonry (URM) buildings pose the greatest threat to public safety. Not including smaller residential structures, there are 274 (pre-1934) URM buildings in unincorporated territory, approximately 80 percent of which are located in the low income Florence-Firestone area or along busy commercial strips in East Los Angeles.
- In addition to the URM's in unincorporated areas, there are approximately 14,500 URM buildings in the 86 cities, mainly located in older business districts. These contain thousands of dwelling units (many of which are low income units) and many jobs and businesses.
- A total of 22 of the 86 cities in Los Angeles County have enacted seismic upgrading ordinances for unreinforced masonry (URM) buildings and approximately half contract for County Sheriff, Fire, and/or Public Works services.
- In addition to URMs, there are tens of thousands, and possibly hundreds of thousands, of other uninventoried potentially hazardous buildings in the County including:
  - Buildings with nonbearing URM walls and partitions;
  - nonductile concrete-frame buildings;
  - inadequately designed precast, tilt-up construction;
  - multistory buildings with soft-stories;
  - inadequately designed structures with geometrical irregularities, including long spans and irregular shapes;
  - mobile homes;
  - residences not properly secured to their foundations; and
  - buildings located in areas prone to liquefaction and fault rupture.
- Since 1928 two dam failures (St. Francis Dam and the Baldwin Hills Reservoir); and one near failure at the Van Norman Reservoir have occurred in Los Angeles County, and are estimated to have claimed approximately 400 lives.
- There are over 90 dams and flood control basins in the County under State and Federal regulation. Seventy-one of these dams are large enough to warrant preparation of dam inundation maps (Plate 6). Nearly two thirds of these are constructed of earth or hydraulic fill, and nearly half are over 50 years old.
- Of the 31 State regulated County dams, seven are not adequately mitigated against maximum credible earthquakes based on a State seismic safety review. Several operate at restricted water levels. Information pertaining to the safety of the other 40 dams shown on Plate 6 is not currently available. Out of 96 County water storage tanks, 31 do not meet current design standards and nine of these pose a possible threat to development.
- More than 200 pre-1971 Caltrans freeway interchanges and overpasses are located in the Los Angeles metropolitan area. Forty-four of these structures need retrofitting. About half of the freeway-to-freeway interchanges in Los Angeles County are either in liquefaction areas and/or in active fault zones.

- Of 1,436 County-owned or maintained bridges, 359 are either pre-1972 single-column support structures or have other pre-1972 design problems and need retrofitting.
- Over half of Los Angeles County is in mountainous and hilly land which is subject to various forms of slope instability, including shallow and deep-seated landslides, mud and debris flows, and rockfalls. Human activity can supplement natural water recharge and can contribute to the initiation of landslides. Plate 5 shows known patterns of existing landslides based on currently available mapping. Landslide mapping (based on uniform standards) is incomplete for much of the County.
- Landslide damage is a frequent occurrence in both the incorporated and unincorporated areas of Los Angeles County, and has resulted in hundreds of millions of dollars of damage. Some, such as the Big Rock and Portuguese Bend slides, have caused extensive damage and lengthy litigation, resulting in very expensive legal settlements.
- It is estimated that up to 99 percent of all proposed development in hillside areas can be safely designed using available geotechnical mitigation methods.
- As a consequence of the close proximity of rugged terrain and extensive urban development, heavy rainfall has frequently caused serious flooding. Damaging floods and flows have occurred at least once per decade since 1916, most recently in 1969, 1978, and 1980. The 1980 floods damaged or destroyed more than 1,500 homes and resulted in Small Business Administration loans amounting to $255 million in the Los Angeles region.
- The flood protection system in Los Angeles County consists of roughly 3,300 kilometers of concrete-lined channels, a network of flood storage reservoirs and large debris flow basins, and an extensive system of dikes and levees. Some segments of the flood control system were designed to serve a lower level of urbanization than is now developing. These segments need to be identified, evaluated, and properly strengthened.
- Nearly 30 feet of subsidence occurred in the Harbor area before stabilization in the early 1960's. Subsidence has been linked to the failure of the Baldwin Hills Dam. Subsidence may reoccur or can be initiated in lowland areas of the County, such as in the Los Angeles Basin and Antelope Valley, in connection with major ground water and/or petroleum extraction operations unless properly managed.
- The mountainous and hilly areas of Los Angeles are covered largely by natural vegetation, much of which is highly flammable chaparral, sage-brush, and grasslands. In an average year, wildfire consumes thousands of acres of the vegetative cover, mostly within areas of older growth with large accumulations of dead vegetation. Nearly 90 percent of all wildfires are caused by man. In recent decades, there have been many damaging brush fires, such as the great Bel Air fire of 1961, which destroyed hundreds of expensive homes.
- The urban environment presents a variety of fire threats. Some of those demanding most attention are in industrial areas, especially where explosive, toxic or highly flammable substances are involved. Older structures, such as those with open stairwells or lacking fire sprinklers pose major fire threats. High-rise fires are particularly challenging due in part to the limitations of conventional fire fighting equipment and the tremendous manpower requirements.
- A major earthquake in the Los Angeles Basin could trigger up to 600 fires resulting in as much as 17.5 billion dollars in insured losses (Scawthorn, 1986). Historically, most earthquake-induced fire disasters occur in areas of earthquake-induced ground failures, and are caused by inadequate restraint of residential gas-fired utilities, malfunction of electrical utilities, spills of flammable materials, and gas leaks.

- The County Fire Department indicates the number of hazardous materials incidents to which it responded rose from 92 in 1985 to over 350 in 1988. A chlorine gas release during the 1987 Whittier Narrows Earthquake emphasizes the vulnerability of the public to earthquake related releases of hazardous materials.
- Los Angeles County's existing safety programs and assets include the following:
  - A General Plan which recognizes the importance of considering safety issues relating to earthquakes, landsliding, flood hazards, fire threats, and steep hillsides during the process of making planning decisions.
  - Analysis of environmental impacts, including safety hazards, for projects under County jurisdiction.
  - Modern regulatory codes, including the Zoning, Subdivision, Building, Fire, and Health Codes, that contain standards and provisions designed to protect public safety.
  - A Five-Year Earthquake Preparedness Plan and a Multi-Hazard Functional Plan for Emergency Operations.
  - A system of emergency operations centers and related emergency communications facilities.
  - Departments and agencies which are professionally trained and equipped to protect public safety and respond to emergencies including:

    Forester and Fire Warden;
    Sheriff; and
    Public Works.
  - Mutual aid arrangements with various local jurisdictions and other levels of governments.

D. SUMMARY OF MAJOR CONCLUSIONS

The major conclusions of this report are summarized below.

- The consideration of safety factors in the evaluation of development projects, including the design of safety mitigation measures and conditions for proposed developments, must be continued and improved.

- Public safety can be improved by reviewing proposals for the development or expansion of critical facilities and requiring appropriate mitigation measures to ensure their continued operation after occurrence of a disaster. Proposals which cannot mitigate hazards to the satisfaction of responsible agencies should not be approved.

- Consideration should be given to amending the Zoning Code to establish a seismic hazards overlay zone. Active fault zones and liquefaction areas have proven to be significant sources of damage in past earthquakes and provide the best choices for application of the overlay zone concept.

- Establishment of an organization to acquire and manage open space lands in hazardous areas, such as unurbanized active fault zones, should be considered.

- Regular amendment of the building and related codes to keep them abreast of new research and improved construction technology must be continued.

- Special investigation requirements for projects in hazardous areas should be continued and strengthened. This should include trenching depths determined on a case-by-case basis for fault explorations, and investigation of liquefaction potential to depths up to 50 feet.

- The hazards associated with unreinforced masonry (URM) buildings must be abated. Top priority must be given to abatement of hazards associated with the 274 identified URM's directly under County jurisdiction in unincorporated areas.

- Abatement programs for other potentially hazardous buildings (other than URM buildings) should be developed and implemented.

- Seismic resistant design of lifelines, including substandard bridges and highway interchanges, needs to be improved. Highest priority must be given to strengthening 44 Caltrans freeway interchanges and overpasses and 359 substandard County bridges.

- Seismically threatened historic buildings should be protected through use of the Historic Building Code.

- The mitigation of nonstructural hazards must be strongly encouraged.

- Hillside management programs and mitigation actions for development in hillside areas should be strengthened. Proper maintenance of cut-and-fill slopes should be a high priority.

- Fire prevention standards for development in wildfire prone areas must be improved.

- Mutual aid programs and communication channels among public agencies should be expanded and improved.

- The overall capability of the flood control system must be carefully monitored to ensure that unanticipated levels of urbanization do not generate runoff volumes that exceed the design capacity of older system segments.

- Flood and debris hazard abatement programs must be maintained and improved, especially flood management in the Antelope Valley.

- Dams in the County should be evaluated to determine their relative probabilities of failure and the vulnerabilities of development downstream to flooding. Appropriate mitigation and emergency response programs should be formulated in response to this evaluation.

- Dam safety and water tank safety, emphasizing older earth filled dams and substandard water tanks, must be improved. High priority for abatement should be afforded to seven substandard dams and 31 inadequately designed water tanks.

- County hazardous incident response capability must be expanded.

- Programs for the safe management of hazardous materials and wastes, with increased emphasis on safe use and storage through onsite planning and management, should be strengthened.

- Expansion of community and workplace self-help capabilities emphasizing improved community and workplace emergency planning and organization, must be strongly encouraged.

- A dispersed system of County heavy rescue bases should be created.

- A state-of-the-art system of emergency operation centers must be developed and maintained.

- Interagency and interjurisdictional cooperation and communications must be strengthened.

- Compatibility of County agency computer network systems should be encouraged to facilitate the inventory and mapping of critical facilities and potentially hazardous buildings; and to generally improve emergency response capability.

- Earthquake insurance services must be improved and made more accessible to property owners.

- Consideration should be given to establishing a reconstruction authority to manage post-disaster rebuilding and recovery.

- Safety research programs should be continued and improved. Research on earthquake recurrence intervals and buried faults should receive high priority.

- Earthquake prediction and early warning capability need improvement. This should include deployment of an array of geophysical monitoring instrumentation in the Los Angeles region similar to that maintained by the U.S Geological Survey in the Parkfield, California area, or the hazard reduction experiments established in the Tokai region of Japan.

- The feasibility of an earthquake warning system should be investigated to provide warning of earthquake events along the San Andreas fault. Automatic alert systems may be utilized for community safety, where feasible.

- Consideration should be given to mapping potentially hazardous buildings and critical facilities and completing a computerized inventory in unincorporated areas and in cities contracting for County emergency services.

- Standardized basic geologic mapping at appropriate scales (possibly 1:24,000 to 1:12,000 scales) must be accelerated. This mapping should emphasize the engineering properties of earth materials.

- Consideration should be given to establishment of an awards program to recognize individuals and organizations who make outstanding contributions to improved public safety.

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

The presence of natural hazards is a condition of life in Los Angeles County. To eliminate, minimize, or plan for the consequences of a natural disaster in Los Angeles County is the purpose and goal of the Safety Element. Through it's goals and policy statements, the Safety Element clearly provides the philosophy and direction taken by the County of Los Angeles to serve the citizens of the County. This report, Hazard Reduction in Los Angeles County, supports those goals. Further, as a technical resource document, it provides the supporting documentation from which the County's action programs were derived. There are no easy solutions. Many of the programs are expensive. Some could impose burdens, both financial and regulatory, upon owners of properties in hazardous areas. Taken as a whole, these policies will affect nearly everyone in the County. Taken further though, it is the hope that these impacts will be worthwhile in the context of disaster reduction for the future. When one considers that a major southern California disaster will also affect nearly everyone in the County, the State, and even the country, it is clear that comprehensive and carefully implemented policies are required.

> "It is the duty of investigators--seismologists, geologists, and scientific engineers--to develop the theory of local danger spots, to discover the foci of recurrent shocks, to develop the theory of earthquake-proof construction. It is the duty of engineers and architects so to adjust construction to the sound character of the ground that safety shall be secured. It should be the policy of communities in the earthquake district to recognize the danger and make provisions against it."
>
> G.K. Gilbert (1909)

Statutory Requirements

California Code Section 65302(i) requires each local government to prepare and adopt a Safety Element as a component of their General Plan. The Safety Element, in coordination with other elements in the General Plan such as the Open Space and Land Use Elements, assists in guiding the prudent growth and physical development of local jurisdictions. The basic objective of the Safety Element is to reduce death, injuries, property damage, and the economic and social impact resulting from a variety of natural hazards (OPR, 1987).

To achieve this objective, cities and counties are called upon to identify and map natural hazards within their jurisdiction and administer zoning and subdivision regulations that take safety hazards into account. It is important to understand that mitigation of a problem is possible if recognized early, and that hazardous zones do not, of themselves, preclude land utilization or development.

The issue of seismic safety, formerly addressed in a separate element, has been recently included under the Safety Element cover, pursuant to California

Government Code Section 65302(g). This revision recognizes that many actions that reduce risk from such hazards as fire, storms, flooding, and landsliding also reduce the risk from earthquakes. In accordance with the statutory requirements of California Code Section 65302(g), the Safety Element must assess threats to the public health and safety from, but not limited to the following:

- Seismic hazards: ground shaking, surface rupture, and ground failure;
- geologic hazards: slope instability, landslides, and unstable ground;
- flood and inundation hazards: tsunami, seiche, dam failure, and storm-induced flooding;
- wildland and urban fire hazard; and
- other safety issues as desired by the community or suggested in the General Plan Guidelines, including the threat of hazardous materials releases, potentially hazardous buildings, protection of critical facilities, and emergency response issues (OPR, 1987).

The scope of California Code Section 65302(g) includes an appraisal of fire agency/emergency response safety concerns such as evacuation routes, peak load water requirements, minimum road widths, and clearances around structures.

Safety Element

The policy and implementation document, hereafter referred to as the Safety Element, provides the impetus for risk reduction action. The goals and policies statements within the Safety Element clearly state the rationale of Los Angeles County's position with respect to hazards and safety. The following are excerpts from the goals and policies section of the Safety Element.

- "Minimize injury and loss of life, property damage, and the social, cultural, and economic impacts caused by earthquake hazards."
- "Protect public safety and minimize the social and economic impacts from geologic hazards."
- "Minimize injury and loss of life, and property damage, and economic and social disruption caused by flood and inundation hazards."
- "Reduce threats to public safety and protect property from wildland and urban fire hazards."
- "Reduce threats to the public health and safety from hazardous materials, especially threats induced by earthquakes."
- "Strengthen County short-term emergency response and long-term recovery capability."

- "Continue to promote research on and mapping of natural and urban hazards; and improve safety information systems for planning, emergency response management and hazard mitigation."

Technical Background Report

This document, which is the background report for the Safety Element, makes available the technical information and in-depth explanations which support element goals and policies. One purpose of the technical report is to identify, describe, and clarify the hazards to safety relevant to Los Angeles County, in accordance with California Code Section 65302(g). The objective is to create a common understanding of the technical and practical aspects of the hazards for the geologist, structural engineer, building officials, planners, and those responsible for emergency response. Expanded explanations of various natural and man-made urban hazards are introduced within the context of hazard mapping and an appraisal of emerging and ongoing safety concerns. The fundamental purpose of this technical report; however, is to promote long-term hazard reduction through prudent land use planning and proactive and retroactive regulatory measures. Information presented in this report should not be utilized for detailed design of future projects.

Methodology and Scope of Study

Detailed methodologies stating the data acquisition process, sources of information, uses, and limitations of individual hazard maps will be provided in the text, however, it is important to discuss the general strategy and scope of work that went into the project. The current project did not include original field work but instead relied upon the most recent and ongoing research to formulate the Safety Element. The study consisted of a thorough review of available published and unpublished reports, maps related to the selected hazards, discussions with public officials, and other professionals with specific knowledge in the subject matter and/or the geographic area investigated.

Eight mylar U.S. Geological Survey 1:100,000 metric scale quadrangles (Universal Transverse Mercator Projection) that cover Los Angeles County were acquired as base maps for the data compilation. Information was compiled from a variety of map scales onto mylar overlays, either through photo enlargement of the original information sources or by transferring the information onto the overlays using section lines, roads, land grant boundaries, and other convenient physiographic or man-made features as guides. In some cases, stereographic aerial photos and large scale topographic maps were used where the 1:100,000-scale lacked sufficient resolution to accurately transfer the data.

Several interim task reports were requested by the County for inclusion into the final background report. A review of the existing Safety and Seismic Safety Elements in the first stages of this study helped define the emphasis of this report. Additional tasks addressed the following subjects:

- Identification of dependent populations in the County;

- a feasibility study of a seismic hazard overlay zone, as an addition to the County Planning and Zoning Code;

- options for guiding new development away from hazardous areas such as cost-transference programs and incentives/disincentives;

- issues relating to post-earthquake recovery such as the feasibility of Federal earthquake insurance legislation and the need for a post-earthquake recovery ordinance; and

- future directions in hazard management and hazard research.

Hazard Analysis and Management

Chapter 3 (Hazard Analysis) and Chapter 5 (Hazard Management) are organized so that each hazard can be cross-referenced with analysis and critique of existing safety programs. The emphasis of Chapter 5 is on hazard management of future development. The following threats are highlighted:

- **Seismic Hazards**

  - Ground Shaking
  - Fault Rupture
  - Liquefaction

- **Geologic Hazards**

  - Landslides
  - Dynamic Slope Instability
  - Hillside Management and Development

- **Flood and Inundation Hazards**

  - Tsunami
  - Dam Failure
  - Floods

- **Wildland and Urban Fire Hazards and Hazardous Materials**

  - Wildland fire
  - Urban and Post-Earthquake Fire
  - Hazardous Materials

The various hazards posed to life and property, and the potential socio-economic consequences of a major earthquake are detailed in Chapter 4. Insight into specific short-term and long-term hazard management needs of the County are also provided for cross-reference with Chapter 6, a chapter that specifically deals with the management of earthquake threats posed by unsafe existing development.

Combined, Chapters 4 and 6 provide a general background and an in-depth review of urban earthquake hazards in Los Angeles County. Chapter 6 also discusses emergency response issues as they relate to disaster response planning and hazard reduction, including several promising options created by recent and ongoing hazard mapping and inventory of hazardous structures. Although seismic hazards are emphasized in Chapters 4 and 6, one may find an overlap of the concerns and mitigation actions regarding earthquake-induced secondary hazards and non-earthquake-induced hazards. This coincidence is most evident in the analyses of flood and urban fire hazards.

Chapter 7, extends the topic of future development. Through an analysis of a seismic hazard overlay zone and cost-transference programs for hazardous areas, this chapter combines two tasks that were specifically requested by the County. Chapter 8 explores post-earthquake recovery issues. We review the need for post-disaster policy and present a proposed draft post-earthquake reconstruction ordinance that utilizes existing County agencies. In addition, Chapter 8 provides an examination of earthquake insurance, emphasizing an analysis of the costs and advantages of Federal insurance. Lastly, Chapter 9 focuses on future research needs and opportunities as summarized from observations and conclusions presented throughout this report.

CHAPTER 2

THE SEISMIC ENVIRONMENT OF LOS ANGELES COUNTY

SECTION 2.1

GEOLOGIC AND SEISMIC SETTING

REGIONAL GEOLOGY

The geologic and seismologic framework of Los Angeles County is dominated by the global concept of plate tectonics. Plate tectonics is a mechanical model that relates large scale geologic processes to the movement and interaction of relatively rigid crustal plates across the earth's surface. An outline of the plate tectonic development of the Los Angeles Region is given for four reasons:

- To relate active faulting and earthquake activity to the "Big Picture";
- to develop fundamental knowledge and understanding of mountain building processes and regional geology;
- to emphasize that the geotectonic setting directly controls our inherent vulnerability to faulting, liquefaction, and subsidence; and
- to foreshadow the risk posed by the rugged relief for landsliding, flood, and fire hazards.

The geology and present day landscape of Los Angeles County is directly attributed to the evolution of the tectonic boundary between the Pacific and North American plates. About 20 million years ago, following a complex sequence of plate interactions that brought an end to subduction west of modern Los Angeles, the plate boundary evolved from one of convergence to transform (lateral) motion. This initiated the northwest movement of the Pacific plate relative to the North American plate along a series of subparallel faults, commonly referred to as the San Andreas Fault System.

The northwest-trending strike-slip faulting associated with this boundary has not been the only influence on the geologic setting of Los Angeles County. The east-west trending Transverse Ranges, a thrust fault terrain caused by north-south crustal shortening, has contributed to the development of physiographic, and geologic "subprovinces" within Los Angeles County (Figure 2.1). As shown in Figure 2.1, the mountain highland areas of the Santa Monica, Santa Susana, and San Gabriel Mountains transect the middle of the County, effectively separating the coastal and valley lowland areas from the Antelope Valley, an elevated desert area located in the Mojave Desert geomorphic province (Figure 2.1). The geologic evolution of Los Angeles County is discussed in this context.

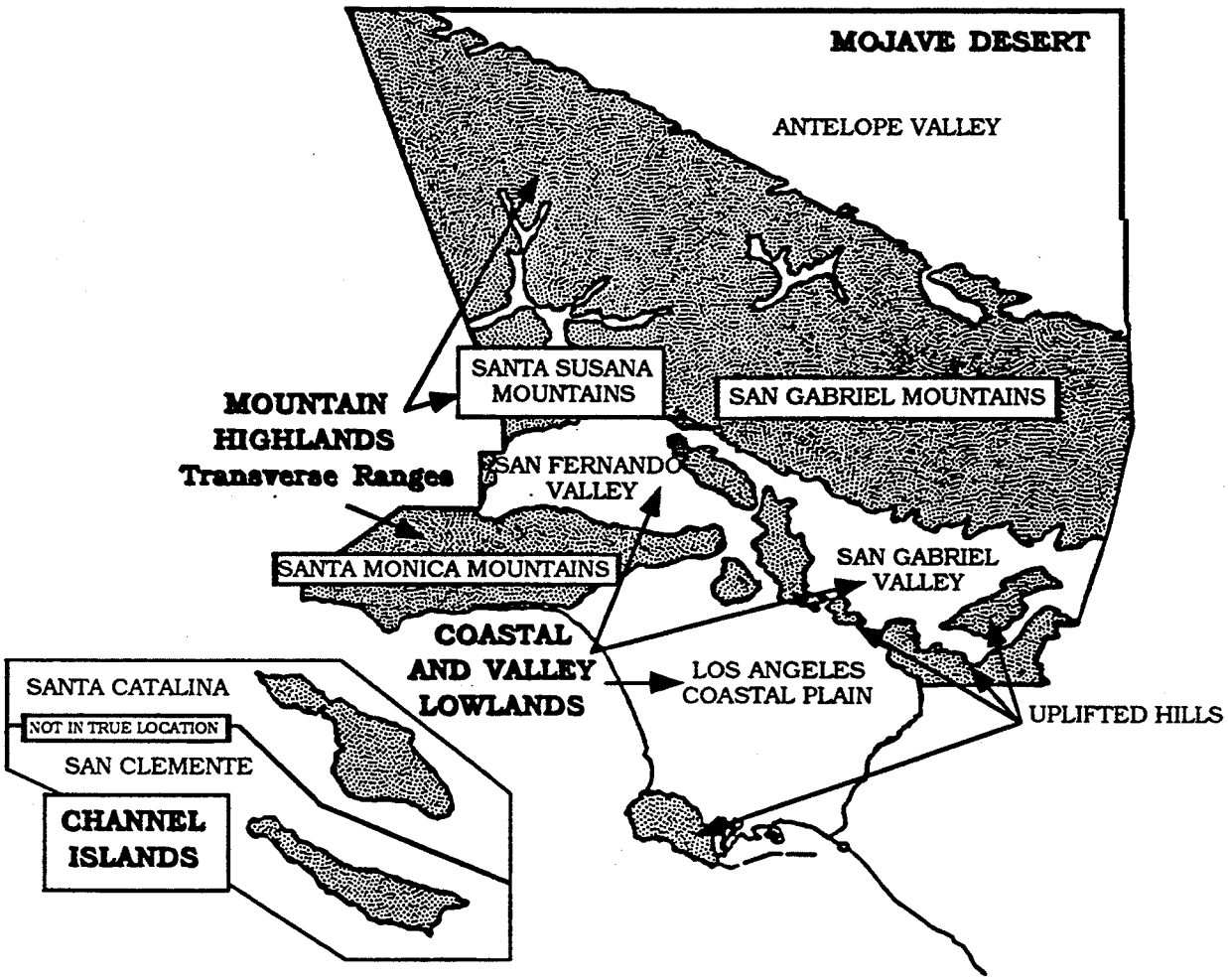


Figure 2.1: Generalized physiographic regions of Los Angeles County.

Coastal and Valley Lowland Areas

The lowland areas south of the San Gabriel Mountains are part of the Los Angeles structural basin. Initial deposition in the Los Angeles Basin area began about 80 million years ago, well before the formation of the structural basin as a distinct entity. The onset of the present tectonic setting deposited as much as 14,000 feet of marine shales and sands in the newly formed northwest-trending structural basin; the majority of deposition occurring between 5 to 10 million years ago (Yerkes, et al., 1965). Contemporaneously faulted and folded by the initial growth of the Transverse Ranges, these marine sediments now rest on a "basement" of sheared, and internally faulted igneous and metamorphic rocks. Locally, approximately 30,000 feet of sedimentary rock cover the extreme relief of the buried basement rocks. Yerkes, et al., (1965) documented as much as 4.5 miles of relief within a distance of eight miles, suggesting a very complex structural basin in three dimensions.

During the last few million years, continued faulting and folding within and adjacent to the structural basin has caused the growth of the Santa Monica, Santa Susana, and San Gabriel Mountains. The Elysian Hills, Repetto Hills, Puente, and San Jose Hills formed from continued movement of buried thrust faults and the accompanying structural warping occurring below the Los Angeles Basin. A simplified schematic cross-section of these buried thrust faults underlying the basin is presented in Chapter 3 (Section 3.1).

The physiographically distinct mountain and valley topography we recognize today was formed from this ongoing faulting and folding, much of which occurred within the last two million years. Evidence of the dynamic history can be found in the rocks throughout the highland areas of the County. These highland areas have partitioned the present day landscape into geographic subregions we identify with the San Gabriel Valley, the San Fernando Valley, and the Los Angeles Coastal Plain (Figure 2.1). The Baldwin, Dominguez, and Signal Hills began to form much later, between 100,000 to 150,000 years ago, in response to movement along the Newport-Inglewood fault (Barrows, 1974). This is just a reminder that mountain building processes are still operating in our area.

Coincident with the accelerated regional uplift, many hundreds of feet of sand and gravel were deposited by ancient streams ancestral to the modern day San Gabriel and Los Angeles Rivers. The underlying basement sedimentary rocks, except for those being uplifted, were masked as alluvial fans began to grow at the base of the eroding highlands. During this time, the sea level fluctuated a number of times and eventually withdrew to the present coast. This has resulted in down-cutting through the terrestrial deposits. These older alluvial fans are being dissected today as uplift continues, forming the present surficial geology of Pleistocene terraces, older alluvium, and more recent Holocene (last 10,000 years) alluvium. This surficial geology composes the floor of our valleys and basins. The U.S. Army Corps of Engineers and the Los Angeles County of Public Works now have in place elaborate flood control systems to prevent the floods that racked Los Angeles in its infancy, the floods that also fostered the growth of these alluvial fans.

Mountain Highlands

The Santa Monica, Santa Susana, and San Gabriel Mountains of Los Angeles County are part of the Transverse Ranges uplift. These mountain ranges are structurally complex. They are bounded on the south by north-dipping thrust faults across their base, and are cut internally by the San Gabriel, and many other faults of various orientations and histories of movement (Figure 2.1).

Contemporaneous with the marine and non-marine sedimentation occurring in the Los Angeles Basin, several marine depositional basins were receiving river-deposited sand and gravel sequences deposited in parts of areas we now identify as rugged mountains. In the San Gabriel Mountains, these older sedimentary rocks (Miocene and Pliocene Age) are now gently to tightly folded, faulted, and are found overlying or in fault contact with 80 million to 1.75 billion year old plutonic and metamorphic crystalline rocks. Crystalline rock forms the bulk of the rock types exposed in the San Gabriel Mountains.

Isolated areas in the mountain highlands are remnants of younger depositional marine/land basin systems that have been uplifted in the last one million years. Such rocks can be found throughout the Transverse Ranges, but in Los Angeles County, they are mostly found in certain constrained geographic areas. The uplifted Santa Susana terrain is composed of Pleistocene rocks of mostly marine origin. The structurally deformed and tectonically uplifted terrain rises as high as 2,000 feet, and possesses a distinctive topography from that found in the adjacent San Gabriel Mountains. Some younger rock types represented in the Santa Monica Mountains are continentally derived (Oakeshott, 1958). Subsequent tectonic activity and uplift of the Santa Monica Mountains produced a sequence of faulted and folded marine sandstone and siltstone rocks. The rocks overlie or are in fault contact with older, deformed metamorphosed sedimentary and crystalline basement. Continued deformation, especially during the last one million years, is responsible for the development of the present steep, rugged, landslide prone terrain.

Antelope Valley

Northeast of the San Gabriel Mountains is Antelope Valley, an elevated desert lying between 2,300 and 3,500 feet in altitude. The Valley is part of the Mojave structural block, a down-faulted structural depression related to the growth of the Transverse Ranges. Bounded by the San Andreas and Garlock faults, the Valley contains as much as 4,000 feet of alluvial fill. Upper Quaternary deposits have accumulated in response to the uplift and erosion of the San Gabriel Mountains during the last half million years.

The Valley is characterized by broad, gently sloping alluvial plains and fans, with remnants of ancient mountains piercing the alluvium as isolated buttes and ridges. Older Pliocene-and Pleistocene-age fan deposits occur as isolated terraces, dissected by younger Holocene-age drainages. Among the most distinctive deposits of the valley fill are the pluvial lake deposits. Formed during wet climatic periods during the Pleistocene, playa lakes such as Rogers

Lake experienced several episodes of filling and desiccation, leaving extensive interbedded sequences of silt, clay, sand, and gravel. Other distinctive rocks are found within the San Andreas Fault Zone. Pervasively fractured in places, the rocks can be very susceptible to debris flows, which are debris filled mud torrents accompanying heavy rains. High ground water conditions can also be found in many low-lying areas along the fault zone.

Channel Islands and Offshore Area

The offshore continental borderland is crossed by numerous faults related to the northwest-trending strike-slip fault system. The Channel Islands have been uplifted along vertical faults related to this system. Although their exposure as islands is related to the present tectonic environment, the basement rocks on San Clemente and Santa Catalina Islands are remnants of regional metamorphism. Metamorphism is caused by melting in the upper plate during the period of Pacific and North American plate convergence. The basement rocks consist of pervasively sheared "melange", and low-and high-grade metamorphic rocks of volcanic and marine origin. This rock type is very prone to landsliding.

SEISMOTECTONIC SETTING

The faulting and deformation operating in Los Angeles County are governed by regional north-south compression, a product of the continued motion between the Pacific and North American plates (Yerkes, 1985). The main trace of the San Andreas fault accommodates over half the strain produced by this motion, with the remaining strain variously distributed through movement on two principal fault sets crossing through the County:

- Northwest-trending faults subparallel to and part of the San Andreas system; and
- east-west-trending thrust faults of the Transverse Ranges.

Faulting is expressed chiefly as right lateral strike-slip motion on vertical faults of the San Andreas system. Faulting with right lateral displacement, with the notable exception of the San Andreas fault, is largely confined to the coastal lowlands and offshore areas of the County. Major northwest-trending faults, such as the Whittier and Newport-Inglewood faults, propagate into the County from the south, but appear to terminate (lose their structural identify) as they approach within 10 to 15 kilometers of the frontal thrust faults of the Santa Monica and San Gabriel Mountains (Figure 2.1).

Reverse or reverse-oblique displacement occurs on faults related to the Transverse Ranges. In Los Angeles County, reverse faulting and crustal shortening are manifested as an "imbricate" system of overlapping thrust faults. Several segments radiate upward and are exposed as frontal thrust faults along the southern boundaries of the Santa Monica, Santa Susana, and San Gabriel Mountains. Other thrusts extend beneath the Los Angeles Basin as "blind thrusts".

The three important points to emphasize when discussing tectonic deformation in Los Angeles County are as follows:

- The County occupies a junction between two major zones of intersecting faults (strike-slip and thrust), both capable of transmitting the strain imposed by the continuing plate motion through structural deformation (i.e., folding, faulting and earthquakes);

- "the deformation caused by these fault structures is as active now as it has ever been and is expected to continue at the present rate" (Atwater and Molnar, 1973); and

- the risk of a damaging earthquake from any one of these faults to the Los Angeles Basin, is approximately five percent, per year (Spangle, 1987).

Character of Seismicity

Earthquakes are caused by intermittent slippage on any pre-existing surface subjected to a shear stress, provided the structure is properly oriented to the stress. The most damaging earthquakes are associated with ruptures across very large surfaces on pre-existing faults (Figure 2.2). In fact, the length of the active segment of the fault is used to estimate the largest earthquake the fault is capable of producing. In California, large damaging earthquakes have been for the most part, concentrated near major known Quaternary faults mapped at the surface. Nevertheless, recent damaging earthquakes have emphasized that large subsurface structures can also generate major earthquakes, such as in the case of the 1983 Coalinga and 1987 Whittier Narrows Earthquakes. The "buried" thrust fault identified in the Whittier Narrows Earthquake suggests that many other unknown faults lie unnoticed below the surface.

Earthquake epicenters commonly align along a northwest-trend when associated with near-vertical strike-slip faults and show tight clusters or short east-west epicentral patterns when related to east-west trending thrust faults (Figure 2.2). These observed patterns of seismicity on faults in the County of Los Angeles, however, can be misleading. As illustrated by the well-dispersed epicentral pattern in Figure 2.2, essentially the whole Los Angeles area is underlain by "seismogenic" structures. Seismogenic structures are any geologic discontinuities in rock at depth that are capable of slipping and producing an earthquake. Elastic strain is commonly released in the upper 15 kilometers (nine miles) of the crust, and particularly between 6 and 10 kilometers (4 and 7 miles), which are the depths at which most earthquakes originate.

Buried thrust faults add a new dimension to the earthquake threat in Los Angeles County. Relatively shallow earthquake sources may underlie vast areas of the coastal and valley lowlands. As yet, not much is known about the potential size or recurrence of earthquakes originating on seismogenic structures associated with buried thrust faults. We do know the potential locations and sizes of future earthquakes on a few of the really major faults in the region, structures which are schematically-illustrated in Figure 2.2.

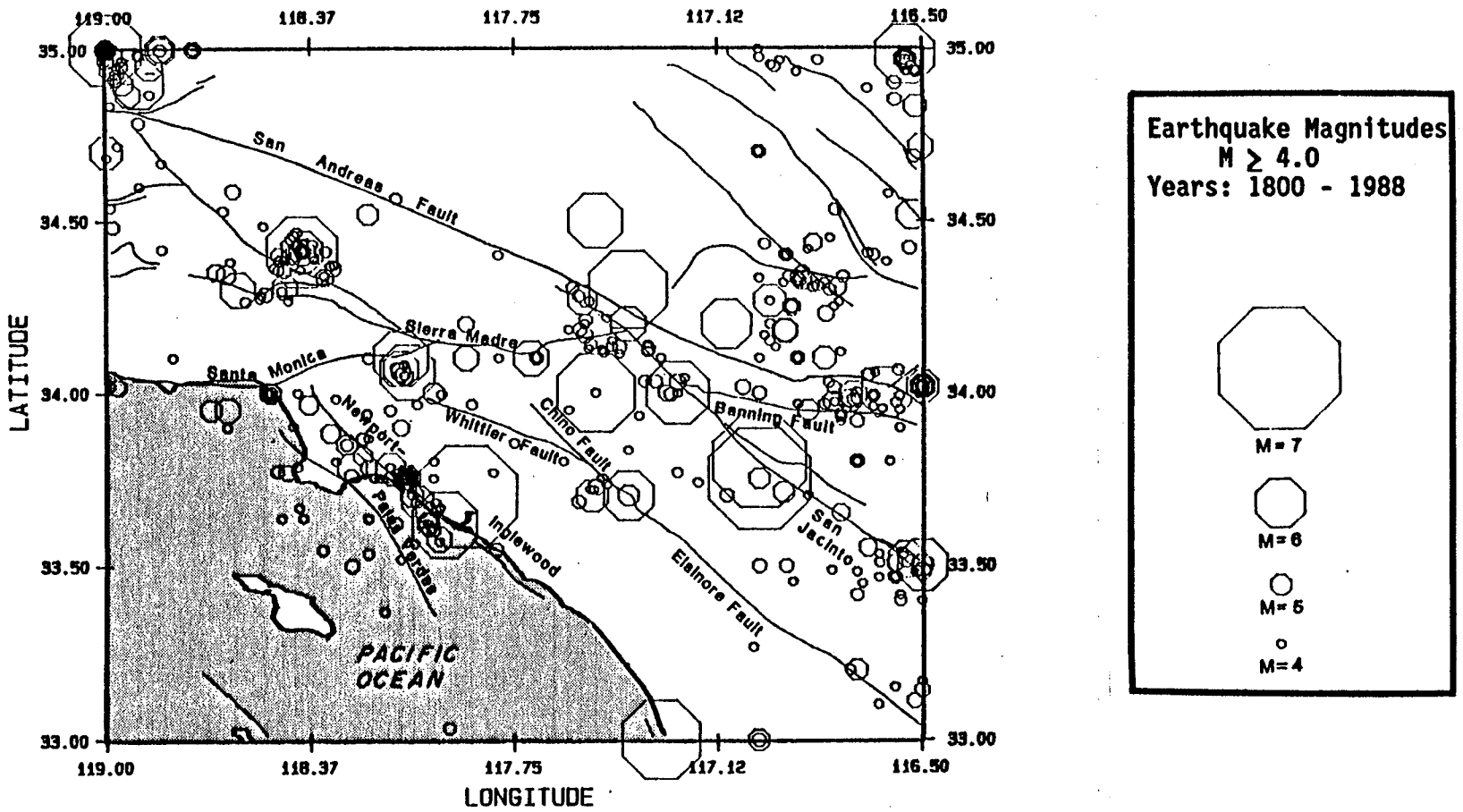


Figure 2.2: Major faults and selected historical earthquakes: ground shaking sources for the County of Los Angeles.

Earthquake Potential

Despite intensive study of the geologic and seismologic framework in Los Angeles County, there remains much to be unearthed concerning the specific earthquake risk of individual faults. Judgement of how often and how large an earthquake will be is based on geologic evidence of past events, historical seismicity, the dimensions of the fault, and it's relation to nearby earthquake-producing faults. Ziony and Yerkes (1985) contend that faults that have moved within the last 750,000 years possess a relatively high degree of earthquake potential, at least relative to the time frame of most development. By their count, there are upwards of 95 "potentially active" faults in the Los Angeles Region that have been active in Late Quaternary time; over half of these are located in Los Angeles County.

Given the state of our knowledge on fault characteristics, interpreting the relative risk that each fault poses is a markedly qualitative judgement. The State of California Alquist-Priolo Special Studies Zone (APSSZ) Act recognizes only five faults as high risk "active" faults. They include the San Andreas fault and varying portions of the Newport-Inglewood, San Gabriel, Raymond, and San Fernando faults. This definition is designed to measure the potential for surface rupture using suspected or proven movement within the last 10,000 years as a yardstick. The APSSZ program does not attempt to measure the earthquake potential, or likelihood of a damaging earthquake, on Late Quaternary faults that are either acknowledged or unrecognized by the State Act.

Table 2.1 is a compilation of maximum credible earthquakes on selected faults in Los Angeles County. A maximum credible earthquake is the largest earthquake a fault is expected to generate, based on fault length. A maximum credible earthquake is also the least probable earthquake a fault is likely to produce. The percentage probability of such an earthquake on a particular fault within a 100 year period is presented in Table 2.1 on the basis of fault slip rate data compiled by Wesnousky (1986) and Ziony and Yerkes (1985). Probabilities are best defined for the San Andreas fault; yet even the activity of other faults that have moved in recent history, such as the San Fernando and Newport-Inglewood faults, still remain largely interpretative. A limitation of Table 2.1 is that reliable slip rates are known for only a few onshore faults in the Los Angeles Region. Even less information exists on offshore faults.

The most probable earthquake to occur within a specific time frame of interest, for example within a 30 to 100 year period, is termed a maximum probable earthquake. Great earthquakes are less likely if a fault is characterized by the occurrence of smaller, more frequent earthquakes. Incorporated into Table 2.1 is the assumption that small or moderate earthquakes are not statistically significant on a particular fault at more frequent time intervals. Therefore, while based on the most up-to-date scientific data, the probabilities listed in Table 2.1 are still a conservative estimate of the earthquake hazard in Los Angeles County. More appropriately, Table 2.1 can be interpreted to be an indicator of our current understanding of the relative activity of faults in the region.

TABLE 2.1

Size and Probability of Major Earthquakes Anticipated on Selected Faults Within or Contiguous to Los Angeles County

	Maximum Credible Earthquake[1]	Percentage Probability of Maximum Credible Earthquakes in 100 Year Period[2,3]	Reference
San Andreas			
Mojave	7.5	77.0	Davis (1988)
Carrizo	8.0	30.0	Davis (1988)
San Bernardino	7.5	77.0	Davis (1988)
Llano	6.1	?	Ziony and Yerkes (1985)
Mirage Valley	6.8	?	Ziony and Yerkes (1985)
San Gabriel			
Northwest (A)	7.0	3.0	Wesnousky (1986)
Central (B)	6.7	5.0	Wesnousky (1986)
Holser	6.6	?	Ziony and Jones (1989)
Santa Felicia	6.1	?	Ziony and Yerkes (1985)
Del Valle	5.8	?	Ziony and Jones (1989)
Clearwater			
Central	6.9	?	Ziony and Yerkes (1985)
San Fernando	6.5	30.0	Wesnousky (1986)
Mission Hills	6.3	?	Ziony and Yerkes (1985)
Santa Susana	6.9	15.0	Wesnousky (1986)
Northridge	6.6	?	Wesnousky (1986)
Sierra Madre			
Segment A	6.4	2.0	Crook et al., (1987)
Segment B	6.5	2.0	Crook et al., (1987)
Segment C	6.5	2.0	Crook et al., (1987)
Segment D	6.5	2.0	Crook et al., (1987)
Duarte	6.5	?	Crook et al., (1987)
Clamshell-Sawpit	6.4	?	Crook et al., (1987)
Cucamonga (Sierra Madre E)	6.6	2.0	Wesnousky (1986)
San Antonio	6.2	?	Wesnousky (1986)
San Jose	6.7	?	Wesnousky (1986)
Indian Hill	6.2	?	Ziony and Yerkes (1985)
Central Avenue	6.1	?	Ziony and Yerkes (1985)
Walnut Creek	6.5	?	Ziony and Yerkes (1985)
Whittier	7.3	13.0	Wesnousky (1986)
Verdugo	6.7	?	Ziony and Yerkes (1985)
Eagle Rock-San Rafael	6.3	?	Wesnousky (1986)
Raymond	6.7	3.0	Wesnousky (1986)
Hollywood	6.4	6.0	
Santa Monica	6.7	?	Wesnousky (1986)
Malibu Coast	6.9	2.0	Wesnousky (1986)
Benedict Canyon	6.3	?	Wesnousky (1986)
Griffith	6.7	?	Wesnousky (1986)
Newport-Inglewood			
Segment A (Long Beach)	6.8	7.0	Wesnousky (1986)
Segment B (Central Los Angeles)	6.9	6.0	Wesnousky (1986)
Charnock	6.2	?	Ziony and Yerkes (1985)
Overland	6.2	?	Ziony and Yerkes (1985)
Palos Verdes	6.7	3.0	Wesnousky (1986)
Cabrillo	6.2	?	
Redondo Canyon	6.4	?	Clark et al., (1985)
San Pedro Basin	>7.0	?	Clark et al., (1985)
Santa Catalina Ridge	>7.0	?	Clark et al., (1985)
Anacapa-Dume	7.0	?	Clark et al., (1985)

1 A maximum credible earthquake is the largest earthquake a fault is capable of generating, involving rupture of the entire fault length. Maximum probable earthquakes are the largest earthquakes most likely to occur within a given time frame, such as 100 years, or within the lifetime of a structure. Maximum probable earthquakes are more commonly used in the design and planning, while maximum credible earthquake data is used to establish safety margins for critical projects. Magnitudes of maximum credible earthquakes are calculated based on a magnitude-length relationship reported by Wesnousky (1986). Rupture of two or more adjoining fault segments at the same time could result in a larger earthquake than the maximum credible.

2 The recurrence of a maximum credible earthquake for a fault is calculated based on the most current, published slip rate for that fault assuming that the accumulated strain in the fault zone is released only by the maximum credible earthquake. This is a conservative estimate of the recurrence interval. Future fault studies may suggest different slip rates than those used here.

3 The probabilities of occurrence of maximum credible earthquakes for the San Andreas fault segments are based on a conditional probabilistic analysis developed by the Working Group on California Earthquake Probabilities (Davis, 1988). A conditional probability takes into account the time lapsed since the last earthquake on a fault, and should be based on relatively reliable recurrence data for a fault. The other probabilities listed here are based on a poisson distribution model. A poisson distribuiton model assumes that the annual probability of occurrence of an earthquake is independent of whether an earthquake has occurred, or not, in previous years. A poisson distribution model is used to characterize the probability of occurence when there is not enough data to define the conditional probability of occurrence of that earthquake.

SECTION 2.2

HISTORICAL EARTHQUAKE DAMAGE

HISTORIC SEISMICITY

Catalogs of earthquake activity for southern California extend as far back as the earliest "felt" event, recorded in 1769 by the Portola expedition as they traveled between the Santa Ana and Los Angeles Rivers. The earliest chronicles of earthquake activity are generally skewed to larger events and their documented effects are related only through subjective personal accounts. The accuracy and completeness of the seismic record has increased over the years, eventually culminating in 1926 with the establishment of the first southern California seismic network. Systematic calculations of earthquake epicenter locations, and the compilation of ongoing earthquake activity began in 1932.

Table 2.2 shows a list of damaging earthquakes, generally MM $\geq$ VII, that have occurred in southern California from 1800 through 1989, and recorded or felt in Los Angeles County. To emphasize significant recent earthquake activity, two events (MM = VI) are also included on the list. Note that 54 damaging earthquakes have occurred along the same families of fault systems that intersect within the County. A simple calculation shows that these 54 damaging earthquakes within a 189 year period yields a return rate of one damaging earthquake every 3.6 years. Implicit in this observation is the extreme risk of the region, and particularly the County, to future events of such magnitude.

Historical context is useful for gaining a perspective on the many issues that earthquake activity poses. Several of the larger earthquakes listed in Table 2.2 have resulted in changes in the regulatory codes and public perception of the earthquake hazard. Historically, damaging earthquakes have often produced the impetus for earthquake risk-reduction activities at all levels of government. The following discussions, in chronological order, are of the more significant earthquakes, or other events that have inflicted damage in the Los Angeles area, and have had an impact on safety planning in California. Toppozada, et al., (1981) is used for the earliest events, and locations and descriptions are generalized. Earthquakes from 1933 to the present are stressed because some fundamental lessons can be learned from a review of their damage patterns.

<u>1855 July 11</u> - The earthquake was felt locally as a strong shock with intensities as high as VIII. A number of buildings were damaged, bells were thrown down at the San Gabriel Mission and an adobe dwelling was destroyed in an area now occupied by the Los Angeles Arboretum in Arcadia. A total of 26 buildings were damaged. The earthquake was probably located on one of the surface faults bordering the Los Angeles Basin, such as the Hollywood-Raymond or Whittier faults. It may have also been related to the subsurface rupture of a buried thrust fault, as was the case in the 1987 Whittier Narrows Earthquake.

TABLE 2.2 - DAMAGING EARTHQUAKES IN SOUTHERN CALIFORNIA 1800-1989

EVENT NO.	YEAR	MONTH	DAY	LATITUDE N.	LONGITUDE W.	M*	MM*	FAULT OR ZONE
1-----	1800	Nov.	22	33.0	117.3	6.5	VII	Rose Canyon (?)
2-----	1812	Dec.	8	33.7	118.1	6.9	VII	Newport-Inglewood-San Andreas (?)
3-----	1812	Dec.	21	34.2	119.9	7.1	VIII	Santa Barbara Channel (?)
4-----	1855	July	11	34.1	118.1	6.0	VIII	Raymond (?)
5-----	1857	Jan.	9	35.3	119.8	7.9	IX+	San Andreas
6-----	1858	Dec.	16	34.0	117.3	6.5	IX	San Andreas-San Jacinto
7-----	1892	Feb.	24	32.6	115.7	6.8	IX+	Laguna Salada (Elsinore)
8-----	1893	Apr.	4	34.3	118.7	5.5	VIII	Santa Susana (?), Simi (?)
9-----	1899	July	22	34.3	117.5	6.7	VIII	San Andreas (?)
10-----	1899	Dec.	25	33.8	117.0	6.8	IX	San Jacinto
11-----	1902	July	28	34.7	120.4	5.4	VIII	Los Alamos
12-----	1907	Sep.	20	34.2	117.4	6.0	VII	San Jacinto (?)
13-----	1910	May	15	33.7	117.4	6.0	VII	Elsinore (?)
14-----	1912	Dec.	14	34.0	119.0	5.0	VII	Offshore (?)
15-----	1915	Jan.	12	34.73	120.23	5.8	VIII	Los Alamos
16-----	1916	Oct.	23	34.9	118.9	5.6	VII	--
17-----	1918	Apr.	21	33.75	117.00	6.8	IX	San Jacinto
18-----	1919	Feb.	16	35.0	119.0	5.0	VII	White Wolf
19-----	1920	June	22	33.97	118.37	4.7	VIII	Newport-Inglewood
20-----	1923	July	23	34.0	117.25	6.0	VII	San Jacinto
21-----	1925	June	29	34.3	119.8	6.8	IX	Santa Barbara
22-----	1926	June	29	34.5	119.7	5.5	VII	Santa Ynez (?)
23-----	1927	Nov.	4	34.6	120.9	7.3	IX	Offshore Point
24-----	1929	July	8	33.9	118.04	4.7	VIII	Norwalk
25-----	1930	Aug.	5	34.3	119.5	5.0	VII	Santa Barbara
26-----	1930	Aug.	31	33.95	118.68	5.2	VII	Anacapa
27-----	1933	Mar.	11	33.62	117.97	6.3	IX	Newport-Inglewood
28-----	1937	Mar.	25	33.41	116.26	6.0	VII	San Jacinto
29-----	1941	July	1	34.37	119.58	6.0	VIII	Santa Barbara
30-----	1941	Oct.	22	33.8	118.2	4.9	VII	Newport-Inglewood (?)
31-----	1941	Nov.	14	33.78	118.25	5.4	VII+	Newport-Inglewood (?)
32-----	1942	Oct.	21	32.97	116.0	6.6	VII	San Jacinto
33-----	1947	Apr.	10	34.98	116.55	6.5	VII	Unknown, probably not Manix
34----	1948	Dec.	4	33.93	116.38	6.0	VII	Mission Creek
35----	1952	July	21	35.0	119.02	7.5	XI	White Wolf
36----	1954	Jan.	12	35.0	119.02	5.9	VII+	White Wolf
37----	1968	Apr.	9	33.19	116.13	6.5	VII	Coyote Creek (San Jacinto)
38----	1969	Apr.	28	33.34	116.35	5.8	VII	San Jacinto
39----	1970	Sep.	12	34.27	117.54	5.4	VII	No. San Jacinto
40----	1971	Feb.	9	34.41	118.40	6.6	IX	San Fernando
41----	1971	Mar.	31	34.29	118.52	5.1	VII	San Fernando
42----	1973	Feb.	21	34.07	119.04	5.3	VII	Anacapa
43----	1978	Aug.	13	34.40	119.68	5.6	VII	Santa Barbara Channel
44----	1973	Aug.	6	33.97	119.45	5.0	-	Santa Cruz Island
45----	1975	May	31	34.52	116.49	5.2	-	Galway Lake
46----	1979	June	30	34.23	116.89	4.9	-	San Bernardino Mtns.
47----	1980	Feb.	25	33.52	116.55	5.6	-	San Jacinto
48----	1981	Sep.	4	33.68	119.10	5.3	-	No. of Santa Barbara Is.
49----	1985	Oct.	2	34.030	117.25	4.7	-	-
50----	1987	Oct.	1	34.06	118.08	5.9	VIII	Elysian Park-Whittier Narrows Quake
51----	1987	Oct.	4	34.07	118.10	5.3	VII	Aftershock on Elysian Park
52----	1988	June	10	34.94	118.74	5.2	VII	-
53----	1988	Dec.	3	34.142	118.16	5.0	VI	Elysian Park (?)
54----	1989	Jan.	18	33.42	118.63	5.0	VI	Fault Complex-Santa Monica Bay

Date of Earthquake is Coordinated Universal Time (Greenwich)

- = No Information

* M = Magnitude (Richter Scale)

** MM = Maximum Intensity (Modified Mercalli Scale)

1857 January 9 "Fort Tejon Earthquake" - Just seven years after California gained statehood, southern California experienced the "great Fort Tejon" Earthquake (M_L = 7.9). Surface rupture along the south-central portion of the San Andreas fault extended southeast from the Carrizo Plain in San Luis Obispo County to Wrightwood, California and perhaps as far as Burro Flat in San Bernardino County. Thus, the Mojave segment of the San Andreas fault in Los Angeles County has experienced a "great earthquake" in historic time (Yerkes, 1985). Several studies related to the future impact of a similar event have been prepared for the region (Davis, et al., 1982; Gulliver, 1981).

In Los Angeles, the actual damage reported was less than that reported in the 1855 earthquake, although there was a very strong, long swaying motion, and the Los Angeles River was thrown from its bed. Houses were reported knocked down in the San Fernando Valley. A comparatively small loss of life is attributed to the sparsely settled character of most of the heavily shaken areas.

1906 April 18 "San Francisco Earthquake" - Although not in Los Angeles County, this earthquake is included in this summary because it was the first "great earthquake" to affect an urbanized area in California and many people were killed. The earthquake occurred on a segment of the San Andreas fault which, at its closest point, approached within about 12 to 15 kilometers (8 to 10 miles) from the center of San Francisco. By comparison, rupture from the Fort Tejon Earthquake, at its nearest, approached within 60 kilometers (38 miles) from the center of Los Angeles.

Heavy property losses occurred in San Francisco and brought attention to post-earthquake fire hazards. In an effort to strengthen standards, buildings constructed following the earthquake were built to withstand heavy winds, since earthquake standards had not been developed yet. In time, these standards were reduced because "San Francisco had no heavy winds".

1920 June 22 - This earthquake was attributed to the Newport-Inglewood fault near the City of Inglewood (Toppozada, et al., 1988). Considerable damage occurred but there was no loss of life. The earthquake exposed the weakness of the local types of construction, especially brick masonry, which had been common in California.

1933 March 10 "Long Beach Earthquake"

One of the most destructive earthquakes in the history of southern California occurred on the southern segment of the Newport-Inglewood fault. The Cal Tech seismic network determined that the hypocenter occurred at a depth of 10 kilometers (six miles) and that the rupture propagated 25 kilometers to the northwest from its epicentral location off Newport Beach, into the Long Beach area. The Isoseismal Map shown in Figure 2.3 shows the heavily damaged area as an elliptical pattern; the long axis extends from Laguna Beach to Marina del Rey. Considerable damage still occurred outside this area, but it was sporadically distributed.

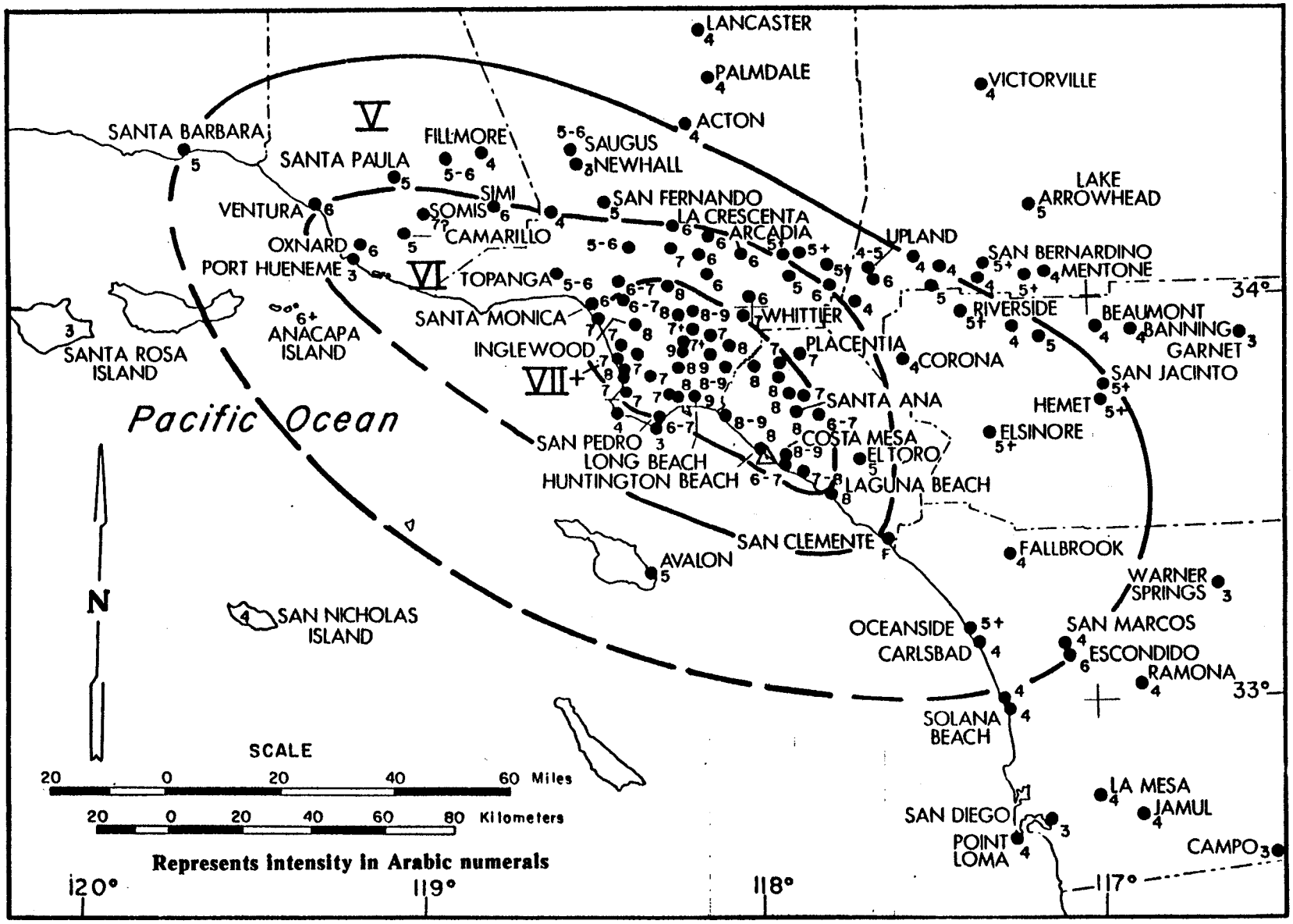


Figure 2.3: Isoseismic map of the 1933 Long Beach earthquake. Arabic numerals indicate Modified Mercalli intensities. (after Toppozada and Parke, 1982).

Wood (1933) indicates that "conspicuous damage is greatest in areas underlain by man-made fill or loose alluvium, especially where saturated at shallow depths with ground water". A subsequent report by Binder, (1952) confirmed Wood's early observations that well-consolidated terrace deposits, well-compacted fill, hilly ground such as Signal Hill, and areas underlain by compact sedimentary rock escaped with considerably less damage even though located in high impact zones shown in Figure 2.3. Well-constructed buildings in even the most vigorously shaken areas, suffered relatively little damage, especially when sited on "well-chosen or well-prepared foundations" (Wood, 1933).

The 1933 Long Beach event exposed the vulnerability of the alluviated Los Angeles basin area to liquefaction and earthquake-induced ground settlement. As noted by Wood, (1933): "along the shore between Long Beach and Newport Beach, and in a few localities a short distance inland, road fills across marshy land, and similar earth construction resting in wet sand or mud, settled, shook apart, or moved laterally, causing considerable damage to concrete highway surfaces and to approaches to highway bridges". Analogous phenomena were observed where piers and landings adjoined the shore in the harbor area. A summary of specific damage is compiled in Table 2.3.

<u>1971 February 9 "San Fernando Earthquake"</u>

In the years prior to 1971, the San Fernando Area was characterized by low to moderate seismicity, not unlike many other areas in the Los Angeles region. The area experienced about ten earthquakes of Magnitude 3.0 between 1934 and 1971. The only other earthquake attributed to the area prior to the San Fernando Earthquake was a small felt event in 1893 (Weber, 1974). The 1971 San Fernando Earthquake measured 6.6 and caught many earth scientists unprepared because the area had not shown any anomalous activity prior to the event. The main shock and the two very strong aftershocks resulted in one of the most damaging earthquakes that had yet occurred in the United States.

The San Fernando Earthquake provided the first test of the newly developed and heavily populated southern California region to the damaging effects of a moderate size earthquake. Most of the economic loss from this earthquake resulted from a combination of intense ground shaking and extensive and severe ground rupture. Principal fault rupture was distributed along the San Fernando and western Santa Susana fault zones over an area as wide as 3 kilometers (1.8 miles). Also contributing to the heavy property losses were the widespread ground lurching, liquefaction, lateral spreading, and differential settlement of unengineered fills and loose alluvium (Weber, 1974). As a result of this earthquake, previously accepted Uniform Building Code Standards and construction techniques common to southern California were reassessed. Many of the damage patterns with respect to utilities, buildings, bridges and infrastructure documented in 1971 remain applicable to present-day development. A summary of selected damages is provided in Table 2.3.

Table 2.3: Damage Patterns of the 1933 Long Beach, 1971 San Fernando and 1987 Whittier Narrows Earthquakes.

1933 LONG BEACH EARTHQUAKE

PROPERTY AND LIFE LOSS

- One hundred twenty casualties; escape and panic are main causes of injuries.
- $40,000,000 dollars losses (1933).
- Isolated fires in residential areas. No fires occur in mercantile/industrial districts or where water pipes are broken. A lack of wind also prevents higher losses from fire.
- Oil facilities suffer damaged internal piping/storage tanks.

LIFELINES

- Water supply pumping stations rendered inoperable; underground distribution mains damaged in areas of ground failure.
- Catastrophic failure of ground level water tank releases approximately 6,000,000 gallons in violent "explosion".
- Broken gas services and devices cause 7 to 19 fires.
- 2 of 25 elevated storage tanks collapse; others damaged.
- Value of post-earthquake communication for emergency response is recognized.

GENERAL CONSTRUCTION

- Unreinforced masonry suffers severe damage; walls collapse, catastrophic collapse of school buildings (thousands of lives spared due to late time of day 5:54 p.m.).
- Extensive structural and nonstructural damage to steel frame fireproof and reinforced concrete frame buildings.
- Simple architectural design is recognized to inhibit severity of damages.
- Well-built frame houses survive with minimal damage--no wholesale destruction of residential buildings.

1971 SAN FERNANDO EARTHQUAKE

PROPERTY AND LIFE LOSS

- 58 dead and 2,543 injured; escape, panic, and collapse of structures are the main causes of injuries.
- $511,000,000 direct dollar loss (1971).
- Approximately 20,000 houses damaged, nearly 830 destroyed; others collapse or are razed later--fires destroy some.
- Oil facilities suffer damaged internal piping/storage tanks.
- Four major hospitals severely damaged and evacuated. Olive View Hospital built under inadequate Building Code Standards.
- Collapse of structural and nonstructural building components traps emergency vehicles.
- Freeway overpasses collapse.

LIFELINES

- Sylmar converter station heavily damaged (40 percent of cost).
- Ground level water supply tanks buckle and again prove vulnerable to ground shaking.
- Gas distribution lines show potential for explosion and fire.
- Underground utilities (gas, water, liquid) prove vulnerable to "buckling" and "pull-apart" through ground failure and fault rupture.
- Embankment failure in Lower San Fernando Dam alarms emergency officials--evacuation declared.
- Modern freeway overpasses prove vulnerable to collapse from intense ground shaking.
- Roads damaged from ground rupture and/or failure--many blocked by shallow rockfalls, rock avalanches, slope/colluvial failures.

GENERAL CONSTRUCTION

- Precast tilt-up, prestressed concrete construction used in light industrial buildings prove vulnerable to severe structural damage, especially roof failure caused by collapse of walls.
- Unreinforced concrete and improperly designed reinforced concrete buildings suffer moderate to severe damage.
- Structural defects and poor construction quality cited as main cause of damage.
- "Soft-story" multi-story buildings such as Olive View Hospital suffer partial or total collapse.

- Unanchored/unbraced nonstructural equipment in industrial facilities experience severe damages (electrical transformers, coolers, boilers, machinery, equipment).

- Nonstructural damages include: collapse of unsupported interior walls, stairways, and lights. Office equipment cited as cause of many injuries.

- Mobilehomes and dilapidated buildings prove vulnerable.

- One-story homes perform better than 2-story homes; 1- and 2-story homes with irregular configuration sustain more damage.

1987 WHITTIER NARROWS EARTHQUAKE

PROPERTY AND LIFE LOSS

- Main shock: three dead, 932 injured; nonstructural hazards and panic are the main causes of injuries; ethnicity becomes a factor in emergency response activity.

- $358,000,000 direct dollar loss (1987).

- One-hundred twenty three single-family homes (Whittier) and 134 apartment units (City of Los Angeles) suffer severe damage.

- 508 medical rescue situations.

- Interjurisdictional earthquake exercise "Response 87" and ongoing emergency response and preparedness programs are credited with reducing overall impact of earthquake.

- Only five earthquake-caused fires; three were linked to natural gas leaks.

- 22 hazardous material situations.

- Large chlorine tank collapses and forces evacuations in Santa Fe Springs; isolated incidents involve spilled chemicals and released asbestos.

- Warning of large chlorine gas release is impeded by inadequate telephone/emergency communication system.

- I-5/I-605 (built mid 1960's) freeway interpass comes perilously close to collapse during major aftershock. Indications that Phase 1 retrofit program remains vulnerable; Caltrans initiates Phase 2 retrofit of single-column design bridges.

LIFELINES

- Burned down or wrapped overhead transmission lines cause brief service disruption; damaged substations cause wider outrages, but overall system performance good because damages were dispersed.

- Speculation begins that burned down overhead distribution lines may cause fire, posing danger of electric shock and blockage of major thoroughfares.

- Mainframe computer system at Southern California Edison down for 32 hours. Widespread belief that computer systems are vulnerable to damage.

- Limited areas without fire fighting fire flow; low water pressure caused by cracks in cast-iron water pipelines. Damage concentrated along welds and corroded segments in 4- to 24-inch diameter watermains.

- Water pipelines, water storage tanks damaged at piping connections, and other types of liquid storage tanks are damaged.

- There are 1,400 earthquake-caused natural gas leaks. 75 percent of leaks associated with appliance water heater connections; the remainder occur in corroded cast-iron distribution pipes, service connections, and internal residence system.

- Eighty-one seismically-active natural gas shut-off valves are triggered (houses, hotels, fire stations, etc.).

- Los Angeles County Earthquake Response: Responsible agencies lose one hour because regular telephone system is saturated; emergency radio frequencies are also overloaded.

GENERAL CONSTRUCTION

- Tilt-up construction is again identified as seismically vulnerable. Out of 120 tilt-ups surveyed in areas experiencing seismic intensity VIII, many pre-1971 tilt-ups partially collapse. Post-1971 buildings also sustained significant damages.

- Partial collapse of pre-1971 tilt-up commercial buildings due to same structural problems experienced during the 1971 San Fernando Earthquake. Some retrofitting techniques perform well.

- Recent trends in design and construction practice of tilt-up buildings reveal a new seismic vulnerability not previously recognized. Building Codes have been improved since 1971, but many 2- and 3-story tilt-ups with irregular configuration have minimized the effect of post-1971 code improvements.

- Interior and exterior nonstructural hazards: falling bookcases, and collapse of lighting fixtures and desk-top computers, and unsupported parking lot walls.

- Strengthened unreinforced masonry buildings sustain no major collapse. The absence of total collapse of unstrengthened URM buildings suggests the magnitude and duration or the earthquake did not provide a true test of seismic capacity.

- Much incipient damage to strengthened and unstrengthened URM buildings: shear cracking of URM piers, shear failure and fallen bricks.

1987 October 1 "Whittier Narrows Earthquake"

The Whittier Narrows Earthquake occurred on an unsuspected feature, a buried thrust fault underlying the Elysian Park-Montebello Hills area (Hauksson, 1988). While the San Fernando Earthquake was also interpreted as a thrust event, it was associated with a recognized north-dipping frontal thrust fault at the base of the San Gabriel Mountains.

The buried thrust system had been known, but not thoroughly studied by earth scientists trained in seismic risk analysis. Consequently, the earthquake potential of these faults caught planners, and geologists by surprise. The implications of these buried thrust faults range from increasing previously accepted annual probabilities for damaging earthquakes to the most disconcerting notion, that such faults may be able to generate a Magnitude 7.5 at depths as shallow as 6 Km (four miles) below an urbanized area. In any case, we can assume that the earthquake threat is increased for Los Angeles County (Al Rogers, personal communication; Davis and Hayden, 1987).

No evidence of fault rupture or ground failure was revealed during this earthquake but structural and nonstructural property damage was extensive. The Magnitude of 5.9 classifies it as a moderate earthquake. If not for the proximity of the earthquake source to major urban centers, the damages would likely have been less severe. Nevertheless, the moderate damage caused by the earthquake provided much information to earthquake researchers on the survivability of retrofitted infrastructures (freeway interchanges) and buildings (unreinforced masonry, concrete tilt-up, etc.). In addition, the lessons learned from the Whittier Narrows Earthquake were also significant, because it tested the Federal, State, and local earthquake mitigation, emergency response, and preparedness programs that had evolved in the wake of the 1971 San Fernando Earthquake. Federal and State-sponsored earthquake research agencies were able to capitalize on an unprecedented collection of data on ground response and other structural and sociological studies for the Los Angeles region. A summary of selected damage, losses, and lessons learned from the 1987 Whittier Narrows Earthquake is presented in Table 2.3.

1989 October 17 "Bay Area Earthquake (Loma Prieta)"

The Bay Area Earthquake, officially named the Loma Prieta Earthquake by the U.S. Geological Survey, occurred during the preparation of this report. Only preliminary information is now available about the impact of this event. The Magnitude 7.1 earthquake originated approximately ten miles north of Santa Cruz along a fault closely associated with San Andreas fault system. In the weeks following the earthquake, as many as 4,000 aftershocks occurred with at least 21 aftershocks over Magnitude 4. There was only sporadic evidence of surface faulting; however, the earthquake did cause noticeable shifting of soils on slopes, in some cases producing gaping fissures in the epicentral area. Numerous water wells in the area were sheared off by landsliding and roads were blocked by earthquake-induced sloughing of huge masses of earth onto public and private roads. Structural damage was widespread within the epicentral area, as well as some 50 miles away in San Francisco and Alameda Counties. The City of Santa Cruz experienced much of the damage with 85 percent of the homes and over 1,600 businesses having structural damage. The City of San Francisco experienced

substantial damage from strong ground shaking that selectively concentrated damage in older 2- and 3-story wood-frame structures. Even though building pounding during shaking has always been considered dangerous, many adjacent buildings pounded but acted to hold each other up. Significantly, buildings at corner locations had no support and selectively collapsed. A total of 65 people were killed and over 3,000 injured. The following structures, facilities and infrastructure had major damage.

- A 4-story unreinforced masonry building, located south of Market Street, killed four people when the brick facade fell onto the adjacent parking lot.
- A 14 block section of the upper deck of Interstate 880 collapsed killing 58, and injuring 400 people.
- A 50-foot section of the Bay Bridge collapsed killing one person.
- Major fires attributed to ruptured gas lines occurred in the Marina District.
- A section of Central Freeway 101 buckled, due to liquefaction.
- The San Francisco Airport closed, due to extensive damage in the air control tower.
- Two people were killed when a mall composed of unreinforced masonry collapsed in Santa Cruz.

The lessons learned from the 1989 Bay Area (Loma Prieta), the 1987 Whittier Narrows, the 1971 San Fernando, and the 1933 Long Beach Earthquakes are important, because they show where we are and where we need to go in terms hazard management. The damage patterns in Table 2.3 and the summary of the Bay Area Earthquake above will be drawn upon to explain an analysis of earthquake vulnerability in Chapter 4. Alternatives for managing these vulnerabilities can be found within sections addressing hazard management in Chapters 5, 6, 7, and 8.

SECTION 2.3

HISTORICAL DEVELOPMENT OF EARTHQUAKE LEGISLATION AND REGULATORY MEASURES

The 1989 Bay Area Earthquake provided a very forceful reminder about the necessity of consistent, prudent planning and strictly enforced building and fire codes. Without planning, modern codes, and the emergency response training and education, the San Francisco disaster would have been truly catastrophic. While natural hazards cannot be entirely eliminated, the disasters that they cause can often be significantly reduced or prevented through informed planning and land use decisions. Earthquake and disaster response planning are still evolving disciplines in California, but collectively, the State and local governments have initiated proactive, long-term measures for reducing hazards in our environment. This is in contrast to the crisis management or reactive regulatory measures, which have characterized many legislative and hazard management decisions in past earthquakes.

Table 2.4 chronologically lists several important legislative actions and key dates in the development of building codes in California since the 1933 Long Beach Earthquake. Table 2.4 shows that earthquake code provisions were not applied to construction until after the damaging 1933 Long Beach Earthquake. Table 2.4 shows that California was the first State to consider proactive approaches for developing earthquake provisions in building codes. However, it was not until the 1971 San Fernando Earthquake that serious reevaluation of the need for even more stringent codes was initiated. The Federally supported Applied Technology Council began such an effort in 1978 (Table 2.4).

In the aftermath of the 1933 Earthquake, State legislation created the Field Act, which mandated special seismic safety construction standards for new public schools (Table 2.4). However, it was 1969 before the State addressed those schools built before 1933, and exempt of the Field Act provisions. The 1969 Garrison Act was the first retroactive provision for earthquake safety abatement, focusing on pre-1934 school buildings (Table 2.4). Following the 1971 San Fernando Earthquake, the State assumed sole responsibility for structural review of other critical elements of the community, including new hospitals, new and existing dams and freeway structures, and new emergency facilities. The Alquist-Priolo Special Studies Act (APSSZ) was also initiated in 1972; it was the first State attempt to regulate development in seismically hazardous areas, specifically in areas susceptible to surface fault rupture. Appendix 1 summarizes a select list of additional State and Federal laws that have implications for local safety planning, specifically those having relevance to the Safety Element.

TABLE 2.4 - CHRONOLOGY OF POST 1933 EARTHQUAKE RELATED LEGISLATION

Year	Event	National Level	State/Local Level
1933	Long Beach Earthquake		Widespread adoption of Uniform Building Code (UBC) Earthquake Provisions Field Act: Public school construction becomes State responsibility
1939			Riley Act: State regulation of buildings larger than two-family dwellings
1959			*SEAOC develops program for improvement of seismic codes in UBC
1969			Garrison Act: First Hazard Abatement effort
1971	San Fernando Earthquake		Inadequacy of old building codes is evident: Earthquake provisions in UBC are reevaluated • Hospital Seismic Safety Act: Hospital construction becomes State responsibility • Safety and Seismic Safety Elements required in General Plan
1974			California Seismic Safety Commission established: Seismic Safety program development
1977		Earthquake Hazards Red. Act passed: National program for earthquake hazard reduction	
1978		Applied Technology Council (ATC) established to strengthen seismic codes	
1979		Federal Emergency Managment Agency (FEMA) established: Lead agency for National EHRA program	
1980			*SCEPP established: Regional Agency to coordinate local and State Hazard Reduction programs
1984			*BAREPP established
1986			California Earthquake Hazards Red. Act passed: Augments National Earthquake Hazard Reduction program
1987	Whittier Narrows Earthquake		Los Angeles County Safety Element update initiated

* SCEPP - Southern California Earthquake Preparedness Project
* BAREPP - Bay Area Earthquake Preparedness Project
* SEAOC - Structural Engineers Association of California

Recently, the Federal and State governments have adopted more proactive, not reactive, management roles through the National Earthquake Hazards Reduction Act (NEHRP) and the California Earthquake Hazards Reduction Act (CHRA). These programs are comprehensive and far reaching attempts at delineating and mitigating hazards through the coordination of Federal, State, and local government agencies. The goals and initiatives of the CHRA are summarized as follows:

- Mitigation, including the expansion of scientific, engineering studies aimed at delineating and predicting geologic, seismologic hazards, and improving construction practices;

- preparedness, including protection of critical facilities and dissemination of disaster preparedness education;

- response, including integration of Federal, State, local plans, and improvement in statewide communication systems; and

- recovery, including military and financial relief for restoration of California's economy.

It is the intention of this Safety Element to build on the lessons learned through historical context, especially since the adoption of the first Safety and Seismic Safety Elements in 1975. Many of these lessons have been articulated through Federal and State earthquake risk-reduction programs. Because the vulnerability of the urban environment to earthquake hazards are better defined today than they were 15 years ago, largely through the coordination of these programs, many hazard reduction strategies proposed in the County Safety Element will be adapted from regional strategies of the CHRA and NEHRP. The research roles of these programs in the Safety Element are discussed in Chapter 9.

CHAPTER 3

HAZARDS ANALYSIS

CHAPTER 3

HAZARDS ANALYSIS

The risk associated with rain-induced flooding, landsliding, and debris flow activity is controlled by the frequency of severe rainstorm activity with sufficient magnitude to initiate such hazards. Likewise, seismic risks from ground shaking, surface rupture, or liquefaction are fundamentally controlled by the return period, or recurrence interval, of earthquake motion strong enough to produce such phenomenon. Terminology developed to estimate the probable risk to such hazards, such as the "100-Year" flood and the "maximum probable" earthquake, emphasizes that there remains a certain amount of uncertainty regarding the scientific prediction of the timing and extent of damage expected from an earthquake or rainstorm.

Probabilistic and deterministic methodologies are two fundamental approaches to hazard analysis that have gained acceptance in evaluating risk, in particular those hazards related to seismic risk. Probabilistic risk analysis attempts to characterize the probability that a particular hazard will occur within a given period of time. Deterministic risk analysis avoids the issue of probability by emphasizing the potential consequences of a maximum conceivable event. The hazard maps referenced in this report emphasize potentially hazardous locations only and do not consider probability of occurrence. A technical assessment and mapping is provided in the strong ground motion section.

This chapter is divided into the following sections:

<u>SEISMIC HAZARDS</u> (Plates 1, 2, 3, & 4)
Strong Ground Motion
Fault Rupture
Earthquake-Induced Ground Failure

<u>GEOLOGIC HAZARDS AND LANDSLIDE AND SLOPE INSTABILITY</u> (Plates 2 & 5)
Rain-Induced Landslides
Earthquake-Induced Landslides
Development-Induced Landslides

<u>FLOOD AND INUNDATION HAZARDS</u> (Plate 6)
Tsunamis
Dam Failures
100-Year Floods

<u>WILDLAND AND URBAN FIRE HAZARDS AND HAZARDOUS MATERIALS</u> (Plate 7)
Wildfire Fire Hazards
Urban Fire Hazards
Earthquake Fire Reporting and Response
Hazardous Materials

The discussions are arranged so that the more technical explanations of methodologies and hazard characteristics are found at the end of each hazard topic, followed by conclusions that have a bearing on implementation of hazard -reduction measures in Los Angeles County. The potential impact on Los Angeles County, in terms of damage to lifeline systems, buildings, critical facilities, elements of land use, and our economy, can be found in Chapter 4, Earthquake Vulnerability Analysis for Los Angeles County. The management framework for hazard mitigation is evaluated in Chapter 5, Hazard Management in Los Angeles County.

SECTION 3.1

SEISMIC HAZARDS

Earthquakes are caused by the violent and abrupt release of strain built up along faults somewhat analogous to the snap of a pencil caused by slowly flexing it until it breaks. When a fault ruptures, energy is propagated sometimes unequally in all directions away from the source (known as the focus) in the form of seismic waves (Figure 3.1). Seismic waves are categorized into two groups: body waves and surface waves. Body waves travel through the crust and eventually reach the ground interface creating surface waves. Both body waves and surface waves cause the ground to vibrate up and down and side to side at different frequencies depending on the frequency content of the earthquake rupture mechanism, the distance from the earthquake source to a particular site, and the path and material through which the seismic wave is propagated (Figure 3.1). A "near field" earthquake, which implies the earthquake source is near the site, is generally composed of high frequency waves, that are more efficient in causing short buildings to vibrate (Figure 3.1). Longer period wave forms, usually associated with surface waves, are manifested at greater distances from the earthquake source, and are more likely to cause high-rise buildings and buildings with large floor areas to vibrate more vigorously. When the frequency composition of an earthquake, the site and the building period coincide, a damaging phenomenon known as resonance can occur. The resonance phenomenon is what causes a glass to shatter when induced to vibrate at the same frequency as the pitch of a singer's voice. Buildings or structures which experience this type of response can suffer severe damage or total structural collapse.

Figure 3.1 shows two possible origins of earthquake risk to Los Angeles County. A near field earthquake threat is posed by a myriad of potential causative faults located beneath the heavily populated metropolitan area. An earthquake occurring on the San Andreas fault, represented in Figure 3.1 by the earthquake epicenter (the point directly above the focus) in Antelope Valley, also presents a serious threat to Los Angeles County. The planning scenario developed by the California Division of Mines and Geology for a Magnitude 8.3 earthquake on the San Andreas fault concluded that the bulk of near field damage and disruption caused by such an earthquake would be concentrated in the North County areas of Santa Clarita, Acton, Agua Dulce, and the Palmdale/Lancaster area (Davis et al., 1982). In contrast, because of the greater population density and concentration of industrial and commercial services, a Magnitude 6.5 or 7.0 earthquake in the metropolitan area would have far more significant impact (Spangle, 1987; Toppozada et al., 1988). Near field damage from such an earthquake could cause catastrophic losses of life and property, and severely strain the County's disaster response capability. The socio-economic consequences of such a disaster could last for years.

FAULTS AND POTENTIAL EARTHQUAKE SOURCES: DIAGRAMMATIC CROSS-SECTION ACROSS LOS ANGELES COUNTY

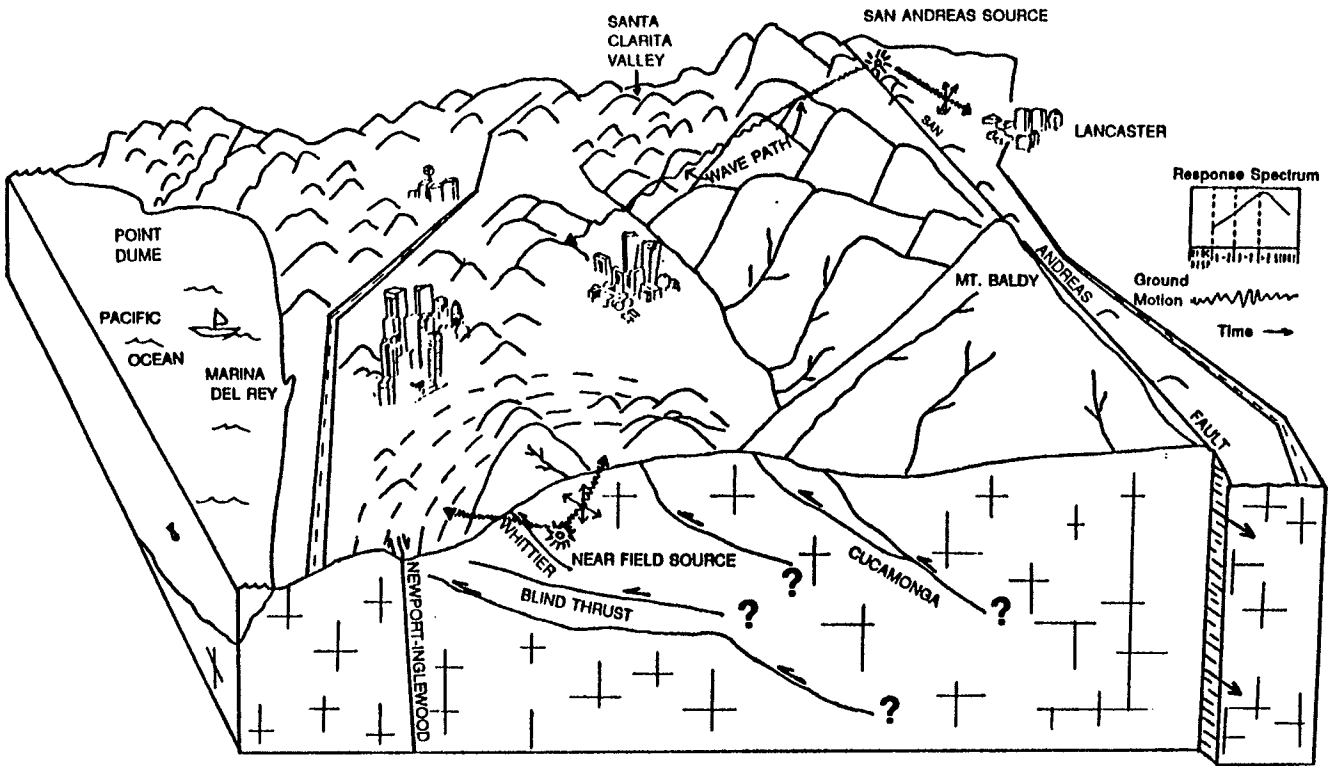


Figure 3.1: Faults and potential earthquake sources: a diagrammatic cross-section across Los Angeles County. This hypothetical profile of the Earth's crust extends roughly from Torrance through Pomona and northeastward, and shows that the County is at risk from local and distant earthquake sources. An earthquake can focus energy in a variety of potential directions (indicated by arrows) with differing resultant effects on ground shaking, locations and types of building damage, and surface rupture, liquefaction, and landsliding potential. The San Andreas is an example of a strike-slip fault while the Cucamonga represents a thrust fault. The Whittier Fault has characteristics of a strike-slip and thrust fault.

Generally, the most widespread, damaging effects of earthquakes are caused by strong ground shaking. Strong ground shaking can catastrophically damage vulnerable structures, most notably large freeway overpasses and unreinforced masonry buildings. It can also trigger a wide variety of secondary hazards such as liquefaction, landslides, local soil subsidence, fire, dam failure, and even toxic chemical releases. Consequently, the prediction of areas susceptible to strong ground motion provides invaluable information to safeguard human lives and property against the destructive effects of future damaging earthquakes.

The following section presents a discussion of strong ground motion, focusing on the feasibility for utilizing predictive ground motion mapping for regional planning purposes in Los Angeles County.

SECTION 3.1.1

STRONG GROUND MOTION

Strong ground motion refers to the severe ground shaking produced by a strong earthquake. A number of variables affect the distribution and potential damage caused by ground shaking. The size and type of fault (e.g., strike-slip or thrust), the rupture orientation, the basin geometry and topography, and the subsurface geology and local near-site conditions are all important variables affecting the spatial distribution and character of strong ground motion. Accelerograph records of the M_L 5.9, 1987 Whittier Narrows event have confirmed that acceleration amplitudes, frequency compositions, and durations of both the horizontal and vertical components of ground vibration can vary widely in a given earthquake in the Los Angeles area. The variance can be a function of the specific earthquake type or the influence of any one of the variables listed above. Figure 3.1 shows seismic waves from a near field earthquake on the Whittier fault spreading asymmetrically from the source, perhaps controlled by alluvial basin geometry, fault type, or interaction of both variables. Small pockets in basin areas are also vulnerable to site amplification. Site amplification is important because certain higher earthquake accelerations and magnification of wave forms and frequencies can induce resonance effects on structures.

Inasmuch as seismic engineering design parameters and predictive ground motion methods attempt to characterize the patterns and strength of shaking caused by an earthquake, it seems reasonable to account for the complexities related to the type of fault, the depth of rupture, and site amplification with the most comprehensive engineering methods available. Indeed, although acceleration amplitude has been commonly used to show predicted ground motion, strong motion records and post-earthquake damage investigations consistently show that peak acceleration alone can be an unreliable parameter for both seismic design and predictive ground motion mapping (Sharpe, 1982). Dynamic response spectra and time history analysis are sophisticated seismic design methods that are recommended for determining the earthquake-resistant design of critical facilities, and are the focus of future design and predictive mapping research (Joyner and Fumal, 1985; Rogers, 1985).

The potential socio-economical impact of a destructive earthquake and the scientific complexity of the problem make it necessary for decision-makers and engineers involved in earthquake related projects to be aware of and use state-of-the-art techniques available for seismic hazard analysis. Predictive strong ground motion models, however, are made to fit specific applications. For example, site specific construction projects require the most complex models and analysis, including consideration of detailed geologic and soil conditions and site amplification studies. Regional ground motion analysis, however, is usually conducted with more generalized input information. The most commonly used method for predicting regional ground motion uses seismic intensity, an empirical method that describes shaking in terms of structural damage and human response (Evernden and Thomson, 1985; Davis el al., 1983; Gulliver, 1986; Toppozada et al., 1988).

Table 3.1: General Relationship Between Greatest Measured Intensity and Magnitude*.

Richter Magnitude, M	Modified Mercalli Intensity Scale (1931) Wood and Newman	Rossi-Forel Intensity Scale (1883)
	I Detected only by sensitive instruments.	
	II Felt by a few persons at rest especially on upper floors; delicate suspended objects may swing.	M I The shock felt only by experienced observer under very favorable conditions.
M3	III Felt noticeably indoors, but not always recognized as a quake; standing autos rock slightly, vibration like passing truck.	II Felt by a few people at rest; recorded by several seismographs.
	IV Felt indoors by many, outdoors by a few; at night some awaken; dishes, windows, doors disturbed; motor cars rock noticeably.	III Felt by several people at rest; strong enough for the duration or direction to be appreciable.
M4	V Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects.	IV Felt by several people in motion; disturbance of moveable objects, crackling of floors.
	VI Felt by all; many frightened and run outdoors; falling plaster and chimneys; damage small.	V Felt generally by everyone; disturbances of furniture, ringing of some bells.
M5	VII Everybody runs outdoors; damage to buildings varies, depending on quality of construction; noticed by drivers of autos.	VI General awakening of those asleep; ringing of bells, swinging chandeliers, startled people run outdoors.
M6	III Panel walls thrown out of frames fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed.	VII Overthrow of movable objects, fall of plaster, ringing of bells, panic with great damage to buildings.
	IX Buildings shifted off foundations; cracked, thrown out of plumb, ground cracked, underground pipes broken.	VIII Fall of chimneys; cracks in walls of buildings.
M7	X Most masonry and frame structures destroyed; ground cracked; rails bent; landslides.	IX Partial or total destruction of some buildings.
	XI New structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides, rails bent.	X Great disasters, ruins; disturbance of strata, fissures, rock falls, landslides; etc.
M8	XII Damage total; waves seen on ground surface; lines of sight and level distorted: objects thrown up into air.	M7 M8

*From Nuclear Reactors and Earthquakes, AEC TID7024.

* Intensity is the rating of the severity of ground motion at a specific location. The scale of measurement is based on the sensations of persons, the behavior of animals, and physical damage to natural and manmade objects. Intensity is used on predictive ground motion maps to characterize expected damages using past damage patterns as a guide.

old or corroded pipelines begin to be damaged, especially cast-iron pipes.

- *MM 8.0 - Many nonearthquake engineered buildings will begin to suffer moderate damage including dislodged exterior and interior plaster fragments and URM veneer. Many URM and potentially hazardous buildings, either through inadequate construction quality or design, experience heavy damage with isolated incidents of partial collapse of the structure and total collapse of nonstructural components, including unsupported parapets or improperly tied concrete walls.*

- *MM 9.0 - Same as intensity MM 8.0 with the exception of the total collapse of a few ordinary brick buildings and buildings constructed of large blocks. Inadequately designed, prefabricated building types may experience large scale foundation and structural damage due to liquefaction and lurching. Many reinforced buildings and well-built wooden structures are likely to experience moderate to heavy damage, including affects caused by liquefaction or ground failure. Nonductile utility lifelines area also likely to be damaged from liquefaction.*

The use of seismic intensity prediction is especially helpful to planners and educators, because it provides a method of relating this information to the layman. However, a number of improvements with respect to mapping seismic intensity are evident. The improvements are primarily concerned with geologic input data and source modeling unique to Los Angeles County. Such limitations can be discussed in the context of Figure 3.2. First and foremost, the geologic data base used to model ground conditions must be improved. The predicted intensity distribution shown corresponds to California Division of Mines and Geology 1:250,000-scale geologic mapping. The U.S. Geological Survey intensity program averages ground conditions over a series of 900 meter grids, which in the Santa Clarita Valley permits only a regional interpretation of the map results. The gross subdivision of alluvial units by seismic response will increase resolution of the seismic intensity predictive model. Detailed borehole subsurface information used to generate this information, however, is limited outside the coastal lowlands and valleys of Los Angeles. Indeed, the physical properties and three dimensional distribution of soft alluvial units and the geometry of alluvial basins are poorly defined in the unincorporated County, especially in the growing Santa Clarita and Antelope Valley areas. In comparing the current USGS seismic mapping resolution with Japanese predictive ground motion maps, we find that ground conditions there are averaged over a 500-meter grid and are supported by geotechnical information derived from over 11,000 boreholes. This detail, which includes the thickness of soft alluvial units, allows amplification factors to be considered.

Another ground condition needing consideration is shallow ground water. The effect of saturated soil on ground motion is controversial and may not be directly correlated with higher seismic intensities (Rogers, 1985). However, the potential for liquefaction in these areas may indicate that more damage may be sustained which is consistent with the definition of seismic intensity. In addition, there is potential error caused by site amplification. Strong contrasts in shear wave velocity between the near surface alluvium and underlying rock can cause dramatic increases in the amplitude and frequency composition of

the seismic vibration, and prolong the duration of shaking when alluvial thicknesses are as little as 30- to 100-feet (10 to 30 meters) (Hays, 1988). Such an alluvial/bedrock sequence is present in Santa Clarita Valley, but is not accounted for in the USGS model.

In summary, the USGS seismic intensity program does not subdivide alluvium into different shaking units nor directly utilize thickness of alluvium or depth to bedrock, which are necessary in considering amplification factors. The USGS program empirically takes these conditions into account but, at present, it appears modeling seismic intensity is suitable for only generalized regional ground motion studies and useful for regional planning purposes. In contrast, greater detail in mapped ground conditions allows more accurate determination of where damage is likely to be focused in a future earthquake and provides information suitable for emergency planning. Such microzonation of ground condition information would increase the resolution of any ground motion model, including those being currently developed to predict building response (Rogers, 1985). Currently, using seismic intensity as a form of regional microzonation, only the most hazardous buildings can be screened. In Santa Clarita Valley, for example, unreinforced masonry structures within a predicted Modified Mercalli intensity zone of eight or greater might warrant closer scrutiny from the Department of Public Works or Fire Department officials charged with responsibility for the safety of buildings occupants.

Lastly, all earthquake sources must be accounted for in a predictive ground motion model. The Whittier Narrows Earthquake revealed the Elysian Park fault as a source for strong ground motion that was not incorporated into the USGS Intensity Program. Likewise, subsurface earthquake sources such as the blind thrust faults under the Los Angeles Basin were not considered in the predictive ground motion maps included in the 1975 Seismic Safety Element. Modifications to the intensity program that incorporate more accurate geologic mapping, alluvial thicknesses, and subsurface sources, while beyond the scope of this project, should be incorporated into the next generation of predictive ground motion maps for the County.

Methodology

There are four procedural steps in the calculation of ground motion intensities in the seismic intensity model by Evernden and Thomson (1985):

1. A formula expressing the rate of attenuation of intensity-related seismic waves in the region to be investigated;

2. a correlation of geologic ground conditions and expected relative intensity (saturated alluvium is used as a reference ground condition);

3. a map giving the distribution of the defined seismic ground conditions throughout the region to be investigated; and

4. a mathematical model of the earthquake source (including location, length of break, and depth of focus).

The seismic intensity method provides a scheme that models the radiation of energy from each segment of the fault, attenuates each such increment according to Step 1, calculates a quantity intended to stimulate the root-mean-square (RMS) acceleration over a time window of 10- to 20-seconds centered on the strongest motion arrival, converts this RMS acceleration into a predicted intensity on saturated alluvium, and then, by using the data from Steps 2 and 3, calculates the predicted intensity for the site ground condition.

Probabilistic Versus Deterministic Analyses

The probabilistic method quantifies the uncertainties in presupposing the time, location, magnitude, and expected ground motion of future earthquakes. In a rather simplified explanation of the method, the cumulative probabilities of "recurrence" for a set of faults within a critical distance of a particular location can be used to estimate the expected ground motion at that location, expressed as an annual probability (see seismic risk-glossary). The probabilistic method, therefore, assigns lower annual probabilities of exceedence to the larger values of peak ground acceleration (PGA) or peak ground velocity (PGV) expected from a catastrophic earthquake. Smaller earthquakes, which occur more frequently, have higher annual probabilities of exceedence. When the probabilistic method is used, the probability of exceedence of different levels of ground motion in a given exposure time is calculated, considering the occurrence of all possible earthquakes and all possible distances from a specific building site.

Probabilistic methods are commonly used in the seismic design of critical facilities, in lieu of design parameters derived from short or incomplete historical records of seismicity. When siting and designing critical facilities such as hospitals, communication centers, or other facilities required to remain functional after an earthquake, longer design probabilities of exceedence approaching 250 years exposure times are needed. This is in marked contrast to the relatively low 50 year exposure times commonly used for ordinary structures.

Ground motion can be illustrated on regional maps using this technique e.g., Site A has a ten percent probability of a certain ground motion being exceeded in a 50 year period while Site B has a 50 percent probability in 50 years of exceeding the same ground motion. The probabilistic method is effective because a probabilistic assessment of risk can be used to accurately prioritize areas where stringent seismic design, or increased mitigation or preparedness planning is warranted. One drawback of this method, however, is that extremely accurate and detailed knowledge of each fault is needed to determine reliable probability values. As indicated by the 1987 Whittier Narrows Earthquake, many significant seismogenic structures exist where the character of faulting is poorly understood, particularly buried thrust faults and offshore faults. The fault database for even well-known or studied faults could be improved. The Malibu Coast, San Gabriel, Holser, Verdugo, and San Jose faults are just a few. Much more research and information are needed for a regional assessment of seismic risk, primarily slip rate data on faults active within the last 750,000 years.

SECTION 3.1.2

FAULT RUPTURE HAZARD

(Plate 1 - Fault Rupture Hazard and Historical Seismicity)

As emphasized throughout this report, a number of "active" faults cross Los Angeles County. The designation of faults as either active or inactive is largely dependent on the classification system used, the purpose of the designation, and the relative importance of the structure under consideration. An "active" fault considered in siting and designing facilities such as hospitals or other critical facilities, may not be considered active in building conventional residential or commercial developments (Figure 3.3). In addition, although the general relationship between magnitude, recurrence interval, and slip rate presented in Figure 3.3 implies fault activity, the classification system does not directly, nor adequately, address surface rupture potential. Rather than use the return period of earthquake magnitude to identify active faulting to identify surface rupture potential, which Bonilla (1970) has associated with magnitudes greater than M_L 5.5 or M_L 6.0, special criteria were developed to assess the risk following the severe fault-related damages sustained during the 1971 San Fernando Earthquake.

The criteria developed by the California Division of Mines and Geology to assess the fault rupture hazard uses geologic evidence to support or disprove prior surface displacement within Holocene time (presently defined to be within the last 10,000 years). In addition to offset Holocene stratigraphy, youthful geomorphology and structural distortion of near-surface Holocene deposits are also considered strong evidence for inferring a high-risk of fault rupture. Linear valleys, offset drainages, and sag ponds represent distinctive landforms suggestive of fault movement within the last 10,000 years. Figure 3.4 shows where geologic evidence can be found to support Holocene activity. An important limitation of this method is that geologic relationships used to discern Holocene offset can be obscured by erosion or landsliding, making an interpretation of risk problematic. Although the return period of earthquakes large enough to cause fault rupture can be 50- to 500-years, as shown in Figure 3.3, there is sufficient uncertainty caused by averaging the recurrence that suggests a chance of surface rupture on smaller time intervals.

A list of faults, either suspected or proven to have experienced surface rupture during Holocene time, is shown in Table 3.2 along with potentially active faults. Potentially active faults are generally faults which have been poorly or inadequately studied, but which appear to have had activity in at least the last 750,000 years. As such, their recurrence rates may be tens of thousands of years long, but still capable of producing moderate to large earthquakes within the design life of many critical or long-lifetime structures. Faults showing no evidence of movement within the last 750,000 years are considered inactive for most purposes. Technical explanations regarding evidence for selected active and potentially active faults, including slip rates, are located in Appendix 2

EARTHQUAKE RECURRENCE AND FAULT ACTIVITY

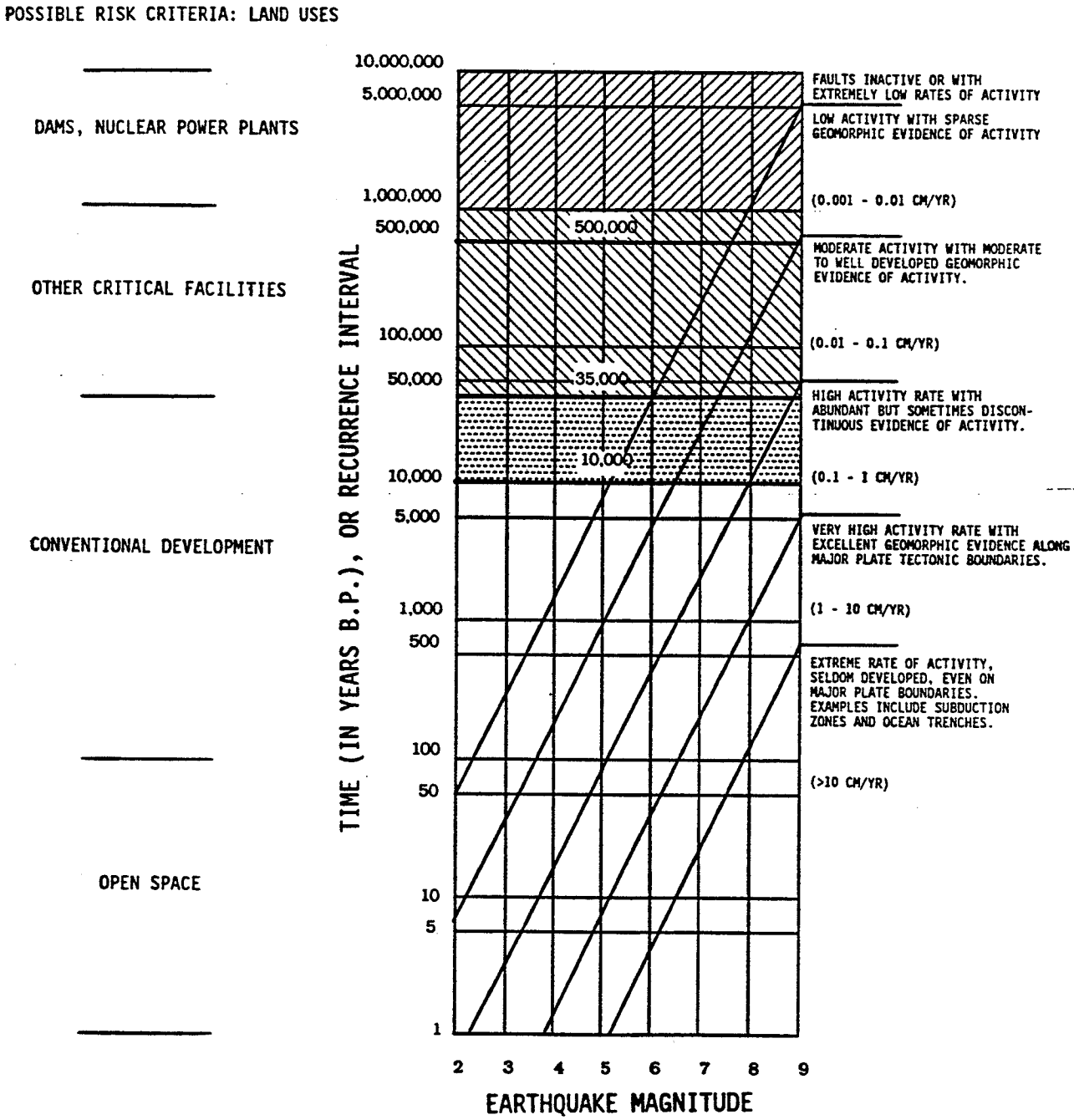
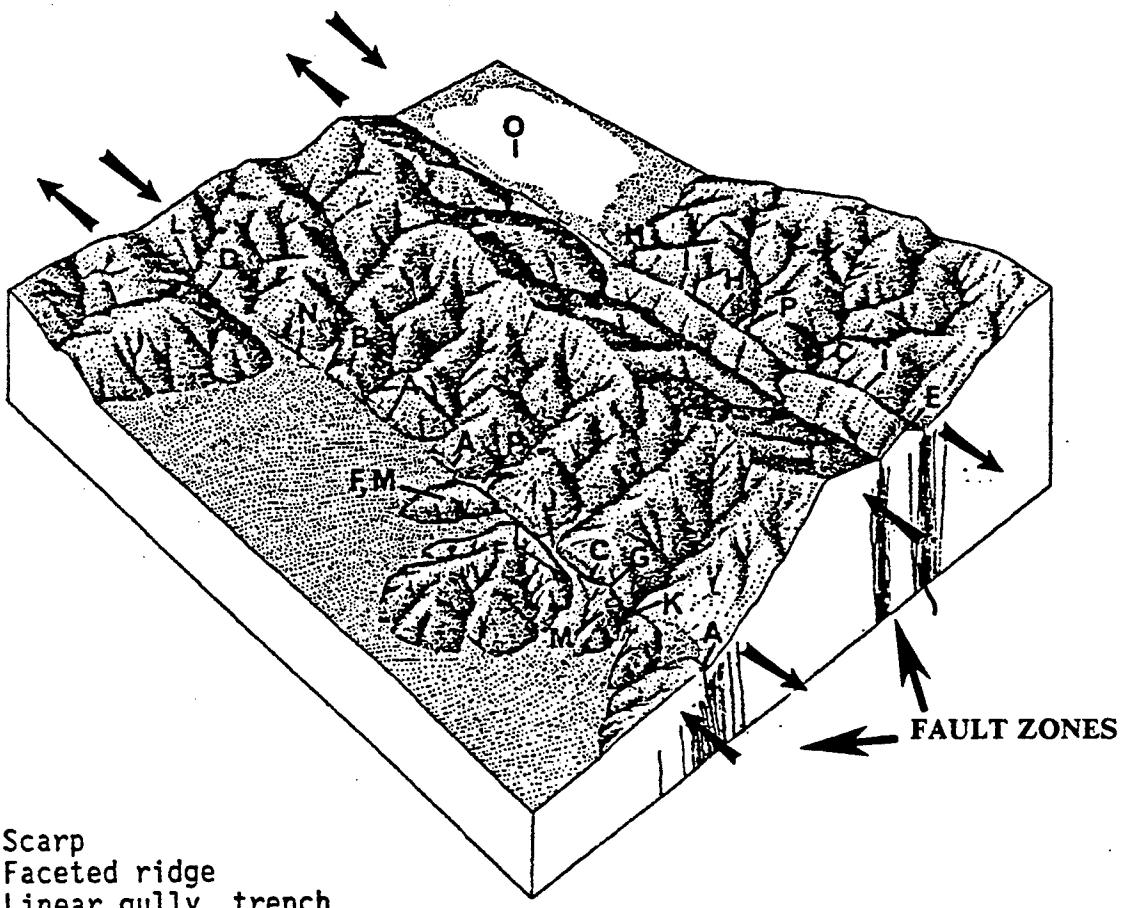


Figure 3.3: Earthquake recurrence and fault activity: earthquake magnitude, fault slip rate, and recurrence (return period) of earthquakes are used to infer relative activity. The graph does not directly reveal the potential for surface rupture (modified after Slemmons, 1977).

FAULT PHYSIOGRAPHY



A. Scarp
B. Faceted ridge
C. Linear gully, trench
D. Linear valley
E. Linear ridge
F. Shutter ridge
G. Notch
H. Hillside valley
I. Bench
J. Offset channel
K. Spring
L. Deflected stream or channel
M. Offset ridge
N. Depression, sag pond when wet
O. Depression (playa basin)

Figure 3.4: Fault physiography: distinctive landforms and drainage patterns aligned along strike-slip faults are visible evidence that fault movement is recent enough to have interrupted the more gradual processes of erosion (modified after Brown and Kockelman, 1983).

TABLE 3.2 - LIST OF ACTIVE AND POTENTIALLY ACTIVE FAULTS IN LOS ANGELES COUNTY

Fault	Sources Used in Map Location	Classification
Faults in the Santa Susana Mtns. San Fernando Valley Area		
San Fernando Fault Zone		
Reservoir	Barrows et al., (1974); Alquist-Priolo (1979)	Active
Mission Wells	Barrows et al.,(1974); Alquist-Priolo (1979)	Active
Sylmar	Barrows et al.,(1974); Alquist-Priolo (1979)	Active
Tujunga	Barrows et al.,(1974); Alquist-Priolo (1979)	Active
Lake View	Crook et al., (1987); Alquist-Priolo (1979)	Active
Mission Hills	Barrows et al., (1974; Oakshott (1958); Weber (1980)	Active
Santa Susana	Yerkes and Lee (1979a); Yeats (1987); Alquist-Priolo (1976)	Active
Northridge	Hill et al., (1979); Yerkes and Lee (1979a); Weber (1980); FER 52	Active
Faults Bounding the Santa Monica Mtns.		
Hollywood	Crook and Ward (1983); Chapman (1980); Hoots (1931); Lamar et al., (1979); Weber (1980)	Active
North Hollywood	Hill et al., (1979); Weber (1980)	Active
Santa Monica - Onshore		
Northern Segment	Chapman (1980); Hoots (1931); Lamar (1978); Weber (1980); Crook and Ward (1983); FER 51	P-Active
Southern Segment	Crook and Ward (1983); County of Los Angeles (1987); FER 51	P-Active
Santa Monica - Offshore	Yerkes and Lee (1979a); Clark et al., (1985)	P-Active
Malibu Coast	Yerkes and Lee (1979a); FER 46	Active
Benedict Canyon	Weber (1980); Lamar et al., (1979)	N/A
Griffith	Weber (1980); Lamar et al., (1979)	N/A
Faults in the San Gabriel Valley and along the Southern San Gabriel Mtns. Area		
Sierra Madre Fault Zone		
Segments: SM-A and SM-B	Crook et al., (1987)	Active
Sierra Madre	Morton (1973); Crook et al., (1987)	Active
Olive View	Barrows et al., (1974); Alquist-Priolo (1979)	Active
Veteran	Barrows et.al., (1974); Alquist-Priolo (1979)	Active
Buck Canyon	Barrows et al., (1974); Alquist-Priolo (1979)	Active
Mount Lukens	Crook et al., (1987); Alquist-Priolo (1979); FER 69	P-Active
Gould Canyon Thrust	Crook et al., (1987); FER 69	Active
Segments: SM-C and SM-D	Crook et al., (1987)	P-Active
Duarte	Crook et al., (1987)	Active
Clamshell-Sawpit	Morton (1973); Crook et al., (1987); Jennings and Strand (1969)	P-Active
Cucamonga	Matti et al., (1985); Shelton (1955); Crook et al., (1987)	Active
Raymond	Morton (1973); Crook et al., (1987); Alquist-Priolo (1979)	Active
York Boulevard	Morton (1973); Crook et al., (1987)	Active

* (FER: Fault Evaluation Report, California Division of Mines and Geology)

Active - Less or equal to 11,000 years
Potentially Active (P-Active) - Greater than 11,000 years; less than 750,000 years.
N/A - Conditionally Active (greater than 750,000 years; less than two million years).
The list above includes splays of active faults that may be included within one fault zone or principal, active fault segment.
Appendix 2 discusses major active and potentially active faults using the general organization presented above.

TABLE 3.2 - LIST OF ACTIVE AND POTENTIALLY ACTIVE FAULTS IN LOS ANGELES COUNTY

(Continued)

Fault	Sources Used in Map Location	Classification
Faults within the San Gabriel Mtns. Area		
San Gabriel Fault Zone		
Segments: SG-B	Weber (1979); Alquist-Priolo (1988); FER 69 Jennings and Strand (1969); Weber (1979)	Active
Segments: SG-A, SG-C, and SG-D	Jennings and Strand (1969); Matti et al., (1985); Weber (1979)	P-Active
Vasquez Creek	Weber (1979); Crook et al., (1987); FER 69	P-Active
Holser	Weber (1979); Unpublished County Maps	Active
Santa Felicia	Ziony and Jones (1989); Unpublished County Maps	P-Active
Del Valle	Ziony and Jones (1989); Unpublished County Maps	P-Active
Clearwater: Central	Weber (1979); Dibble (1960); Crowell et al., (1982)	P-Active
Clearwater: Northwest Segment	Weber (1979); Weber (1986)	N/A
Whitney Canyon Fault	Stitt (1985); Jennings and Strand (1969); Weber (1979)	N/A
San Antonio Canyon Fault	Matti et al., (1985); Rogers (1967)	Active
Faults in the Los Angeles Basin Area		
Los Alamitos	Ziony and Jones (1989)	P-Active
Norwalk	Ziony and Jones (1989)	P-Active
Newport-Inglewood Fault Zone		
Inglewood	Poland et al., (1959); Alquist-Priolo (1986)	Active
Potrero	Poland et al., (1959); Alquist-Priolo (1986)	Active
Avalon-Compton	Poland and Piper et al., (1956); Alquist-Priolo (1986)	Active
Cherry Hill	Poland and Piper et al., (1956); Alquist-Priolo (1986)	Active
Reservoir Hill	Poland and Piper et al., (1956); Alquist-Priolo (1986)	Active
Charnock	Poland et al., (1959); Ziony and Jones (1989) County of Los Angeles (1987)	P-Active
Overland Avenue	Poland et al., (1959); Ziony and Jones (1989)	P-Active
Palos Verdes Fault Zone		
Offshore	Clarke et al., (1985); Ziony and Jones (1989)	Active
Onshore	Woodward-Clyde (1983); FER 43; Ziony and Jones (1989)	Active
Cabrillo Fault Zone		
Offshore	Ziony and Jones (1989); Clark et al., (1985)	Active
Onshore	Ziony and Jones (1989); Cleveland (1976)	Active
Faults in East County, Los Angeles		
San Jose	Rogers (1967); Shelton (1955); FER 68	P-Active
Indian Hill	CDWR (1970); Shelton (1955)	P-Active
Central Avenue	Rogers (1967); Morton (1976)	P-Active
Northern Chino-Corona Segment	Rogers (1967); Fife et al., (1976)	P-Active
Walnut Creek	County of Los Angeles (1987b); FER 68	P-Active
Whittier Fault Zone	Yerkes (1960); Yerkes (1972); FER 41	Active
Workman Hill	Jennings and Strand (1969); Lamar (1973); County of Los Angeles (1987b)	P-Active
Whittier Heights	Lamar (1973); County of Los Angeles (1987b)	N/A

Potentially Active

Proven or probable Late Quaternary (10,000 to 750,000 years) movement is cited in the literature or unpublished reports (Appendix 2). Potentially active faults require special studies, but not setback.

Conditionally Active

Certain Quaternary faults may be considered potentially active when the age of the fault is between 750,000 years and two million years. Such faults have conditional special land use or critical facility regulations. They are shown on Plate 1 and listed as conditionally active. The County may encourage special studies along these faults, but will most likely consider their presence only in the siting and/or design of critical facilities.

Interpretation of the Fault Rupture Hazard

Several factors must be considered in interpreting the fault rupture hazard for a particular fault:

1. Age of fault.
2. Type of fault.
3. Reliability of the fault location.
4. Evidence for age faulting.
5. Present subsurface investigation data base.
6. Type of proposed structure and use.

Age of the Fault

The date of the last surface rupture on a given fault has a direct bearing on the need for special study zones. The Division of Safety of Dams and the California Division of Mines and Geology use the Holocene age as a cut-off age for active faulting. The APSSZ Act recognizes the Holocene age to be "about the last 11,000 years", and therefore uses this age as a condition for designating a fault active. Since passage of the APSSZ Act, geologists have recognized the regional variation in the onset of the Holocene, and have arbitrarily assigned an average age of 10,000 years before present to the beginning of the Holocene.

Type of Fault

The type of fault is related to the history of apparent movement along the fault plane, and specifically to the current sense of movement. The sense of slip controls how a fault displaces and cracks the ground during surface rupture. The following explanations describe how the type of fault affects the character of surface rupture.

- Strike-Slip Faults - impact relatively narrow zones around fault rupture (Bonilla, 1967). Because the surface is displaced horizontally on a near vertical fault, the distribution of shearing is normally confined near the main fault trace. In some cases, localized tilting or gentle folding can be expected. Secondary faults (tear faults) are common as branching splays from the main fault.

- Thrust Faults - characteristically have wider zones of impact during surface fault rupture. They are formed in a compressional environment as one block overrides another on steep (reverse) to shallow dipping (thrust) fault planes (Figure 3.5). The broad and seemingly random rupture pattern caused by the 1971 San Fernando Earthquake is an example of the type of pattern capable of being generated by shallow dipping thrust fault mechanisms. When displacement occurs, the overthrusting ground can be expected to shear the relatively thin cover of rock and alluvium overlying the fault plane. In some cases the depth from the surface to the fault plane can be extremely small and cover a wide area away from the surface expression of the fault.

- Normal Faults - are relatively uncommon in Los Angeles County. They are formed in an extensional tectonic environment, manifested as the down-dropping of one block relative to another. The surface expansion of a normal fault is variable due to topographic influences, and due to complexities in the fault surface itself. Surface deformation from an earthquake would be constrained within the immediate fault zone, but could be locally complex due to secondary fracturing and subsidence.

Reliability of the Fault Location

The reliability of a fault location is controlled by the availability of direct evidence in the surface and subsurface materials. The nature of the faulted material and the depositional environment may act to conceal a fault's exact location. Instances of this type of faulting are depicted on Plate 1. For example, a review of the literature concerning the Northridge Hills fault zone indicated a number of different map traces proposed by different workers. The fault is concealed by young sediments along most of its trace, even though minor warping of the surficial sediments have been observed along some portions (Treiman, 1989; personal communication). Such instances may inhibit a geologist's ability to locate the fault adequately. In the case of the Northridge Hills fault, the California Division of Mines and Geology Fault Evaluation Report showed all of the mapped fault traces to account for the uncertainty in the location of the fault. This technique was used to depict the entire "area" of potential faulting for other concealed or complex fault zones, where possible, on Plate 1.

Evidence for Assessing the Fault Rupture Hazard

Depending on the site, there can be a variance in the quality of evidence of faulting which has a direct bearing on interpreting risk. In many areas in southern California, faults are covered by thick Holocene alluvium or disrupted by landslides, debris flows, or colluvial cover. Evidence of active faulting

been discovered at the base of Holocene materials over 18 feet thick; however, the County Building Code states that exploratory trenches are required to be no deeper that five feet. In such cases, the fault could be falsely classified as inactive or nonexistent. Chapter 5 will propose some investigative guidelines for faults in areas where evidence for the recency of faulting is likely to be difficult to attain, poor, or nonexistent.

The Present Subsurface Investigation Data Base

There is a broad range of variability in the degree of subsurface investigation on the faults in southern California. Many of the well publicized active faults in California have had substantial investigation and yet information gaps remain to be filled. Subsurface investigations have just begun on some of the less well known active faults. A better system of compiling fault trench localities and updating the information on Plate 1 needs to be formulated in conjunction with technical review of such studies. Until better information is accumulated, an important guideline for designating a special studies requirement should be based on the premise of "guilty until proven innocent".

Type of Proposed Structure and Use

The planner must consider the types of facilities and acceptable risk in the case of active, potentially active, and conditionally active older faults. In addition, where an investigation is inappropriate and not likely to yield additional information, such as a fault located in deep alluvial fill, acceptable risk cannot be accurately determined. In such cases, the County regulations can be conservative, but the extent and scope of the regulations depends on the level of risk the County is willing to accept, given the uncertainty. County fault zone regulations should remain flexible as the activity of the fault becomes better known.

Uses and Limitations

Plate 1 was constructed to assist in the regional planning of future development. Because the scale of the map only allows resolution to a maximum of 500 feet, the map should not be used in lieu of site specific investigations. The primary goal of the map is to aid in the reduction of potential property damage and increase the safety of the public by identifying fault rupture hazards in the County not currently recognized by the State mandated Alquist-Priolo Act.

Public safety will be increased by recognizing the potential fault hazards shown on Plate 1. An important limitation of the map is caused by the uncertainty in attempting to predict the limits of future rupture on a given fault. Ground rupture can be extremely complex, as indicated by the random pattern associated with the 1971 San Fernando Earthquake (Plate 1). Because fault rupture may occur outside of the shaded fault area, the symbol should be used only as a map key showing the fault age designation and should not be used to enforce special studies.

Conclusions

- Public Safety will be increased by planning mitigation measures around all active and potentially active faults.
- Offset and warped Holocene stratigraphy and youthful geomorphology are evidence of active faulting and high-risk of potential future surface fault rupture.
- Potentially active faults (10,000 to 750,000 years) pose mainly a ground shaking hazard to normal development, but may be considered high-risk when siting critical facilities.
- Buried thrust faults appear to pose a low-risk of surface rupture, but more information is needed to totally preclude the potential threat.
- Strike-slip faults have relatively narrow zones of impact while thrust faults may have complex rupture of the ground surface located above the overriding fault block.
- Each active fault poses unique problems to subsurface investigation depending on the geologic and geomorphic environment and must be considered on a case by case basis.
- Decision makers need to consider the sensitivity and unacceptable risk for siting critical facilities on potentially active and conditionally active faults.

SECTION 3.1.3

EARTHQUAKE-INDUCED GROUND FAILURE

The historical earthquake damage summary in Table 2.2 shows that the 1933 Long Beach and 1971 San Fernando Earthquakes were accompanied by either costly or nearly catastrophic damage from earthquake-induced ground failure. Liquefaction was a factor in the failure of the hydraulic fill embankment on the Lower Van Norman Dam. The destruction of the Juvenile Hall facility in the San Fernando Valley was caused by lateral spreading, which is a particularly damaging form of liquefaction that results in shallow flow failures on gently-dipping ground (Figure 3.6). Ground failure of artificial fill in both earthquakes also caused damage to bridge approaches and roadways (Figure 3.6). Because damaging liquefaction can be induced with seismic intensities of only MM = VII, and predictive ground motion maps indicate such intensities can occur relatively frequently in Los Angeles County, the region is extremely vulnerable to future property damage from earthquake-induced ground failure (Figure 3.1).

Liquefaction and lateral spreading failures result in the most severe disruption of near-surface materials. Heavy structures tend to settle or overturn during liquefaction, causing severe structural and foundational distress (Figure 3.6). Structures may settle up to several feet below grade while buried tanks or other buoyant infrastructure may rise to the surface. Especially at risk to liquefaction are retaining walls and levee structures at port and harbor facilities. As with fault rupture, liquefaction and ground failure can impact utility, flood control, and transportation lifelines. Damaged roadways could prevent access for emergency response vehicles and complicate evacuation operations. Severed water distribution lines can impair fire fighting capability or, if associated with waste waterline breaks, might contaminate the drinking water supply (Figure 3.6). Likewise, certain utility lifelines may cause explosions or fires. The potential impact of earthquake-induced ground failure makes a regional assessment of areas prone to such phenomenon useful to regional and disaster response planners.

Several state-of-the-art procedures exist to regionally delineate areas prone to ground failure. The fundamental basis of each method is essentially identical with all methods requiring the regional compilation of two component variables: 1) the distribution of sediments prone to liquefaction, represented by youthful, cohesionless, granular surficial and/or subsurface materials, and 2) the distribution of shallow or perched ground water. Thus, the following discussion of ground failure hazards will be composed of three subsections, including an interpretive map of susceptibility:

- **Section 3.1.3.1:** Ground Failure Susceptibility (Engineering Geologic Materials - Plate 2)
- **Section 3.1.3.2:** Shallow Ground Water (Shallow and Perched Ground Water - Plate 3)
- **Section 3.1.3.3:** Liquefaction Susceptibility (Liquefaction Susceptibility - Plate 4)

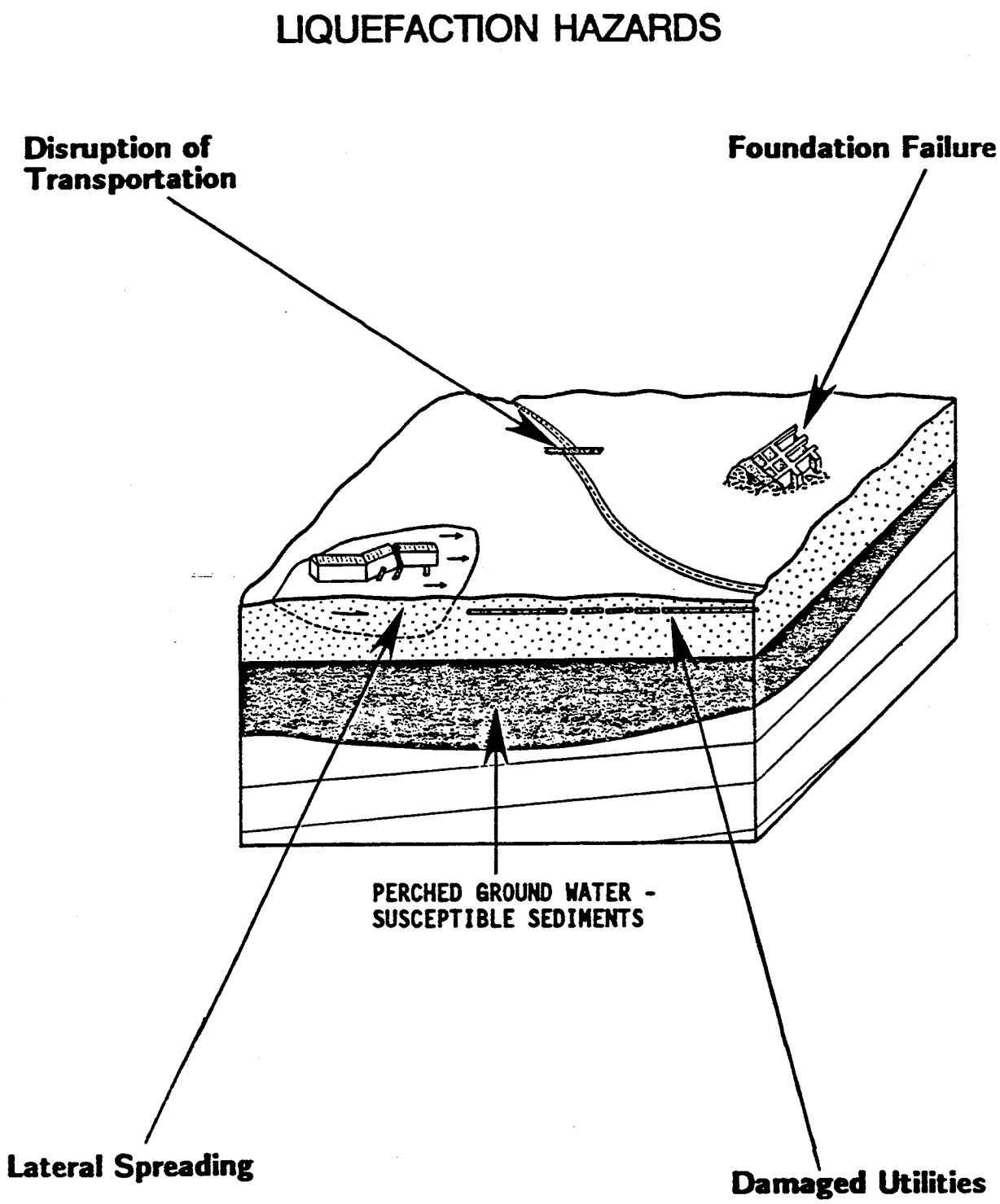


Figure 3.6: Liquefaction hazards: Los Angeles County has proven vulnerable to liquefaction hazards (above) during the 1933 Long Beach and 1971 San Fernando Earthquakes.

SECTION 3.1.3.1

GROUND FAILURE SUSCEPTIBILITY
(Plate 2 - Engineering Geologic Materials)

Case histories of liquefaction and earthquake-induced ground failure have firmly established the sediment age, type, and textural characteristics most susceptible to deformation and displacement from ground shaking (Committee on Earthquake Engineering, 1985). At the site specific level of investigation, material properties such as the grain-size distribution, density, and plasticity are the primary factors used for determining the susceptibility to ground failure (Seed and Idriss, 1983). Generally speaking, sediment materials most susceptible to liquefaction are medium dense to loose cohesionless materials. However, within the range where liquefaction is possible the following soil characteristics apply to liquefaction susceptibility:

Most Susceptible	Least Susceptible
Fine to coarse sand and silt mixtures	Clayey sand and silt (clay < 15%) Sandy gravels (gravel < 50%)
	Clayey sand and gravels (< 15% clay and liquid limit < 35%)

(from Seed and Idriss (1983) and Sherburne (1981))

More appropriate for regional interpretations of material susceptibility is the influence of sediment age and the mode of deposition (Lajoie and Helley, 1975). Youd and Perkins (1978) link the recency of deposition with susceptibility, such that materials deposited in the past few hundred years are the most susceptible. Sediment generally becomes more resistant to ground failure with increasing age as natural processes tend to cement, compact, and gradually pre-stress and pre-strain the material. The correlation between susceptibility and depositional mode is derived from observations that materials deposited by water or wind along shorelines, river channels, and flood plains, frequently suffer the most severe near-surface disruption (Tinsley, et al., 1985). By comparison, alluvial fan deposits demonstrate less relative susceptibility. Apparently the differing sediment transport processes affect their packing and grain-to-grain arrangement.

The U.S. Geological Survey (USGS) and California Division of Mines and Geology (CDMG) have recently devoted their resources toward regionally delineating areas prone to ground failure in the Los Angeles area (Ziony, 1985; Sherburne et al., 1981). The most comprehensive studies conducted in Los Angeles County, such as the study by Tinsley, et al., (1985), utilized soil profile development, patterns of historical flooding and flood deposits as mapping criteria to delineate Quaternary units. State-of-the-art cone penetrometer methods from selected borehole data provided textural control for these mappable geomorphic units. A cone penetrometer provides control by correlating penetration resistance to soil types within the geomorphic units defined. Tinsley, et al., (1985) delineated

the relative susceptibility of three units, defining sediments deposited within the past 1,000 years as the most susceptible, sediments deposited during the last 10,000 years as highly to moderately susceptible, and Pleistocene deposits (formed between 10,000 and 1.7 million years ago) as unlikely to liquefy.

As part of the same group of earthquake hazard studies, Tinsley and Fumal (1985) utilized measurements of shear wave velocity at 84 sites in the Los Angeles area to verify the correlation between velocity and the age and textural characteristics (grain-size, consistency, relative density) of alluvial sediments. The age and textural characteristics of the surficial geologic materials as defined by Tinsley and Fumal (1985) are shown in Table 3.3 in relation to the liquefaction units defined by Tinsley, et al., (1985).

Methodology

The studies just mentioned are used in the construction of the basin materials component of the Engineering Geologic Materials Map (Plate 2). The information pertains only to the coastal lowland and valley areas of Los Angeles County. The subdivision of alluvial units susceptible to ground failure in the outlying, largely unincorporated county areas is identified through analyses of USGS and CDMG textural descriptions of Quaternary age sediments. In all regions, the distribution of surficial materials was checked and modified using large scale geologic or soil maps where appropriate. The information sources incorporated into the basin component of Plate 2 are listed in Appendix 4 and identified in the references section.

The methodology selected to subdivide the surficial materials attempts to show two seismic characteristics of the alluvium:

- Susceptibility to ground failure; and
- relative seismic shaking response.

The two seismic characteristics are shown simultaneously by combining the very high to moderate susceptibility units of Tinsley et al., (1985) into a single susceptible Holocene unit. The integration of this susceptible unit with the textural units defined by Tinsley and Fumal (1985) produced a hybrid map showing the physical properties most important in interpreting both susceptibility to ground failure and the relative materials response to seismic shaking. Predictive shaking response, as defined by Rogers et al., (1985), decreases with an increase in the age of the sediment and the average rock size of the surficial materials. Through comparison with the original source data, it was determined that this qualitative measure of shaking response could be shown without modifying ground failure susceptibility. The omission of the highly liquefiable unit merely allowed a more conservative liquefaction classification system. The explanation and interpretations of the alluvial basin units defined on Plate 2 are explained in detail in Table 3.4 and shown schematically in Figure 3.7. Figure 3.7 shows an oblique view of a hypothetical alluvial fan cross-section relating the alluvial basin units defined in this report with the depositional

GENERALIZED DEPOSITIONAL MODEL

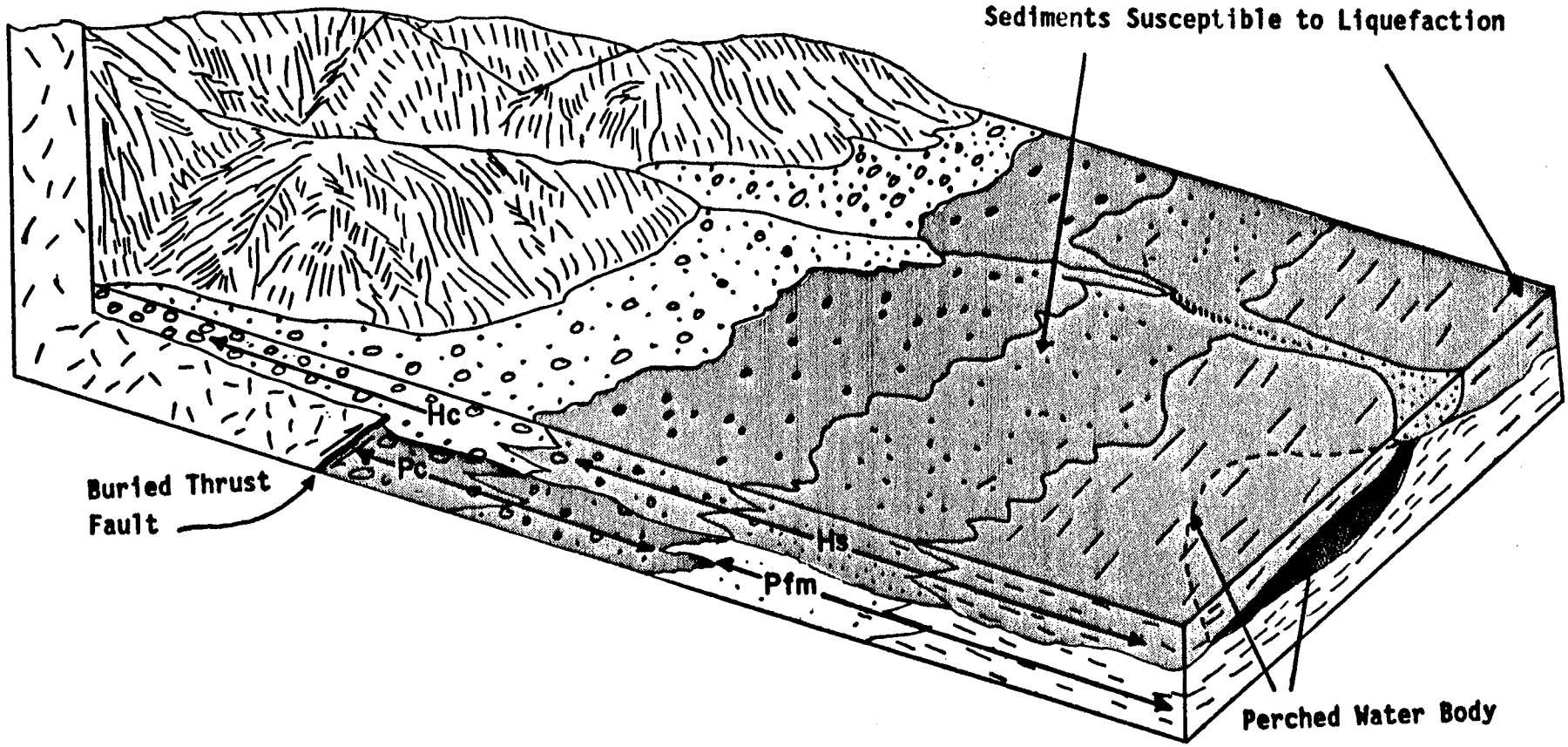


Figure 3.7: Generalized depositional model showing the correlation between different surficial alluvial units in the coastal and valley lowlands (modified after Tinsley et al., 1985); Table 3.3 explains the shading; Table 3.4 defines the geologic symbols used to designate range of material textures found within the alluvial units.

Table 3.3: Ground Shaking and Liquefaction Soil Properties*

	GROUND SHAKING	LIQUEFACTION	
	TINSLEY AND FUMAL (1985)		TINSLEY ET AL., (1985)
HOLOCENE	Fine-grained sediment (silt and clay)	QY2	Late Holocene Alluvium: gravel, sand, silt, and clay: unconsolidated, uncemented: herein restricted to areas that flooded historically, including tidal marshes. Thickness 0 to 3m. Age less than 1,000 years.
	Medium-grained sediment (sand)		
	Coarse-grained sediment (gravel)	QY1	Undifferentiated Holocene Alluvium: gravel, sand, silt, and clay: uncemented, unconsolidated: Thickness 0 to 30m. Age 1,000 to 10,000 years. Locally may include thin deposits of Late Holocene alluvium.
	Very coarse-grained sediment (cobbles and boulders)		
PLEISTOCENE	Fine-grained sediment (silt and clay)	Q0A	Undifferentiated Late Pleistocene Alluvium: gravel, sand, silt, and clay: moderately to well-consolidated; often slightly cemented; locally well-cemented.
	Medium-grained sediment (sand)		
	Coarse-grained sediment (gravel)		
	Very coarse-grained sediment (cobbles and boulders)		

* Common shading in Figure 3.7 highlights the soil texture properties and geomorphic descriptions (defined above) that were combined to derive the hybrid alluvial component of the Engineering Geologic Materials Map (Plate 2). Explanations of alluvial units shown on Plate 2 are located in Table 3.4.

environment. Environments where coarse units are dominant are inferred to have less potential for violent shaking relative to finer-grained units of the same age.

Susceptible Holocene units outside of the coastal lowland and valley areas of Los Angeles County, mainly in the Antelope Valley and within the Transverse Ranges, are not differentiated for two reasons: 1) previous studies have not adequately mapped and classified Quaternary age sediments for purposes of seismic zonation, and 2) existing descriptions of Quaternary age sediments suggest many Pleistocene alluvial units are similar in texture to Holocene age sediments, and thus may show the same degree of susceptibility to shaking (Ponti and Burke, 1980). The subdivision shown in Table 3.4, in most cases, lumps all unconsolidated Holocene and Pleistocene sediments into a single Quaternary unit, defined as Qs for "Quaternary susceptible". If additional information from the source references listed in Appendix 4 identified very coarse alluvial facies or well-consolidated units of older alluvium, the undifferentiated Quaternary unit is classified as Qc for Quaternary (coarse). Lower susceptibility to liquefaction is inferred for Qc units.

As shown in Table 3.4, further differentiation was also possible for the highest and most obvious Pleistocene terraces in the Antelope Valley (Pc). Perhaps the most unique mappable unit indicative of susceptibility to ground failure in the Antelope Valley is ancient lake (pluvial) deposits. The interbedded sequence of clays and unconsolidated sediments is a mapped perched water body, an important characteristic conducive to saturated ground failures (Duell, 1984).

Uses and Limitations of the Engineering Geologic Materials Map

The basin component of Plate 2 has a variety of uses; however, the immediate use in this section is to derive the liquefaction susceptibility map and to infer, where appropriate, the inherent seismic response of the mapped units. The map can also be used to aid in developing a seismic intensity map.

The regional nature of the data compiled by even the most large scale and liquefaction-directed studies used in this compilation suggests that errors in lateral variations of the physical properties and/or susceptibility of the alluvial materials are present. A site specific study is the only practical way of determining if a site is truly liquefiable. Based on state-of-the-art methodologies from the following references, site specific studies can be expected to yield very accurate appraisals of site vulnerability to ground failure. These references include:

- Committee on Earthquake Engineering, 1985, Liquefaction of soils during Earthquakes; Report for MIT Workshop, National Academy Press, Washington, D.C.

- Idriss, I. M., 1985, Evaluation of Seismic Risk in Engineering Practice; Proceedings, 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Vol. 1, pp. 255-270.

Table 3.4: Map Symbols and Explanation of Surficial Alluvial Sediments - Engineering Geologic Materials - PLATE 2.

ALLUVIAL SEDIMENTS WITHIN THE LOS ANGELES BASIN, SAN FERNANDO VALLEY AND SAN GABRIEL VALLEY

Holocene

Hs - Unconsolidated, predominantly silty, clayey, fine to medium, coarse sands, and moderately coarse gravels with lenses of medium to coarse sands, Late Holocene (0 to 1,000 yrs.) and early Holocene (1,000 to 10,000 yrs.) sediments deposited in stream channel, alluvial fan, flood plain and near-shore environments.

- The highest susceptibility to ground failure and seismic response are inferred (Rogers et al., 1985).
- The highest intensities are expected where Hs overlays geologic units with significantly higher shear velocities (large impedance) such as bedrock (Medvedev, 1962; Borchardt, et al., 1975).

Hc - Unconsolidated, predominantly very coarse gravels, cobbles, and boulders. The coarsest facies of Late Holocene, early Holocene, and present stream channel and alluvial fan deposits are included in this unit. Potential susceptibility to ground failure and highest relative seismic response are inferred.

Pleistocene

Pfm - Moderately to well-consolidated and locally cemented, sands and minor gravels, and finer deposits of silt and clay. Includes older alluvium, flood plain, and Late Pleistocene marine and nonmarine terrace deposits.

Pc - Moderately to well-consolidated and locally cemented, sands, gravels, cobbles and boulders. Includes Late Pleistocene terrace deposits and older alluvium.

ALLUVIAL SEDIMENTS OF ANTELOPE VALLEY AND SANTA MONICA, SAN GABRIEL, AND SANTA SUSANA MOUNTAINS

Undifferentiated

Qs - Unconsolidated to poorly consolidated, fine to coarse-grained, alluvial fan, stream channel and flood plain deposits. Includes interbedded colluvial lake deposits in Rosamond Lake and Rogers Lake areas in Antelope Valley (Ponti and Burke, 1980).

- The highest susceptibility to ground failure and seismic response are inferred.

Qc - Unconsolidated to moderately consolidated, very coarse channel deposits. Includes older alluvium and terrace deposits. Lowest susceptibility to ground failure and relative seismic response are inferred.

- In Antelope Valley, the unit also represents firmly lithified alluvial materials surrounding dry Playa Lakes (Ponti and Burke, 1980; Duell, 1984).

Pleistocene

Pc - Where differentiated this unit consists of prominent outcrops of weakly consolidated poor to moderately sorted deposits exposed on high terraces adjacent to mountain and foothill areas or along stream channels lower susceptibility to ground failure and seismic response is inferred (Ponti and Burke, 1980).

- Ishihara, K., 1985, Stability of Natural Deposits during Earthquakes; Proceedings, 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Vol. 1, pp. 321-376.

- Seed, H. B., Idriss, I. M., and Arango, I., 1983, Evaluation of Liquefaction Potential using Field Performance Data; Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 3, pp. 458-482.

Because reference to relative shaking response has been inferred, mention of several other variables controlling this phenomena is appropriate. Given a fixed earthquake source and magnitude, earthquake ground motion depends on the directed focusing of the stress released during the earthquake, the duration of shaking, the basin geometry, and the subsurface structure and stratigraphy, which can all serve to amplify seismic energy into frequencies of interest for engineering purposes. The delineation of ground materials susceptibility to seismic response is only a preliminary step in seismic zonation.

Conclusion

- County resources should be devoted to subdividing and mapping alluvial units (Qs and Qc Plate 4) for engineering characteristics, including compilation of existing and future standard penetration testing (ASTM D1586), especially in the Antelope Valley, along the San Andreas Fault, and in alluvial areas in the San Gabriel Mountains.

SECTION 3.1.3.2

SHALLOW AND HIGH GROUND WATER CONDITIONS (Plate 3 - Shallow and Perched Ground Water)

Since the early 1900's, the development of ground water basins in the coastal lowland and valleys of Los Angeles County has caused regional lowering of ground water levels. The development of ground water basins in the Santa Clarita and Antelope Valleys is likely causing a similar trend. In a general way, the depletion of ground water can be credited with reducing the liquefaction hazard in Los Angeles County. However, high ground water conditions continue to exist quite extensively, including parts of Antelope Valley, the flood plains of the Los Angeles and San Gabriel Rivers, and the Santa Clarita Valley. More localized high ground water conditions also persist, partly due to the discontinuous nature of the sand and clay lenses associated with perched water bodies, and partly from human activity involved in recharging water into shallow water aquifers. In other areas, localized ground water is naturally present because of faulting, such as along the San Andreas fault. Some of these areas are too small to show on a regional scale. This section discusses and delineates, where possible, the regional areas where saturation of susceptible sediments is most likely. Knowledge of the saturated depth of such sediments is critical to the assessment of the County's vulnerability to liquefaction and lateral spreading, which are the most damaging modes of earthquake-induced ground failure.

Engineering borehole data provides the best information on shallow and perched ground water. Engineering borehole data was used extensively during research sponsored by the National Earthquake Hazard Reduction Program, as part of U.S. Geological Survey Professional Paper 1360. Tinsley, et al., (1985) used an extensive compilation of post-1944 data on water level measurements from selected shallow aquifer water wells and engineering boreholes to delineate areas of shallow ground water. The geotechnical and engineering investigation reports conducted through 1981 and incorporated into this study provide the best data available for the metropolitan area of Los Angeles County.

The Los Angeles County Coastal Barrier and Replenishment Project (CBRP), a project designed to prevent salt-water intrusion, is the only known project concerned with shallow ground water monitoring. Localized areas of perched ground water are not emphasized on County Public Works ground water maps. The agency is mostly concerned with shallow aquifer production or contamination, which involve ground water bodies much too deep to assess liquefaction susceptibility. Other local and State agency areas, although involved in reviewing shallow and perched ground water data, are not involved in compiling ground water information on maps. Because the outlying unincorporated areas of the County were not included in the compilation by the U.S. Geological Survey Professional Paper 1360, the State Division of Mines and Geology and local agencies provided the bulk of ground water information for these areas. An exception to these sources is a report evaluating the feasibility of a ground water monitoring

network in the Antelope Valley, (Duell 1987) which provided information on perched and shallow ground water.

Methodology

Shallow ground water is defined as less than or equal to 50 feet below the surface. The ground water data base used in preparation of Plate 3 is derived from the following sources:

- USGS Professional Paper 1360 (Tinsley, et al., 1985).
- County of Los Angeles Department of Public Works, Coastal Plain Shallow Aquifer Ground Water Contour Map, Fall 1987.
- USGS Water Resources Investigations Report 84-4081, (Duell, 1987).
- CDMG Special Paper 60 (Davis, et al., 1982).
- CDMG Special Report 113 (Fife, et al., 1976).
- Interviews with County and California Division of Mines and Geology, Geologists and unpublished County documents.

Areas of shallow and perched ground water delineated by the sources cited were directly transferred to the 1:100,000-scale maps used in the data compilation. If reference sources showed an overlap of high ground water information, the more conservative choice was used to generate a composite representation of high ground water. The only shallow aquifer map for Los Angeles County, dated Fall 1987, existed for the coastal plain. This map did not emphasize perched ground water areas and was, as a result, less conservative (useful) than the other sources.

The delineating lines may not be ground water contours. In some cases the enclosing lines represent isobaths, i.e., meaning they are lines enclosing an area where specific shallow ground water data was available. The isobaths may approximately coincide with ground water contours in some areas, as they appear in some cases to compare favorably with historic pre-1949 high water levels in the Los Angeles Basin (Tinsley, et al., 1985).

Geographic areas or cultural development that were found to be associated with shallow and perched ground water include:

- Flood control channels and unregulated streams.
- Reservoirs.
- Ground water recharge facilities.
- Flood control basins.

- Ground water barriers: basin faults.
- Coastal areas.

Uses and Limitations of the Shallow Ground Water Map

The map was constructed specifically to produce a liquefaction susceptibility map by comparing areas of high ground water with sediments susceptible to ground failure. It will serve only as an information source that can be periodically updated with new information. The liquefaction susceptibility map will be the map most likely to be used to implement County policy.

The shallow ground water map emphasizes areas of high ground water for the five major physiographic and ground water basins in Los Angeles County. Information on shallow and perched water conditions outside these areas either was unavailable, or too small to be shown at a regional scale. In addition, because the engineering borehole data used in the metropolitan area did not consistently penetrate to 50 feet below the surface, the existence of shallow ground water was not totally precluded in some areas.

Three points must be emphasized with regard to the limitations of this map. The first is that future changes in ground water management policy could elevate regional ground water and perched water to pre-1944 levels, thus rendering the map unrepresentative of actual conditions. Secondly, the map does not address seasonal fluctuations due to increased precipitation. Lastly, the map is constrained by the existing data base and the regional nature of the map. This last point makes the map unsuitable for site specific applications, due to the highly irregular and localized nature of perched and confined aquifers.

Conclusion

- Information from private consultants, and local, State and Federal agencies requiring geotechnical, environmental, or hazardous waste monitoring reports should be utilized to evaluate the hydrology and transcience of high ground water in areas identified as liquefiable on Plate 4, and to establish the presence of perched or high ground water in the Antelope Valley, the San Andreas Fault, and alluvial areas in San Gabriel Mountain area.

SECTION 3.1.3.3

LIQUEFACTION SUSCEPTIBILITY
(Plate 4 - Liquefaction Susceptibility)

Earthquake induced ground failure is classified in accordance with the severity of deformation sustained by the sediment and the degree of saturation of the sediment. The following definitions will lay the ground work for the following discussion:

- Differential dynamic settlement: This ground failure mode occurs in dry to partially saturated sediments, and is caused by the subsurface densification or consolidation of loose, cohesionless sediments. Without full saturation, the sediment material retains partial internal shear strength during sustained earthquake shaking, creating displacements of up to one meter. Settlement may occur in either natural sediments or artificially emplaced fill.

- Liquefaction: This ground failure mode is the most severe. It is caused by the total loss of internal shear strength during ground shaking. High pore pressures built up in the sediments during repeated vibration cause the sediment to behave as liquid, especially when ground shaking continues for long periods. Liquefaction is often accompanied by sand boils and ground lurching, which cause fissuring and cracking of the ground surface as surface waves pass through these areas. If liquefaction occurs on gently sloping terrain, extremely large lateral displacements may occur within near surface units and within the lower, subsurface units that actually control the extent of the lateral spread. Two types of liquefaction failures occur on sloping alluvial or coastal plains:

  - Flow failures develop on slopes greater than five percent and can move distances of kilometers (Youd, 1978).

  - Lateral spreads develop on slopes between .5 and five percent and can move distances of several meters (Youd, 1978).

Methodology

A liquefaction susceptibility map delineates areas where subsurface conditions appear conducive to liquefaction, lateral spreading, and other water-saturated ground failure modes. Plate 4 is an interpretive, hybrid of the maps showing susceptible alluvial sediments and shallow and perched ground water. As a first step in constructing the Liquefaction Susceptibility Map, the Engineering Geologic Map (Plate 2), and the Shallow Ground Water Map (Plate 3) were overlain. Liquefiable areas were identified where susceptible sediments coincided with, or were interpreted to coincide with, areas of shallow ground water.

Interpretation of Liquefaction Susceptibility

The depths to ground water chosen to represent relative susceptibility to liquefaction were based on the work of others. The following studies have used the indicated ground water depths as criteria for labeling relative liquefaction susceptibility:

Depth Below the Surface (feet)	
0 - 10:	high
10 - 30:	moderate
30 - 50:	low
50 and below:	very low

(Tinsley et al., (1985) and Youd et al., (1978))

Depth Below the Surface (feet)	
0 - 50:	documented
50 and below:	questionable

(Sherif and Ishibashi (1978))

Based on the regional nature of the map and the consideration of interpretations used by the workers cited above, the following criteria are used to establish relative liquefaction susceptibility on Plate 4:

Liquefiable Sediments (0 to 30 feet) - L

The designation as liquefiable can be interpreted to define high to moderate susceptibility. In addition to overlaying the two component maps to produce this susceptibility designation, any areas interpreted in Professional Paper 1360 as having at least a low to moderate susceptibility to liquefaction are also included within this unit.

In areas along the coast, along youthful stream drainages, and on the perched water body in the Antelope Valley, where detailed liquefaction studies have not yet been performed, liquefaction susceptibility is based solely on interpretation. In these areas liquefaction potential is inferred from probable coincidence of shallow marine or ground water with susceptible sediments. The apparent areal distribution of liquefiable sediments is correlated with the following:

- Physiography - marshes, rivers, flood plains, embayments.
- Flood control projects.
- Ground water impediments (barriers to ground water flow, e.g., faults, lateral changes in sediment permeability, or juxtaposition with impervious bedrock).

- The distribution of the ground water borehole data set.

Potentially Liquefiable Sediments (30 to 50 feet) - PL

A potentially liquefiable designation identifies areas with relatively low potential for liquefaction. In addition to the 30- to 50-foot ground water criteria, potentially liquefiable areas are also identified where very coarse-grained (Hc) sediments are in contact with shallow ground water.

Low Liquefaction Susceptibility - LL

Low liquefaction sediments are generally not identified on Plate 4. They are identified only when necessary, or for example, in situations where Pleistocene units are encircled by liquefiable units. Pleistocene units are defined by Tinsley, et al., (1985) as having low potential for liquefaction. However, Pleistocene sediments, such as the structurally deformed Pleistocene units represented by PQ (Plate 2), may experience slope instability through liquefaction processes or failure of low strength clays sensitive to earthquake motions. Slope failures of this type are addressed within Section 3.2, Earthquake-Induced Slope Instability.

Very Low Liquefaction Susceptibility - VL

Areas underlain by bedrock possess very low liquefaction susceptibility. They are labeled only in those situations where a liquefiable or potentially liquefiable unit surrounds an area of bedrock and make their differentiation necessary to interpret the map.

Uses and Limitations of the Liquefaction Susceptibility Map

The regional nature of the liquefaction susceptibility map makes it useful for general planning purposes. Additional potential uses include:

- Initial prioritization of areas of infrastructure and/or lifelines in need of repair or strengthening.
- Initial prioritization for the abatement or mitigation of hazardous and critical structures.
- General identification of sites unsuitable for critical facilities.
- Identification of areas with the highest potential emergency response needs.
- Planning of evacuation and access routes to and from critical facilities.

- Prioritization of areas where larger scale mapping and research is more appropriate for localized risk assessment related to the previously mentioned alternative uses.

County areas susceptible to liquefaction may be more extensive than estimated from the data base used in this study. This is especially relevant in unincorporated areas but also applies to well studied locations in the metropolitan area. In the unincorporated County, the engineering characteristics of alluvial materials, such as the packing and size distribution, needs to be researched further. Techniques such as the standard penetration test (ASTM D1586) recommended by Seed, et al., 1985 provide a quick, accurate, and practical method for such assessments.

The thickness of susceptible sediment layers is the least accurate parameter of the Liquefaction Susceptibility Map in the metropolitan area. The thickness can be important because even though an area might be identified as liquefiable, the susceptible unit may be situated above the water table, and thus preclude the saturation factor necessary for liquefaction. Furthermore, because the total sum of internal strain within the material increases with the thickness of the susceptible unit, some surficial or subsurface layers may be too thin to cause damaging settlements.

The last point is essential for determining the relative severity of ground deformation from location to location. The map could be adapted to show expected damage if layer thickness were taken into account. Another adaption that would allow a better interpretation of risk would be to show the annual probability for liquefaction. This adaption is based on the ability to assign probabilities of recurrence for earthquake strong ground motion intense enough to cause liquefaction (Section 3.1.3).

Lastly, the areas of high water used to produce the susceptibility map does not indicate what the potential for liquefaction might be if management practices change. Recharge practices and cessation of ground water pumping increases the potential for liquefaction. Los Angeles County contributes a large percentage of ground water recharge in the County through various flood control projects. The degree of liquefaction susceptibility depicted on Plate 4 does not represent the consequences of high seasonal precipitation for several consecutive years and the accompanying rise in ground water levels.

Earthquake-Induced Ground Settlement

Damaging settlements can occur in areas outside of those identified as susceptible to liquefaction. Ground settlements are generally less severe than those experienced during liquefaction, however, displacements of a meter or more have occurred during some large earthquakes, and settlements of 5 to 30 centimeters are rather common (EERI, 1986). The areas most susceptible to this hazard will be those underlain by dry to partially-saturated granular, cohesionless sediments. Special delineation was not considered necessary for earthquake-induced settlements because all alluvial areas are susceptible to this failure type. The Hs and Qs units (susceptible units - Plate 2) are considered

the most vulnerable to earthquake-induced ground failure. The County should consider requirements for special investigations to determine the amount of potential displacement if susceptible sediments are encountered during development using ASTM procedure D1586.

Conclusions

- Based on existing data, geotechnical site investigations for liquefaction susceptibility should be required in liquefiable areas to at least a depth of 30 feet. Requirements for critical facilities or potentially hazardous buildings vulnerable to foundation or structural damage from liquefaction should be more conservative. Geotechnical investigations up to a depth of 50 feet may be appropriate.

- Geotechnical investigations in alluvial areas that are not yet identified as liquefiable (0 to 30 feet) should continue to address the potential for liquefaction and differential dynamic settlement.

- The National Research Council (1985) acknowledges that significant improvements are necessary for protection of critical facilities from the liquefaction threat. Localized ground water monitoring programs in susceptible areas occupied by critical facilities should be considered, so that adequate precautionary measures can be readied during periods of high ground water conditions.

- Dewatering, treatment of soil materials, and an evaluation of existing County regulations concerning the effectiveness of existing regulations for liquefaction resistant foundations and frames should be considered and possibly applied to liquefiable areas shown on Plate 4.

- The potential for lateral spreading should be emphasized where liquefiable areas coincide with slopes measuring between .5 and five degrees.

- An analysis of the benefits or disadvantages of ground water recharge with respect to the potential increase in liquefaction risk should be considered in determining long-term ground water policy.

- Periodic refinement of Plate 4 with any additional information acquired during the acquisition of standard penetrometer data with perched and shallow ground water information should be attempted so that the next generation of liquefaction potential maps can be built upon on the existing data set.

- The areal thickness of all susceptible alluvial units and the annual probability that liquefaction will be induced in a given geographic area from a particular earthquake should be included in the next generation of liquefaction potential maps.

SECTION 3.2

GEOLOGIC HAZARDS AND LANDSLIDE AND SLOPE INSTABILITY

(Plate 5 - Landslide Inventory)

A comparison of average annual losses from geologic, flood, and earthquake hazards shows that ground failures such as landslides, expansive soils, and subsidence are the primary causes of economic impact on development (Figure 3.8). As of 1983, annual financial losses to both public and private property in the United States were estimated to approach as much as $1.5 billion dollars from landsliding alone (Schuster and Fleming, 1983; Schuster, 1978). Consistently rising real estate costs in southern California highlight concerns for increased economic losses from all types of ground failure, considering both annual economic impact, as well as the potential for sudden economic impact. Figure 3.8 shows that economic losses from landslides are second only to earthquakes (Figure 3.8).

Los Angeles County is vulnerable to a variety of geologic hazards, including landslides, expansive and collapsible soils, and subsidence. Landslide damage alone in southern California amounted to several hundred million dollars as a result of the intense rainstorms of 1978 and 1980, with areas in Los Angeles County sustaining over half of this damage (Slosson and Krohn, 1982). The losses were attributed to landslides, debris flows, mudflows and artificial fill slope failures. Expansive soils, although related to saturation and failure of hillsides during heavy rains, are more widespread and less periodic than most landslide hazards. Damage from expansive soils generally can occur in relatively flat lying or hillside areas and can be hastened by landscape irrigation, without any long-term rainfall. Expansive soils cause mostly moderate foundation distress but because of the ubiquity of the problem, total damages and annual losses can be significant (Figure 3.8).

The rapid expansion of development onto alluvial fans in the Antelope Valley, including sites near Lancaster, Palmdale, and Leona Valley, precipitates concern for potential damage from collapsible soils. Numerous examples from other jurisdictions in the southwestern United States demonstrate that by not adequately considering collapsible soils, widespread areas of development can be adversely affected. Relatively new development in Albuquerque, New Mexico, which has an arid environment similar to that of the Lancaster/Palmdale area, is suffering widely scattered, rapid settlements, causing extensive damage to both private property and infrastructure. Development within the Antelope Valley is vulnerable to this same problem.

Regional subsidence has also affected portions Los Angeles County. Broad areal subsidence associated with the historical withdrawal of ground water or petroleum

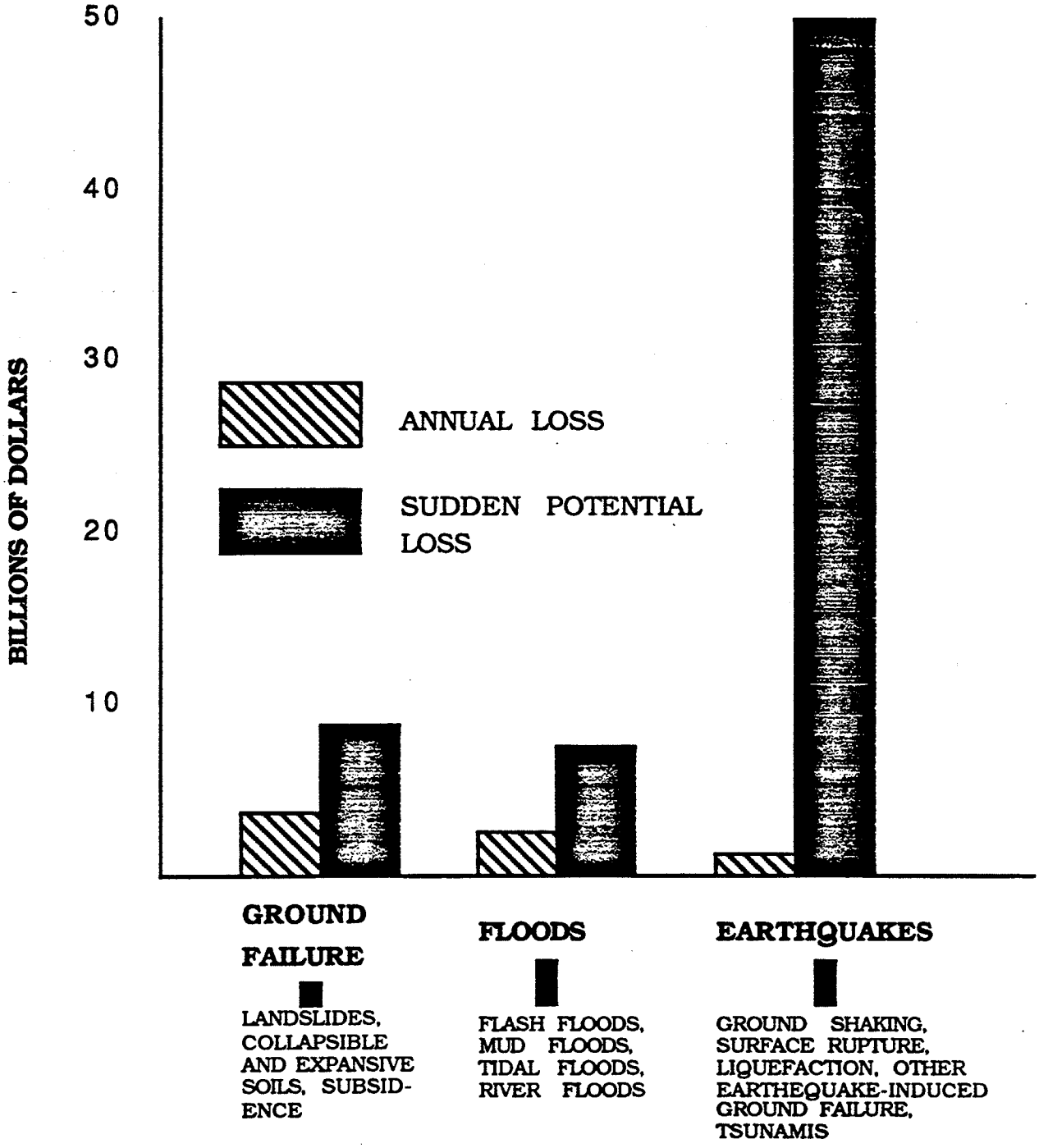


Figure 3.8: Estimates of average annual losses and the potential for sudden economic loss from selected natural hazards in the United States (after U.S. Geological Survey).

sank areas between 2 and 5 feet through the mid-1960's throughout the Los Angeles Basin, and as much as 29 feet in the Long Beach area (Wentworth et al., 1970). Subsidence in the Baldwin Hills Area is suspected of being a factor in the failure of the Baldwin Hills Dam in 1963 (Kresse, 1966). Potential disasters such as the Baldwin Hills incident justifies the continued mitigation of regional subsidence through artificial pumping of water into tapped reservoirs throughout the Los Angeles Basin. Subsidence problems must also be mitigated as they are recognized in other parts of the County, most notably in the Antelope Valley.

In this report, landslide and slope instability hazards are emphasized because of the immediate relevance of landslide hazards to safety concerns, and the proven vulnerability of Los Angeles County to the sudden economic impact from such ground failures. Landslides caused by earthquakes threaten widespread blockages of evacuation routes and, where building setbacks are inadequate, they pose a hazard to development located either at the base or top of steep terrain (Figure 3.9).

Landslides caused by heavy rains also warrant concern in the Safety Element (Figure 3.9). The debris and mudflows associated with the intense rainstorms of 1969, 1978, and 1980 caused nearly 30 fatalities and extensive damage to residential development, small businesses, and agriculture. Heightened concern for hillside development is now justified more than ever, because of the continuing residential development of potentially unstable unincorporated hillside areas in the Puente and San Jose Hills, and the Santa Monica, Santa Susana, and San Gabriel Mountains. Proper hillside management is essential due to the number of potential causes of slope failure. Landslides can be precipitated by the influence of improper slope design or poor grading practices. Other development-induced failures may be caused by the dysfunction of structures designed to manage runoff. Improper slope maintenance of hillsides after development, and/or broken water and septic utilities may also precipitate slope failure (Figure 3.9). This section will focus on the direct correlation between adequate project design and building regulation enforcement for landslide hazard reduction.

The following discussion of landslide hazards will be composed of five subsections, including a landslide inventory for the County of Los Angeles:

- **Section 3.2.1:** Landslide Susceptibility
  (Engineering Geologic Materials - Plate 2)

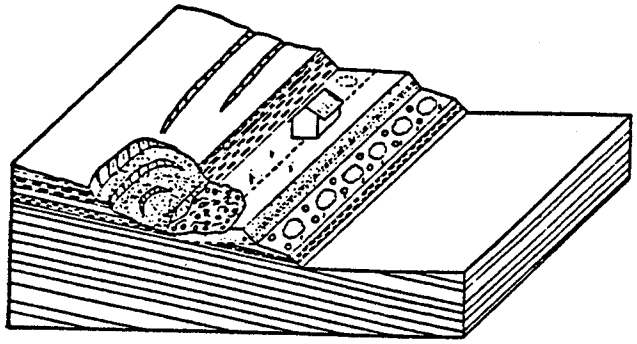
- **Section 3.2.2:** Landslide Inventory
  (Landslide Inventory - Plate 5)

- **Section 3.2.3:** Earthquake-Induced Slope Instability
  (Table 3.7 - Probable Earthquake-Induced Slope Failures: Los Angeles County)

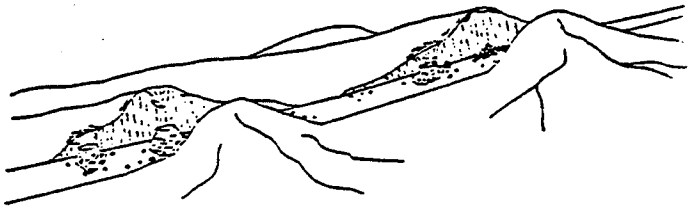
- **Section 3.2.4:** Rain-Induced Slope Instability
  (Table 3.8 - Probable Rain-Induced Failures: Los Angeles County)

- **Section 3.2.5:** Development-Induced Slope Instability
  (Figure 3.12 through 3.14) - Hillside Development Constraints and Solutions)

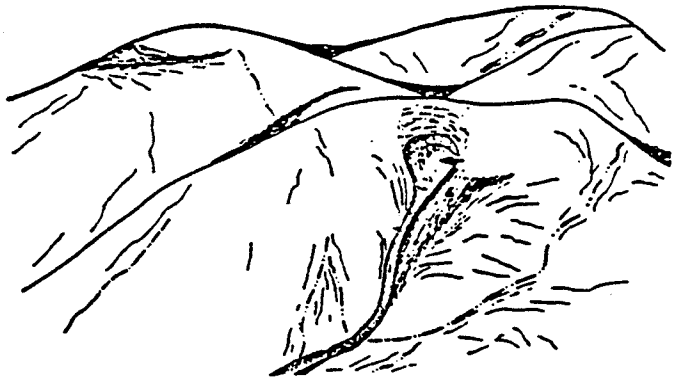
LANDSLIDE HAZARDS



Development-Induced



Earthquake-Induced
(modified after EERI, 1986)



Rain-Induced Debris Flow
(Source USGS)

Figure 3.9: Landslide hazards threaten public safety and property.

SECTION 3.2.1

LANDSLIDE SUSCEPTIBILITY

(Plate 2 - Engineering Geologic Materials)

In this section, the bedrock component of the Engineering Geologic Map (Plate 2) is discussed in terms of the effect that lithology (rock type) has on slope failure potential. The roles of topographic relief and geologic structure are then introduced to lay the foundation for considering earthquake-induced, storm or rain-induced, and man or development-induced failures in the County. Based on the landslide inventory (Plate 5) and research of earthquake and storm-induced slope failures in the County, the probable distribution and character of future failure hazards are predicted on a regional scale, albeit in a general way. The objective of this regional assessment is to provide information for the following purposes: 1) to lessen public exposure to injury and property loss, 2) to lessen the impact on lifelines from landslide disruption, and 3) to reduce the impact of landslide hazards on emergency response.

Methodology

The bedrock component of the Engineering Geologic Map (Plate 2) shows the regional distribution of bedrock materials in the County. Table 3.5 is a correlation matrix showing the general rationale for subdividing the various formational bedrock types in Plate 2 on the basis of material properties. The initial subdivision was based on age and lithologic classifications delineated on California Division of Mines and Geology (CDMG) 1:250,000-scale geologic maps. Further subdivision of these units was based on the physical characteristics described by Wentworth (1970) and analyses of numerous CDMG and United States Geological Survey (USGS) geologic maps (map scales 1:12,000 - 1:62,000). Large scale map sources used in compiling geologic data onto Plate 2 are listed in Appendix 4 and are keyed to references provided in the back of this report.

Geologic mapping coverage for the County is extremely discontinuous. Even where mapped, many areas are not mapped in detail at usable scales (1:24,000) or with geologic data necessary to interpret environmental constraints on development. Ideally, geologic mapping would include abundant bedding or joint surface inclinations relative to the slope angle. This data allows developers, planners, and consultants to ascertain whether out of slope bedding slippage will be a constraint early in the project review process. Adequate descriptions of geomorphic landforms indicating the type of landslide or the presence of scars indicative of debris flows are necessary components of geologic mapping for environmental impact.

Using the existing map coverage, bedrock unit distinctions on the Engineering Geologic Map are assigned primarily on physical characteristics to infer

potential failure style based on the underlying rock type. If grouping of one geologic unit with another appeared more appropriate for interpreting landslide type, then the age of certain units on Plate 2 (such as Tsh for Tertiary units - greater than two million years old), may not match the accepted geologic age. Certain formations, facies, or members of formations may also be grouped into engineering units according to their distinctive properties, such as when descriptions of conglomerate or fractured sandstone indicate susceptibility to a particular type of failure mechanism. As an example, the metamorphic rocks in the eastern San Gabriel Mountains are shown as Bm, and not as metasedimentary rocks (Ms), because the dominant failure style in this terrain is rockfalls. Table 3.5 emphasizes that some formations can experience multiple properties by listing a geologic formation under different engineering lithologic units. The bedrock units defined in Table 3.5, such as Bm, Tsh, or Tcs, are critical to the interpretation of tables provided later in this section showing potential failure styles of earthquake-induced and rain-induced landslides, as they are keyed to particular geographic areas in the County.

Uses and Limitations of the Engineering Geologic (Map Bedrock Units Only)

The bedrock units listed in Table 3.5 are defined for the purposes of the landslide section. Pleistocene alluvial units shown on Plate 2 are also susceptible to slope instability if oversteepened by construction activity or where locally incised by drainages. They are not included in Table 3.5 but their slope stability should closely match those of the PQ units. Holocene units susceptible to shallow angle earthquake-induced slope failures (lateral spreading) are addressed under earthquake-induced ground failures in Section 3.1.3 of this chapter (lateral spreads and flows).

The bedrock geology is not shown with equal accuracy throughout the County due to insufficient and/or discontinuous large scale geologic mapping. Certain physical aspects of some formations were also unable to be shown at the 1:100,000-scale map used in the data compilation. These constraints, including the small scale of the map, preclude any interpretation beyond a regional scale.

Based on mapping gaps indicated during this review, a more intense geologic mapping program emphasizing engineering properties should be initiated in selected areas of interest to the County. As will be discussed in the following section, such detail is needed to derive an accurate map of relative slope susceptibility that takes into account the multiple variables associated with slope instability.

Conclusion

- Inadequate and/or discontinuous large scale geologic mapping, including the small scale of Plate 2, preclude any interpretation beyond a regional scale.

TABLE 3.5

CORRELATION OF GEOLOGIC MATERIAL UNITS WITH LOCATION AND FORMATION NAMES.

(A GEOLOGIC EXPLANATION FOR PLATE 2)

GEOGRAPHIC DISTRIBUTION →

UNITS ↓	SANTA MONICA	SANTA SUSANA MTS.	NORTH COUNTY/S.G. MTS.	UPLIFTS IN L.A. BASIN	CHANNEL ISLANDS
PQ	Not widespread	Saugus Fm. Pacoima Fm.	Crowder Fm. Harold Fm. Meeker Mine Fm. Peace Valley Fm. Sandberg Fm.	La Habra - San Pedro Palos Verdes - Coyote Hills Timms Pt - Lomita Marl Monterey - Inglewood Pacoima	———
Tsh	Modelo Fm. Lower Repetto Fm. Lower Fernando Fm. Monterey Fm. Sespe Fm. Calabasas Fm.	Modelo Fm. Pico Fm. Ilajas Fm.	Modelo Fm.	Monterey Fm. Lower Fernando Fm Repetto Fm. Puente Fm.	Undifferentiated limestone.
Tss	Towsley - SantaSusana Pico - Topanga Martinez - Chico Sespe Tuna Canyon	Mint Canyon Fm. Towsley Fm. Topanga Fm. Santa Susana Fm. Jurassic Chico Fm.	Upper Pico - Ritter Mint Canyon - Fiss Topanga - Anaverde Vasq uez - Oso Cyn. Tick Cyn. - Punchbowl Hungry Valley - Castaic	Topanga Fm. Upper Fernando Fm.	———
Tcs	Topanga Fm. Coal Canyon Fm. Tuna Canyon Fm.	Towsley Fm. Topanga Fm. Santa Susana Fm.	Topanga Fm.	Lower Fernando Fm. Sycamore Canyon member- Puente Fm.	———
Tv	Conejo Volcanics Zuma Volcanics	Conejo Volcanics	Glendora Volcanics Gym Hill Fm. NeenachVolcanics Vasquez Volcanics	Glendora Volcanics Zuma Volcanics	Undifferentiated basaltic and rhyolitic rocks.
Ms	Santa Monica Slate Trabuco Fm.	Chatsworth Fm.	Pelona Schist Portal Schist	Catalina Schist	Melange Franciscan Series Ollas Series
Bm	Undifferentiated Igneous and Metamorphic Rocks.	Undifferentiated Igneous and Metamorphic Rocks.	Undifferentiated Igneous and Metamorphic Rocks.	Undifferentiated Igneous and Metamorphic Rocks.	Undifferentiated Igneous and Metamorphic Rocks.

SECTION 3.2.2

LANDSLIDE INVENTORY

(Plate 5 - Landslide Inventory)

Many municipalities have produced small scale landslide risk maps (Slope Stability Maps) as part of their Safety Element (Los Angeles Seismic Safety Element, 1975; Santa Barbara, 1979). The low resolution and small scale of the slope instability maps have made their interpretation difficult and rendered the maps useless for most applications. Two main criticisms of these early maps are that the susceptibility to sliding is based primarily on bedrock formations conducive to deep-seated landslides, not on shallow landslide failure styles. Also, because important parameters affecting slope stability cannot be addressed at such small map scales, the maps were unrepresentative of actual conditions. Important controlling factors affecting slope stability, such as topography (slope angle and slope height), orientation of the slope face relative to geologic structure, underlying vegetation, and a myriad of other variables are difficult to utilize even at scales as high as 1" = 2,000 feet. Geologic information related to slope instability is commonly only visible at the site scale of investigation using air photo interpretation and 1:100-scale mapping. Even then, subsequent subsurface investigations often reveal important geologic constraints not observable from surface inspection.

Landslide hazard and slope stability maps at 1" = 2,000 feet exist for some areas of the unincorporated County, published by the State-funded Landslide Hazard Identification Program (LHIP) of the CDMG. Utilizing a much more comprehensive approach for designating relative slope stability by using adequately scaled geologic and topographic maps, the program produced detailed slope stability maps suitable for land use planning. More importantly, the program also evaluated the relative susceptibility of some terrain to debris flows and other particularly dangerous forms of shallow, rapid slope failures.

The production of another relative slope susceptibility map for Los Angeles County is inappropriate at the scale of geologic resolution existing for most of the County. Until the influence of bedrock lithology, structure, slope angle and vegetation can be extended to areas outside of the limited mapping by the LHIP, and at scales of at least 1" = 2000 feet, a susceptibility map should be postponed. The landslide inventory presented in Plate 5, along with the Bedrock Map (Plate 2), provide an initial step in the future production of a complete Slope Susceptibility Map by identifying areas where information is lacking and by keying failure styles to geologic rock types in tables presented later in this section. Although the emphasis has been on using slope stability maps for regional planning, it must be recognized that almost any slope can be rendered unstable by construction activities, that almost any unstable slope can also be mitigated by construction activities, and that adequate geologic investigation is necessary regardless of the assigned relative slope stability.

Methodology

Plate 5 is a regional landslide inventory of various types of landslide assemblages, including single "composite" slope failures composed of several types of failure styles and potential shallow surficial slope failures. Table 3.6 lists the dominant failure styles characteristic to Los Angeles County. The order of landslide classes, as listed from top to bottom for each geographic area in Table 3.6, denotes the most ubiquitous slope failure process characterizing that particular terrain. The table, as well as Plate 5, are weighted towards representing deep-seated bedrock landslides. A tabular summary describing specific characteristics of each landslide type is provided in Appendix 5. The various classes of landslides listed in Table 3.6, such as soil slip, slump flow, or block glide, present differing constraints on hillside development that can be interpreted from the descriptions provided in Appendix 5. Appendix 5 provides similar explanations for interpreting Table 3.7 (earthquake-induced failures) and Table 3.8 (rain-induced failures) to be introduced in the following sections.

The data sources used in the compilation of the map are indicated on Plate 5 and keyed to references listed at the back of this report. Detailed surficial mapping specifically aimed at identifying landslide morphology exists in certain areas at 1:24,000 by the USGS and CDMG. This high quality mapping coverage extends into all of the mountain highland areas of the County, but remains discontinuous. The vast majority of the remaining County is moderately well covered by some form of geologic mapping at scales ranging from 1:125,000 to 1:48,000. These USGS and CDMG maps display varying degrees of accuracy and completeness, as some were not primarily directed at identifying landslides in the County, much less attempting any formal subdivision of failure type. An inspection of Plate 5 reveals that the discontinuous nature in mapping quality throughout the County has led to apparent instances of localized, abrupt cessation in certain failure styles. One such instance occurs north of Castaic. Shallow surficial failures appear to end abruptly at this latitude where LHIP mapping terminated. Other examples of this nature exist elsewhere where mapping coverage controls the apparent landslide pattern.

A landslide as shown on Plate 5, unless otherwise stated, is a mass of rock, soil, and/or debris that has been displaced downslope by sliding, flowing or falling. Many of the larger landslides depicted on Plate 5 include "potentially active" cohesive block glides and disrupted slumps that have migrated downslope in prehistoric time through translation or rotation along one or more planar or curvi-planar slip surfaces. They will typically involve displacement of bedrock but may exhibit many failure styles, especially along their peripheral boundaries. This combination of failure styles is referred to as composite or complex landsliding, and by far represents the most common landslide type represented on Plate 5 (Campbell, 1975; Weber, 1982). The presence of a landslide on Plate 5 makes no definitive statement as to its stability, either present or future. Many landslides in developed areas were stabilized or removed as a process of the development.

TABLE 3.6

GENERAL CHARACTERISTICS OF LANDSLIDE HAZARDS IN LOS ANGELES COUNTY.

AREAS	Common Slope Failure	Remarks
Santa Monica Mountains	Block glides Block glide flows Rotational slumps Soil slips/slumps Earth flows Debris flows Soil falls/Rock slides	Approximately 15% of active block glides are influenced by man's activities. > 95% are ancient "Potentially Active" and "Active" bedrock landslides.
Santa Susana Mountains and Santa Clarita Valley	Block glides Soil slips/slumps Earth flows Debris flows Rock falls	Roughly >60 % are potentially active and active block glides. > 40 % of surficial failures are earth flows, debris flows, and rock falls.
Verdugo Mountains and San Gabriel Mountains	Landslide rubble including rock falls, topples and debris/slide avalanches; Block glide-falls Block glides Debris-flows Soil slips/slides	> 75 % of failures are landslide rubble. >25 % of block glides and slumps are potentially active and active.
Uplifts in Coastal Lowland and Valley	Block glides Block glide-flows Rotational slumps Slump-flows Rock falls Debris flows Earth flows	> 75 % are block glide or slumps of which > 25 % are reactivated or caused by man. Includes potentially active and active landslides.
North County/ northeastern slope of San Gabriel Mountains	Landslide rubble including rock falls, topples, avalanches and rock and debris slides Block glides, Earth flows Debris flows	>75 % landslide rubble Ancient to presently active.

The minimum size of an individual landslide shown on the landslide inventory map is five acres. Deeply to moderately deep-seated landslide clusters less than five acres are not shown, because most areas in the County are not mapped in enough detail (1:24,000), and even if mapped, would not have any application at such a regional scale. Clusters of smaller slope failures, however, may be delineated as a single feature or, where landslide mapping coverage is poor, they may also be identified as discrete landslides. This is done to demonstrate that landslides in certain areas may be characterized by smaller landslides such as slumps, debris flows, rockfalls, or other typically smaller failure types, perhaps as a function of rock type or geologic structure. These anomalous landslide areas are only shown where CDMG or Landslide Hazard Identification Program mapping differentiated surficial failure styles, such as in the Santa Clarita Valley Region, and in other isolated locations where they were mapped by Leighton (1966).

Uses and Limitations

The landslide inventory provides a regional illustration of landslide hazardous areas in Los Angeles County at a scale useful for general land use planning. It should not be used as a means for implementing County hillside policies. Hillside Areas, as defined in the General Plan (slopes greater than 25 percent), should be used to implement hillside management policy and evaluate building permits. This approach assumes all slopes are unstable, either as generally outlined on Plate 5, or where slope angles locally exceed an established critical angle of 18 degrees (25 percent grade). The distribution of landslides as defined by the inventory, and the discussion in the following sections, provides documented evidence of the inherent instability of the hillside environment in the County. The existence of a landslide potential in areas where landslides are not shown on Plate 5, cannot be precluded.

The landslide inventory is not a risk susceptibility map, so it does not attempt to depict relative slope stability. The influence of bedrock lithology, slope angle, and structure, at the very least, must all be considered to generate an accurate susceptibility map (Treiman, 1985). However, the landslide inventory can help in prioritizing slope mitigation efforts against apparent landslide and/or slope failure risks evident from Plate 5. For example, if a primary disaster or evacuation route traverses an area of mapped landslides, such as the abundant rockfalls in the San Gabriel Mountains (Table 3.6), the County may decide to inspect the route in detail and install rock nets, deflection fences, rock bolts, or even reroute the road (Bertero, et al., 1984). Accordingly, if a primary route is planned through areas where the materials are susceptible to rockfalls or avalanches, route planning of the road to avoid steep cuts may be feasible.

Conclusion

- Any slope can be rendered unstable by construction activities and almost any unstable slope can also be mitigated by accepted geotechnical methods. Geologic investigation is necessary regardless of an assigned relative slope stability or regional landslide mapping program.

SECTION 3.2.3

EARTHQUAKE-INDUCED SLOPE INSTABILITY

Los Angeles County, because of its mountainous terrain and high seismic activity, is at risk to earthquake-induced landslide hazards. A large earthquake could cause thousands of landslides within just a few minutes, exposing the population to a far greater risk than caused by any single landslide. Earthquake-induced slope instability can bury people and property, block roads necessary for emergency response, and sever important lifelines.

Tens of billions of dollars in damage from seismically-induced landslides have been incurred worldwide in this century alone, and in many cases have caused more financial loss than the effect of the ground shaking (Keefer, 1984). In particularly hazardous, perhaps extraordinary conditions, catastrophic earthquake-induced landslides have caused thousands of deaths through burial of entire cities below steep mountainous terrain (Wilson and Keefer, 1985). The 1971 San Fernando Earthquake triggered hundreds of small slumps, debris slides, and rock falls on the slopes of the San Gabriel Mountains. That extremely large slides were not observed has been attributed to the low moisture content of the slopes at the time of the earthquake (Weber, 1982). Nonetheless, the smaller slides showed that potentially adverse consequences could occur just from the ubiquity of road blockages triggered by widespread landsliding; landsliding of sufficient size and area capable of incapacitating vital evacuation or emergency response activities.

Future earthquake-induced slope failure and landsliding in Los Angeles County will closely correlate with the failure styles inherently characteristic to the underlying terrain, as described in Table 3.6. Observations of earthquake-induced, or dynamic slope instability, following the 1971, San Fernando Earthquake confirm this supposition (Clark, et al., 1979). During the San Fernando Earthquake the largest slides were generated in basement and certain sedimentary rocks. These particular failures consisted of rockfalls and were concentrated in highly jointed, fractured crystalline basement (Bm) and in massive, cliff-forming conglomeratic units (Tcs or Tss) (Clark, et al., 1979). There were limited occurrences of reactivated, large deep-seated landslides in some Tertiary units (Tsh and Tss), but they represented only a small percentage of the total slope failures generated (Weber, et al., 1982). Widespread shallow, surficial failures in Plio-Pleistocene (PQ) and Pleistocene terrace deposits (Pfm and Pc) were relatively common and widespread; however, they were small in magnitude.

The pattern of failures exhibited during the San Fernando Earthquake (M_L = 6.4) is consistent with earthquake-induced failures observed from worldwide historical records of earthquakes of similar magnitude (Keefer, 1984). The February 4, 1971 San Fernando Earthquake, however, occurred during a relatively dry winter. Had the ground been saturated by rainfall, the largest slides might have been more extensively reactivated. Given that the historical data set on reactivation of

large, deep-seated slides is incomplete, it is conceivable that such large landslides could be generated if either of the following conditions are met: 1) the landslide is marginally unstable (saturated) or 2) the earthquake is of extremely large magnitude (Keefer, 1984). Even larger shallow slope failures from a larger earthquake threaten more severe property damage and disruption of lifelines than was observed following the San Fernando Earthquake.

Assessment of Seismic Landslide Susceptibility

The special circumstances involving saturated earthquake-induced failures are not addressed in detail in this section. Instead, the emphasis of the regional assessment is concerned with relatively dry ground conditions. The regional review is based on the seismic slope response data acquired following the San Fernando Earthquake and the historical reviews and previous interpretations provided by Keefer (1984), Wilson and Keefer (1985), and Harp and Keefer (1985). The analysis predicts failure styles only in a general way and assumes all hillside areas in Los Angeles County are susceptible to the threshold of shaking necessary for seismic activation.

Shallow Failures

The predominant style of future earthquake-induced slope failure will be characterized by shallow, internally disrupted failures such as soil slides (sometimes referred to as soil slips), rockfalls, and rockslides. Table 3.7 shows these surficial failure types keyed to various hillside areas in the County and to specific engineering geologic units, as they are defined in Table 3.5 and shown on Plate 2. Table 3.7 is read from left to right, showing the engineering geology in the order of their suspected probability for experiencing a particular failure type. For example, in the Santa Monica Mountains, rockfalls will have a higher probability of occurring in bedrock units (Bm) relative to Tv, Tcs, and Tss units. The most susceptible slope angles for each failure type are listed along the same row to the right of failure style. Rockfalls in the Santa Monica Mountains are more likely to occur on slopes greater than 50 degrees, whereas, rockslides are expected on slopes greater than 45 degrees. The distinction is subtle, but any future interpretive maps in the County showing slope stability must consider such information after acquiring the needed structural controls from accurate geologic mapping, such as localized joint or bedding orientations. As shown in Table 3.7, all units are susceptible to shallow failures, and as indicated by Wilson and Keefer (1985), shallow failures may also occur on slopes with no previous history of failure. Shallow failures may also occur in some Pleistocene terrace deposits (Pfm - Pc). Surficial failures will be concentrated on intermediate slopes (35 to 40 degrees) of weathered colluvial material. Although hundreds of failures are likely, many will be of small magnitude, as observed during the San Fernando Earthquake.

TABLE 3.7 PROBABLE EARTHQUAKE - INDUCED SLOPE FAILURES LOS ANGELES COUNTY: CORRELATION WITH GEOLOGIC MATERIALS

A CORRELATION OF FAILURE STYLE WITH UNITS FROM PLATE 2

	GEOLOGIC MATERIALS	EARTHQUAKE INDUCED FAILURE TYPE	SUSCEPTIBLE SLOPES
SANTA MONICA MTS.	All units	Soil slides	If colluvium is present 15° < slope < 50°
	Bm, Tv, Tcs, Tss	Rock Falls and Rock Slides	Slope > 50° Slope > 45°
	Tsh, Ms	Deep-seated slumps and block glides	Slope > 15° reactivation of existing failures
SANTA SUSANA MTS. and SANTA CLARITA VALLEY	All units	Soil slides	If colluvium is present 15° < slope < 50°
	Tv, Tcs, Tss	Rock Falls and Rock Slides	Slope > 50° Slope > 45°
	PQ	Shallow slumps	Slope > 15° reactivation of existing failures
	Tsh	Shallow and deep seated slumps	
VERDUGO MTS. SAN GABRIEL MTS	All units	Soil slides	If colluvium is present 15° < slope < 50°
	Tv, Tss, Ms	Rock Falls and Rock Slides	Slope > 50° Slope > 45°
	Tsh, Ms	Shallow and deep seated slumps	Slope > 15° reactivation of existing failures
UPLIFTS IN LOWLAND AND VALLEY	All Units	Soil Slides	If colluvium is present
	Tsh, Ms, Tss	Deep-seated slumps and block glides	Slope > 15° reactivation of existing failures
	Tsh, PQ, Pfm, Pc, Tcs, Tss	Shallow slumps	Slopes > 15°
	Tv, Tcs, Tss	Rock falls and rock slides	Slopes > 35°
NORTH COUNTY	All Units	Soil slides	If colluvium is present 15° < slope < 50°
NORTHEASTERN SLOPE OF SAN GABRIEL MTS.	Bm, Tv, Tss	Debris slides, rock falls, rock slides, and rock avalanches	Slopes > 35°
CHANNEL ISLANDS	All units	Soil slides	If colluvium is present 15° < slope < 50°
	Tsh, Ms	Deep-seated slumps and block glides	Slopes > 35°
	Bm, Tv, Ms	Rock Falls	Slopes > 35°

1. Shallow slumps may occur in Pfm deposits- slopes > 10° .
2. Existing failures of less than 10 acres may not be shown on Plate 5.
3. Rock falls and rock slides in Qc or Pc also on slopes > 45° .
4. The order of rock types (geologic materials) roughly indicates the frequency of the failure type. (First listed = greater frequency)
5. Predominately dry conditions are assumed.

1. Campbell (1975)
2. Harp and Keefer (1985)
3. Morton and Kennedy (1979)

Rockfalls and Rockslides

Most rockfalls and rockslides will be restricted to road cuts and artificially-cut slopes, making their mitigation necessary when emergency access or regress is paramount. Rock failures will be abundant in the San Gabriel Mountains, where large outcrops of crystalline (Bm) and massive sandstone (Tss) rocks occur on steep slopes throughout the entire area (Table 3.7). Rockfalls and slides will occur in well-jointed intact rocks, while rock avalanches will result from failure of the steep, unstable talus slopes, especially common on the northeastern slope of the mountain range (Morton and Kennedy, 1979). Numerous rock failures are also likely in units dominated by cobbles and boulders (Tcs). A potentially catastrophic 100,000 m^3 rock avalanche has been identified at the mouth of Topanga Canyon (Harp and Keefer, 1985). Harp and Keefer (1985), also raise concern that downslope areas below the massive conglomerates on Cahuenga Peak and Mount Hollywood may be subject to large rock avalanches. In general, Plate 2 identifies the most extensive occurrences of massive conglomerates capable of producing the largest volume of debris and the largest boulder-sized fragments; however, localized conglomeratic units and thinly-bedded sandstone units of certain formations are not adequately represented. Harp and Keefer (1985) indicate that small beds of conglomerates and/or heavily fractured or nonextensive susceptible units can also produce catastrophic damage. Therefore, it is recommended that Table 3.7 and Plate 2 provide only the impetus for more detailed, larger scale studies in areas susceptible to rock failures.

Artificial Fills

Earthquake shaking ($M_L \geq 6.5$) will trigger numerous slumps in old, poorly compacted artificial fill. Highly susceptible fills are those related to housing developments, railroad embankments, the outer edges of highway embankments, dikes and bridge abutments (EERI, 1986). Bridge and highway approaches settled due to slope failure, displacing the roadway as much as 2 to 3 feet during the San Fernando Earthquake (Oakshott, 1971).

Seasonal Influences

Rain-saturated slopes, in addition to increasing the likelihood for reactivated, deep-seated slides, could affect the run-out distance and velocity of soil slides (Harp and Keefer, 1985). If a potential soil slip is completely saturated, the shaking could liquefy and mobilize the soil slide downslope as a high velocity debris flow. At the present time there is not enough data to determine how much the risk of debris flow activation would be increased by ground shaking; however, it is obvious that some increase is likely. Campbell (1975) speculated that if saturated conditions were extraordinary, moderately deep-seated landslides might even give rise to catastrophic failures capable of burying large downslope areas. Increasing the severe losses from such a phenomena are the rapid debris flows that could emerge from the toes of these slides if activated. The characteristics of deadly debris flows are discussed in the following section.

Conclusions

- Tens of billions of dollars in damage thousands of deaths have been attributed to small to extraordinary earthquake-induced landslides in the 20th century on a worldwide basis.

- The 1971 San Fernando Earthquake triggered hundreds of small slumps, debris slides, and rockfalls on the slopes of the San Gabriel Mountains. That extremely large slides were not observed has been attributed to the low rainfall.

- Small surficial slides may have adverse consequences on emergency response for isolated hillside areas given the expected ubiquity of road blockages triggered by widespread landsliding.

- Surface rupture caused by shutter ridge phenomenon and other topographic focusing effects may significantly disrupt surficial materials in hillside areas. This slope failure process is controlled by near surface geology, which in many cases may be attributed to pre-existing landslides, bedding planes, and other discontinuities.

SECTION 3.2.4

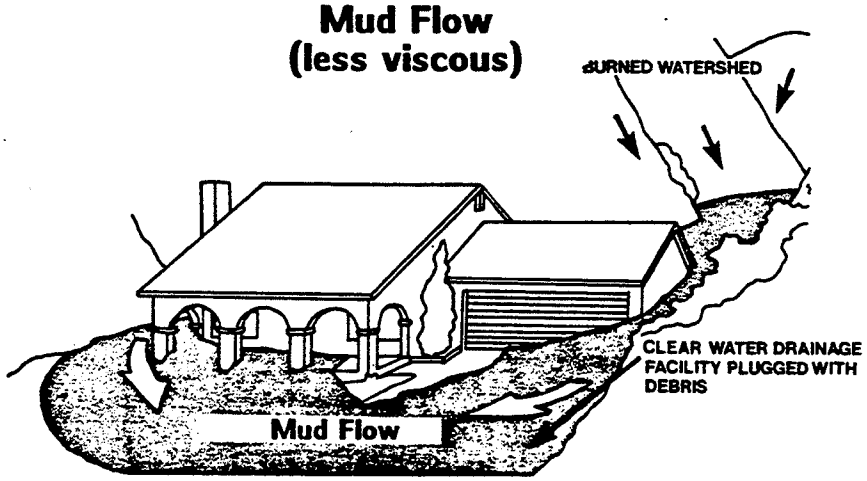
RAINSTORM-INDUCED SLOPE INSTABILITY

Los Angeles County has had much experience with damaging rain-induced slope instability. As reported by the Los Angeles Times and other media sources, the damage was mainly the result of "mudslides". The official terminology adopted by the National Flood Insurance Program (Campbell, 1985) defines rain-induced failures along a continuum, beginning with clear water and mud floods and progressing into mudflows and debris flows (Figure 3.10). Unless otherwise stated, mudflows and debris flows will be referred to simply as "flow failures" in the discussion that follows. The emphasis will be on debris laden flows occurring on/or at the base of steep terrain not covered by the National Flood Insurance program. The following summary of selected rain-induced landslides and "flow failure" events in California during the last 20 years is introduced as background:

- 1969 - Flow failures were responsible for 24 deaths throughout southern California, many of them occurring in Los Angeles County (Weber, 1984). Flow failures became associated with burnt watershed areas, and costly damage was incurred on developments situated below the recently burned San Gabriel Mountains. However, Campbell (1975), noted that much of the damage and all the fatalities resulted from mudflows and debris flows originating from unburnt slopes. Damages were documented Countywide, but the largest concentration of occurrences of slope instability were located in the Santa Monica and San Gabriel Mountains, and the Santa Clarita Valley area. An exceedingly low estimate of $6 million in property damage was recorded, prompting State and Federal disaster agencies to emphasize accurate documentation of landslide related financial losses (Campbell, 1985).

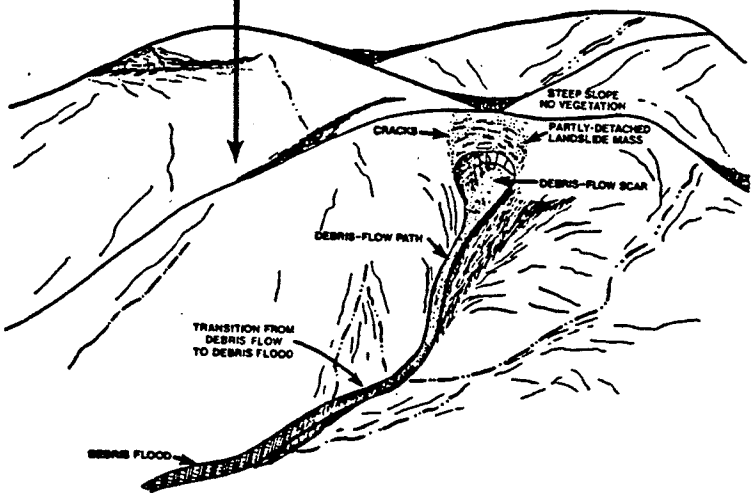
- 1978 - Two major rainstorms triggered destructive debris flows, many originating from burnt hillside areas in the San Gabriel Mountains. Also recurring were serious damages from debris flows originating from unburnt slopes in the Santa Monica Mountains and hillside areas in the coastal lowlands and valleys, particularly in Monterey Park and the Baldwin Hills. Areas underlain predominately by units more susceptible to rotational and block glide failures, although experiencing debris flows, received most of their damage through reactivation of deep-seated bedrock failures.

Mud Flow
(less viscous)



HOME CONSTRUCTED IN BOTTOM OF CANYON OVERRUN BY DEBRIS

Class of Phenomenon	Event	Location		Covered by NFIP	Status of Hazard Mapping
FLOOD	Clear Water Floods	Floodplains	Drainage Channels and Alluvial Fans	Yes	Now Mapped
	Mud Floods				Not Now Mapped
LANDSLIDES	Mud Flows	Hillslopes		No	
	Debris Flows and Other Landslides				



Debris Flow
(more viscous, composed of rocks, cobbles, and mud)

Figure 3.10: Mud and debris-flow hazards: rapid velocity slope failures with variable degrees of saturation. Debris flows may originate from hollows, as shown below, or can be associated with mud flow incidents such as the circumstance shown above. Gravity, earthquakes, or a sudden flow of debris-laden water can be a triggering mechanism (modified after FEMA and USGS).

Pervasive and costly failures did occur on both graded and natural slopes in the Repetto Hills (including Monterey Park), in the form of shallow slumps, earth flows, and debris flows. Storm-triggered landslide damage in the City of Los Angeles alone, to both private and public property, was estimated at $100 million (Slosson and Krohn, 1982). The affect of damages on small businesses due to the loss of productivity, on agricultural activities because of damaged crops, or other subtle consequences were not factored into the loss estimation.

- 1980 - A series of six rainstorms hit southern California from February 13 to 21, 1980, causing major landsliding. Several people were missing and presumed killed in the San Gabriel Mountains and one woman was killed in the Santa Monica Mountains by debris flows (Davis, 1982). Fifty people were evacuated from an apartment in Montebello when a large slope behind the complex came close to failing (Weber, 1980). In the Santa Monica Mountains, sewer mains broke as result of landslide movement, releasing 80 million gallons of raw sewage. Throughout the County, but especially in the Santa Monica Mountains, huge boulders, rocks, and masses of earth materials from roadcuts, partially severed roads traversing steep terrain. Landslide damage was estimated at $500 million dollars in southern California counties with the City of Los Angeles experiencing approximately $140 million in losses to private and public property (Slosson and Krohn, 1982). The losses were attributed to landslides, debris flows, mudflows, and other related slope failures. Loss estimations began to include direct costs from public and private repairs and indirect costs from socioeconomic effects (Campbell, 1985).

  During the 8-1/2 day period, 111 homes were destroyed and more than 1,350 were damaged (Weber, 1980). More than $130 million dollars were requested in the form of Federal disaster relief. The Small Business Administration made nearly 255 million dollars in low interest loans to 2,965 businesses and 12,851 homeowners (Weber, 1980). $95 million dollars were paid directly from the Federal Emergency Management Agency National Flood Insurance Program, but as noted earlier, coverage was limited to clear water and mud floods (Figure 3.10).

- 1983 - Major damage (totals estimated at about $300 million including reactivated bedrock landslides) occurred in the San Francisco Bay Area. Confirmed deaths were tallied at 19 with five more people missing and presumed dead. The dead and missing were the result of 11 debris flows and one major rapid block slide associated with peripheral debris flows emanating from the frontal lobe of the slide mass (Brown, 1984).

Assessment of Rain-Induced Slope Instability

Table 3.8 shows several geographic hillside areas in the County and their susceptibility to various types of rain-induced failures. This discussion focuses on debris flows caused by geologic and topographic instability, rather than on those caused by increased hillside erosion following a fire. The fire/flood sequence is discussed under Section 3.3 "Flood and Inundation Hazards". As discussed previously in Table 3.7, the order of bedrock units (from

left to right) under the geologic materials column identifies the most vulnerable unit to the type of failure listed to the right under the failure type column. Farther to the right, the slope angles most susceptible to these types of failures are also presented. Again, as with Table 3.7, Table 3.8 is highly generalized and does not consider the many other variables controlling slope stability, such as the geologic structure. The table does demonstrate the range of landslide failures of concern to County agencies responsible for hillside management.

Table 3.8 shows that debris flow failures are independent of the underlying rock type. Because flow failures originate from soil slip features in colluvial soil (slope wash) and ravine fill, their distribution depends on an adequate volume of debris in the source area, the necessary slope angles, and a prolonged period of saturation (Table 3.8). Slabs of various viscosities can attain velocities of ten feet per second as they scour through ravines downslope and impact and inundate residences and businesses below. The velocities of debris flows are increased even more when perched water causes a buildup in pore pressure in the slope (Reneau and Dietrich, 1987). The buildup in pore pressure can literally cause the flow failure to shoot out of the slope. Such conditions may occur on the bedrock-colluvium contact or within stratigraphic sequences of layered geologic units in many localized areas of the County.

Figure 3.10 shows that debris flow failures, in addition to not being covered by the National Flood Insurance Program, are not mapped by the Federal Emergency Management Agency. Recent research summarized by Reneau and Dietrich (1987) indicates that geomorphic features may be employed as a method to delineate debris flow sources and hence debris flow susceptibility. Hollows are bowl-shaped geomorphic scars located at the top of swales and serve as a source area for debris flows. They constitute an important mappable feature in hillside areas that could help to better guide development away from these narrow debris chutes in the early stages of development. Significantly, experience in northern California has demonstrated that these mappable features can be subtle. Case studies have shown that hollows can be invisible on 1:24,000-scale U.S. Geological Survey topographic maps, and if located in heavy brush, may not even be detected on standard aerial photographs. This suggests that large scale geologic and geomorphic mapping is needed to provide the best possible maps showing debris flow susceptibility.

Conclusion

- Debris flow failures may occur in any hillside area, their distribution depending on an adequate volume of debris in the source area, necessary slope angles, and a prolonged period of saturation (Table 3.8).

TABLE 3.8 PROBABLE RAIN - INDUCED SLOPE FAILURES IN LOS ANGELES COUNTY: CORRELATION WITH GEOLOGIC MATERIALS

A CORRELATION OF FAILURE STYLE WITH UNITS FROM PLATE 2

AREA	GEOLOGIC MATERIALS	FAILURE TYPE	SUSCEPTIBLE SLOPES	REMARKS
SANTA MONICA MTS.	All units	Debris and mud flows Earth flows	18° > slopes > 56° Slopes > 27°	Most destructive 27° >slopes>56°
	Bm, Tv, Tcs, Tss	Rock falls, slides, topples	Slopes > 56°	Large avalanches possible
	Tsh, Ms, Tss	Composite rotational slumps and block glides.	Slopes > 15°	Damage due to foundation distress
	All Units	Artificial fill failures	Slopes > 15°	
SANTA SUSANA MTS. & SANTA CLARITA VALLEY	All units	Debris and mud flows, Earth flows	18° > slopes > 56° Slopes > 27°	High concentration in PQ & Tss Small slumps upslope
	Tv,Tss, PQ	Rock falls and rock slides	Slopes > 56°	
	Tsh, Tss	Composite rotational slumps and block slides.	Slopes > 15°	Largest most common on dip slopes
	All Units	Artifical fill failures	Slopes > 15°	
VERDUGO MTS. SAN GABRIEL MTS.	All units	Debris and mud flows	22° > slopes > 40° 18° > slopes > 56° (unburnt)	Especially vulnerable to fire-flood sequences
	Bm, Tv, Tss	Rock falls, slides, topples	Slopes > 45°	Snowmelt can contribute to risk
	Tsh, Ms	Composite rotational slumps and block glides	Slopes > 15°	Not abundant
	All Units	Artificial fill failures	Slopes > 15°	
UPLIFTS IN LOWLANDS AND VALLEYS	All units	Debris and mud flows Soil slips/ Earth flows	18° > slopes > 56°	Scattered occurrences of flows
	Tcs, Tss, Tv	Rock falls and slides	Slopes > 18°	
	Tsh, Ms	Composite rotational slumps and block glides	Slopes > 35°	Prevalent in Puente/San Jose Hills; most common on dipslopes
	All Units	Artificial Fill Failure	Slopes > 15°	Erosion/Rilling is very common
NORTH COUNTY NORTH-EASTERN SLOPE OF SAN GABRIEL MTS.	All units	Debris and mud flows	18° > slope > 56°	Spring thaw contributes to risk
	Bm, Tv, Tss, PQ	Composite rock fall, avalanche, block slide	Slopes > 56°	Snow avalanches can dam up and accumulate debris.
		Large rock falls and slides		Abundant near fractured rock adjacent to fault zones
	All Units	Artificial fill failures	Slopes > 15°	Rapid moving large blocks and rubble

1. Debris flows occur at peak rain fall.
2. Reactivation of slumps and glides may not be apparent until long after storm.
3. The order of rock types, or geologic materials, roughly indicates the frequence of failure type.
4. Destructive potential occurs when soil slips (debris source) originates on higher slope angles.

1. Campbell (1975).
2. Campbell (1982)., and Weber and Willis (1983).
3. National Research Council, (1982).
4. Morton and Kennedy (1979).

SECTION 3.2.5

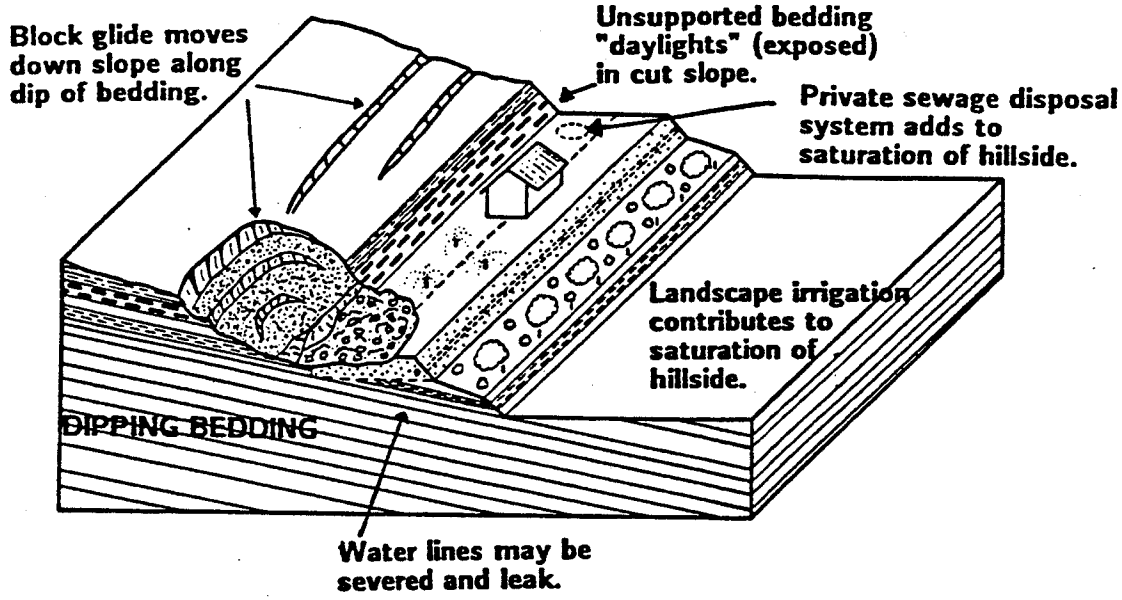
MAN AND DEVELOPMENT-INDUCED LANDSLIDING

During the last 20 years, improvements in grading codes and tract development techniques have reduced the potential for damage from landslides to hillside development constructed under their provisions. Most developers find proper site investigations and project design not only economically feasible, but a required component of hillside development in the County of Los Angeles. The overall cooperation expressed by private industry lies in the philosophy that the cost of preventing landslides is far less than the cost of correcting post-development failures. Weber (1982) and Brown (1984), however, have observed that some of the properties most damaged during the 1980 and 1983 storm events in California involved recently constructed buildings. This suggests that grading and hillside project design regulations in the building code should be considered evolving programs that must be improved from time to time, as new potential problems become evident. The crux of the hillside development issue then, is to regularly review existing codes for improvements, and provide for clear and enforceable standards on all hillside improvements.

Los Angeles County provides a model program for hillside development, as authorized in the General Plan and defined in the County Building Code. Foremost is the requirement for geologic investigations in all hillside areas. Appendix 3 shows geologic investigation guidelines approved by the California Division of Mines and Geology. Private consultants may, at their discretion or unless directed otherwise, adopt such criteria in fulfilling hillside development regulations. Leighton (1976) estimated that 95 to 99 percent of all proposed development in any hillside area can be safely designed if proper investigation and grading practices are followed.

Downhole logging, trenching, sampling, and lab analyses are fundamental aspects of any geotechnical investigation. During this stage of development, the detailed investigations may reveal numerous slope stability problems not evident from earlier phases of the investigation. This initial design phase and any modifications proven necessary during the actual grading operation helps ensure the future integrity of the building pad. Based on detailed subsurface data, the geotechnical consultant prepares site plans and cross-sections, indicating the distribution of alluvium, artificial fill, bedrock types, potentially problematic geologic structures, and existing shallow hydrogeologic (perched water) conditions.

Figure 3.11 shows examples of slope problems that have characterized hillside development in Los Angeles County. Most of the conditions shown in Figure 3.11 represent elements of actual case histories, generally caused by hillside development prior to the establishment of adequate safeguards in the form of grading codes. It also shows the types of failures the current, more stringent codes, are designed to prevent. The top schematic of a typical cut and fill development demonstrates that bedding surfaces that dip out-of-slope can be



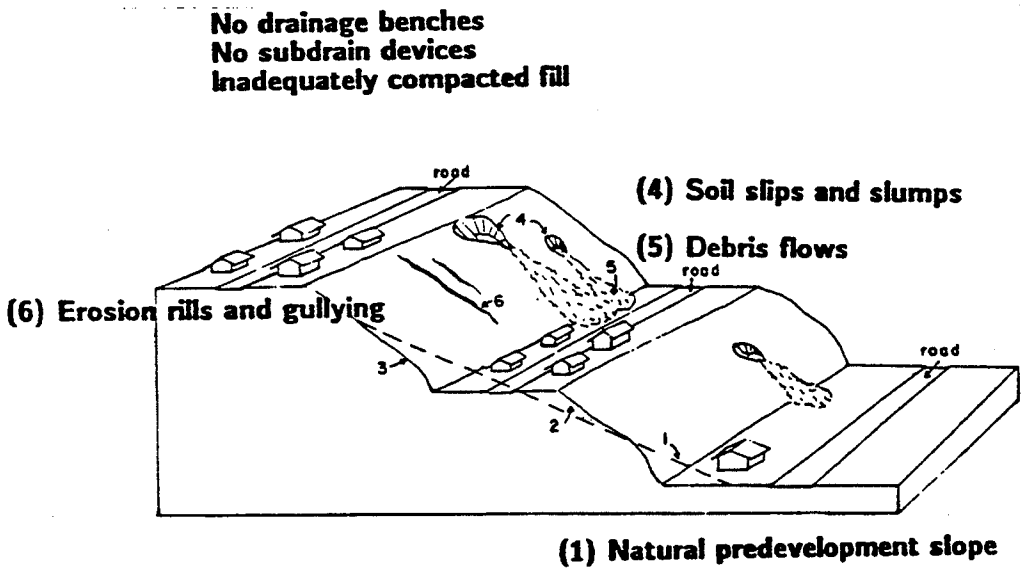


Figure 3.11: Slope instability caused by improper hillside development. Out of slope bedding is made unstable through the overwatering of slopes and leaky sewage systems (above). Improper grading practices or inadequate design for out-of-slope bedding, or poorly-indurated (loose) sandy bedrock in the slope face, can lead to erosion, slumps, and landsliding, especially when the slope is over-steepened (below) (modified after Leighton, 1966; Weber et al., 1982).

highly unstable unless mitigated. In this case the bedding provides a "slip plane" that causes the downslope movement of discrete blocks or masses of earth capable of disrupting building foundations, swimming pools, or anything else in its path. Some of the more pertinent causes of postdevelopment hillside failures are also illustrated in Figure 3.11, including the addition of water through landscape irrigation, leaking waterlines, and private sewage disposal systems. Artificially introduced water into the slope makes marginally stable slopes more prone to failure. Weber, et al., (1982) estimated that an average homeowner adds the equivalent of tens of inches of rainfall a year by just landscape watering. As illustrated in Figure 3.11, once slope movement occurs and breaks waterlines or swimming pools, the problem becomes worse and may even cause rapid failure of the fill. Such problems may also result from settlement of improperly compacted fill, making the origin of the problem difficult to ascertain unless a post-failure investigation is immediately performed.

Once in place, hillside development significantly alters the natural landscape in such a way as to promote erosion of slope materials. The County requires developers to devise specific hillside protection measures to alleviate this problem. For example, as illustrated in the bottom schematic in Figure 3.11, the developer may grade the property to direct rainwater away from the lot and towards drainage devices, or plant the slopes to prevent erosion. Selected factors involved in initiating deeply-rooted or surficial slope failures in cut and fill development are listed in Table 3.9. The goal of the Safety Element is to promote hillside development practices that avoid such consequences.

Hillside Development Constraints and Solutions

Hillside development in Los Angeles County has proven vulnerable to several types of slope instability. Slope stability options must be patterned to the particular geologic and engineering conditions, density and pattern of development, and economic considerations. A series of examples illustrate main problems responsible for past slope failures, as well as established engineering solutions (Figures 3.12, 3.13, 3.14). They are summarized as follows:

- Unsupported bedding "daylights" dipping out-of-slope;
- oversaturation of bedrock from natural or artificial sources reactivates ancient "potentially active" landslides; and
- intense rainfall causes runoff and increased erosion of unprotected slopes.

TABLE 3.9 - SELECTED CAUSES OF SLOPE FAILURES

Potential Causes of Failures - Cut Slopes

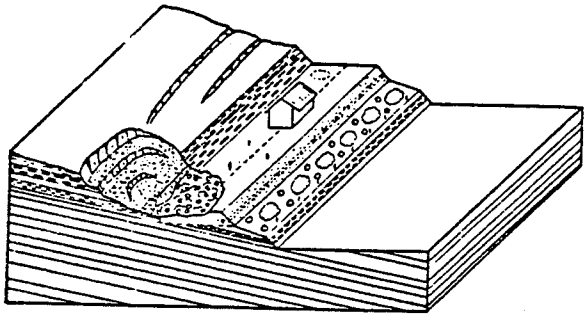
1. Excessively steep, greater than 2:1, natural and graded slopes.
2. Slopes formed of easily erodible sandy material.
3. Abundance of gopher and ground squirrel holes can facilitate infiltration of water during rainy seasons and cause deterioration of slopes.
4. Out-of-slope dipping bedrock.
5. Improper or lack of brow ditches above slopes; brow ditches help prevent water cascading down the slope face.
6. Inadequate vegetation to prevent shallow surficial failures.
7. Excessive water in slopes: landscape watering, broken utilities, cesspool seepage or poorly located cesspools.
8. Graded slopes which lack drainage terraces or benches. Benches intercept rainfall runoff and reduce erosive gullying.

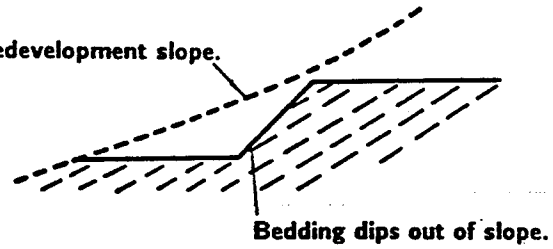
Potential Causes of Failure - Fill Slopes

1. Excessively steep, greater than 2:1, slopes without adequate structural reinforcement.
2. Placement of fill materials on loose natural materials, existing vegetation, or trash materials.
3. Placing the fill in layers that are too thick and not adequately compacted.
4. Excessive watering of the slope.
5. Poorly maintained benches allowing infiltration.
6. Improper drainage due to lack of subdrain and back drains.
7. Poor compaction (back-rolling) of the slope face during construction.

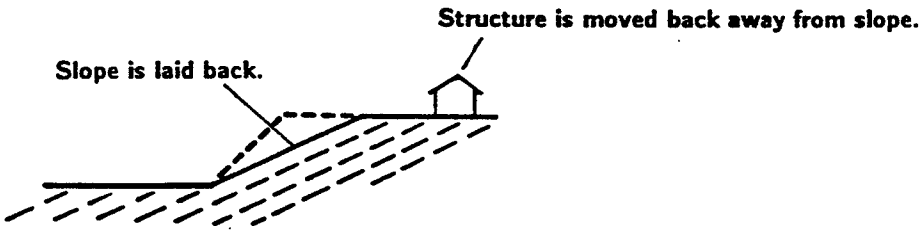
PROBLEM

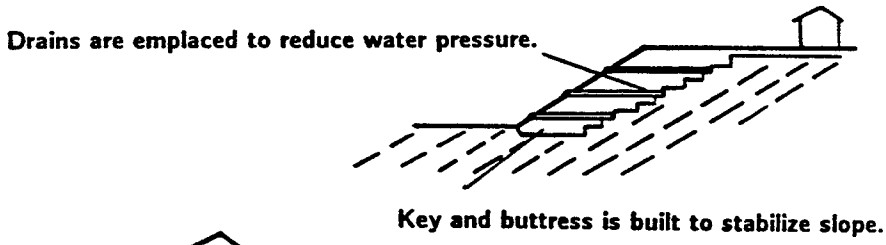
UNSUPPORTED BEDDING DAYLIGHTS AND IS DIPPING OUT OF SLOPE





SOLUTION





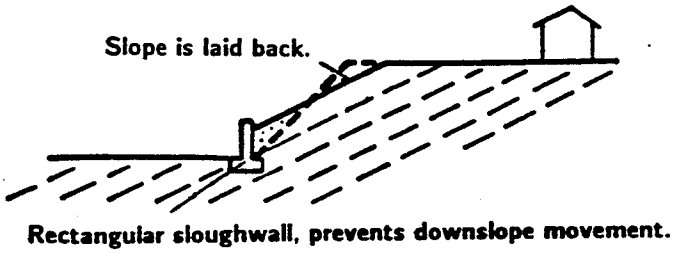


Figure 3.12: Solutions exist for slopes that were graded and designed prior to current grading standards (modified after Leighton, 1966).

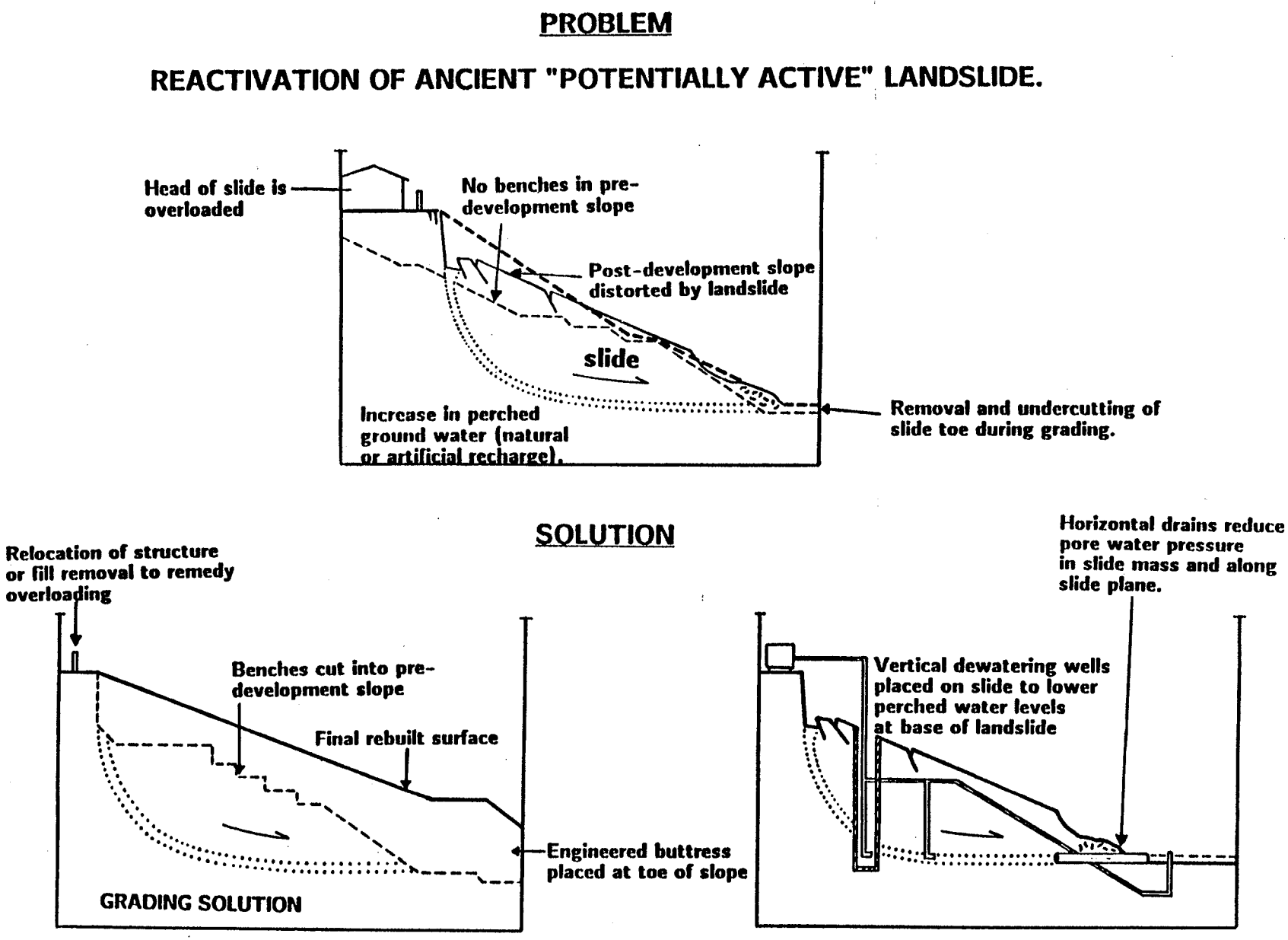
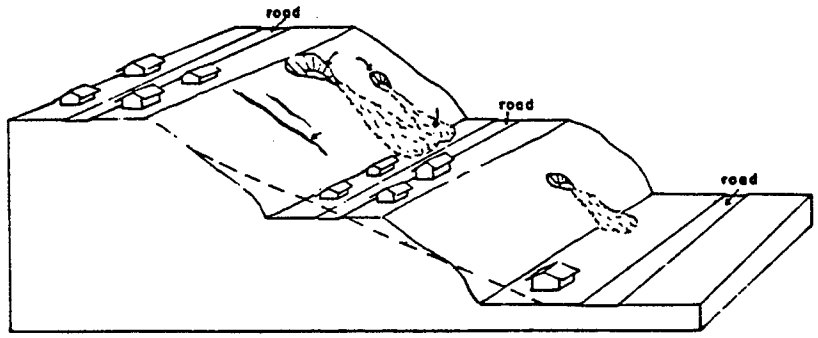


Figure 3.13: Solution for mitigating landslide hazards (modified after Leighton, 1966).

PROBLEM

HEAVY RAINS CAUSE OVERSATURATION, RUN-OFF, AND EROSION OF HILLSIDE.

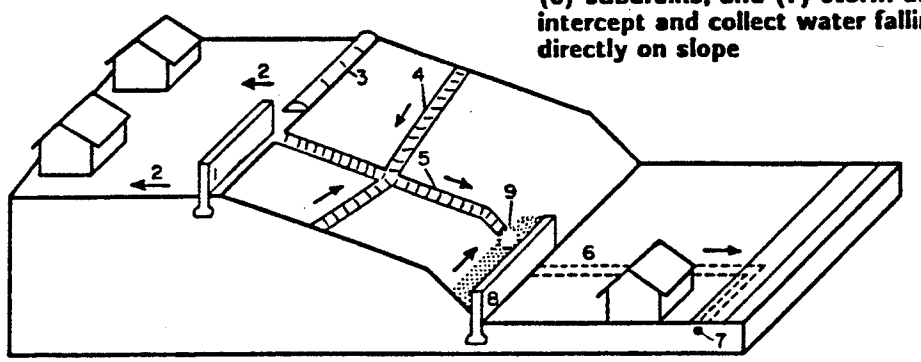


SOLUTION

(3) Berms prevent water from draining down slope

(2) Regrading diverts drainage away from slope

(4) Bench drains, (5) slope drains, (6) subdrains, and (7) storm drains, intercept and collect water falling directly on slope



(8) Slough wall intercepts debris flows

(1) Retaining wall protects from lateral movement of fill

(9) Fill graded to divert water into subdrains into (6) outlet pipe and (7) storm drain

Additional Measures

Slope surface covers - Gunite, building blocks, and clear plastic sheeting (temporary) prevent erosion

Vegetation cover - Deeply rooted, drought resistant, fire resistant vegetation prevent excessive erosion

Figure 3.14: Solutions for mitigating slope erosion (modified after Weber, et al., 1982).

Case History: Big Rock Mesa Landslide, Los Angeles County - 1989

The Big Rock Mesa Landslide is an example of a prehistoric "potentially active" landslide complex that became activated after years of development. The landslide is actually composed of six major translational block glides covering an area of about 190 acres, of which at least 155 acres are involved in the recent movement (Michael, 1986). At least 81 residences are located within the main failure area. A brief synopsis of events, summarized from Michael (1986), leading to the current situation is presented in the following paragraphs:

1. Early development occurred on a small portion of the landslide complex between 1940 and 1960. The earlier development adhered to less stringent subdivision and building code regulations. By 1961, a local rise in perched water and shallow aquifer levels was detected. During the review stages for later development in 1963 there was disagreement as to the appropriate means of controlling sewage effluent, as standards were not yet clearly defined.

2. By 1972, evidence of high ground water levels resulted in the first warnings that dewatering might be necessary. Merifield (1973) noted possible precursor movement in the form of tensional cracking. Fractures were definitely correlated with movement in 1979 and by late 1983, residents became fully apprised of the seriousness of the slide.

3. Residents decided to sue various public agencies, including the County, for negligence for allowing development to continue with only onsite sewage disposal. County Water Works District 29 filed a cross-complaint naming residents and all previous private consultants.

4. The parties engaged in the suit agreed to a $97 million out-of-court settlement for 240 Malibu residents in 1988/89.

The Big Rock Mesa Landslide provides a prime example of the types of problems inherent in developing hillsides in Los Angeles County, even with the continued improvement and application of one of the most state-of-the-art building codes in the United States. The landslide complex also illustrates the complex legal and technical issues that hillside development presents. Because of the litigation, a multiplicity of theories regarding the cause of the landslide have been advocated by numerous experts representing their clients. There is general agreement that a rise in ground water served as the triggering mechanism; however, the source of the water became a legal issue (Michael, 1986). The fact that all of the major failures were centered around concentrations of septic tank effluent injection sites suggested this could have been a significant source of artificial recharge (Michael, 1986). However, the significant movements also occurred following heavy rain periods of 1969, 1978, and 1980, suggesting this also could have contributed to the instability.

Another issue was that continuing piecemeal development of the landslide allowed builders to avoid the landslide mitigation question. The argument was that their relatively small projects could not feasibly stabilize, nor destabilize, such a large landslide. This suggests that retroactive and proactive measures, governing long-term stability of large "potentially active" landslides, should

be part of a comprehensive hillside management program rather than considering each project on a case-by-case basis.

Conclusions

- Regular review of existing building code regulations is necessary to improve hillside safety and prevent future economic losses to public and private property.
- Proper slope design should include the worst-case effects of fluctuating perched water levels.
- Fill slopes are most stable if constructed at 2:1. To achieve the same margin of safety for slopes steeper than 2:1, structural reinforcement should be considered.
- Adequate building setbacks and structural mitigation provide the most effective strategy of ensuring safety and preventing losses from debris flows and earthquake-induced slope failures.
- Construction of structural reinforcement along road cuts adjacent to primary and secondary evacuation routes provides the greatest margin of safety by ensuring access and regress for emergency response.
- Adequate monitoring of perched water in existing hazardous landslide areas provides the earliest recognition of potential problems.
- The cooperation of private property owners is essential in a comprehensive hillside safety program. Homeowners should be provided with easily accessible geologic and other appropriate information, and incentives or disincentives to achieve slope stability.
- A comprehensive hillside program must include provisions for post-development problems, including dewatering contingency plans, regulations designed to reduce all sources of artificial ground water recharge, and regulations for subsequent development on adjacent properties.
- Alternative comprehensive programs for new development on large "potentially active" landslides should be considered, including strategies on managing the development of such areas when it is occurring on a parcel-by-parcel or small subdivision basis.
- Geologic and geomorphic field mapping is a necessary element of a debris flow susceptibility mapping program. Other slope stability maps are only feasible if adequate geologic information, such as rock type, geologic structure, and topography are mapped at scales of at least 1:24,000.
- A proactive program of public education explaining the financial benefits of homeowner slope maintenance, the consequences for slope problems related to their activities on their property, and the need for full homeowner cooperation is a necessary component of any hillside management plan.

SECTION 3.2.6

SUBSIDENCE AND UNSTABLE SOILS

Certain areas of Los Angeles County are prone to regional downwarping and rapid subsidence. Withdrawal of underground fluids, and tectonic elevation changes produced during extremely large earthquakes are most important in terms of potential causes. This section focuses on land subsidence initiated exclusively by the withdrawal of oil and water. Consistent with nonearthquake-related geologic hazards, a review of collapsible and expansive soils is also presented to emphasize that potential geologic impacts, as well as geotechnical constraints, can largely be avoided through adequate planning and investigation.

Oil Field Subsidence

Subsidence related to oil resource development in the Los Angeles Basin became an issue in the 1950's and 60's. Of the 15 main oil fields in the Los Angeles Basin, the Beverly Hills/Cheviot Hills, Santa Fe Springs, Wilmington, and Inglewood Oil Fields displayed significant subsidence during that time period (Wentworth et al., 1970). In the Wilmington Oil Field, damage to industrial facilities, buildings, utilities, and transportation facilities, and the threat of inundation to low-lying areas in Long Beach, prompted oil companies to begin pumping large amounts of water or steam into reservoir rock to counteract the subsidence. This had the effect of repressurizing the oil reservoir and immediately began slowing subsidence rates. By the early 1960's, water injection/flooding operations are believed to have minimized subsidence in the other rapidly subsiding oil fields in the Los Angeles Basin as well (Castle and Yerkes, 1976).

In Los Angeles County, the City of Long Beach and the State Division of Oil and Gas presently administer a post-oil production plan to ensure that subsidence does not resume. This is especially critical given the progressive abandonment of oil wells in the South Bay area. Similar post-oil production plans, which include repressurization of underground aquifers and oil reservoirs, are advocated in other past subsidence areas in the Los Angeles Basin (Castle and Yerkes, 1976). It is significant that with the exception of the City of Los Angeles, and the post-production plan in the Long Beach area, no other local agency currently monitors elevation changes in past subsidence areas. The County ceased vertical surveying of unincorporated and adjacent areas in 1978. Such documentation is essential to establish the need for repressurization following oil well abandonment.

Along the margins of subsidence areas, and along existing discontinuities in overlying bedrock, subsidence can cause faulting or extensional ground fissures. For example, Castle and Yerkes (1976) described earth cracks in the Baldwin Hills/Inglewood Oil Field, some with several inches of displacement. Some of these earth cracks are identified as fault rupture hazards (see Plate 1) and have been mapped as Alquist-Priolo Special Study Zones. Whether the displacement was

caused by tectonic distortion, known as fault creep, or due to the withdrawal of underground fluids, has not been substantiated by the State Division of Oil and Gas. Continuing creep, if any, along these fault/fissure segments is not presently monitored by any government agency.

Subsidence Caused by Ground Water Withdrawal

Subsidence caused by ground water withdrawal is documented throughout the southwestern United States in areas such as the San Joaquin, Santa Clara, Temecula, and San Jacinto Valleys in California, and the Phoenix and Tucson Basins in Arizona. There are several areas in Los Angeles County that are also potentially sensitive to withdrawal of ground water. Depending on the depth and mechanical properties of the aquifer and overlying sediment, alluvial areas such as Antelope Valley, Santa Clarita Valley, and San Jose Valley (in Los Angeles County) can subside if ground water management resources are not managed properly. Hydrocompaction is a common cause of subsidence and has resulted in extensive fissuring of the ground surface in many agricultural areas of the Southwest (Holzer and Clark, 1981).

Subsidence was identified as an issue in the Antelope Valley as early as 1966 by Miller (1966) and appears to continue today. The U.S. Geological Survey Water Resources Division is currently studying subsidence and ground fissuring on the Edwards Air Force Base (Bill McKafery, 1990 Personal Communication). Considering the ongoing rapid growth in the area, subsidence is also a critical issue in the remainder of Antelope Valley. Severe damage to urban development could result if ground fissures develop in response to subsidence, and alarmingly, such ground rupture has been documented in the Antelope Valley. T.L Holzer and M.M. Clark (1981), in an unpublished report for the Soil Conservation Service, described an arcuate earth fissure approximately 600 meters long and up to 2.3 meters deep about 11 kilometers east-northeast of Lancaster. Additional fissuring north of Quartz Hill and in other localized areas is also reported but no regional studies have been conducted to determine the extent of the potential problem (Bill McKafery, 1990 Personal Communication). If several jurisdictions are utilizing a continuous ground water aquifer resource in the Antelope Valley, and ground water extraction is found to be the cause, subsidence management would require regional cooperation among these agencies.

Collapsible Soils

Collapsible soils are low density, silty to very fine-grained, predominantely granular soils, containing minute pores and voids. When saturated, these soils undergo a rearrangement of their grains and a loss of cementation, resulting in substantial and rapid settlement under relatively low loads. A rise in the ground water table or an increase in surface water infiltration, combined with the weight of a building or structure, can initiate rapid settlement and cause foundations and walls to crack. Collapsible soils generally result from rapid deposition close to the source of the sediment where the materials have not had contact with enough moisture to form a compact soil after their deposition.

Collapsible soils are associated with recently deposited Holocene alluvium in arid and semi-arid environments. They also coincide with other Holocene alluvium and older unconsolidated sediments with the same properties. Collapsible soils are most commonly associated with wind laid sands and silts, and mudflow sediments deposited during flash floods.

Collapsible soils exist in the Antelope Valley and many other alluvial areas of the County, including the Santa Clarita Valley. Although also found in the northern canyons of the Repetto and Whittier Hills, including such areas as Hacienda Heights and Rowland Heights, collapsible soils indigenous to these areas may not collapse unless they are subject to excessive loads (greater than 2 to 3 feet of overburden). In the Antelope Valley, collapsible soils may fail with a minimal amount of increased overburden. The rapid increase in population and building activity in the Antelope and Santa Clarita Valley necessitates awareness of this problem by public officials, consultants, developers, future homeowners, and contractors. The raw data for mapping this hazard exists in the form of Bureau of Reclamation Soil Survey Maps and Quaternary sediment mapping performed by Ponti and Burke (1980). While the mapping of collapsible soils is beyond the scope of this project, a future study should be directed at preparing a collapsible soils distribution map, especially for the Antelope Valley.

Expansive Soils

Expansive soils, more commonly referred to as adobe, swell when they become wet and shrink when they dry out. Consequences of this expansion and contraction are cracked building foundations and, sometimes, severe structural distress of buildings themselves. The economic impact on the private sector and public property due to expansive soils is an ongoing problem in Los Angeles County. Although expansive soils are now routinely alleviated through the County Building Code, problems related to past inadequate codes constantly appear. Expansive soils can result in cracked foundations, interior and exterior wall separations, disjointed slabs or porch steps, tilted posts or fences (soil creep), and sometimes ruptured utilities.

Although their occurrence in the County is often associated with geologic units having marginal stability characteristics, the distribution of expansive soils can be widely dispersed. They can occur in hillside areas as well as low lying alluvial basins. Determination of the origin of structural distress in an existing structure requires assessment not only of expansive soils, but also recognition of the impact of poor compaction practices, settlement, and landsliding. Once verified, mitigation can be achieved through reinforcement of the existing foundation, or alternatively, through the excavation and removal of the expansive soils material in the effected area. Moisture control and modified drainage can also minimize the effects of expansive soils. For new development, future problems with expansive soils can be largely prevented through proper site investigation, soils testing, foundation design, and quality assurance during grading operations.

Conclusions

- Subsidence related to oil and ground water withdrawal, or tectonic strain, is an ongoing phenomenon in the Los Angeles Basin and other parts of the County. No vertical surveying arrays in the County, outside the jurisdiction of the City of Los Angeles, are monitoring sensitive areas where historic subsidence has been documented, and may reoccur, or where damaging subsidence may initiate in the future.

- Continued repressurization of oil reservoirs and elevation surveying, both during and after oil field production, are essential components of a program to prevent subsidence from reoccurring. Severe damage to buildings, road and rail ways, bridges, and pipelines could result if subsidence-induced faulting and ground fissuring are reactivated.

- Prudent ground water management practices need to be followed in Antelope, Santa Clarita, and other valleys in the County. Future objectives in areas proven sensitive to subsidence, and Antelope Valley in particular, include:

  - Increased leveling for vertical changes in elevation and mapping of ground fissures;

  - synthesis of well data and gravity, seismic, and other geophysical methods to characterize the underlying aquifer; and

  - cooperation of involved ground water jurisdictions to prevent or mitigate subsidence in an alluvial basin.

- Increased awareness of collapsible and expansive soils by public officials, consultants, developers, future homeowners, and contractors will encourage proper investigation, foundation design, and use of drought resistant landscaping to mitigate potential problems before they occur.

- Expansive soils are widely distributed in Los Angeles County. Proper site investigation, soil testing, foundation design, and enforcement of construction grading practices, as defined in the County Building Code, are the most efficient planning tools for locating, assessing the severity of, and mitigating expansive soils in a proposed development.

- Existing County programs for managing hazards such as expansive and collapsible soils should be regularly reevaluated for improvements.

SECTION 3.3

FLOOD AND INUNDATION HAZARD

(Plate 6 - Flood and Inundation Hazard)

Los Angeles County is vulnerable to a wide range of flood hazards, including those caused by earthquakes, intense storms, and failure of man-made structures. Although the impact on Los Angeles County from the 1964 Alaskan Earthquake tsunami was relatively minor, two damaging regional tsunamis caused by the 1812 Santa Barbara and the 1927 Point Arguello Earthquakes suggest faults off the coast of Los Angeles could generate similar large local tsunamis. The concern for tsunami impact is heightened mainly because the short historical record does not adequately characterize the long-term tsunami risk. In addition, the potential impact on the number one port facility in the United States from a large tsunami could seriously impact the economy of Los Angeles County.

Two dam failures have occurred since 1928 within the County, followed more recently by the near failure of the Van Norman Dam during the 1971 San Fernando Earthquake. The failure of just one of the larger reservoirs or flood control basins located in the County during peak storage could devastate large urban areas. Like any other widespread flood, dam breakage could also contribute to the contamination of ground water, create health risks from dysfunction of sewage facilities, and initiate a wide range of other secondary hazards including the spread of fire and generation of debris capable of destroying structures in the flood path. The failure of water and oil storage tanks during an earthquake also pose significant localized hazards to public safety.

Intense storms present a flood hazard for developments located in narrow canyons in mountainous areas and on alluvial fans in the Antelope Valley. Because of the difficulty in modeling flooding on alluvial fans, certain 500 year floods may also pose an equal or only slightly greater risk than 100 year flood plains in these areas. A particularly dangerous combination, intense storms coupled with burnt watersheds, place developments located at the base of steep mountainous terrain at extreme risk to mud floods and mudflows.

The Flood and Inundation Hazards Section is organized into the following sections:

- **Section 3.3.1: Earthquake-Induced Inundation (Tsunami and Dam Failure)**
- **Section 3.3.2: Storm-Induced Flooding (100 and 500 year Flood Plains)**

Topics such as seiching, water tank failures, and mud floods and mudflows are included as subsections in the text, but are not shown on Plate 6 (Flood and Inundation Hazard), due to the scale of the maps and the hazard.

SECTION 3.3.1

EARTHQUAKE-INDUCED INUNDATION: TSUNAMI AND DAM INUNDATION

TSUNAMI HAZARD

Tsunamis, often wrongly referred to as "tidal waves", are long period sea waves produced by large-scale sudden disturbances of the sea floor, like those accompanying displacement of the sea floor during earthquakes or seafloor landslides. Once generated, a tsunami can travel thousands of miles without a reduction in size, propagating at speeds as high as 500 miles per hour away from the source of the disturbance. Although virtually undetectable at sea, the incident waves interact with the shallow sea floor topography upon nearing a landmass, causing the characteristic increase in wave height, or run-up (defined as the maximum elevation reached by the wave above the initial water level). The coastline configuration and offshore topography may accentuate the wave, by focusing tsunami surges into narrow inlets, harbors, embayments, or other low-lying areas along the coast (URRNSF, 1988). Tsunami approach is typically preceded by near-shore water withdrawal followed by a series of wave surges.

In the past century, over 51,000 people have been killed and hundreds of millions of dollars of damage have been caused worldwide by tsunamis (Bernard, 1988). A review of historical tsunami damage patterns reveals important lessons concerning the vulnerability of shoreline development to damages (Table 3.10). Direct causes of damage, intuitively, are attributed to the impact of the wave surges on exposed structures located on the shoreline. The most vulnerable structures are wood frame, or light weight structures, particularly those poorly anchored to their foundations (Table 3.10). Well-built, properly anchored, massive structures consistently show a high survival rate even in high impact areas (URRNSF, 1988). Other tsunami effects include the undermining of foundations and destabilizing of structures caused by the erosive forces accompanying the surging torrent inland and the ensuing withdrawal (URRNSF, 1988).

Particularly relevant to Los Angeles County are the potential secondary hazards caused by tsunamis. Debris such as boats, cars, or poorly anchored structures, dislodged from the initial wave impact or scouring effects of the tsunami, can contribute to damage by impacting other structures and hampering search and rescue operations (URRNSF, 1988). Fires caused by the collision of dislodged fuel tanks and fuel trucks with electrical facilities have accompanied a number of historical tsunami incidents. Creating the potential for conflagration, water surges have been known to spread fire rapidly and ignite other flammable structures (URRNSF, 1988). Historical damage patterns show that the threat of fire and hazardous materials releases is greatest in industrialized areas, located within potential areas of inundation (Table 3.10).

TABLE 3.10 - HISTORICAL TSUNAMI DAMAGE PATTERNS

- Proximity to the earthquake source is not necessarily correlated with severity of damage. A distantly generated tsunami can be just as damaging as one generated nearby.
- Direct wave impact, erosive water forces and water saturation are the main damage mechanisms.
- Erosive water forces from the initial wave impact and the receding torrent can scour and destabilize structures and foundations.
- Well-built structures tend to withstand wave forces even in high impact areas along the shoreline.
- Poorly anchored buildings can be loosened by water forces and swept off their foundations.
- Buildings and structures can be damaged through impact by dislodged debris such as a boat, car or another building.
- The severity and magnitude of both primary and secondary effects from fire, contamination, and debris impacts (logs, boats, cars, etc.) are a function of water forces interacting with land use within the impact area, i.e., industrial versus open space.
- Port and industrial activities are subject to a greater range of risks than commercial or residential areas. A high percentage of the damage from these "secondary" impacts is generated by waterfront uses which are often industrial. Secondary effects such as fire are equally, if not more destructive, than direct water damage.
- Improperly anchored fuel/oil storage facilities can ignite and carry fire inland.
- Wood structures in the waterfront area tend to become fuel for fire and contribute to the conflagration.
- Impact by floating debris to electrical facilities can cause fires.
- Contamination can originate from hazardous materials stored in impacted structures.
- Marine uses and structures such as wharves piers, docks, and moored boats do not withstand tsunamis. Instead they tend to break loose, thereby becoming hazardous floating debris.
- Lifelines such as roadways, bridges, airport, runways, railroad lines and trestles are particularly vulnerable to inundation and undermining.
- Immediate response, search and rescue, and cleanup efforts can be hampered when roads and bridges are blocked by tsunami debris or undermined by erosion or damaged by ground failure.

(Compiled after URRNSF, 1988)

Historically, the inadequate execution of evacuation plans and public warning procedures following an official tsunami warning are blamed for most losses of life during a tsunamis (URRNSF, 1988).

Tsunami Hazards in Los Angeles County

The Los Angeles County coastline is subject to tsunami risk from distant, Pacific-wide sources and local near field sources. The Pacific wide areas of concern to southern California appear to be the Colombia-Ecuador Region, the Alaska/Aleutian Trench area and the Peru-Chile Trench area off Chile (Houston, 1980; Houston and Garcia, 1974). Indeed, the 1960 Chile and 1964 Alaska Earthquakes produced the largest tsunamis ever recorded in southern California. The 1964 tsunami produced wave heights of four feet in San Pedro Bay, Los Angeles Harbor and Long Beach Harbor, causing $200,000 damage to several small boat docks, pilings, and the Union Oil Company fuel dock (Wilson and Torum, 1972). Most of the damage was the result of swift currents of up to 12 knots in the Cerritos Channel and wave oscillation (seiching) of up to five feet in the inner harbor (McColloch, 1985). State-wide, the event caused over $32 million dollars in damage and 16 fatalities, with northern California suffering by far the greatest share of losses (Lander, 1987; McColloch, 1985).

Little data exists to evaluate the potential for a near field, or local tsunami generated off the coast of southern California. Historically, the southern California area has been affected by only two locally generated tsunamis. The 1812 Santa Barbara Earthquake reportedly produced run-up heights of approximately 10 or 12 feet at Gaviota (McColloch, 1985). The better documented, 1927 Point Arguello Earthquake (M_L = 7.3), produced wave heights as much as six feet (Steinbrugge, 1982). A purely historical assessment suggests that the southern California area is at minor risk from a locally generated tsunamis and only a moderate risk from those generated from more distant sources. In the final analysis; however, tsunami risk cannot be adequately determined from such a short historical record. Like earthquakes, geologic evidence is needed to estimate the actual long-term tsunami threat (Lander, 1987). The lower magnitude threshold for tsunami development is considered to be approximately M_L 6.5. Faults offshore Los Angeles, including the San Pedro Basin, Anacapa-Dume, Palos Verdes Hills, and Santa Monica faults, all appear capable of producing this size of earthquake and the necessary vertical offset making it conceivable that a local earthquake-induced tsunami could impact the coast in the future (McColloch, 1985; Griggs and Savoy, 1985). Adding to the risk is the possibility of a seismically triggered seabottom landslide in Santa Monica Bay, which can be large enough to generate a damaging tsunami with little or no warning.

State-of-the-art assessment of tsunami vulnerability is evaluated using numerical simulation techniques. This method is especially applicable in southern California because there is a lack of historical precedent to show the location of particularly vulnerable areas. Numerical simulation assessments, including work by URRNSF (1988), Shuto (1987), Goto and Shuto (1983), and Liu and Erickson (1983), involve modeling the source, run-up, and velocities of the incoming surges. Vulnerability is then determined by estimating the impacts of direct and

secondary tsunami effects on land uses and building types in the inundation zone (Table 3.10).

There have been no numerical simulations from a near field source in the Los Angeles area. A 1975 flood insurance study by Houston and Garcia of the U.S. Corps of Engineers predicts run-up heights based on modeling Aleutian and Chilean Trench sources. The predicted run-up heights are roughly estimated to be in the range of those expected for a Magnitude 7.5 earthquake off the shore of Los Angeles. Inundation areas were purposely not shown in their study because the model was not sophisticated enough to accurately show flood water heights and water velocities while simultaneously taking into account onshore topography and land-based structures (Garcia, personal communication, 1989; Camfield, 1987).

Methodology

There are three principal areas along the Los Angeles coastline which are particularly vulnerable to inundation by tsunami. These areas are the Belmont Shore/Seal Beach coastal segment, the Long Beach and Los Angeles Harbor, and the Marina del Rey/Ballona Creek area. In addition, several smaller areas of inundation exist at the mouths of moderately sized drainages along the Santa Monica Coast, including the Malibu and Topanga Beach areas. The scale of the map (1:100,000), used in the compilation of data does not provide accurate resolution where tsunami inundation can be expected to be on the order of tens of feet.

The primary source of information used in constructing the tsunami component of the Flood and Inundation Hazard Map (Plate 6) is a study by Lee, et al., 1982. It is basically an updated and more sophisticated version of the studies put forth by Houston and Garcia (1974) and Houston (1980). The Federal Emergency Management Agency study by Lee and others (1982) demonstrates the composite effect of two distant tsunamis originating on the Alaskan-Aleutian and the Peru-Chile Trench.

The 500-year tsunami defined by Lee, et al., 1982 appears to be the most appropriate for use on the Flood and Inundation Map for County planning purposes, due to its conservancy. Hwang and Lee (1979) suggests that because recurrence remains the least understood parameter in determining tsunami risk for southern California, the larger recurrence interval (500-year) is more appropriate for planning purposes. Supporting the more conservative run-up heights calculated for the 500-year tsunami is the general agreement between historical run-up heights in southern California (6 to 12 feet maximum) and the 2 to 14 foot run-up heights predicted in the study. An assessment of the vulnerability of the coastal community was beyond the scope of their study.

The tsunami run-up heights used on the Flood and Inundation Map (Plate 6) represent the height of the modeled 500-year tsunami wave as it crosses the shoreline at mean low-low water (MLLW). The limit of tsunami inundation shown on the Flood and Inundation Map was generated by extrapolating the wave height inland to the corresponding contour. U.S. Geological Survey 1:24,000-scale quadrangles and NFIP flood insurance maps were used to aid the transfer of wave height to the appropriate contour. Quadrangles south of and including Ballona

Creek permitted the use of 5-foot contour intervals in extrapolating the tsunami run-up.

Uses and Limitations

The maps allow tentative development of criteria for assessing the vulnerability of a specific proposed or existing land use area located within the tsunami zone of inundation. There is no probability assigned to the inundation potential, but because it projects the most conservative estimate consistent with current research, the inundation area functions as a first level estimate of the potential hazard. The projected run-up and inundation areas shown on Plate 6 are suitable for first level analyses of emergency preparedness and evacuation planning.

Coastal communities at higher tsunami risk such as Anchorage, Alaska have developed detailed, large scale maps suitable for computer modeling of tsunami impact on land uses, and for defining impact-reduction zones aimed at mitigating direct and secondary tsunami hazards (URRNSF, 1988). These communities are at higher risk because frequent tsunami recurrence justifies this classification. The Los Angeles shoreline might be considered at risk for two reasons: 1) the apparent vulnerability of economic and industrial facilities and other sensitive land uses that are presently located in first level tsunami inundation areas, and 2) the uncertainty caused by the short historical tsunami record, as compared with the return period of local faults.

Inundated areas shown on Plate 6 may show horizontal error of as much as 500± to 1,000± feet in the largest inundated areas. Coastal strips narrower than 250 feet are shown by a shaded pattern, but are not able to be portrayed accurately at the 1:100,000-scale used in the compilation. The increase in inundation areas caused by potential tectonic subsidence and the effect of wave addition caused by a tsunami occurring during mean high-high water (MHHW) tide level is not represented in the run-up heights shown on Plate 6. In some instances, coastal structures may block wave run-up thereby protecting inboard facilities that appear to be within the normal inundation zones. Conversely, coastal structures could also act to "focus" or channel wave run-ups even higher than those shown.

Coastal Subsidence

Coastal subsidence is considered here as an inundation hazard because historical data suggests that some offshore, near-field earthquakes can cause substantial regional subsidence of coastal areas of up to a few meters (URRNSF, 1988). In the tectonic regime of Los Angeles, regional earthquake-induced changes in elevation should be expected. The 1971 San Fernando Earthquake was associated with a regional uplift of two meters, an expected result of a compressional thrust-type earthquake (Oliver, et al., 1974). Significantly, Oliver, et al., (1974) also documented broad areas of subsidence on the order of 1.6 meters accompanying the uplift. This suggests the coastal area might be susceptible to significant regional subsidence and inundation in the future, especially if

associated with a near-field tsunami generating earthquake. At this time, the most viable method to determine large scale crustal movements is to conduct a detailed study of the marine terraces along the coast, and compare their movements with similar age materials within the Los Angeles Basin.

DAM INUNDATION HAZARDS

Historical precedent emphasizes the potential for catastrophic dam failure in Los Angeles County. The 1963 Baldwin Hills dam failure, which totally destroyed 41 houses and damaged 986 houses and 100 apartment buildings, cost millions of dollars to recover and rebuild (FEMA 1987-145). Five people lost their lives in the 1963 disaster, luckily far less than the 400 + lives lost or missing in the failure of the St. Francis Dam in 1928 (Outland, et al., 1963). The 1928 dam failure inundated the entire downstream area of Santa Clarita Valley and impacted both Los Angeles and Ventura County. To manage dam safety from a regional perspective, a compilation of selected dams and debris basins are presented in Plate 6. The following is an overview of dam safety and vulnerability, an evaluation that will elaborated on further in Chapters 4 and 5.

The issue of dam safety can be traced to three major events within the County of Los Angeles. The sudden failure of the St. Francis Dam led to the 1929 enactment of legislation providing for supervision over non-Federal dams in the State. Following the 1963 failure of the Baldwin Hills Dam, the State water code was amended to require a more stringent inspection and review of existing and proposed off stream storage facilities and entire reservoir basins. After the near failure of the Lower Van Norman Dam following the 1971 San Fernando Earthquake, an extensive reevaluation of acceptable risk and seismic safety of all hydraulic fill dams was initiated. The principles, which were almost universally accepted for establishing seismic safety of dams prior to the 1971 San Fernando Earthquake have now been demonstrated to be largely inadequate (Task B, 1972).

The statutes governing dam safety in California, Division 3 of the Water Code, currently place responsibility for dam safety under the jurisdiction of the California Water Resources Division of Safety of Dams. Specific exemptions from their jurisdiction, beyond those that define 25 feet in dam height or 50 acre-feet in storage capacity as minimum requirements, apply to levees, railroad and highway fills, circular tanks, elevated tanks, and Federal dams (Department of Water Resources, 1986).

Section 8589.5 of the California Government Code presently requires that inundation maps and emergency response plans be prepared for certain dams and debris basins within the jurisdiction of the State. The lead agency for this program, the California Office of Emergency Services, requires that owners provide inundation maps in the event of a catastrophic breach of the impoundment facility (California Department of Water Resources, 1986). Exemptions from the inundation mapping program are based on minimum storage capacity and crest height of the dam or debris basin (California Department of Water Resources, 1986). The U.S. Army Corps of Engineers voluntarily participates in the inundation mapping

program for water impoundment dams under Federal jurisdiction, although not required to do so.

There are over 90 dams and debris basins under State jurisdiction within the County of Los Angeles (California Department of Water Resources, 1988; Cliff Nomura, 1988 personal communication), and several dams or debris basins under Federal jurisdiction. Reservoirs serve several functions including water supply and recreation. Many are part of a cooperative effort between the Los Angeles County Flood Control District and the U.S. Army Corps of Engineers to provide flood protection to the Los Angeles Region. The extensive system of debris basins are used to catch sediment and prevent reservoir infilling during seasonal rains.

Dam Failure Potential

Historically, the worldwide data set indicates few instances of catastrophic dam failure caused by earthquakes (EERI, 1986). In fact, little evidence of any serious earthquake-induced failures involving concrete dams is found in the literature. The fact that no major "disasters" involving concrete dams are reported may indicate their inherent stability during large earthquakes (EERI, 1986). Additionally, most engineered, mechanically compacted dam embankments or fills of earth or rock materials have performed well under seismic shaking. However, dam embankments, constructed of marginally compacted hydraulic fills or similar materials, are vulnerable to ground failure or settlement. The embankment failure of the Lower Van Norman Dam in 1971 is an example of this potentially disastrous condition. As noted in the section concerning liquefaction, when fill material is saturated, and consists of loose, cohesionless materials, liquefaction and lateral spreading may occur within the saturated zones. Earthquake-induced settlement of dam abutments or foundations have also caused abrupt losses in "freeboard" and minor overtopping of the dam, yet like the expected hazard from reservoir seiching, these few instances have had relatively minor impact on developments downstream.

Historical data demonstrate that from 1766 to 1944, only 308 incidents of dam failure occurred in the 1,620 major earth and concrete dams that were surveyed (Pasklov, 1983). Significantly, of these 308 failures, only one percent are attributed to earthquakes. The worldwide data indicate that, rather than earthquakes, the majority of dam failures in either earthen or concrete dams are caused by foundation failures, inadequate spillways, and poor construction or site selection.

Dam failure incidents in Los Angeles County support most of the conclusions drawn from historical data. The failure of the St. Francis Dam and of the Baldwin Hills Dam, are believed to have been caused by a variety of reasons, none of them directly attributable to an earthquake. The reasons given for the 1928 failure include the placement of the dam abutment on unstable bedrock (landsliding or dissolution) or poor foundation construction (fissuring and cracking in the embankment, resulting in "piping") (FEMA, 1987-145). Piping within the embankment can be initiated by earth movement, either associated with slope movement, fill settlement, or faulting (Seed, 1981).

The 1963 Baldwin Hills failure is believed to be related to poor site location and dam design. The dam was placed over a splay of the Newport-Inglewood fault, but rather than movement from an earthquake, the weight of the reservoir, combined with regional subsidence initiated by oil field withdrawal, is believed to have led to reactivation of creep along the fault splay (Kresse, 1966). This movement is believed to have initiated piping through the dam lining, eventually undermining the dam abutment through continued erosion.

Most dam failures, 82 percent based on a study by the International Commission of Large Dams (ICOLD), can be attributed to overtopping and foundation failures, including piping. Overtopping may result from inadequate spillway design, or poor maintenance or operational practices. For example, a clogged spillway may result in water pouring over other parts of the dam resulting in erosion and subsequent failure. In general, concrete dams are more susceptible to failure from overtopping, while earthfill dams are more likely to fail as a result of seepage and piping through the foundation abutment (FEMA, 1986).

All earthen dams exhibit some seepage through the structure, which must be controlled in velocity and amount. If uncontrolled seepage is initiated, erosion along the downstream abutment allows eroded cavities to propagate (pipe) through the foundation; piping can lead to the complete failure of the dam structure. Piping action is commonly recognized by an increased seepage flow rate, discharge of muddy or discolored water, sinkholes on or near the embankment, and the development of a whirlpool in the reservoir. Uncontrolled flow of water over the dam, around the dam, or adjacent to the dam most commonly occurs during severe storms. Earthen dams that have been designed to cover precipitation and runoff parameters, acceptable 30 or 40 years ago, are most prone to hydraulic failure. Design and procedural modifications are employed to mitigate this problem.

Methodology

The dam inundation information shown on the Flood and Inundation Map (Plate 6) is compiled from large scale maps supplied by the Los Angeles County Department of Public Works, the Los Angeles Department of Water and Power, and the U.S. Army Corps of Engineers. The inundation areas are based on an assumed catastrophic failure of the dam during peak storage capacity. The inundation boundary shown on the map encompasses all probable routes that a flood might follow after exiting the dam or canyon opening, thus the map shows very large and conservative inundation areas. There are 71 water impoundment facilities, some of which originate outside of the County, which require inundation maps inside the County of Los Angeles (Table 3.11). Both Federal and State jurisdiction dams are included in Table 3.11 and the acronyms are keyed to the dam and debris basins shown on Plate 6. The age of the dam, type of dam construction, and the regulated drainage are also included on the table. Dams constructed of earth or rock material are indicated by acronyms "ERTH" or "ERRK". Dams with other symbols represent various concrete dam designs.

Some debris basins are included on the map since the Office of Emergency Services has required the preparation of an inundation map for these structures despite being generally considered low risk inundation hazards (Don Keene, 1988 personal communication). Their potential risk is inferred to be low because the structures hold saturated debris and water only intermittently during winter storm periods. Eleven (11) County facilities have been granted exemption from the inundation mapping program.

TABLE 3.11 - TABULATION OF DATA FOR DAMS AND DEBRIS BASINS

Name	Storage Capactiy (dekameters)^3	Type	Year	Stream
AST - Ascot	270	Erth	1926	Los Angeles Trib.
BDD - Big Dalton Dam	1173	Mula	1929	Big Dalton Wash
BDT - Big Dalton Debris	259	Erth	1960	Big Dalton Wash
BR1 - Burbank Reservoir #1	26	Erth	1928	Los Angeles Trib.
BR4 - Burbank Reservoir #4	42	Rect	1955	Los Angeles Trib.
BR5 - Burbank Reservoir #5	95	Rect	1949	Los Angeles Trib.
BPR - Brand Park	39	Erth	1930	Los Angeles Trib.
BTD - Big Tujunga Dam #1	7434	Vara	1931	Big Tujunga Creek
BQD - Bouquet Canyon	45029	Erth	1934	Bouquet Creek
CCR - Chevy Chase 968	57	Erth	1927	Sycamore Creek
CST - Castaic	431725	Erth	1974	Castaic Creek
CTR - Century	86	Cora	1913	Malibu Creek
CWL - Cogswell	12885	Rock	1935	San Gabriel West Fork
DCD - Dry Canyon	1406	Hydf	1912	Dry Canyon Creek
DG - Devils Gate	5637	Grav	1920	Arroyo Seco
ECD - Encino	12075	Erth	1924	Encino Creek
ERD - Eagle Rock	313	Erth	1953	Los Angeles
ESD - Elysian	20	Erth	1903	Los Angeles Trib.
EW - Eaton Wash Debris Dam	894	Erth	1936	Eaton Wash
FMT - Fairmont	9260	Hydf	1912	Antelope Valley
FRB - Forebay (Elderberry)	40705	Erth	1974	Castaic
G9R - Glen Oaks 968 Reservoir	35	Erth	1949	Los Angeles
GLR - Glorietta East	88	Rect	1932	Verdugo Canyon Trib.
GSR - Greystone	74	Rect	1970	Los Angeles
GVD - Green Verdugo	122	Erth	1953	Tujunga Wash Trib.
GVR - Garvey Reservoir	1986	Erth	1954	Rio Hondo Trib.
HLD - Highland	78	Erth	1909	Arroyo Seco Trib.
HSD - Hansen Dam	32932	Erth	1940	Tujunga Wash
LAD - Los Angeles Dam	12335	Erth	1977	San Fernando Creek
LDT - Little Dalton Debris	265	Erth	1960	Little Dalton Canyon
LFD - Lower Franklin	1135	Hydf	1922	Franklin Canyon
LO - Live Oak	301	Grav	1922	Live Oak Creek
LOR - Live Oak Reservoir	3084	Erth	1975	Marshall Creek Trib.
LPD - Lopez Dam	1628	Erth	1954	Pacoima Wash
LRB - Laguna Regulation Basin	-	Erth	1970	Laguna Wash
LRD - Little Rock	3330	Mula	1924	Little Rock Creek
LSW - Lake Sherwood	3207	Cora	1904	Triunfo Creek
MBL - Malibu Lake Club	617	Cora	1923	Malibu Creek
MHD - Mulholland	4978	Grav	1924	Weid Canyon
MOR - Morris	33921	Grav	1935	San Gabriel River
MSJ - Morris St. Jones	190	Erth	1952	Eaton Wash Trib.
PCD - Pacoima	4825	Vara	1929	Pacoima Creek
PDD - Puddingstone Div.	170	Erth	1928	San Dimas Creek
PMD - Palmdale Dam (Harold)	5181	Erth	1891	Antelope Valley Trib.
PRD - Pradc Dam	387781	Erth	1941	Santa Ana River
PST - Puddingstone	21204	Erth	1928	Walnut Creek
PW - Portrero	976	Grav	1967	Portrero Valley Creek
PVR - Palos Verdes Reservoir	900	Erth	1970	Sweetwater River
PYR - Pyramid	220796	Rock	1973	Piru Creek
RVR - Riviera Reservoir	94	Rect	1962	Santa Monica Canyon Trib.
RWD - Rowena	118	Erth	1911	Ballona Creek Trib.
SAB - Santa Ana Debris Basin	148	Erth	1960	Santa Anita Wash
SAD - Big Santa Anita Dam	993	Vara	1927	Rio Hondo Trib.
SCD - Stone Canyon Dam	10372	Erth	1924	Stone Canyon Creek
SDB - Sawpit Debris Basin	180	Erth	1955	Sawpit Wash
SDD - San Dimas	1542	Grav	1922	San Dimas Creek
SF - Santa Fe Basin	39606	Erth	1949	San Gabriel River
SGD - San Gabriel Dam	55031	Errk	1938	San Gabriel River
SLD - Silver Lake Dam	2020	Erth	1976	Ballona Creek
SMD - Sierra Madre	60	Cora	1928	Little Santa Anita Creek
SND - San Antonio Dam	9502	Erth	1956	San Antonio Creek
SPD - Saw Pit Dam	356	Cora	1927	Saw Pit Creek
SVD - Sepulveda	21494	Erth	1941	Los Angeles River
SYD - Santa Ynez	439	Erth	1968	Santa Ynez Canyon
TCD - Thompson Creek Dam	676	Erth	1928	Thompson Creek
TSD - Thompson Dam	1244	Erth	1925	Middle Canyon
WGR - Wrigley Reservoir	76	Erth	1930	Suisan Creek
WLR - Westlake Reservoir	11348	Erth	1972	Tree Springs Creek
WN4 - Whittier Reservoir #4	39	Erth	1931	San Gabriel Trib.
WND - Whittier Narrows Dam	82718	Erth	1957	San Gabriel River
WPR - Weymouth Memorial Reservoir	186	Rect	1966	Los Angeles
WSR - Western Reservoir	-	Erth	-	-

- = Not Available
Erth = Earth Material
Grav = Gravity
Hydf = Hydraulic Fill
Vara = Variable Radius Arch
Rock = Rock Construction
Errk = Earth and Rock Construction
Rect = Reinforced Concrete Tank
Mula = Multiple Arch
Cora = Constant Radius Arch

NOTE: Inundation Area Shown on Plate 5.

Uses and Limitations

The dam inundation portion of the Flood and Inundation Hazard Map (Plate 6) shows only the regional vulnerability of Los Angeles County to dam failure. The actual risk of dam failure is not conveyed. To convey the actual risk, the map should, at a minimum, consider the sensitivity of the land use below the dam or reservoir, the structural integrity and age of each dam, the likelihood of a catastrophic earthquake, and a myriad of other unknowns, including the long-term geologic threat from underlying geologic hazards. Since the Office of Emergency Services does not require an evaluation for structural risk as part of the inundation mapping program, an integral element needed to interpret the potential for dam failure is missing. Therefore, Plate 6 should be used only to identify areas where more data is needed to accurately infer the risk for planning purposes. As stated on all State and Federal dam inundation maps, the required mapping is only to be used to represent worst-case scenarios for planning purposes.

Other Earthquake-Induced Flooding

Structural failure of water-retainment facilities is not limited to dams and debris basins. Other structures capable of causing floods upon failure are dikes in the waterfront areas, flood control dikes (levees) along channelized streams, and large ground level storage tanks. As indicated in the prior section, levees and water tanks are exempt from jurisdiction by the State, yet they are vulnerable to ground failure, ground rupture, and earthquake shaking. Dike structures are vulnerable to the same style of failure criteria that dams are exposed to during an earthquake, except that simultaneous high river flow is a prerequisite during the earthquake. Extremely high floods beyond the design capacity of the system can also cause failure of these flood control devices. Historical precedent alludes to the vulnerability of large capacity water tanks (Table 2.2, 1933 Earthquake). Ground level water tanks can fail from internal pounding created by the rocking motion of the water inside the tank. Since these structures are not under State jurisdiction, the County Public Works should regularly review their water tank safety programs.

Coastal Embayment and Reservoir Seiche Hazards

Seiches are waves that rock back and forth (like a pan of water tilted back and forth) in enclosed or semi-enclosed bodies of water such as lakes, reservoirs, bays and harbors. They can be triggered by long period earthquake ground motion from distant earthquakes, or from large displacements of the ground surface beneath a body of water. In reservoirs, seiches could generate short-term overtopping and inundation of surrounding or downstream areas. In addition, earthquake-induced landsliding could cause seiche-like waves that could also result in short-term overtopping, if the failure occurred in a critical portion of the reservoir. Although not a seiche hazard, a local crustal uplift applied

to a reservoir with respect to the dam might result in a loss of freeboard and long-term overtopping and inundation of the area down gradient (EERI, 1986). Historically, seiches have not caused much damage and there is not, at this time, a readily-applicable method for predicting their occurrence or their area of inundation.

In contrast to dams, seiching can be a significant damage factor in port and harbor facilities, particularly dry docks. A tsunami surge or simply the shock wave from even a moderately-sized near field earthquake can cause boats and ships docked in an embayment to rock as the seiche builds in amplitude. If the amplitude of seiching is large enough, docked boats and other floating facilities adjacent to dry docks may be damaged from impact. The amount of this damage is directly related to the size of the earthquake and the duration of the seiching.

Conclusions

- Secondary hazards caused by flooding can significantly increase damage in any potential inundation area, be it caused by tsunami, dam failure, or failure of a water storage tank. Unanchored objects, such as cars or structures, may impact and ignite flammable sources and spread fire, or damage facilities storing hazardous materials, causing widespread contamination problems.

- The historical record is too short to accurately infer the tsunami risk for Los Angeles County, making acquisition of geologic evidence of prehistoric tsunamis the only alternative for characterizing the long-term threat. Available evidence does not preclude the potential for a damaging tsunami to impact the coastline of Los Angeles County from a distant or local origin.

- The potential economic losses from damaged port and harbor facilities in San Pedro Bay warrants increased emphasis on tsunami damage reduction strategies through cooperation with Federal, State, and other local jurisdictions.

- Computer modeling offers the most accurate method of developing tsunami damage prevention strategies. The tsunami component of the Flood and Inundation Hazard Map could be used to prioritize where detailed mapping and evaluation is warranted, either based on the sensitivity of the land uses present in vulnerable unincorporated areas of the County, or where the County may have emergency response agreements with coastal communities. Detailed mapping would include the following:

  - Preparation of a fine grid topographic map in prioritized areas at a map scale between 1:1200 feet and 1:12000.

  - Computer modeling of the interaction of tsunami surges and harbor seiches, with land uses, and other land based variables, especially secondary hazards such as debris, fire, or contamination sources.

  - Modeling high velocity currents in inland channels, seiching in enclosed harbor areas, and the impact of tsunami on proposed wave buffer zones or impact reduction structures placed in the inundated area.

- Sufficient warning time, adequate warning procedures and execution of emergency response plans, and efficient public response are paramount to reducing losses of life in tsunami inundation areas, or any other inundation area, provided that contingency plans have been prepared.

- The worldwide data indicate that, rather than earthquakes, the majority of dam failures in either earthen or concrete dams are caused by foundation failures, inadequate spillways, and poor construction or site selection.

- Two dam failures and one near failure since 1928 in 51 years warrant special concern for future dam failure incidents in Los Angeles County. Equal concern for seismic and nonseismically-induced failures of other flood control projects, such as dikes and levees, should also be emphasized in emergency preparedness plans.

- Additional information useful for assigning the risk of dam failure is needed to supplement the dam inundation area information shown on Plate 6. The sensitivity and location of various land uses, the structural vulnerability of the dams, the probability for peak capacity, and other pertinent risk variables should be synthesized and mapped to accurately describe risks for the dam inundation areas shown on Plate 6.

- High-risk dam inundation areas, determined from the data synthesis above, could be used to prioritize areas where emergency response and damage reduction strategies might be employed in future or existing development.

SECTION 3.3.2

STORM-INDUCED FLOODING

(Plate 6 - Flood and Inundation Hazard)

FLOOD CONTROL

During the history of Los Angeles County, the mountains, hillside areas, and the coastal lowlands and alluvial valleys have all proven vulnerable to various degrees of flooding from intense winter storms. In the 1940's, the U.S. Army Corps of Engineers designed the major flood control channels, along the Los Angeles and San Gabriel Rivers and the Rio Hondo. These projects were built in the 1950's and the early 1960's. With increased urbanization, however, the standards and conditions under which these projects were built have changed. Based on data collected from the 1978 and 1980 floods, the Los Angeles District of the U.S. Army Corps of Engineers have developed new design standards for flood control structures. These new "frequency standards" are based on a flood with a probability of occurring once in 100, or once in 500 years (Sree Kumar, personal communication, 1990).

Today, the Los Angeles County Department of Public Works, assisted by the Los Angeles District of the U.S. Army Corps of Engineers, provides protection to life and property from flood hazards in most areas of the County, including the San Fernando and San Gabriel Valleys, the Los Angeles Basin, and some drainages in foothill and mountain areas. The structural flood protection system consists of roughly 3,300 kilometers of concrete-lined channels, 20 reservoirs, over 130 debris basins, as well as an extensive system of dams, levees and stabilization structures (California Department of Water Resources, 1980, 1984; Los Angeles County Department of Public Works, 1988). The system is designed for the U.S. Army Corps of Engineers "standard project floods" which vary between 1-in-100 year to 1-in-250 year flood events depending on the drainage (Department of Water Resources, 1984). New flood channels, if maintained by the Department of Public Works, have to be designed for a "capital flood", which is based on a rainfall with a probability of occurring once in 25 to 50 years, depending on the development project. The Department of Public Works standards are generally more conservative than the 1-in-250 year flood standard used by the U.S. Army Corps of Engineers (Sree Kumar, personal communication, 1990).

In general, the main channelized flood control system has performed well over the years. The most recent tests occurred during the strong storms of 1978 and 1980. State-wide, these flood events caused a total of 56 deaths and an estimated 500 million dollars in property damage (Garza and Peterson, 1982). Some problems and failures with the County structural system were common, yet the cost-benefit ratio and performance of the system proved that flood control is a necessary component of the urban infrastructure that should be adequately maintained (Evelyn, 1982). The severity of the storms was well within the flood level used in designing the flood control system, but was much less than that which could occur during the operating life of the project (National Research Council, 1982).

Flood Managed Areas

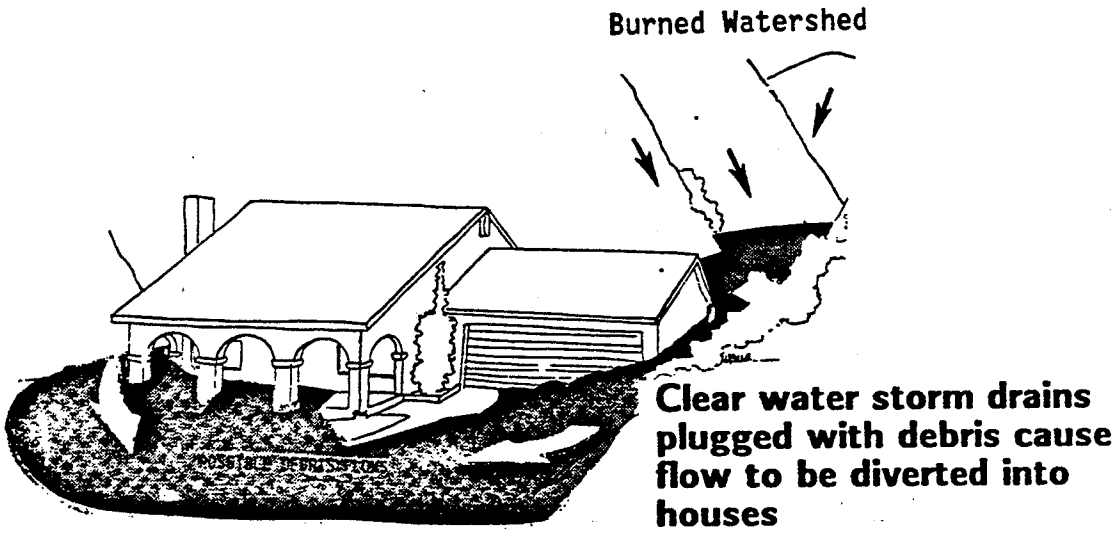
Despite the high level of protection that the system provides against flood hazards, some projects may be deficient, especially in the design capacity of flood protection projects in the urbanized, low-lying areas of the County. The National Research Council (1982) suggested that higher runoff resulting from increased urbanization may require upgrading of the major flood control channels, facilities which were designed and built to older Army Corp of Engineer's standards. The U.S. Army of Corps of Engineers has developed new "flood-frequency standards" to identify those areas that could be damaged by severe floods because of such deficiencies; preliminary 1-in-100 and very conservative 1-in-500 year flood limits have been prepared for several main drainages, including the San Gabriel, Rio Hondo, and Los Angeles Rivers. These maps are in conflict with the flood limits used by the National Flood Insurance Program (NFIP), which are based on 1-in-100 year flood standards developed in 1974. The maps used by the NFIP are currently being compared against the U.S. Army Corps of Engineer's standards (Sree Kumar, personal communication, 1990). To avoid future deficiencies related to the adequacy of runoff parameters, the Department of Public Works has modified its flood design methodology (Sree Kumar, personal communication, 1990). New Department of Public Work's projects must conform to current "level of flood and drainage protection standards", design standards that are based on rainfall flow rates, which unlike runoff rates, do not increase with increasing urbanization (Department of Public Works, 1986).

Debris Basin Overflow: Mud Floods, Mudflows, and Debris Flows

There is historical precedent in Los Angeles County for losses due to overflow from debris basins and the resulting "flood" problems in foothill and mountain areas of the County (Figure 3.15) (Weber, 1984; National Research, 1982). Debris basins are designed to catch sediment during normal runoff conditions and prevent the inundation of structures from various debris or mudflow events. Debris basins are usually placed at the base of mountains or stream and canyon heads, to capture the periodic excessive debris loads during above-normal flow events. During particularly strong storms, and especially when the watershed has been recently burnt, large volumes of mud and water are able to overburden the County-maintained debris basins and culverts as well as smaller, city-owned and privately-owned debris catchment devices (National Research Council, 1982). If one segment of the protection system fails, perhaps due to a large rock or tree clogging a diversion culvert, debris flows, mudflows and mud floods may travel toward a residence and cause local inundation (Figure 3.15). As discussed in the landslide section, less viscous flows such as mud floods and mudflows are insured against damages by the National Flood Insurance Program.

Building the housing pad out of the path of potential flows is one solution to the problem (Figure 3.16). Damage is only prevented as long as the design capacity of the debris basin or flood control feature used to control the flow is not exceeded. Proper maintenance of the various bottle necks in the system, including individual storm drains, is vital (Figure 3.15). Vulnerabilities of

Development in the Paths of Mud and Debris Flows



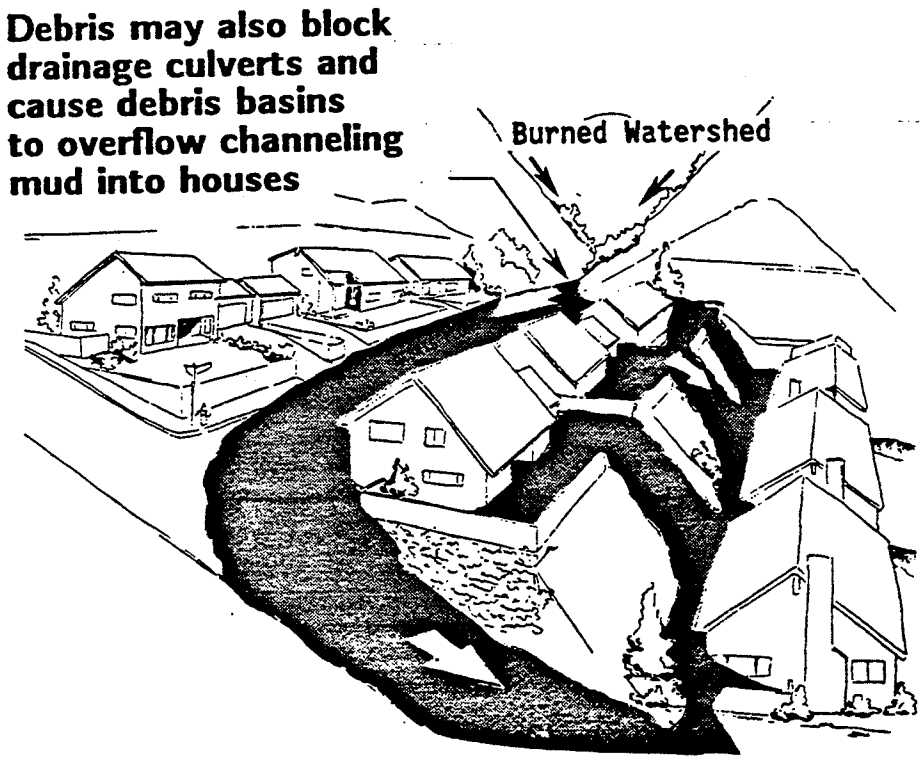


Figure 3.15: Development in the paths of mud and debris flows: during periods of heavy rainfall, and especially following a fire in a contributing watershed, mud and/or debris can inundate development located in stream or canyon heads at the base of steep mountainous terrain. Mudflows are covered by the National Flood Insurance Program (after Department of Water Resources, 1980).

Flood Control for Mud and Debris Flows

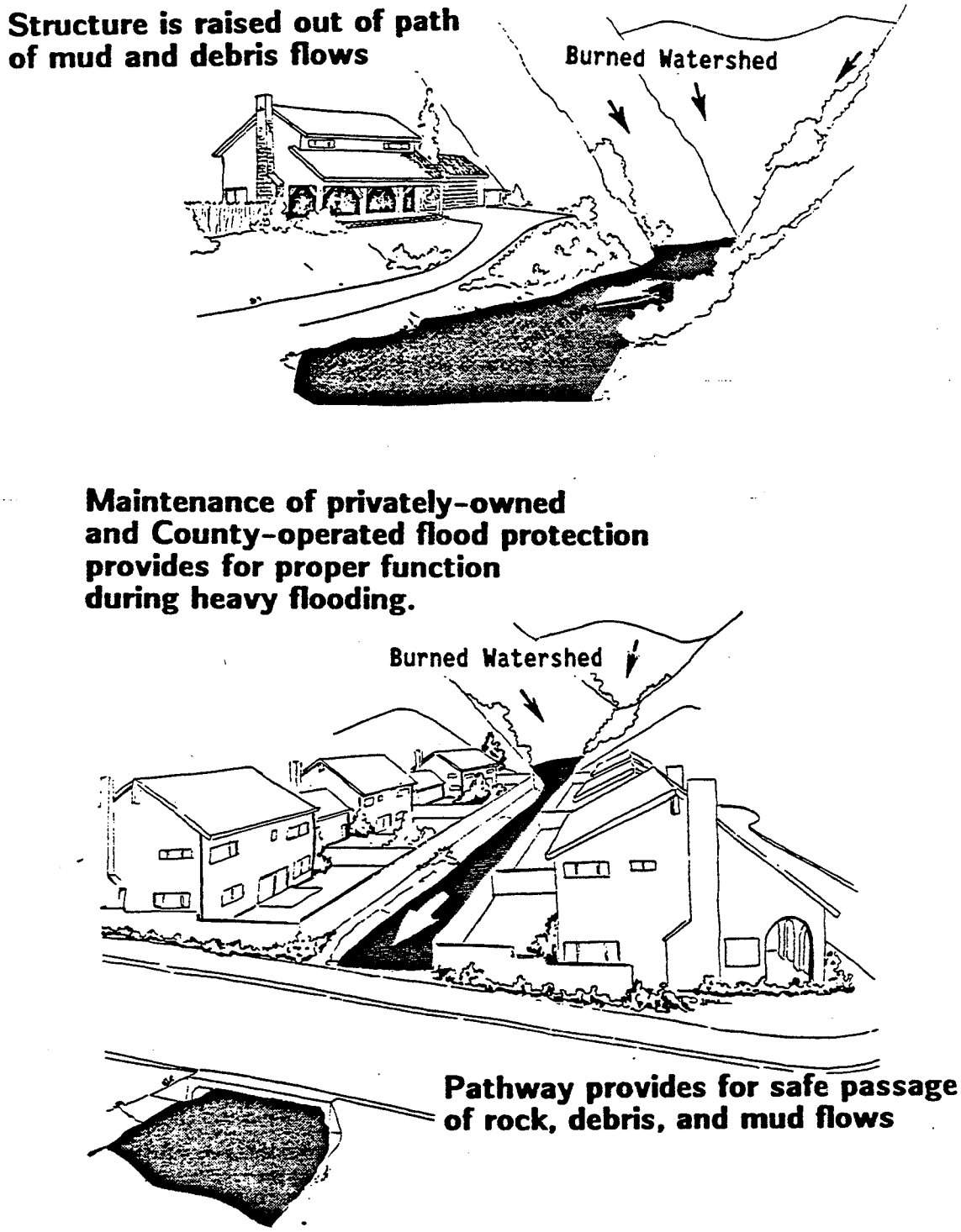


Figure 3.16: Flood control for mud and debris flows: examples of selected flood prevention methods to counter the threat of mud and debris flows (after Department of Water Resources, 1980).

the system are recognized by the County, prompting additional contingencies to be performed if an area is shown at a high risk of flooding.

Aware of the potentially deadly safety hazard posed by these floods, the County Department of Public Works emphasizes emergency preparedness by warning residents of heightened flood potential. Public Works may advise residents and homeowners to construct pipe-and-timber deflectors, board up windows and/or doors with plywood, and warn the local law enforcement officers that evacuation may be necessary during heavy rains. These warnings are usually reserved for areas of recently burnt watersheds, which greatly increases chances for flooding and flow hazards.

The County performs emergency clean-up and maintenance of debris basins and channels during and after periods of heavy rainfall to ensure their proper function. The County's Department of Public Works can mobilize more than 400 workers with almost 400 pieces of earthmoving equipment, including bulldozers, front loaders, dump trucks to scoop up the gravel and mud that can choke debris basins and other flood control features.

In addition, as emphasized in Figure 3.15, the failure of a smaller flood protection feature such as a storm drain on private property can result in much flood and inundation damage as well. The Department of Public Works is responsible for maintenance of County debris basins, while cities that have not turned over their facilities to Public Works for maintenance are responsible for the flood protection features in their jurisdiction. Private individuals are responsible for small flood control structures on their land.

The locations of areas vulnerable to mud and debris flows change from year to year, depending on the location of burnt watersheds. The volume of debris varies from storm to storm as well; however, exceptionally damaging floods and flows have occurred at least once a decade since 1916. Despite these hazards, development of vulnerable hillside areas continues. One important strategy to mitigate flooding is to educate property owners to accept and enforce suitable regulations for private flood control features. The hazards from mud floods and mudflows, including the effects of impact and inundation, must be explained. Continued expansion of the County emergency heavy equipment capability for maintaining flood control features during high risk periods is also likely to become more important as hillside development proceeds.

A "debris and mudflow alert" could involve actively informing private residents about heightened "awareness and maintenance" of the flood protection features around their property. This would augment the existing DPW handbook "Homeowner's Guide to Flood, Debris, and Erosion Control". Despite all maintenance and preventive efforts by the County and homeowners, intense rains and sediment will still periodically overload the flood system. A possible solution exists in real time warning and evacuation. A "real-time" warning system for landslides and landslide-initiated debris flows has just been established within the San Francisco area by the U.S. Geological Survey, which instantaneously alerts residents who desire to wait out the storm warning of imminent danger. The Japanese have implemented mudflow/debris flow emergency response systems that include trip wires and camera monitors. These types of programs and their potential value to Los Angeles County could be feasible if applied to several historically vulnerable areas of the County. The Department of Public Works does have a notification and warning system by which they notify the local Sheriff of developing conditions. This warning system is based on an automated system of

field gauges that monitor precipitation amounts, river stages and reservoir levels in real time, and is useful in forecasting peak flows in main drainages (Los Angeles County Department of Public Works, 1988).

UNREGULATED DRAINAGES

Stream and Canyons

Unregulated drainages are those drainages without structural flood control protection, such as concrete-lined channels or debris flow basins. Without structural flood devices, regulation of peak and lesser flows is not possible. Unregulated drainages include those upstream of debris basins in mountainous areas which are also prone to flood problems. The rapid development occurring in or near the Santa Monica, Santa Susana, and San Gabriel Mountains makes this flood hazard an issue because new development can expedite the flow of flood waters from previously harmless drainages onto older developments. In addition, when unregulated drainages are exposed to infrequent, intense rainfall, the streams can aggrade, or build up with sediment during heavy flooding, or degrade, exposing apparently safe roadways and dwellings to flooding and inundation.

Antelope Valley

Antelope Valley has unique flood problems because of the flood hazards posed by alluvial fans. The alluvial fans emanating from the highland areas contain numerous unchannelized meandering and braided streams subject to flash flooding. Alluvial fans are prone to three distinct flood channel patterns, represented by single channel, multiple channel, and sheet flow patterns. Where each process predominates depends on accurate information on the specific flood flow, slope angle of the fan, and sediment transport characteristics. Generally, however, a flood will remain in a single channel for a certain distance below the apex, followed by branching into multiple channels, which eventually passes into a sheet flow in the lower fan areas.

The guidelines currently used by the Federal Emergency Management Agency assume that the location of the stream channel on a fan is essentially random, with an equal probability of flooding occurring anywhere across the fan. Hence, all development on the fan is exposed to some probability of flooding (Dawdy, et al., 1988). Significantly, this probability may not correlate with normal assumptions regarding 100 year and 500 year flood plains used for normal stream channels, such as that shown in Figure 3.17 and represented by drainages such as the Santa Clara River. Therefore, although Federal Emergency Management Agency Maps used to administer the National Flood Insurance Program (NFIP) show 100 year flood plains and 500 year flood plains in the Antelope Valley, the essentially random nature of flooding on alluvial fans emphasizes that some 500 year flood plains may be at higher risk than designated (Dawdy, et al., 1988).

Northern portions of the County are not within the Los Angeles Flood Control District because the area lacks a large enough tax base to install the necessary, but expensive, structural flood control facilities that would be required for extensive development to occur (Don Keene, 1988 personal communication). Man-made structures such as levees, highway embankments, and lined-channels, if capable of withstanding major floods, can confine probabilistically determined flow paths within specific portions of a fan. Detention or debris basins constructed above the fan apex can also regulate or reduce the flood water and sediment flow on to the fan, but should be viewed as a temporary solution. Maintenance of debris basins in active fan beds would be a very intensive operation, requiring almost annual debris removal.

Man-made channels that convey the flow from its source to a natural outlet are the Department of Public Works' preferred solution (Sree Kumar, 1990 personal communication). In fact, most of the County has outlets to dispose of all storm runoff to the ocean. However, Antelope Valley has unique drainage problems because it has not outlet to the ocean. The drainage system in Antelope Valley naturally funnels all storm water to Rosamond Dry Lake, an area subject to development. It is the current policy to provide detention basins to hold the water upslope from Rosamond Dry Lake until it evaporates or percolates into the ground.

Methodology

The flood component of the Flood and Inundation Hazard Map (Plate 6) emphasizes unregulated drainages in unincorporated mountainous areas of the County. With the exception of Lancaster and Palmdale, unregulated drainages in the Antelope Valley are also shown, represented by alluvial fan flood limits. Areas prone to mud flood and mudflow problems in unprotected, rapidly developing foothill and canyon areas are not shown on this map due to limitations of scale.

Information used in the construction of the flood hazard component of the Flood and Inundation Hazard Map is derived from the following sources:

a. Unpublished maps and interviews with officials of the Los Angeles Department of Public Works, and;

b. The Flood Insurance Rate Maps of the Federal Emergency Management Agency National Flood Insurance Program.

The Flood and Inundation Hazard Map portrays flood magnitude and frequency, showing those areas that would be affected by 1-in-100 and 1-in-500 year floods. The boundaries of flood hazard zones were determined from flood insurance rate maps issued by FEMA, and augmented with information supplied by the Los Angeles County Department of Public Works. Selected additional drainages in need of future flood plain management or additional flood protection, as identified by Public Works, are also included on the map.

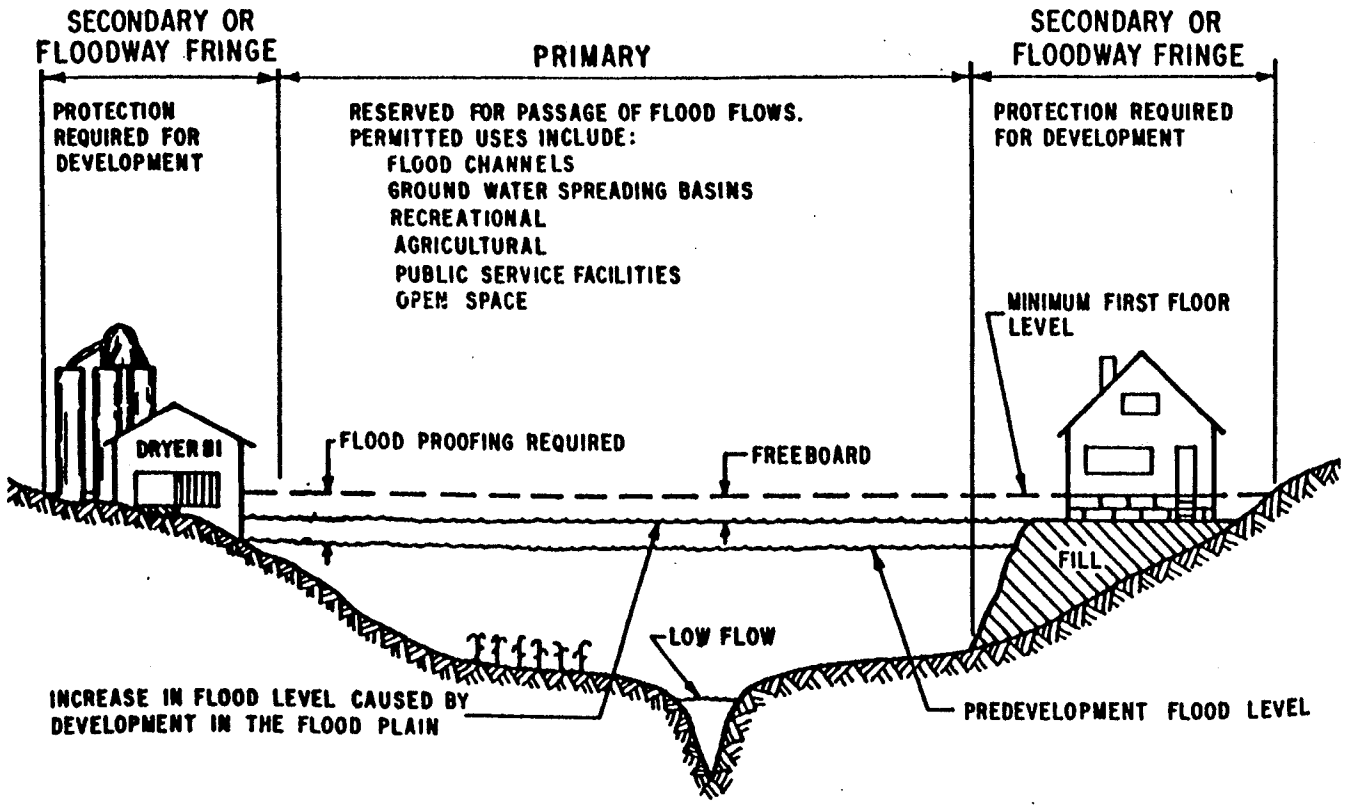


Figure 3.17: Selected examples of structural and nonstructural flood management in primary and secondary flood plains (after California Department of Water Resources, 1980).

Uses and Limitations

The maps can be used by the Department of Regional Planning to identify and prioritize flood management for drainages and flood prone areas in developing unincorporated areas of the County. Early identification may assist in the timely implementation of cost-effective, low impact, nonstructural flood management methods. Nonstructural flood management emphasizes land uses more tolerable of occasional flooding. Figure 3.17 shows a flood zone management strategy advocated by the National Research Council (1982) for nonalluvial fan stream channels. Figure 3.17 also shows various alternative development criteria for building in 100 year flood plains advocated by the National Research Council (1982) and the California Department of Water Resources (1980). The expected rise in flood levels with continued development in the flood plain is schematically illustrated in Figure 3.17.

Flood proofing and flood forecasting are essential safety components for developments proposed within flood-prone areas. Brief definitions of these concepts include the following:

- Flood proofing consists of measures which render buildings less vulnerable to floods. It is part of a comprehensive flood protection program which reduces flood damage through structural improvements and siting practices for buildings. Examples include buildings constructed with impervious walls without outer openings, or flood vulnerable buildings constructed with columns and patios in lower inundation-prone stories. There is a possible conflict between this latter solution and soft-story structural design in seismically active areas.

- Flood forecasting and warning involves the prediction of river stages on unregulated streams and the timely notification of authorities for emergency response and evacuation purposes. The system requires elaborate data collection facilities to compile large amounts of current data on precipitation and river stages. Even where flooding is infrequent, the public should be informed of the possibility of an extreme flood event to assure prompt and effective action.

Conclusions

- When using 100 or 500 year flood limit standards, such as those used by the U.S. Army Corps of Engineers, the effect of expanding urbanization and increased runoff needs to be accounted for in the design of flood protection structures in the metropolitan areas of the County.

- Determination of accurate runoff factors, and placement and construction of sediment-carrying channels and sedimentation and detention basins represent the best structural flood control approaches for presently unregulated drainages. Control of development in areas of extreme flood and inundation hazard along unregulated drainages provides the safest alternative for flood protection until emplacement of adequate flood control systems can be achieved (National Research Council, 1982).

- Alternatives for flood management in the Antelope Valley consist of: 1) guiding development away from flood hazard areas on alluvial fans, 2) construction of concrete channels and detention basins, and/or, 3) channelizing flood waters to a single large excavated channel.

- Coupled with continued County maintenance of debris flow basins during times of peak rainfall, public support and coordination is necessary in preventing disastrous mud flood and mudflow problems.

- Programs should be designed to educate existing and future homeowners of the hazards of mud floods and mudflows, including how to evaluate potential problems and contact County agencies for expedient and efficient mitigation.

- Design standards for storm drains and debris flow basins should be reviewed to represent the most recent estimates of sediment influx and peak rainfall when approving private flood protection devices, especially when they are to be the responsibility of the County for maintenance during peak flooding (Department of Water Resources, 1980).

- Improved flood proofing, flood forecasting, and warning procedures and warning technology for clear water, mud flood, and mudflow prone areas provide viable long-term objectives for the protection of public safety from flood hazards.

SECTION 3.4

WILDLAND AND URBAN FIRE HAZARDS AND HAZARDOUS MATERIALS

(Plate 7 - Wildland and Urban Fire Hazards)

The residents of Los Angeles County live with a variety of fire hazards and threats to their lives and property. The fire hazards are of two categories: wildland and urban fires (Figure 3.18). Wildfires are those fires of any size which burn in woodland, brushland, and grassland areas. Urban fires are those fires which burn in developed urbanized areas and include both industrial and residential fires. At the interface between brush-woodland area and urban areas, wildland fires can become urban fires and vice versa. This vulnerability is especially critical when strong Santa Ana winds in the late summer and early fall months can fan wildland fires, facilitate the spread of airborne cinders, and ignite adjacent moderately to heavily urbanized areas. It will be shown that climatic factors, by supporting fire prone vegetation and causing the unique Santa Ana weather conditions, make Los Angeles County especially vulnerable to wildland fire hazards.

Special fire hazards are also posed by earthquakes. Earthquake-induced fire may occur in both wildland and urban environments. In Los Angeles County, the urban environment is vulnerable to earthquake-induced fires because of the increasing intensity of development in some areas and the possibility of reduced fire fighting capability caused by damaged waterlines. Fire suppression is especially critical in industrial areas and high-rise buildings. High-rise buildings pose special problems even in non-earthquake related fires because of height limitations of fire fighting equipment (ladders, etc.), and the high probability that such buildings house large numbers of residents in need of evacuation. The special circumstances of fire reporting and response in an earthquake situation is also addressed in this section.

Los Angeles County is vulnerable to unauthorized releases of hazardous materials (Figure 3.18). This is despite a number of State and Federal regulations that have been adopted over the past few years to reduce the risk of release of toxic hazardous materials or the ignition of explosive hazardous substances. These potential hazards could prove fatal to hundreds or thousands of individuals near the release site. Currently, information vital to emergency response teams in dealing with fire, explosion, or release of hazardous materials is not being provided by businesses. Furthermore, regulations governing the storage, handling and usage of hazardous materials are not being followed by businesses, which increases the risk of a hazardous materials incidence. The 1987 Whittier Narrows Earthquake enlightened many to the special risk of atmospheric releases of

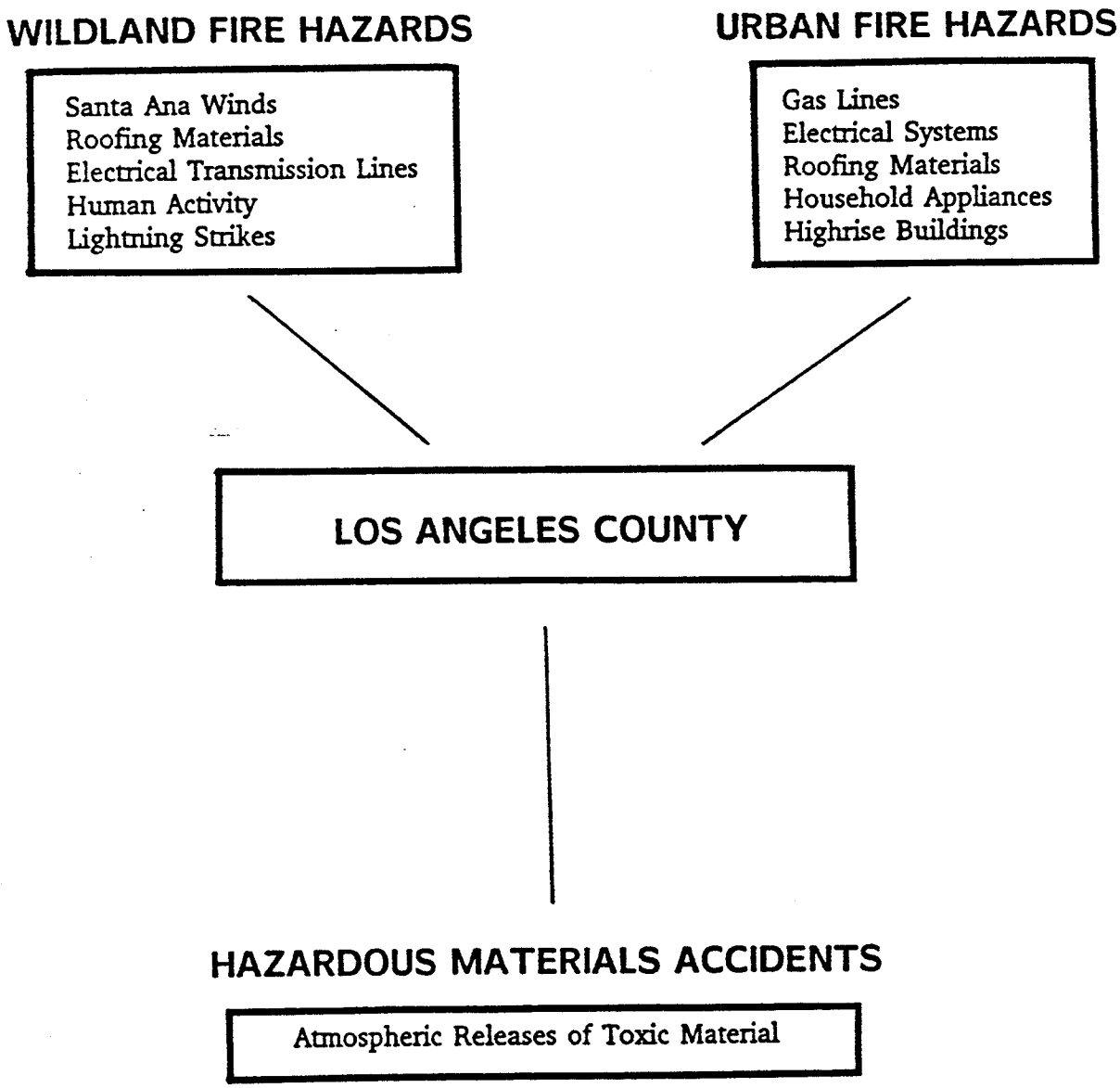


Figure 3.18: Wildland, Urban, and Hazardous Material Hazards in Los Angeles County.

hazardous materials when a chlorine gas leak resulted in the threatened evacuation of a large number residents. The potential for catastrophe is heightened by the unpredictable nature of toxic gas plumes.

This section emphasizes the vulnerability of Los Angeles County to earthquake and nonearthquake-induced wildland and urban fire hazards and hazardous material releases. In addition to the information concerning County Fire Prevention Management in this section, other fire programs will be discussed in Chapter 5, Hazard Management, Section 5.1.4 (Wildland and Urban Fire Hazards and Hazardous Materials). Likewise, the implementation status of several mandated State and Federal regulations governing hazardous materials are provided in that same section. The following discussion of wildland and urban fire hazards and hazardous materials hazards will be composed of four subsections, and will reference a generalized fire hazards Map (Plate 7 - Wildland and Urban Fire Hazards).

- **Section 3.4.1:** Wildland Fire Hazard
  (Wildland and Urban Fire Hazards - Plate 7)
- **Section 3.4.2:** Urban Fires
  (Wildland and Urban Fire Hazards - Plate 7)
- **Section 3.4.3:** Earthquake Fire Reporting and Response
- **Section 3.4.4:** Hazardous Materials
  (Table 3.12 - Hazardous Materials Incidents)

SECTION 3.4.1

WILDLAND FIRE HAZARDS

(Plate 7 - Wildland and Urban Fire Hazards)

The attractive climate of southern California, which helps make the area a desirable place in which to live, is also responsible for turning its grassy and woodland areas into highly volatile tinder boxes, especially during the summer and fall of each year. These areas are the sites of wildfires, some of which are spectacular and especially devastating to man and the native ecosystem. In 1987, 1,800 wildfires burned roughly 13,000 acres; of these fires, 97 percent burned ten acres or less. Most of the burned acreage was caused by the 11,000-acre Ruby Canyon Fire (LACFD, 1988). The number of acres burned each year by wildfires is variable and is due to several factors, the most important of which is weather conditions during the critical fire months. The key factors governing wildfire propagation are climate (weather), fuel (vegetation) and slope angle (topography) (Radtke, 1986).

Wildland Fires: Climatic, Fuel, and Topographic Factors

The most critical times of year from a weather standpoint are the late summer and fall months when the Santa Ana winds and bring hot, dry desert air into the region. The resulting increase in air temperature and drop in humidity produce an extreme fire danger in woodland and brushland areas. The critical moisture content of vegetation for high fire danger is 60 percent and occurs principally during late July, September, and October. The fire danger caused by the decrease in moisture content is compounded by an accompanying concentration of flammable oils in certain species of vegetation, thus drastically increasing the potential for a wildfire (USFS, n.d.). This is especially true of wildland areas where a fire has not occurred for a number of years, thus increasing the bulk and density of hillside vegetation.

The plant communities in Los Angeles County consist of variable mixtures of woody shrubs and herbaceous species and are the principle fuel consumed by wildfires. Grassland areas have the lowest requirement for ignition and thus have the highest fire frequency. Fire frequency also tends to be high in the coastal sage subunit. The woody chaparral species have the highest potential for severe wildfires because of the density of the plant community, and the natural concentration of flammable oils accompanying the loss in moisture during Santa Ana conditions (Radtke, 1986).

Critical factors affecting the flammability and fire behavior of the shrub communities are:

- Moisture content of the fuel.

- Fuel loading.
- Ratio of fine, dead fuel to living fuel.

Fuel loading is defined as the amount of plant material per acre. A factor of 40 tons/acre is the critical point for a fire hazard in older growth (Radtke, 1986). Mature and older plants have an increased fire danger when their stands contain over 60 percent dead material (Radtke, 1986). The chaparral covered hillsides surrounding the County's urban areas are presently in decline and are producing more dead vegetation. Extreme fluctuations of rain and heat inherent to southern California contribute to the increase in dead vegetation. It is believed that this increase in dead vegetation will result in an increase in the number and severity of wildland fires (LACFD, 1987). Controlled burning of identified areas of older growth or dead vegetation is the current state-of-the-art approach for reducing fuel loading.

Fire cycles are also governed by the plant succession patterns that follow a wildfire (Radtke, 1986). After a major fire (usually in woody species), grassy areas flourish in the burned area for 2 to 3 years and present a high probability for low intensity fires. The grasses give way to a renewed growth of woody species. During the first ten years of this growth, fire hazards are low. As the woody stands mature and dead vegetation begins to accumulate, the potential for a major wildfire increases.

Steep mountainous topography, coupled with high fuel loading factors, poses the most difficult fire suppression problem because of access problems and the potential intensity of the wildfire. South-facing slopes, which are drier than those facing north, will burn more readily than north-facing slopes; however, in general, the steeper the slope angle, the greater the fire severity. In Los Angeles County, canyons and topographic saddles have been shown to be especially prone to fire damage (Radtke, 1986).

Historical Causes of Wildland Fires

Wildfires are seldom, if ever, directly caused by earthquakes. The potential for earthquake-induced wildland fire does exist from downed power lines, severed gas lines, upset campground fires, or structure fires that could be caused by an earthquake. The principal causes of wildfires, however, are the accidental or deliberate actions of man. Data kept by the Angeles National Forest for the period 1973 to 1987 indicates that the largest single cause of wildfires was incendiary (29 percent). For the same 15-year period, 86.2 percent of the wildfires in the Angeles Forest were caused by man. The remaining 13.8 percent is attributed to other sources, such as lightning strikes. The County Sheriff's office in Malibu, recognizing the probability of man-induced fires, coordinates an Arson Watch Program through participation of concerned residents. Such a program also promotes efficient reporting of any fire regardless of the origin.

Methodology

The Generalized Fire Hazard Map (Plate 7) depicts the following themes related to wildfires in a generalized manner:

- Fire Zone 4 (High Fire Hazard brush and woodland areas; steep topography and little or no development).
- Additional Brush Fire Hazard Areas (same criteria as Fire Zone 4).
- Major Electrical Transmission Lines in Wildland Areas.

The Wildland and Urban Fire Hazard Map (Plate 7) was compiled from several sources onto a 1:100,000-scale topographic map. No field verification of the data was attempted. This compilation was then photo-reduced to a scale of 1" = 2 miles. Plate 7 could be used by itself or in combination with other hazard maps in a general way for regional land use planning studies. It is of little or no value to the fire department per se' as they use 1:5,000-scale or larger maps for fire prevention and control. The methodology, and analyses for each Wildland fire hazard theme follows.

Fire Zone 4 - Plate 7

The boundaries of Fire Zone 4 were taken from the current Los Angeles County 1:126,720-scale fire zone map (Anonymous, 1987). The data was manually transferred to the 1:100,000-scale map using section lines, roads, land grant boundaries, canals, and other convenient features as guides. Fire Zone 4 encompasses most of those areas having a potential for woodland and brush fires. The map could be used, in a general way, to indicate where consideration should be given to a variety of fire prevention measures such as, fire retardant or resistive roofing, increased water flow standards, brush clearance, etc. The fire hazard posed by the types of vegetation and difficulty of access associated with these areas justifies such action.

While Fire Zone 4 covers a large area, users of the map should be aware that much of Fire Zone 4 covers Federal land in the Angeles National Forest and Santa Monica Mountains National Recreation Area (SMMNRA) and that fire protection responsibility on most of the forest lands lies with the U.S. Forest Service (USFS), with whom the County has a mutual aid pact covering these lands. Within the national forest, the USFS has the primary responsibility for extinguishing non-structure fires, while LACFD has the primary mission of suppressing structure fires. The primary fire-related mission of each agency is thus complimentary and not competitive. In actual fire emergencies, each agency fights both wild and structure fires. The USFS recognizes that fire fighting is not its primary function. Its fire crews are generally on duty Monday to Friday, 9:30 a.m. to 6 p.m., and can respond quickly during those hours. At other times, it could take a couple of hours for USFS to assemble and deploy a fire fighting team. During these times, LACFD could be called upon if a fire involved structures or brushlands near the forest boundary. LACFD has fire suppression responsibility in the Santa Monica Mountains National Recreation Area, and by contract, for all State lands in the County.

The area covered by Fire Zone 4 is continually shrinking due to the encroachment of urban development. Fire Zone 4 was established in May, 1937 by County Ordinance 2913, with the Forester and Fire Warden having the authority to adjust the Zone's boundaries to reflect increased management of forest, brush, and grass fire hazards resulting from encroaching development. County Ordinance 10259, adopted in April, 1971, restored wood and shake shingles as approved materials in Fire Zone 4.

The woodland, urban interface areas of the County are of three general types:

- The mixed interface of structures scattered throughout rural areas. When a fire starts, individual homes become hard to protect because of the large area burning and the few homes at risk.

- An occluded interface characterized by isolated areas of wildlands within an urban area (e.g., Verdugo Mountains). Many buildings are at risk, but the relatively small wildland areas are not as subject to conflagration.

- A classic interface where homes, especially those crowded onto small lots press against wildlands along a broad front, (e.g., Granada Hills). Numerous homes are put at risk by a single conflagration and significant loss of life is possible.

Additional Brush Fire Hazard Areas - Plate 7

The boundaries of the brush fire hazard were placed at the urban-wildland interface as interpreted from the 1:100,000-scale U.S. Geological Survey Topographic Maps covering the County. The boundary was manually plotted on the 1:100,000-scale map using cultural and topographic features as guides.

The Generalized Fire Hazard Map shows other wildland areas designated as "Additional Brush Fire Hazard Areas." These are wildland areas outside of Fire Zone 4 but having features similar to these included within Fire Zone 4. Such fire hazard areas, within the jurisdiction of incorporated cities, are concentrated largely within the eastern Santa Monica Mountains, the hillside areas of the San Gabriel Mountains adjacent to the Los Angeles basin and valleys lowlands, the Verdugo Mountains, and the Palos Verdes Peninsula. Within wildland areas, fires are most likely to start in areas of man's activity such as roads, campgrounds, cabins, wood cutting areas, power lines, and the urban-wildland interface.

Major Electrical Transmission Lines in Wildland Areas - Plate 7

The major power transmission lines shown on Plate 7 are taken from the earthquake planning scenario studies of Davis, et al., 1982 and Toppozada, et al., 1988. The power line alignments are shown on the 1:100,000-scale topographic base map and were manually traced onto the map overlay. Only that part of a power line alignment that crosses wildlands is shown on Plate 7.

Wind-downed power lines cause an average of two to three wildfires a year. While this is only 1 to 2 percent of the total fires each year, this type of ignition has the potential for causing the largest conflagration of any single source (USFS, n.d.), because electrical transmission lines cross extremely steep and inaccessible terrain. "Burned-down" power lines in wildland areas may arc or be knocked down, in a manner similar to wind-downed lines. "Burn-down" is a result of the lateral motion of earthquake shaking. The hazard posed by burned-down transmission lines in wildland areas is compounded by the fact that immediately following an earthquake, fire reporting capability can be jeopardized by failed communication lines. In addition, many fire fighting agencies will be coping with urban fire or heavy rescue duties.

Conclusions

- The County is at high-risk to wildland fires due to wet year - dry year climatic cycles, Santa Ana weather conditions, the types of vegetation supported by the mediterranean climate, and the extreme inaccessibility posed by steep mountainous topography adjacent to developed areas.

- Fire Zone 4, additional brush fire hazard areas, and developed areas immediately adjacent high fire hazard areas in the County, require innovative strategies to enforce stringent fire enforcement measures including fire-resistive construction materials, brush clearance, fire breaks, and fuel load management requirements.

- Improvements in fire reporting, local fire fighting capability, and homeowner prevention, in and adjacent to wildland fire hazard areas, would augment County fire suppression resources, increase the effectiveness of mutual aid agreements, and increase overall fire safety, regardless of the origin of the wildland fire.

SECTION 3.4.2

URBAN FIRE HAZARDS

(Plate 7 - Wildland and Urban Fire Hazards)

Urban fires, be they residential or industrial, are an everyday event in the County and are a constant hazard to its residents. This section does not address these daily hazards although they are extremely important to the populace. This section focuses on the urban fire hazard that is likely to be created by a large, damaging earthquake located in or near the County. Additional discussion of earthquake-induced urban fire hazards is also located in Chapter 4.

In the United States, fires following earthquakes have caused the largest losses associated with earthquakes. Damage from post-earthquake fires in the County will probably dominate shaking damage (Scawthorn, 1986). Expected insured losses from a major earthquake in the County are estimated to be $5.9 billion from shaking and $9 billion from ensuing fires (Scawthorn, 1987). Total fire loss within the Los Angeles Basin (essentially the County) has been predicted at $5 to $17 billion, depending upon the size of the earthquake (Scawthorn, 1987). A large event could trigger 500 to 600 fires requiring fire department response. Of these, 300 to 500 can be expected to be large fires (Scawthorn, 1987).

The crux of the urban fire problem as it relates to earthquakes is that multiple, nearly simultaneous, fires will be ignited. These fires, extinguishable alone and under normal conditions, could grow into conflagrations or fire storms because fire agencies may be unable to respond to all of them (Scawthorn, 1986). In the aftermath of the 1989 Bay Area (Loma Prieta) Earthquake some 500 fire incidents were reported, of which only 27 involved structural fires (EERI 89-03). The fire losses in San Francisco, although dramatically portrayed in the Marina District, can be considered low, at least compared to the losses that might have occurred if the winds had been stronger.

Urban Fire Spread

The subject of interbuilding fire growth and spread has not been well-studied (Scawthorn, 1986). In general, however, fire growth is related to building density, building construction (wood versus fire resistive materials), the presence and amount of flammable materials, wind speed and direction, width of fire breaks, water supply, time of fire department arrival, and available fire fighting resources. One of the more important factors in the spread of fires is branding, especially in areas where wood roofs are present and where accompanied by dry Santa Ana winds. Branding is usually expressed on roofs, which are the most susceptible part of a structure in relation to fire vulnerability and spread. For this reason, some relatively urbanized jurisdictions have banned wood roofs (e.g., San Francisco). The Wilshire Terrace Fire of December 1989

experienced multiple ignitions, fueled by burning cinders fanned by strong Santa Ana winds. This simultaneous pattern of ignition stretched urban fire fighting resources to their limit.

Historical Causes of Urban Earthquake-Induced Fires

The principal causes of earthquake-related fires include open flames, electrical malfunction, gas leaks, and chemical spills. The open flame hazard is prevalent with unanchored gas heaters or gas-fired hot water heaters, which could tip over during ground shaking. Whatever their causes, there is a clear trend of a greater number of ignitions with increasing earthquake intensity.

A large earthquake will likely damage a building's built-in safeguards such as sprinklers and firewalls thus lessening its resistance to fire spread. There is also serious concern about the availability of water to fight a fire, due to disruption of local supply mains. The rate of growth of an uncombatted fire will double every seven seconds, during the period of fire initiation (Scawthorn, 1987). Local fire fighting capability and preparedness is practiced by businesses and neighborhoods in Japan. Such action is necessary to ensure timely and effective fire suppression response when multiple fires are ignited.

An unknown number of arson fires will be set when owners of damaged property realize that their insurance covers fires from earthquakes, but not the actual shaking damage itself (Scawthorn, 1987). These additional fires could overwhelm the County Fire Department. The available evidence to date from earthquakes elsewhere suggests that arson has not been a big problem, but none of these were in areas which had such inflated property values as Los Angeles County.

Methodology

The Wildland and Urban Fire Hazards Map (Plate 7) depicts the following themes related to urban fires in a generalized manner:

- Areas of Potential Industrial Fire Hazards.
- Clusters of High-Rise Buildings.
- Areas of Known Accumulations of Shallow Explosive Gas.
- Natural Gas Pipelines.

Areas of Potential Industrial Fire Hazards

Plate 7 depicts in a general way, two types of industrial fire hazards: 1) those related to petrochemical complexes, and 2) all other industries. The map outlines, in a general way, major industrial areas which include traditional manufacturing, warehouse districts, transportation facilities, and petrochemical

facilities. Fires in these areas have the potential for using a large share of a fire department's resources.

While industrial areas included on Plate 7 may include concentrations of manufacturing, warehouse, transportation, and petrochemical facilities, mining and retail facilities are excluded from this category. The facilities included in the petrochemical complexes include oil fields, refineries and tank farms as these are readily identified on reference sources. The other category includes diverse facilities such as warehouses, automobile assembly lines, smelters, breweries, etc. A 1:206,000-scale industrial map of the Los Angeles Region (Western Economic Research, 1988) and a County zoning map were used to identify general industrialized areas. These regions were then compared with current U.S. Geological Survey 7-1/2 minute topographic quadrangle maps to better delineate the boundaries of the industrial areas and to exclude features such as mining operations and shopping malls. The boundaries were then manually drawn on a 1:100,000-scale map. The boundaries of oil fields were taken from the California Division of Oil and Gas Map (1974) or determined by well distribution on 7-1/2 minute topographic maps and then plotted on Plate 7. Undeveloped areas presently zoned for industrial are also shown on the Fire Hazards Map. Zoning classifications, however, are subject to change and should be considered in interpreting the map.

The petrochemical component of the fire hazard map, specifically refineries, tank farms, offshore oil production sites, and active and abandoned oil fields, is significant. Recent, notable post-earthquake fires were a 1952 butane fire in Kern County, a two-week refinery fire in Japan in 1964, and fires at storage tanks in Anchorage following the 1964 earthquake (Toppozada, 1988). In 1923, a major earthquake near Tokyo resulted in an immense fire which killed tens of thousands of people. The response of the County's petrochemical centers to future large earthquakes is unknown, but their vulnerability to damage and subsequent fire cannot be discounted, especially in areas of poor soil conditions or where pipelines cross active faults, and liquefiable sediments.

The map can be used for general land use planning in terms of siting future industrial growth, especially that which could pose a serious fire hazard or could be involved in hazardous materials. This map is especially useful for siting and planning studies when it is used in conjunction with maps of active faulting, unstable soils, and other geologic hazards. The map has limitations. It does not distinguish the kinds of industries and associated fire hazards except to differentiate petrochemical from nonpetrochemical based industry. Individual industries, which are located away from the generally industrialized areas are not shown, but they are capable of generating fires similar to those that could occur within the industrial areas. The map cannot be used to predict the degree of severity of a potential fire in industrial and nonindustrial areas, or to predict fire loss within any given industrial area.

Clusters of High-Rise Buildings

Plate 7 in a general way, identifies major clusters of high-rise buildings within Los Angeles County. The buildings are principally office buildings, apartments, and hotels. The map can be used for general planning purposes as an indication

of where high-rise fires could occur. The map does not identify the older, and possibly more fire-hazardous structures which were built prior to World War II. Such fire hazardous buildings were specifically referenced for abatement in the 1975 Seismic Safety Element and considerable progress has been made in improving the safety of these buildings in the last 18 years.

The Los Angeles County Fire Code defines a high-rise structure as one being over 75 feet tall (County Ordinance 86-0004, Section 2). Because of this, and the limitation of available reference data, high-rise structures are here defined as having eight or more floors. Using this as the only constraining factor, high-rises may include office buildings, hotels, residential buildings, schools, or hospitals, etc. The location of high-rise buildings built after 1946 was taken from Western Economic Research Company, Inc. (1986) and clusters of these buildings were plotted on the 1:100,000-scale map overlay. During the period 1900 to 1940, however, numerous 10- to 13-story buildings were built in the County in what were then the downtown areas of Los Angeles, Hollywood, Pasadena, Glendale, and Long Beach. This data was obtained by the interpretation of stereo paired 1952 aerial photographs and plotted on the map overlay using streets as guides. Only clusters or groupings of high-rise buildings are plotted on the Generalized Fire Hazard Map, while individual high-rise buildings that are not parts of clusters of high-rises, are not shown.

Fires in high-rise buildings place inordinate demands upon a fire department as was demonstrated by the First Interstate Bank fire in downtown Los Angeles on the evening of May 4, 1988. The fire took 3-1/2 hours to knock down and 383 firemen and paramedics were onsite for most of this time. As a result of the fire, the City of Los Angeles has drafted a sprinkler ordinance which is awaiting final approval by the City Council (1989). The Wilshire Terrace fire of December, 1989, required an even greater effort from the Los Angeles Fire Department.

Areas of Known, Shallow Accumulations of Explosive Gas

Several areas in the County are known to be the sites of shallow methane accumulations. The best known is the Fairfax District where, in March, 1985, a methane explosion leveled a Ross Dress for Less Store, injuring 21 persons, and damaging other nearby buildings. As a result of this tragedy, the City of Los Angeles enacted an ordinance requiring businesses in the area to install gas meters and monitor them every day. The ordinance is credited with sparing the same area from an explosion on February 6 and 7, 1989, when methane gas again bubbled to the surface.

The map shows the known areas of shallow methane accumulations determined by the work of Geoscience Analytical, Inc. (1986), who studied only the Salt Lake, Los Angeles City, Santa Fe Springs, and Whittier oil fields in the County. Undiscovered areas of shallow methane concentrations may exist elsewhere in the County. The City of Los Angeles has under consideration (early 1989), a project to more thoroughly explore the City for shallow gas pockets and to determine their origins. The absence of the explosive gas pattern on the map is not a guarantee of the absence of gas in the soil. Most of the shallow methane found to date seems to be spatially associated with shallow oil/gas fields.

Natural Gas Pipelines

The major natural gas pipelines depicted on Plate 7 are also taken from Davis, et al., (1982) and Toppozada, et al., (1988), checked for accuracy and augmented with large scale maps provided by Southern California Gas Company. The pipeline alignments are based upon those shown in these reports and were manually drawn on the 1:100,000-scale map using cultural features as guides. The vulnerability of the natural gas distribution system (pipe diameters 8 to 20 inches) is discussed in more detail in Chapter 4.

Conclusions

- The principal causes of earthquake-related fires include open flames, electrical malfunction, gas leaks, and chemical spills. The open flame hazard is prevalent with unanchored gas heaters or gas-fired hot water heaters, which could tip over during ground shaking.
- The most susceptible part of a structure in relation to fire vulnerability and spread is the roof, especially Santa Ana winds conditions are present (branding).
- Urban fire danger increases with increasing building density if proper consideration for fire breaks, green belts, and flammability of construction materials is not heeded.

SECTION 3.4.3

EARTHQUAKE FIRE REPORTING AND RESPONSE

Fires are usually reported to a fire department by one of four methods:

- Telephone;
- automatic detection and reporting devices;
- direct travel to a fire station by a citizen (a.k.a. citizen alarm); and
- radio.

The telephone system may or may not be damaged by an earthquake, but it will certainly be incapacitated due to overload. Automatic detection and reporting devices, presently installed on a small portion of commercial property, may be damaged and produce numerous false alarms, thus diverting resources away from real fires (Scawthorn, 1987). A review of previous earthquakes has revealed that citizen alarms may be the only feasible method for reporting fires in areas afflicted by strong ground shaking (Scawthorn, 1987). Unconventional fire reporting methods, such as helicopter observation will be of some use, but they will only be able to identify and report fires that have achieved general alarm status (Scawthorn, 1987). Innovative methods that can accommodate emergency radio frequencies of the County Fire Department using communication satellites have also been suggested. Delays in reporting fires will allow them to grow larger.

Recent California earthquakes have shown that fire departments have functioned well, but that they are inundated with demands for all types of emergency response, not just fire suppression. Communications systems are a critical, but highly vulnerable element in emergency response (Scawthorn, 1986). Recent medium-sized emergencies (e.g., 1987 Whittier Narrows Earthquake) have overloaded the LACFD communications system.

During a catastrophic emergency that is likely to follow a major earthquake, LACFD response will be guided by a policy of triage, that is, one of prioritizing emergency fire, medical and rescue responses, allocating their departmental resources on the basis of urgency and chances for survival. For this reason, not all requests for help will be answered and many citizens will probably have to depend upon their own resources for 72 hours or more before governmental help can be expected.

Mutual aid pacts with other jurisdictions are generally structured for non-emergency conditions and may break down, further delaying response time. Some incorporated jurisdictions do not have any emergency response plan. Los Angeles County currently lacks sufficient cooperation even among cities with emergency response plans. In the event of a major catastrophe, some LACFD officials believe it could take the department 24 to 48 hours to recover and become reasonably

operational. This estimate could be understated if there is no emergency coordination with other cities in the County.

Response to individual requests for help may be impeded by blocked streets due to traffic jams or collapsed structures (Scawthorn, 1987), and water supplies may be disrupted by earthquake damage to local pipelines and regional aqueducts.

As fires are fought, one of three things will probably happen to the blaze:

- It will be brought under control and extinguished.
- It burns within a few city blocks until a greenbelt or wide road, or similar firebreak is reached, after which it burns itself out.
- It grows into a firestorm or conflagration and burns until a large natural firebreak such as the ocean or edge of an urbanized area is reached and the fire is ultimately suppressed.

Conclusions

- Post-earthquake emergency communication capability needs to be reviewed on a regular basis not only because of the importance to fire reporting and response but also to allow adequate damage assessment of freeway interchanges, bridges, petrochemical facilities and other crucial or potentially hazardous community assets.
- Increased cooperation and coordination with other jurisdictions is essential for efficient fire and emergency response.

SECTION 3.4.4

HAZARDOUS MATERIALS

(Plate 7 - Wildland Fire and Urban Fire Hazards)

The number of hazardous materials responses by the Los Angeles County Fire Department's Hazardous Materials Squads each year has steadily increased from 92 responses in 1985 to 350 responses in 1988 (Table 3.12). Two significant events are summarized below:

- 1988 - A large vapor cloud was spotted by Engine 50 of the Los Angeles County Fire Department while returning from an incident. Captain Wolfe recognized the cloud to be chlorine gas. The source was a large 2-walled shed owned by Grow Group, Inc. in Commerce. The Hazardous Materials Unit, an evacuation team, representatives of South Coast Air Quality Management District and the Los Angeles County Health Department responded to the incident. An estimated 28,000 citizens were evacuated. Approximately 30 citizens went to area hospitals with eye and respiratory irritation. Three fire fighters (including two members of the Hazardous Materials Unit) were sent to the hospital with burns and irritated skin and eyes. The cause of the release was due to contamination of the waste trichloroisocyanuric acid stored in the shed.

- 1989 - Los Angeles County Fire Department was notified to respond as backup to the Ventura County Fire Department and Ventura County Hazardous Materials Unit for a chlorine leak at Travelin West Textiles, Inc. in Simi Valley. Two members of the Ventura County Hazardous Materials team were hospitalized after a large pressure release of liquid chlorine froze and destroyed their Cryo suits when they entered the building, and attempted to secure the valves on the 30,000 pound leaking chlorine tank. The Los Angeles County Hazardous Materials Unit entered the building and secured the leaking tank.

The figures outlined in Table 3.12 show that Los Angeles County has a growing problem with the storage, use and/or handling of hazardous materials, despite the strict regulations adopted over the past few years. An earthquake of medium or strong intensity could result in hazardous materials releases, either by upsetting improperly stored materials through ground movement, or through urban fires setting off chemical fires in areas where quantities of chemicals are stored. In the event of a large earthquake there is the possibility of thousands of individuals being injured or killed from an extremely toxic hazardous materials release, before local officials could be mobilized and secure the release. Hazard Materials Management in Los Angeles County is discussed in more detail in Chapter 5, under the topic of "Future Development".

Table 3.12: Los Angeles County Hazardous Materials Incidents*

1985		
Hazardous Materials Squad 87	- 37	
Hazardous Materials Squad 105	- 55	Total - 92
1986		
Hazardous Materials Squad 76	- 38	
Hazardous Materials Squad 87	- 73	
Hazardous Materials Squad 105	- 33	Total - 144
1987		
Hazardous Materials Squad 76	- 42	
Hazardous Materials Squad 87	- 119	
Hazardous Materials Squad 105	- 50	Total - 211
1988		
Hazardous Materials Squad 76	- 72	
Hazardous Materials Squad 87	- 178	
Hazardous Materials Squad 105	- 100	Total - 350

* Hazardous materials incidents responded to by the Los Angeles County Fire Department **Hazardous Materials Response Units.**

Methodology

The general distribution of industrial areas depicted on Plate 7 may illustrate a mappable component for assessing the vulnerability of Los Angeles County to hazardous accidents, be they earthquake or nonearthquake induced.

Plate 7 shows the general distribution of industrial centers in Los Angeles County. If larger, high-risk facilities can be established as having a higher concentration in areas zoned for industry, then Los Angeles County appears to be extremely vulnerable to secondary disasters from unauthorized, damage-induced releases of hazardous materials. A recently released study by the California Public Interest Research Group (CALPRIG, 1989) indicates that the County is extremely at risk from toxic releases, given the population density and concentration of chemicals in the region. The risk to earthquake-induced releases of hazardous chemicals was not specifically addressed; however, the study concluded that 636 Los Angeles County companies in 1987 released 29.7 million pounds of toxic chemicals under nonearthquake conditions. These companies are identified as those that manufacture or use at least 10,000 pounds of one of more than 325 chemicals specified as potentially hazardous by the Environmental Protection Agency (EPA). The amount released during 1987 consisted of both routinely and accidentally emitted chemicals, as well as fumes lost through evaporation. The distribution of total releases by city confirm a relatively close relationship between industrial areas, and larger hazardous material users. Thus, the distribution of industrial areas depicted on Plate 7 may illustrate a mappable component for assessing the vulnerability of Los Angeles County to hazardous accidents. However, as will be pointed out in Chapter 4, there are a number of hazardous materials sources outside these areas. Some of these hazardous material sources, which may include university chemical laboratories and even hardware stores, are not as easily grouped according to land use.

Conclusions

- The County is becoming increasingly vulnerable to hazardous materials accidents. New hazardous materials accident plans should include innovative methods to contain, combat, or neutralize toxic plumes, evacuate the public, and target areas for preparedness.

- Cooperation and contingency planning between the County fire and adjacent fire departments, owners of facilities storing, using, or involved with transporting hazardous materials, and the public is essential to the health and safety of the public.

CHAPTER 4

EARTHQUAKE VULNERABILITY

CHAPTER 4

EARTHQUAKE VULNERABILITY

The analysis in Chapter 3 shows that Los Angeles County is vulnerable to a wide range of hazards. Of these hazards, earthquake-related hazards are the most devastating in terms of the sudden potential for catastrophic losses. The historical earthquake damage patterns outlined in Chapter 2 (Table 2.2) for the 1933 Long Beach, the 1971 San Fernando, and the 1987 Whittier Narrows Earthquakes emphasize not only the sudden economic and social losses, but also the recurrent nature of certain earthquake damages. The damage patterns in the epicentral area of the Loma Prieta Earthquake, and in the Bay Area some 50 miles away, confirm this continued vulnerability despite efforts to improve building codes and reinforce existing developments. Disrupted gas lines caused fires in the older Marina District in San Francisco and residential fires in the Santa Cruz/Watsonville area. Up to 85 percent of the houses in mountain areas in the epicentral area suffered structural damage and more than 200 were totally uninhabitable (Los Angeles Times, October 21, 1989). A lack of water pressure also impaired fire suppression in some instances and, as displayed during the earthquakes in Los Angeles County, communication and electrical power also proved vulnerable to earthquake damage.

Other historic earthquake damage patterns were also revealed again in the Bay area earthquake, specifically the destruction caused by ground shaking. The Loma Prieta Earthquake caused sixty-four deaths, the majority of which were attributed to the collapse of aged buildings or infrastructure. About 18 years after the collapse of the Foothill and Golden State Freeway interchange during the 1971 San Fernando Earthquake, the collapse of the Nimitz Freeway and a segment of the Oakland Bay Bridge exposes the continuing vulnerability of the pre-1971 freeway system. More disturbing is the reality that many elements of our infrastructure may be more vulnerable than relatively modern freeway structures. The ages of some bridges, dams, and other infrastructure in Los Angeles County are approaching 60 to 70 years.

The 1987 Whittier Narrows Earthquake was an alarming reminder of the earthquake vulnerability of Los Angeles County. Although causing only three deaths and $358 million in reported damage, the Magnitude 5.9 earthquake generated 22 hazardous material situations and threatened the emergency evacuation of an entire neighborhood in Santa Fe Springs. Classified as a "moderately-sized" event, the earthquake also severely damaged the I-5/605 Freeway interchange, collapsed and partially destroyed many unreinforced masonry buildings and destroyed 123 single-family homes (Table 2.2). Certain tilt-up concrete buildings, proven vulnerable during the 1971 San Fernando Earthquake, were again severely damaged during the Whittier Narrows Earthquake (Chapter 2 - Table 2.2).

For perspective, the 1971 San Fernando Earthquake, just a few decimal points higher on the Richter scale than the Whittier Narrows event, produced much higher levels of strong ground motion and extensive ground failure. Combined with rampant fault rupture and post-earthquake fires, the earthquake resulted in the

destruction of nearly 830 single-family homes. That earthquake also severely damaged four major hospitals, causing the complete collapse of the Veterans Administration Hospital and structural condemnation of the Olive View Hospital. The 1971 earthquake caused the evacuation of thousands of people due the potential failure of the Lower Van Norman Dam. Los Angeles County should be concerned about existing development for four main reasons:

- Los Angeles County is at risk from a number of faults with the potential of generating magnitudes from 6.5 to 7.0, in addition to the 8+ Magnitude earthquake expected on the San Andreas fault;

- many buildings and structures, including critical facilities and high-risk facilities, constructed through the 1930's, 40's, 50's, 60's, and even the 70's and 80's continue to be vulnerable to various degrees of damage in a major earthquake;

- the Los Angeles Times (November 5, 1989) reports that as many as 100,000 people continue to live in unreinforced masonry buildings throughout the County, not including the many other County residents who live or work in a variety of potentially hazardous buildings (as defined by the Seismic Safety Commission); and

- catastrophic numbers of injuries and fatalities and a drain on County medical, emergency, and disaster control resources could result from widespread damage and/or collapse of critical facilities, or hazardous buildings and infrastructure.

Figure 4.1 shows three general categories of community assets subject to risk in Los Angeles County: community facilities, general development, and the population and economy. Lifeline systems such as the infrastructure supplying gas, electrical, power, water and even transportation to the community are critically important to emergency response and recovery from a disaster. Los Angeles County also possesses numerous public and private facilities in its "building stock" that are either vital to emergency response and disaster recovery efforts, or threaten catastrophic losses to life and property in the event of their failure. Such elements of the building stock, including infrastructure such as dams and freeway overpasses, are included in the category of "critical facilities". Potentially hazardous buildings, high occupancy buildings, and dependent care facilities also possess special attributes that place them at greater risk than other structures in the building stock. High occupancy and dependent care facilities are considered to be critical facilities.

Upon close inspection, any critical facility can be a potentially hazardous building or structure. Two variables governing the vulnerability of any structure are its age and structural characteristics (SSC 1987-03). FEMA (1988-154) suggests that, as of 1988, the years 1934, 1949, 1952, 1973, 1976, and 1985 reflect key successive improvements of seismic design provisions in the building code, and may reveal clues as to the structural integrity of the building or structure.

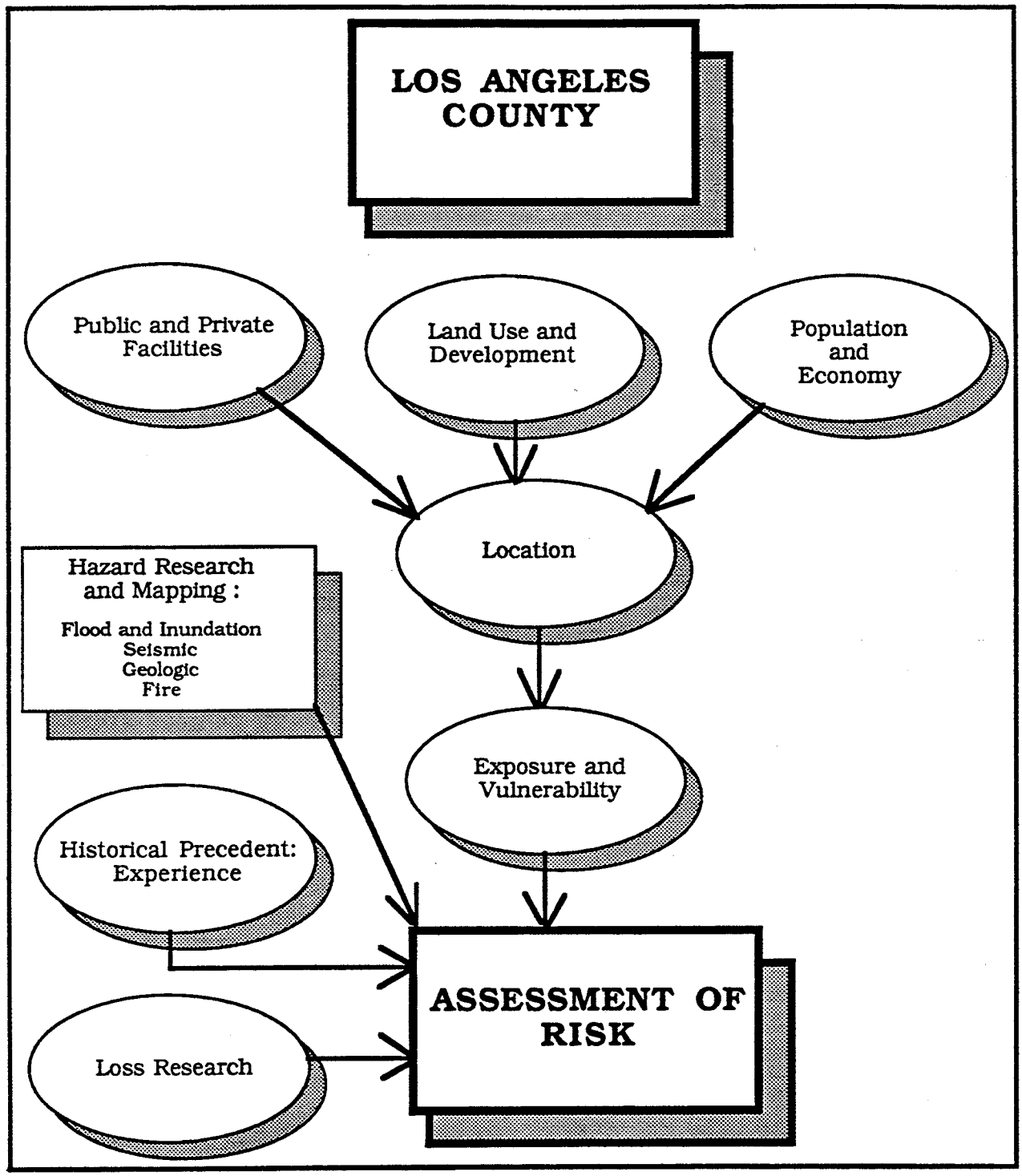


Figure 4.1: Schematic flow diagram showing the risk assessment process.

Existing and future development patterns also influence the earthquake vulnerability of the County. Historical precedent and earthquake loss research confirms that the vulnerability of development increases according to the relative exposure to a hazard (Figure 4.1). The vulnerability of residential buildings can be considered within the context of land development patterns and potential economic losses of the community. The vulnerability of the economy and the population, composing the third general category of risk, also considers the potential loss of tax revenue and other socioeconomic consequences of an earthquake, as well as the vulnerability of the population itself (Figure 4.1).

The analyses of critical facilities provided in Chapter 4 is organized to convey the importance of protecting or strengthening such elements of our community. The analyses will vary according to the amount and depth of available loss research in the literature, such as included in recent earthquake scenarios and insurance studies. Additionally, the scope of the map elements included on Plate 7 (Wildland and Urban Fire Hazards) and Plate 8 (Critical Facilities and Lifeline Systems) will also be a factor on which elements are analyzed in detail. Although a comprehensive definition of critical facilities would include more types of facilities (see glossary), critical facilities are reviewed in this chapter according to the following outline:

- Lifeline system facilities, including any utilities and transportation elements that are essential at times of emergencies and/or pose threats of fire or contamination (Plates 7 and 8);

- critical facilities and infrastructure including hospitals, facilities storing hazardous materials, high occupancy buildings, and dams and freeway overpasses. (Plates 7 and 8);

- potentially hazardous buildings (Plate 7); and

- dependent care facilities that house populations with special evacuation considerations and service needs (Plate 8 and Tables 4.3 through 4.7).

The chapter concludes with an indirect assessment of economic facilities and is organized as follows:

- Land use and development in Los Angeles County; and

- economic and socioeconomic vulnerability of Los Angeles County, including consideration of its unique diversity of population and social issues.

Earthquake vulnerability is focused on in this Chapter because of the omnipresent threat of the "Big One". The objective is to establish the framework for a comprehensive, proactive hazard reduction plan emphasizing existing development through long-range programs, including rehabilitation, retrofitting, and/or strengthening operations. While this Chapter may reference potential solutions, a detailed analyses of existing and proposed long-range County safety programs is given in Chapter 6.

SECTION 4.1

LIFELINE SYSTEM FACILITIES

Lifeline systems and facilities are defined in the Safety Element as those services necessary in emergencies such as power systems, other major utilities, and the transportation system. Selected elements of the lifeline system may have overlapping classification as emergency response (essential) facilities such as hospitals, high-risk facilities including dams and roadway infrastructure, and dependent care facilities like major social care centers or jails. The emphasis in this section will be on vulnerabilities affecting functional loss of the lifeline system, the fire vulnerability, and the potential for contamination problems, specifically from damaged infrastructure.

Methodology

The California Division of Mines and Geology (CDMG) has published two earthquake planning scenarios based on the hypothetical rupture of the San Andreas fault (Magnitude 8.3) and the Newport-Inglewood fault (Magnitude 7). Most lifeline information is compiled from these two scenarios completed in the Los Angeles area by Davis, et al., (1982) and Toppozada, et al., (1988). Additional sources include maps supplied by the Southern California Gas Company and lists of freeway structures supplied by the California Department of Transportation. The Los Angeles County Department of Public Works County disaster routes are plotted along with the State and Federal freeway system. The hospitals, communication stations, and County maintenance warehouse locations are also taken from disaster planning maps supplied by the Department of Public Works.

Uses and Limitations

Plate 8 is a plot of selected lifeline systems, nodal facilities (power plants, electrical substations), communication centers, Los Angeles County Public Works maintenance centers, and County evacuation/disaster routes. Because natural gas utility lines are shown on Plate 7, the Fire Hazards Map is also referenced in this section. An overlay of the Hazard Plates (1 through 6) with the Critical Facilities and Lifelines Map could be used to generally identify the most vulnerable segments of each map element/system. Their use should be limited to preparedness planning on a regional scale. Site specific investigations must be utilized to determine the actual risk of damage, but the maps may assist in pinpointing areas where more detailed studies may be necessary. It is important to emphasize that the design, age, and quality of construction, as well as local geologic ground conditions, will influence the seismic performance of any individual component of the lifeline system. Generally, older facilities will be more susceptible to damage.

The 1 inch = 2 miles scale of the maps allows only the largest utility features to be plotted. In addition, to preserve map clarity, water aqueducts and waste water collectors are not shown on Plate 8.

Assessment

Table 4.1 is a tabular summary of vulnerabilities of selected lifeline systems and critical facilities in Los Angeles County. The assessment of vulnerability considers not only the exposure of lifeline facilities and critical facilities to structural damage, but also the severity of repercussions in the event of their failure, or their impact on economic recovery. This may include secondary impacts such as:

- Loss of function (FL);
- fire vulnerability (F);
- contamination (C); or
- impaired emergency response (ER).

The degree of vulnerability is assigned qualitatively, based on loss research, historic precedent (Tables 2.2, 3.10), and recent observations from the Loma Prieta Earthquake. Cursory review and analyses of Hazard Plates 1 through 8 also provide some insight into the assessment. Lifelines systems and critical facilities are discussed in this Chapter (4) and Chapter 6; and conclusions from sections in these chapters provide much of the basis for the generalizations presented in Table 4.1.

Table 4.1 attempts to account for various improvements that have been made in mitigating certain hazards, it illustrates what kind of hazard is most likely to damage a specific lifeline or critical facility, provides a list of secondary hazards, and assigns a qualitative measure of relative vulnerability to each element. For example, above ground utilities and below ground facilities may both be moderately vulnerable to earthquake hazards; however, electrical power systems are more vulnerable to damage from high frequency ground shaking from a near-field (immediate vicinity) earthquake, while underground facilities are mostly at risk from ground failure or liquefaction.

Functional Loss

Plates 7 and 8 show that lifeline systems consist of both nodal facilities and a lifeline network that extends over the entire County. The location of utility lifelines are guided by right-of-way routes and are constrained by jurisdictional law or property ownership. By virtue of the extended nature of the system, lifelines are inherently exposed to many hazards along their path. In addition, the performance of a utility system at one location can be disrupted by a disturbance or failure at another location within the network. Although utility companies often segment their systems to reduce the potential for system

Table 4.1: General Vulnerability Assessments for Selected Critical Facilities and Infrastructure Systems in Los Angeles County *

POTENTIAL IMPACTS

1 = Structural or Foundation Failure
2 = Functional Loss (if Primary Issue)
3 = Contamination (Hazardous Materials)
4 = Fire Hazards and Response Issues
5 = Emergency Response Issues
7 = Economic Issues

	CRITICAL FACILITIES				TRANSPORTATION					UTILITY LIFELINES AND HIGH RISK INDUSTRIES										
HAZARDS	FLOOD CONTROL DAM	RESERVOIRS	HOSPITALS	DEPENDENT CARE	FREEWAY STRUCTURES	DISASTER ROUTES	AIRPORT	RAILROAD	PORT FACILITIES	ELECTRICAL POWER	ELECTRICAL TRANSMISSION	NATURAL GAS PUMPING STATIONS	NATURAL GAS TRANSMISSION / DISTRIBUTION PIPELINES	GAS UTILITY- BUILDING INTERFACE	WASTE WATER	WATER SUPPLY - FIRE FIGHTING	PETROLEUM PIPELINE	PETROLEUM REFINERIES	HAZARDOUS MATERIALS / STORAGE FACILITIES	INDUSTRIAL ZONES
GROUND SHAKING	1 2 5	1 2 5	1 2 5	\	1 2 5	2 5	2 5	2	2 6	2	2 4	2	2 4 5	2 4 5	2 3	2 4 5	3	3 4 5	3 4 5	2 3 4 6
FAULT RUPTURE	1 2 5	1 2 5	1 2 5	\	1 2 5	2 5		2	2 6		2	2	2 4 5	2 4 5	2 3	2 4 5	3	3 4 5	3 4 5	3 4 5 6
LIQUEFACTION	1 2 5	1 2 5	1 2 5	\	1 2 5	2 5	2	2 6	2 6		2	2	2 4 5	2 4 5	2 3	2 4 5	3	3 4 5	3 4 5	2 3 4 6
SLOPE INSTABILITY	1 2 5	1 2 5	\	\	2 5	2 5	\	2 6	\		2			\	2 3	2 4 5	3	\	\	
TSUNAM/DAM FLOOD	1 2 5	1 2 5	\	\	2 6	2 5	\	2 6	2 3 4 6				\		2 3			3	3 4 5	3 4 5 6

● MOST VULNERABLE ◐ MODERATELY VULNERABLE ○ LEAST VULNERABLE

\ NOT ASSESSED, NOT APPLICABLE OR CONSIDERED MINOR RELATIVE TO OTHER ISSUES.

* *A generalized assessment of probable scenarios resulting from a 6+ magnitude earthquake in the metropolitan area of Los Angeles, or from an 8+ magnitude earthquake on the San Andreas fault. Chapters 4 and 6 discuss these issues further.*

failure, a large earthquake may overwhelm this safeguard. Service disruption is termed a loss in function.

Modified Mercalli (MM) seismic intensities of VIII or greater can have a significant impact on electrical power networks, and electrical substations in particular (Toppozada, et al., 1988) (see Tables 3.1 and 4.1). Generally, high ground shaking intensities are associated with relatively young alluvial sediments and shallow ground water. Plate 4 shows that many areas with these ground qualities exist throughout the County, most notably along the San Andreas fault, within the Santa Clarita Valley Area, and at dispersed localities throughout the Antelope Valley. Toppozada, et al., (1988) also denotes wide areas of the Los Angeles basin lowlands and valleys as susceptible to very high shaking intensities, many of them associated with the ground conditions as stated above. For planning purposes, Southern California Edison estimates that a major earthquake could disrupt services for up to three days, depending on the amount and importance of the system subjected to strong ground motion (i.e., the size of the earthquake). A major earthquake on the San Andreas fault could result in as much as 4 to 5 days of power disruption to certain areas of north County, mainly those located within a few miles of the fault (Davis, et al., 1982). Other considerations for earthquake-induced power losses include:

- All 12 thermal electric power plants are located in areas of predicted heavy ground shaking (MM VIII-IX) (Plate 8);
- power distribution will be disrupted primarily due to damage sustained by major and minor substations from high frequency earthquake shock waves originating within a few widths of the fault zone;
- the larger the quake, the larger the area impacted and the accompanying difficulties in power restoration;
- electrical power transmission line damage is not expected to severely impair power distribution; power can be easily rerouted (Plate 8);
- hydroelectric power plants outside of the County can be expected to adequately supplement any temporary decrease in local power production from damaged power plants, especially after the first few days (Plate 8);
- priority will be afforded restoration of power to hospitals and emergency response services (critical facilities usually have back-up power capability); and
- commercial businesses over wide areas may be disrupted for up to three days, unless plans for emergency power are implemented.

Emergency response communication is paramount in post-disaster recovery situations. Communication is vulnerable not only to functional loss from electrical power supplies, but also from telephone saturation and direct damages to individual communication elements (Schiff, et al., 1988). The 1987 Whittier Narrows Earthquake exposed a number of unexpected communication problems, one being caused by the increased reliance on computers for emergency communications (Table 4.1). Schiff, et al., (1988) specifically noted problems associated with

the emergency 911 number. Having revealed this previously unrecognized vulnerability, short-term plans include using emergency radio frequencies and avoidance of overhead communication lines by exploring the use of geostationary satellites to manage post-earthquake operations (Holden, et al., 1989). Because of the vulnerability of computer systems, they should not be a primary element of any disaster response or hazard reduction function without provisions for an adequate back-up system. This contingency would allow emergency response operations to continue uninterrupted in an emergency.

Transportation systems are essential elements of the emergency response system and their functional loss is of critical concern. Structural failures within the transportation system add to the potential for injuries as well as impaired emergency mobility (Table 4.1). Pre-1971 freeway overpasses are considered most vulnerable to severe ground shaking; however, serious damage to any freeway overpass is possible at intensities greater than MM VIII (Toppozada, et al., 1988; Preistley, 1988). Plate 8 shows the locations of vulnerable freeway interchanges recognized by the California Department of Transportation. The freeway data is not complete as interchanges are not plotted in the Santa Clarita and Antelope Valley.

Disabled transportation has the potential for serious short-term and long-term impacts on the community. As hinted by the 1989 Loma Prieta Earthquake, short-term contingencies must address the logistics of caring for large numbers of people effectively stranded in heavily damaged areas, if the roads are closed by earthquake damage. Short-term problems also involve evacuation and emergency response operations which can be hampered by road blockage. In mountainous areas, debris from rockfalls poses the greatest threat (Table 4.1). In inundated areas, the remaining flood debris can impair access, whether caused by tsunami, dam break, or breaching of a levee (Table 4.1). Alternative emergency routes should ideally satisfy a number of criteria: 1) avoid high-risk freeway interchanges and bridges, 2) be at grade, wide and unflanked by tall buildings, structures or other sources of debris that can block the road, 3) avoid unstabilized steep slopes and/or high road cuts, and 4) avoid roadways vulnerable to liquefaction or fault rupture.

Consideration for the medium to long-term recovery must also be afforded to function of the transportation system. The two major bridge collapses in the Loma Prieta Earthquake reveal the need for alternative transportation resources or strategies, including mass transit and car pooling, to reduce traffic loads on heavily damaged roads. Long-term reconstruction of the transportation system is reflected in County recovery plans. Plate 8 shows selected disaster routes identified by the Los Angeles County Department of Public Works that they suggest should be emphasized for repair following a major damaging earthquake.

Selected transportation disaster forecasts reported in the CDMG earthquake scenarios include:

- A Magnitude 7 earthquake on the Newport-Inglewood fault will cause impaired function of local railroad service; however, the railroads are expected to remain a viable transportation service except in the port area where the system is extremely vulnerable to damage (Toppozada, et al., 1988).

- Adequate functioning of airports is expected in either the San Andreas or Newport-Inglewood Earthquake scenarios. Landing of aircraft, especially C-130 and C-141 military cargo planes is possible even if the control tower is damaged (Toppozada, et al., 1988). This assumes clement weather conditions and good visibility. Vehicle access, computer function, adequate back-up power supply, and provisions for large numbers of stranded travelers are considered primary problems at airports (Schiff et al., 1988). Adequate back-up power and computer performance are vital to air traffic control. Although runways may not be damaged, air traffic control must continue to manage multiple landings and taxi patterns.

The San Andreas Earthquake scenario concluded that, at worst, the County can be expected to lose 2 out of 3 aqueduct systems for maximum periods of up to 3 to 6 months (Plate 8) (Davis, et al., 1982). Local storage reservoirs and the Colorado Aqueduct are expected to accommodate the loss of the northern aqueducts owned by the City of Los Angeles Water and Power and the California Department of Water Resources aqueducts. The key issue for relatively isolated communities will be the inability to acquire potable water. Local drinking water supply lines and/or wells are likely to be damaged by ground failure and landsliding in areas near the earthquake source, as was common in the Loma Prieta Earthquake.

Earthquake-Induced Fire

Both CDMG earthquake scenarios for the Los Angeles region conclude that petroleum pipelines constitute a low fire hazard potential (Plate 7). Toppozada, et al., (1988) note that crude petroleum fuels are not easily ignited, and emphasize that the primary consequences of ruptured lines will probably be contamination or impaired production within some petroleum dependent industrial/commercial industries. Refined oils, on the other hand, can ignite and result in explosions if damaged and are so indicated in Table 4.1.

The natural gas distribution system and the main connections, in particular, are fire hazards (Plate 7). In an extremely severe earthquake, hundreds of fires could occur in street locations along the distribution system, especially if the lines have not been recently retrofitted (Toppozada, et al., 1988). A Southern California Gas Company safety program has greatly reduced the risk of gas distribution fires by improving welds on the larger diameter (24- to 30-inches) pipelines in the transmission system and replacing old distribution pipes (57- to 24-inches) with flexible plastic pipes (Toppozada, et al., 1988). Their strengthening program is an ongoing effort. Potential service disruption to the general public could number in the tens of thousands in a worst-case scenario involving fault rupture on the Newport-Inglewood (Toppozada, et al., 1988) or other major basin fault. Disruption would most likely be caused by damage concentrated at the building/utility interface (ESS, 1988).

Seismic gas shut-off triggers performed adequately during the 1987 Whittier Narrows Earthquake and their potential use in reducing post-earthquake fire hazards is becoming increasingly popular among homeowners and some industries (Schiff, et al., 1988; Table 2.2). Southern California Gas has indicated that these automatic pressure-actuated shut-off valves may not have feasible

applications for the main gas distribution and transmission system. The Japanese utilize gas shut-off triggers to reduce gas pressure, isolate damaged segments, and purge the system in a 3-step process, depending on the level of ground motion detected by the sensors. Although the system is safeguarded by three levels of warning, the complete purging of the system could be set by a false alarm and take up to a month to restore normal service (Bertero, et al., 1988). Given this assessment, applications to the regional gas network are not likely in the near future.

As mentioned earlier, a primary threat to service disruption is the interface between buildings and the gas distribution system. These same gas lines connecting with the gas distribution system, combined with ruptured gas-fired appliance connections (water heaters, stoves, etc.), also constitute a risk of post-earthquake fire. The fire threat could be in the form of hundreds of small residential fires (Schiff, et al., 1988). More than 100 such fires were reported after the San Fernando Earthquake.

Transmission lines are subject to "burn down" caused by arcing of the lines as a result of swaying motion. This vulnerability has been observed as the cause of some summer Santa Ana wind-driven wild fires (Chapter 3: Urban and Wildland Fires and Hazardous Materials). Overhead electrical lines are supposed to automatically deenergize if the electrical flow is disrupted. In the event this safeguard does not function properly, the possibility of electrical shock and fire ignition exists (Table 4.1). Even if the hazard does not occur, downed transmission lines can draw off vital utility and emergency response resources needed to repair or verify that the system does not pose a hazard (Schiff, et al., 1988). Schiff, et al., (1988) recommends as one possible solution, the deployment of seismic current-reduction triggers along segments of the transmission system, in addition to existing safeguards.

Although it can be considered a loss of function by residents, disruption of water utilities will most seriously affect fire fighting capabilities. Water supply conduits can be ruptured in areas of ground failure and cause significant losses in water pressure (Schiff, et al., 1988). Such rupture would be concentrated in older cast-iron segments, as was observed after the San Fernando Earthquake (Table 4.1).

Floods can contribute to a potential fire hazard. Fire conflagration is possible wherever fuel is present and a medium exists for rapid spreading (URRNSF, 1988). Post-disaster experience indicates that fuel sources and ignition sources in potential inundation areas should be immobilized. Secondary fire hazards can also be caused by failure of elevated or ground level tanks storing flammable liquids that are not adequately designed or contained by dikes or other means (Toppozada, et al., 1988).

Contamination

Crude and refined oil pipeline ruptures could produce a third type of post-disaster consequence, that of local contamination. Waste water collection systems, such as those operated by the Sanitation Districts and the County

Department of Public Works, also have the potential for contamination along the main collectors or any of the many hundreds of miles of 6 to 144 inch collector lines (Davis, et al., 1982; Toppozada, et al., 1988). Wholesale discharge of untreated or under-treated sewage could pose long term problems to the quality of local ground water resources and public health. This can be a serious problem in that sewers must be repaired before water service can be restored, an effort that could take months if damage is pervasive. As many as 1,200 sewer breaks occurred as a result of the 1971 San Fernando Earthquake (EERI 89-03).

Hazardous materials are another source of contamination, but cannot be shown at the map scale used for Plate 8. Industrial facilities, dry cleaners, science and research labs, gas stations, neighborhood grocery stores, and even individual homes may be potential sources of hazardous materials. Careless handling and storage of hazardous materials could result in dangerous liquid and gaseous releases during an earthquake or other disaster. Los Angeles County is especially at risk from this hazard due to the concentration of large chemical producers/users within its borders.

Conclusions

- Most emergency functional losses will be manageable following an earthquake because adequate planning for emergency power has been made. Utilities estimate that a major earthquake on any fault may impose emergency power contingencies for up to three days, and locally for as much as 4 to 5 days.

- The damage patterns in the epicentral area of the Loma Prieta Earthquake confirm the recurring nature of hazards posed by either dysfunction of utilities or hazards created by damaged utilities.

- Earthquake-induced fire incidents most commonly involve residential units and are caused by broken connections to water heaters and stoves or ruptured house lines connecting with the main gas distribution system.

- Pre-1971 freeway overpasses are considered most vulnerable to severe ground shaking at seismic intensities greater than MM VIII, an intensity that could occur at numerous locations throughout the County.

- One possible solution to electrical transmission system caused fires, in addition to existing safeguards, is the deployment of seismic current-reduction triggers along segments of the transmission system.

SECTION 4.2

CRITICAL FACILITIES AND INFRASTRUCTURE

Some representative critical facilities and land uses have been plotted on various maps included in this report. The review in this section will be directed at these map components. They consist of the following:

- Hospitals;
- industrial zones (high-risk industrial facilities);
- high occupancy facilities;
- dams and flood control facilities; and
- freeway structures (Plates 6, 7, and 8).

Hospitals

A more detailed statistical review of hospitals can be found in an assessment of dependent populations in Los Angeles County in Section 4.4. However, a cursory vulnerability analysis is somewhat revealing. Plate 8 shows that all the major acute care hospitals (capacity greater than 500 people) are located within the metropolitan area of the Los Angeles Basin. Other hospitals located throughout the County are generally associated with major population centers.
In the earthquake scenario for the Newport-Inglewood fault, Toppozada, et al., (1988) estimate that of the 88 hospitals within the predicted areas of strong ground motion (within 5 to 25 miles of the fault), 25 percent of the total bed capacity, or 7,000 beds out of a total of 28,000, will be unusable.

The 1972 State of California Hospital Act preempts new construction of hospitals from local control. However, the majority of the hospitals in the County are pre-1972, suggesting that many County hospitals might be subject to damage from strong ground shaking from a major earthquake on a nearby fault. With the exception of the Antelope Valley, no hospital shown on Plate 8 is more than 3 to 4 miles from any of the active faults listed in Appendix 2 and shown on Plate 1 (Fault Rupture). In addition, many older hospitals may not only have structural deficiencies, but inadequate fire protection safeguards as well. Fire alarms, sprinkler systems, and numerous evacuation routes are designed into all new hospitals and should be a retrofit requirement for older hospitals. The reasons for emphasis on the continued function of hospitals after a major earthquake are the following projections:

- Steinbrugge, et al., (1981) estimated that a 7.5 Magnitude earthquake on the Newport-Inglewood fault could cause between 4,000 to 21,000 deaths and 16,000 to 80,000 hospitalized casualties depending on the time of day of the earthquake.

- Davis, et al., (1982) reported that an 8.3 Magnitude earthquake on the San Andreas fault could cause between 3,000 and 14,000 deaths and 12,000 to 55,000 hospitalized casualties.

Although the numbers represent worst-case scenarios, they do demonstrate the need to provide structural and fire safety as well as backup power and communication systems to hospitals. The figures also illustrate the greater degree of damage expected from an earthquake in the metropolitan area of Los Angeles, and highlights concern for the numerous other faults crossing the County (Plate 1). An earthquake along any of the other active faults in the County would create its own unique damage and loss distribution, controlled by the location of the epicenter.

High-Risk Industrial Facilities

Vulnerability to hazardous materials releases is introduced in Chapter 3 (Wildland and Urban Fire Hazards and Hazardous Materials). The main conclusion from that section was that industrial areas shown on Plate 7 illustrate a regional vulnerability to hazardous materials releases. An overlay with Plate 1 (Fault Rupture Hazard) or Plate 4 (Liquefaction Hazard) shows that many industrial zones are located within hazardous areas. Buildings storing hazardous materials in these areas are vulnerable to structural damage not only from fault rupture and liquefaction, but also from strong earthquake ground motion with seismic intensities as low as MM VIII (Table 3.1). Furthermore, many industrial areas are also within tsunami and dam inundation areas. The summary of historical tsunami damage patterns indicates that hazardous materials should be strictly controlled within potential inundation areas. The County of Los Angeles maintains three hazardous materials response units specially trained to contain hazardous materials releases. These units are located in Carson, the City of Industry, and Valencia.

While response and containment capability is a high priority, three other elements of a hazardous materials program should be considered. The first is the identification and safe management of hazardous materials on-site. The second is evaluation and mitigation of structural and nonstructural components (tanks, storage facilities) of a building, especially those directly involved with using or storing chemicals or explosives. Lastly, consideration should be given to emergency safeguards incorporated into hazardous material management procedures, such as emergency shutoff valves and early warning devices (see Chapter 6).

High Occupancy Buildings

Catastrophic failure of a single high-occupancy structure could result in hundreds of deaths and injuries, making them a greater risk than many other structures. The risks involved with high occupancy buildings stem from difficulty in implementing emergency response, disaster control, and evacuation procedures. High occupancy structures include medium- and high-rise apartments and offices, major industrial facilities, auditoriums, shopping malls, theaters, and virtually any other place containing more than 500 people (URRNSF, 1988). They can also include public and private facilities considered in other sections of this chapter, such as dependent care facilities. Plate 7 shows the distribution of post-1946, high-rise office buildings greater than 8-stories in height in Los Angeles County. Specific limitations of the map are noted in Chapter 3 (Wildland and Urban Fire Hazards and Hazardous Materials). Lightweight, short structures are more likely to be damaged by near-field earthquakes produced by a local fault. In contrast, a taller or larger building, is more likely to respond destructively to long period shaking from distant earthquakes. During the 1952 Kern County Earthquake, multistory steel and concrete buildings in Los Angeles sustained the bulk of local damage; 1 and 2-story structures were the least affected. The 1989 Loma Prieta Earthquake shows that improvements in structural design of high-rise buildings is paying off since no significant structural damage to the 400+ high-rise buildings in the downtown area of San Francisco was evident.

Most post-1946 mid-story and high-rise buildings utilized various UBC earthquake provisions that incorporated ductile, steel moment frames in their construction. This frame bears the greatest resistance to permanent building damage and explains the resilience of most multi-story structures. However, the increased flexibility of the building increases the risk of nonstructural interior damage from falling lamps, ventilators, office equipment, and interior non-load bearing walls (SSC, 1988-03). The possibilities of internal damage leading to fire in a high-rise could be catastrophic. Fire departments in some cases do not have the equipment readily available to combat high-rise fires (see Chapter 3 - Wildland and Urban Fire Hazards and Hazardous Materials). Numerous pre-1946, high-rise buildings between 10 and 13 stories are located in the downtown areas of Los Angeles, Hollywood, Pasadena, Glendale, and Long Beach. Within the City of Los Angeles alone, some 200 URM buildings are in the 13-story range, placing them at very high-risk of massive structural failure (Deppe, 1989; November 5, Los Angeles Times).

Potential evacuation problems inherent to high occupancy structures also became evident as a result of the Loma Prieta Earthquake. Candlestick Park was filled with some 60,000 people that Tuesday, at 5:04 p.m. on October 17th. The structure only sustained some minor structural damage; however, the greatest factor facilitating the relatively smooth evacuation was that the earthquake struck during daylight. Had the earthquake been a few hours later, there may have been thousands of panicked people injured trying to escape in the darkness. This highlights the importance of back-up power generators, communication systems, and proper planning of evacuation routes for high occupancy facilities.

Dams and Flood Control Facilities

The ages and structural characteristics of dams are reviewed in Chapter 3 (Flood and Inundation Hazards - Table 3.11). Over half of the dam and debris basins listed in Table 3.11 are over 50 years old (pre-1940). Over half of the dams and debris basins listed in Table 3.11 are also constructed of either earthen materials or hydraulic fill material. Nearly three quarters of all dam failures in Western Europe and the United States between 1900 and 1969 occurred in dams constructed of fill material (FEMA 1987-145). Based on a review of dam failures from 1900 through 1975 by FEMA (1987-145), older earthen or hydraulic fill dams are particularly prone to failure from piping, seepage, and overtopping of the dam. Significantly, such failures do not usually result from earthquakes, but from larger than expected storm runoff.

Several dams in Santa Clara and Santa Cruz Counties experienced various damage during the 1989 Loma Prieta Earthquake. One of the more significantly damaged dams was the Austrian Dam with a crest height of nearly 180 feet. Earth and rockfill dams typically displayed longitudinal cracks along the crests, abutments, and/or the upper portions of the dam faces (EERI 89-03). Subjected to bedrock accelerations in the range of .4 g, the overall performance of these dams was good. None of the dams demonstrated signs of potential failure. Further, the risk to the public was considered low at the time of the earthquake due to the low water levels of the reservoirs.

The fact that two dam failures and one near failure have occurred within a 61 year period in Los Angeles County, underlines the vulnerability of this element of the infrastructure. Davis, et al., (1982) and Toppozada, et al., (1988) consider the potential for earthquake-induced dam failure to be small in their earthquake scenarios for the San Andreas and Newport-Inglewood faults. However, recognizing that potential for catastrophic losses of a dam failure far outweigh such an assessment, the earthquake scenarios recognize the potential for worst-case planning purposes.

Freeway and Roadway Systems

Following the collapse of the Foothill and Golden State Freeway interchanges during the 1971 San Fernando Earthquake, the California Department of Transportation (Caltrans) embarked on a three phase retrofit program. Phase One involved using steel cables to tie down elevated freeway decks. Phase One affected 1,262 bridges and overpasses and was 99 percent completed by 1987. Phase 2 of the retrofit program will reinforce highway single support columns by wrapping them with flexible steel bars. The single column design problem almost caused the near collapse of the I-5/605 Freeway interchange during the 1987 Whittier Narrows Earthquake. Significantly, retrofitting does not guarantee against damage or collapse. For disaster planning purposes, the highway network in Los Angeles County is also vulnerable from damage caused by liquefaction and faulting, and closure from landsliding.

There are well over 200 pre-1971 single support column freeway structures in the southland with some vulnerable freeway interchanges used by an average of up to 292,000 vehicles daily (Los Angeles Times, November 5, 1989). Caltrans retrofit priority is based on the documented seismic hazard (faulting, liquefaction, strong ground shaking) and the age and design of the structure. The 30 high-risk structures shown on Plate 8 (total structures number 44, but are included in a single map symbol) are concentrated near the Raymond, Sierra Madre, and Duarte fault systems, and the Newport-Inglewood fault.

Because freeways are commonly planned along flood plains, many freeway-to-freeway interchanges are located in liquefaction prone areas. An inspection of Plate 4 and Plate 8 shows as many as 20 freeway interchanges are threatened with liquefiable ground conditions. Davis, et al., (1982) concluded in the earthquake scenario of the San Andreas fault that Interstate 5 through Newhall could also sustain damage, but did not specifically identify high-risk structures. The potential for freeway collapse caused by an earthquake on the San Gabriel fault (Chapter 3, Figure 3.2) should initiate further assessment of highway and roadway structures in this area, as well as in the Antelope Valley. This is especially critical, due to localized liquefaction hazards in these areas.

Conclusions

- As with lifeline systems, the vulnerability of any structure is dependent on the age, location with respect to a particular hazard, and seismic design deficiencies.

- Many hazardous facilities that store, use, or transport hazardous materials exist in the Los Angeles metropolitan area and are vulnerable to structural and nonstructural damage from strong ground motion, fault rupture, and liquefaction.

- Many older hospitals (pre-1972) may have structural deficiencies, and may also possess inadequate fire protection safeguards such as fire alarms, sprinkler systems, and numerous evacuation routes.

- Retrofitting of hazardous structures does not guarantee the structure will not sustain serious damage or total collapse, since older structures may sustain damage that cannot be anticipated given the numerous possible earthquake scenarios.

- Future emphasis should be placed on evaluating the structural safety of freeway and roadway systems outside of the Los Angeles Basin and the potential effect of strong ground motion, faulting, and liquefaction on certain freeway-to-freeway interchanges in the Los Angeles Basin.

- An important risk factor of high occupancy buildings is the difficulty of implementing emergency response, disaster control, and evacuation procedures.

SECTION 4.3

POTENTIALLY HAZARDOUS BUILDINGS

Potentially hazardous buildings are defined as follows:

"those structures built for human occupancy under inadequate construction standards, flawed design, or any other structural or nonstructural problem that renders the building sufficiently less earthquake-resistant or safe" (SSC 87-01).

Potentially Hazardous Buildings

Seismic design codes in the United States have undergone numerous and intermittent changes in the last 70 years, generally when existing standards were reviewed following a destructive earthquake (Table 2.3; Chapter 2). Earthquake resistant provisions became widely adopted in local building codes in Southern California following the 1933 Long Beach Earthquake. In 1959-60, the Structural Engineers Association of California (SEAOC) established lateral force requirements for use in the Uniform Building Code (UBC). Various versions of SEAOC requirements were incorporated into the Earthquake Regulation and Resistant Seismic Design section of the UBC through 1974. Between 1974 and 1978, the Applied Technology Council (ATC) began development of comprehensive seismic design provisions, specifically involving lateral force requirements for adoption into the UBC.

Following the 1987 Whittier Narrows Earthquake, amended lateral forces requirements and additional code amendments once again improved seismic design standards. In light of the continuing code changes and progressive improvements in seismic design standards over the years, the California Seismic Safety Commission (SSC) has recognized that certain types of existing buildings may be potentially hazardous. The SSC (1987-03) has recognized the following building types with a history of poor performance during past earthquakes in Los Angeles County:

- Unreinforced masonry (URM) buildings;
- certain tilt-up concrete buildings;
- nonductile concrete-frame buildings;
- buildings that have long spans, irregular shapes, or weak "soft-stories";
- dilapidated buildings that have not been properly maintained or buildings that have been weakened through modification;
- mobile homes and homes not tied to their foundations;
- nonstructural hazards (interior and exterior); and

- buildings located in geologically hazardous areas such as those subject to earthquake-induced fault displacement, landsliding, or soil liquefaction.

URM Buildings

Unreinforced masonry buildings (URM) have performed poorly in every damaging California earthquake. This was confirmed in the epicentral area of the Loma Prieta Earthquake in the City of Santa Cruz where a shopping mall composed of URM construction collapsed and killed three people. Considered the foremost threat to public safety of all potentially hazardous buildings, URM buildings are likely to sustain the greatest amount of damage during future earthquakes in Los Angeles County (SSC, 1987-03). They are also expected to be the cause of most life-threatening situations. Scawthorn and Gates (1983) estimated that as many as 15,000 URM buildings may exist within the County of Los Angeles. A total of 8,380 such buildings have been identified in the City of Los Angeles alone (Spangle, 1987). Only 274 URM buildings are present in unincorporated County areas.

In 1986, the State legislature enacted the unreinforced masonry building law (Chapter 250, Statutes of 1986; SB 547 (Alquist); Government Code Section 8875 et seq.) requiring a complete inventory of URM buildings by January 1, 1990. The law calls for the identification and development of mitigation programs for buildings with URM load bearing walls that support the floors and roof, and buildings with nonstructural URM infilled walls.

The law covers all types of URM construction. Consisting of mainly pre-1933 buildings in Los Angeles County, the SSC (87-03) references the following:

- URM buildings with unreinforced brick, concrete block, terra cotta (hollow tile), adobe, or stone bearing walls;

- Steel-frame buildings with interior or exterior infill walls, interior partitions, or shaft walls of URM; and

- Concrete-frame buildings with URM construction, either interior or exterior infill walls, interior partitions or shaft walls.

Warehouse and "similar" buildings with few occupants are exempt unless they are used for emergency supplies. Warehouses converted to retail, office, or residential occupancies are not exempt. Historical buildings are exempt from the identification phase; however, the Seismic Safety Commission recommends reviewing these buildings for adequacy with respect to Section 37602 of the California Health and Safety Code for seismic hazards.

Mitigation involves either strengthening or removing the identified structures. Local ordinances are to be imposed to enforce retrofitting, however, a recent survey by the Los Angeles Times (November 5, 1989) indicates that only 21 jurisdictions within the County have seismic safety ordinances in place. It is also noteworthy that neither Los Angeles City or County Ordinances address walls with URM infilling. URM infilled walls are hazardous because they can literally explode outward in an earthquake. It is important to note that in terms of

vulnerability, present load-bearing wall retrofit technology does not protect the building from serious structural damage, only from total collapse.

Tilt-Up Concrete

The 1971 San Fernando Earthquake exposed the vulnerability of the commonly used tilt-up concrete construction. Pre-1971 construction of this type is vulnerable to seismic events because of detailing flaws at the abutments of walls and ceiling elements. Inadequate detailing or tying together of the structural components of the building allows walls to pull away allowing the ceilings to collapse. Despite building code changes following the San Fernando Earthquake, there is now speculation that some post-1971 precast concrete tilt-up buildings may also be vulnerable. Recent trends (post-1971) in tilt-up construction have been to increase the height, reduce the shear wall area, and increase the complexity of the building configuration using minimal post-1971 UBC seismic provisions. During the 1987 Whittier Narrows Earthquake, complex tilt-up buildings displayed vulnerability to shaking (Hamburger, et al., 1988). Wall anchorage detailing for tilt-up construction, instituted in the post-1971 Building Code, however, functioned adequately during the 1987 Whittier Narrows Earthquake. Significantly, these buildings were also of simple geometric design (Hamburger, et al., 1988).

Nonductile Concrete Frame

Heavier concrete buildings are inherently more vulnerable to earthquake damage. As earthquake ground motion impacts such a building, the structure tends to follow the ground movement away from the stationary position. The heavier the structure, the greater its resistance to movement. Heavy, rigid buildings behave in a brittle manner and shake more violently. Thus, they are more apt to sustain structural damage than more lightweight and/or "flexible" structures.

Pre-1934 and pre-1947 low-rise brick and concrete-frame buildings, respectively, have the highest risk in this category (SSC, 1988). High-rise office buildings built between 1960 and 1973 often used nonductile frames as well. Some of these pre-1973 UBC reinforced concrete buildings may have inadequate design characteristics and/or inferior construction quality, and are therefore potentially hazardous (BAREPP, 1985). The State does not mandate retrofit of these types of structures.

Soft-Story - Complex Design

The collapse of the Olive View Hospital in the 1971 San Fernando Earthquake was due to soft-story construction. Figure 4.2 shows that vertical irregularity in design causes the concentration of earthquake forces at the soft-story. Thousands of existing apartment buildings, hotels, motels, etc., have underground parking structures that utilize such a design. Post-1971 Building Codes corrected this problem and the 1989 County Building Code is even more stringent. However, new requirements are not retroactive to existing development.

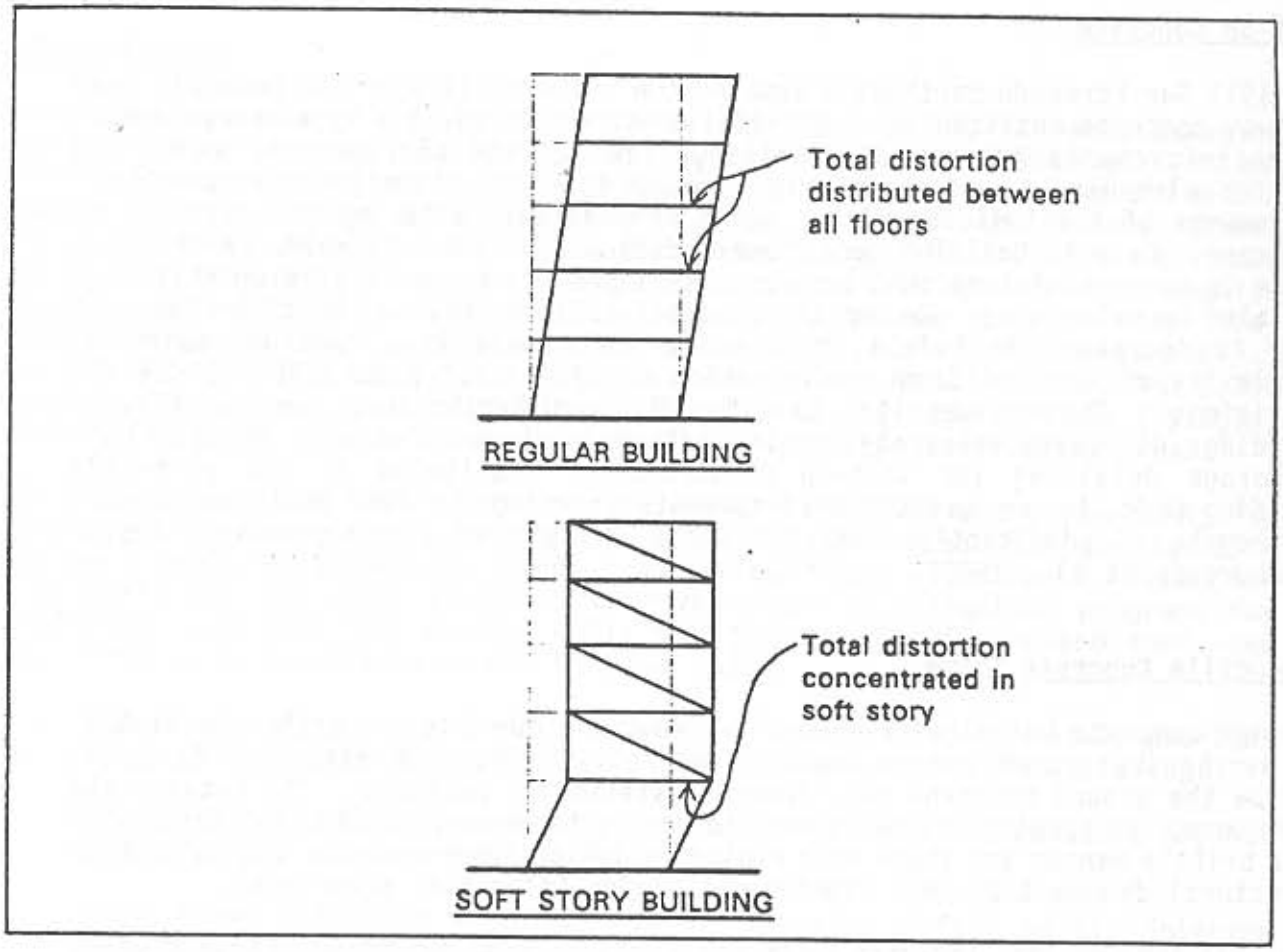


Figure 4.2: Vulnerabilty of soft-story buildings (after Holmes, 1984).

Generally, any irregular or oddly-sized building endows less seismic resistance than buildings with conventional dimensions and shapes. Typical configuration problems include multistory buildings with irregular plan and vertical design (soft-story), discontinuous shear walls, variations in building mass, stiffness or strength, and poor detailing or tying together of the structural system (Arnold and Reitherman, 1982).

Dilapidated Buildings

Earthquakes exploit the weak components in a structure. Buildings with incipient structural damage from any origin are more prone to earthquake structural damages (Deppes, 1988). Various causes of distress range from poor quality construction materials to the progressive deterioration of a concrete foundation or structural system, or even existing damages caused by landsliding or expansive soils.

Mobile Homes and Single Family Homes with Unbolted Foundations

Mobile homes and any other unsecured buildings can be shifted off their foundations and subject to damages (BAREPP, 1985). The Loma Prieta Earthquake destroyed 195 homes in the town of Watsonville, many of them knocked off their foundation. Pre-1952 Uniform Building Codes did not require that single-family homes be bolted to their foundations and there are no retroactive regulations covering this type of home. There are literally tens of thousands of single-family residential homes that were constructed in the housing boom following World War II and before 1952, not to mention the tens of thousands that were built through the 1940's.

There were also 234 mobile homes that sustained major damage during the Loma Prieta Earthquake in the epicentral area of Watsonville. Mobile homes are especially at risk from earthquakes because of their inherent vulnerability to fire.

Nonstructural Hazards

Nonstructural components are elements of a building or structure not involved with the structural support system. They can become damaged or dislodged during an earthquake and result in either serious injury or death, or impair the function of the facility. Damaged emergency power generators could cripple the functioning of an essential facility. Damaged hazardous waste containers could cause a hazardous waste spill. Such elements of a structure are termed functional nonstructural hazards. Total economic loss from functional nonstructural damages could easily be as much as ten times the structural loss of the building if loss in equipment and functional ability are taken into account (Holmes, 1986). This is especially true of earthquakes of moderate intensity where little structural damage occurs.

Architectural features attached to the outside of buildings, such as parapets, cornices, and balconies, can fall during an earthquake. URM veneers are the most

vulnerable to earthquake shaking. Certain tile roof shingles can become dislodged by shaking, posing a hazard to those exiting the structure.

Serious injuries and loss of function can occur in buildings even if they do not collapse. Falling ceilings and light fixtures, shattered glass, stuck elevators, and toppling equipment and furniture are capable of causing death and injuries during an earthquake. These hazards can be reduced in a variety of ways such as installing safety glass or placing plastic over windows to prevent glass from shattering; anchoring filing cabinets, book cases, and heavy office equipment; and firmly attaching suspended light fixtures and ceiling panels. Strong shaking can dislodge ceiling asbestos in older buildings causing complete loss of use, such as occurred at Cal State Los Angeles following the Whittier Narrows Earthquake.

Overview of Potentially Hazardous Buildings

Scawthorn and Gates (1983) modeled a County inventory of buildings, based on the estimated percentages of 13 building types in 40 land use categories (Table 4.2). The 40 categories were chosen to represent the main land planning groups: residential, commercial, industrial, utility, and institutional. Using input from the Building and Safety Departments of both the City and County, each category of land use under the major groups was subjectively evaluated for probable percentages of building type. The purpose of the model inventory was to generate estimates for potential earthquake-induced economic losses.

Although the percentages are only approximate, Table 4.2 can also be used to portray apparent trends in the use of hazardous construction. Furthermore, except in the case of unreinforced masonry, the structural characteristics do not necessarily imply a potentially hazardous building category. Table 4.2 does yield the following general observations:

1. Residential areas possess the greatest percentage of URM construction; and

2. commercial and industrial areas possess the greatest share of tilt-up construction.

Several Federal and State seismic safety programs exist to retrofit existing development, either for fire hazards or structural hazards. However, the majority of potentially hazardous buildings summarized in this section are not covered by retroactive state laws. The only existing mandatory retrofit program involves URM buildings and they are to be imposed by local ordinances. The 1933 Field Act regulated School Safety for new construction but it was not until the Garrison Act, passed much later in 1969, that older public schools of URM construction were required to be upgraded or abandoned. Until 1986, the State did not require private schools to meet State seismic design standards.

Another area of potential improvement in retroactive seismic upgrading concerns hospitals. The 1972 Hospital Act governs the construction of new hospitals. Unless undergoing voluntary renovation, there are no mandatory retroactive provisions requiring seismic upgrading. This is despite a survey by the Office of Statewide Health Planning and Development that shows that 80 percent of

Table 4.2: Los Angeles County Model Building Inventory*

	LAND USE CATEGORY	1 CONCRETE BLOCK 1-4	2 TILT-UP 1-2	3 WOOD 1-2	4 WOOD 3-4	5 CONCRETE 1-2	6 STEEL 1-2	7 CONCRETE 3-4	8 STEEL 3-4	9 CONCRETE 5-9	10 STEEL 5-19	11 UNREINFORCED MASONRY**	12 REINFORCED MASONRY	13 STEEL >20*
RESIDENTIAL	ESTATE	3		85								4	8	
	SINGLE-FAMILY			87								5	8	
	DUPLEX/ROW HOUSING			84								11	5	
	LOW RISE APARTMENTS/CONDOMINIUMS			84								11	12	
	MEDIUM RISE APARTMENTS/CONDOMINIUMS			75								13	12	
	RURAL CLUSTERED			89								6	8	
	RURAL DISPERSED			96								7	4	
	MOBILE HOMES/TRAILER PARKS	4		92									4	
	HIGH RISE APARTMENTS/CONDOMINIUMS									69	21		10	
COMMERCIAL	MAJOR OFFICE USE	12		10	3	38	7		5		10	3	12	
	MAJOR OFFICE USE - 8+ FLOORS													
	REGIONAL SHOPPING CENTER	13	27	4		44		3					9	
	NEIGHBORHOOD SHOPPING CENTER	13	7	72				1				1	7	
	STRIP/ROADSIDE COMMERCIAL	6		82								6	6	
	COMMERCIAL RECREATION	18	3	62		6	2						9	
	HOTEL/MOTEL	16		61	8							3	12	
	GENERAL COMMERCIAL	21	9	58								2	8	
INDUSTRIAL	OIL AND GAS EXTRACTIVE	6				3	91							
	RESEARCH AND DEVELOPMENT	24	18	9		24	18							
	MOTION PICTURE	27	15	49									7	
	MANUFACTURING AND ASSEMBLY	15	34	35		7							9	
	PETROLEUM REFINING/PROCESSING	10	9			4	46	12	13			1	5	
	MAJOR RENTALS	5	5			25	65							
	WHOLESALING AND WAREHOUSING	19	45	5		13	10			3			5	
DEPENDENT CARE AND OTHER CRITICAL FACILITIES	AIRPORT	14	15	27		10	15	10				1	8	
	RAILROAD	7		33		28	11					16	5	
	HARBOR FACILITIES	4		32		24	28					7	5	
	ELECTRIC POWER FACILITIES	10	5			50	25						10	
	LIQUID WASTE DISPOSAL FACILITIES	25				50	25							
	COMMUNICATION FACILITIES	32	5	10		40				4	3		6	
	SPECIALIZED USE INSTITUTIONAL	22		40		19	4	4	4	4			7	
	GOVERNMENT OFFICE AND FACILITIES	21		50	3	12						4	10	
	EMERGENCY RESPONSE FACILITIES	27		27		28							18	
	MAJOR HEALTH CARE FACILITIES	6		17		47		10	5				15	
	ELEMENTARY SCHOOL	7		49		16	15						13	
	JUNIOR HIGH SCHOOL	13		29		37	3						18	
	HIGH SCHOOL	13		19		38	6	7					17	
	COLLEGE/UNIVERSITY/OTHER SCHOOL	16	3	5		48	7	4					17	
	TRADE SCHOOL	16		27		32	3					1	21	
	RELIGIOUS FACILITY	16		42		21	3					2	16	

* Expressed in percentages of building type, structural material, and number of floors for each land use category: residential, commercial, industrial, and critical facilities (after Scawthorn and Gates, 1983).

existing hospitals in the State of California do not meet Hospital Act standards (Los Angeles Times, 1989). These examples suggest that the County must, in many cases, pursue their own local safety programs, or at least strongly advocate action at the State level.

Chapter 6 will review several County safety programs that will deal with many of the concerns presented in this section. The emphasis will be on providing alternatives for a comprehensive hazardous building retrofit program, alternatives for screening potentially hazardous buildings, and using available information on seismically hazardous areas as an aid in implementation. A cursory analysis of the damage patterns in the Bay Area suggests hazardous areas can be used as a component of a retrofit program. A comparison of damages from the 7.1 Loma Prieta Earthquake showed a close correlation of damaged areas with areas previously identified as hazardous on maps produced by the Association of Bay Area Governments. The Seismic Safety Commission considers geologically hazardous areas such as those subject to earthquake-induced fault displacement, landslide, or soil liquefaction as an integral component in identifying potentially hazardous buildings (SSC 87-03).

Conclusions

- According to the definitions for potentially hazardous buildings given by the California Seismic Safety Commission, there could be tens, and maybe even hundreds of thousands of potentially hazardous buildings in Los Angeles County, an estimate which includes all 86 cities.

- Unreinforced masonry buildings (URM's), including bearing wall and infilled nonstructural components, are likely to sustain the greatest amount of damage and cause the most deaths and injuries if a major earthquake occurs in the metropolitan area of Los Angeles.

- The majority of potentially hazardous buildings summarized in this section are not covered by retroactive State laws.

- It is estimated that approximately 14,500 URM buildings may exist in 86 cities of the County. An additional 274 URM buildings are in incorporated areas.

- Only 22 jurisdictions within the County have seismic safety ordinances in place aimed at retrofitting URM buildings.

- The City and County of Los Angeles seismic upgrading ordinances address only URM bearing walls, even though URM infilled non-load bearing walls pose a major risk to occupants of a structure.

- Buildings located in geologically hazardous areas such as those subject to earthquake-induced fault displacement, landslide, or soil liquefaction can be used as a way of prioritizing retrofitting plans.

SECTION 4.4

DEPENDENT CARE FACILITIES

Dependent care facilities are defined as those buildings that house dependent populations. They include educational facilities, hospitals, prisons, and major social care facilities including group care homes and elderly-care facilities. Dependent populations consist of individuals who have restricted mobility and cannot be expected to cope independently in the event of a catastrophic event such as an earthquake, flood, or fire. Specifically, dependent populations addressed in this section are located in the following facilities:

- Hospitals;
- convalescent or retirement homes;
- community care facilities for the mentally handicapped;
- day care facilities;
- schools; and
- prisons and detention facilities.

In cases where facilities involve disabled occupants, evacuation and emergency response issues are critical. In a fire, young children or the elderly cannot be expected to proceed to the nearest exit without considerable management, especially if located in a large facility. Where the occupancy is involuntary such as jails and prisons, public safety during the evacuation and transfer of inmates must be ensured. Vital resources that would be used to manage inmates could impair other emergency response activities that could arise in a major earthquake. School facility management requires the added responsibility of reuniting children with parents in the immediate post-disaster period.

Dependent facilities can be roughly divided into four groups: health (hospitals), social services (retirement homes, physically or mentally handicapped facilities, and day care facilities), schools, and prisons. A current list of dependent populations residing in these facilities can be obtained from the State Department of Health Services, State Department of Social Services, the State Department of Education and County Office of Education, and State Department of Corrections.

For many dependent facilities, the lack of useful criteria with which to prioritize their compilation, their dispersed nature, and the shear number of facilities makes it extremely difficult to show all such facilities at the scale of the 1" = 2 miles. Instead, Plate 8 shows the distribution of selected hospitals, community care centers (capacity greater than 200), and major jail facilities, augmented by a series of tables in this section, showing types of facilities by size of occupancy. In the following discussion, occupancy can be

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considered correlative to the density and concentration of individuals who would need assistance during an emergency. This phase of the analysis is believed to be the best method with which to convey the vulnerability of such facilities. Additional risk variables involve the structural characteristics of a building and its location with respect to hazardous events.

Health Facilities

There are several types of health care facilities but not all house patients or residents. Examples which do not are neighborhood and psychology clinics. The six types of health care facilities in which patients reside are shown in Table 4.3. This inventory of facilities is further divided by the facility's capacity, defined as the maximum number of patients it is legally entitled to hold by state licensing regulations.

There are 590 health care facilities in the County, 161 of which are general acute care hospitals (Table 4.3). Nursing facilities comprise 65 percent of the total number of health care facilities. Occupancy capacities of health care facilities range from less than 50 to more than 600 people. Significantly, however, approximately one-half of all health care facilities have a capacity between 51 and 100 people, implying that relatively few dependent care facilities have very large occupancies in Los Angeles County. There are only 14 high capacity- high occupancy facilities with 500 or more people, all of which are acute care hospitals. Major acute care hospitals are shown on Plate 8 along with other selected acute care hospitals included on disaster maps of the Department of Public Works.

Social Services Facilities

The types of community care facilities, sometimes referred to as social care facilities, listed in Table 4.4, house either the elderly, mentally or physically handicapped, or preschool children. In total, there are more than 11,000 community care facilities in the County. The facilities are described in terms of their capacity, as well as their location (incorporated or unincorporated). Only six percent of all community care facilities are in unincorporated areas. However, the number of facilities represented by this six percent is 721. More than half of these facilities are adult residential centers which house developmentally disabled or mentally disordered adults between the ages of 18 and 60. There are only three facilities which house more than 200 people and they are plotted on Plate 8. Nineteen facilities house between 100 and 200 people.

Schools

The number of public school districts, public schools, and enrollments in the 1986-87 school year are shown in Table 4.5. There are over 2,800 public and

Table 4.3: Health Care Facilities°

Facility	Capacity (number of tests) 1-50	51-100	101-200	201-300	301-400	401-500	501-600	600+	TOTAL
General Acute* Care Hospital	16	38	49	21	16	7	5	9	161
Skilled Nursing	53	223	87	17	1	--	--	--	381
Intermediate Care	8	9	3	--	--	--	--	--	20
Acute Psychiatric Hospital	9	6	5	2	--	--	--	--	22
Chemical Dependence Recovery Hospital	--	--	--	--	--	--	--	--	1
Adult Day Health Care	3	2	--	--	--	--	--	--	5
TOTAL	89	279	144	40	17	7	5	9	590

NOTE: The data is compilation of facilities in incorporated and unincorporated County areas.

-- Means none or zero

* Included on plate 8 (Critical Facilities and Lifeline Systems).

° Health Care Facilities licensed by the State Department of Health Services, Los Angeles County, California (Source: California Department of Health Services, Licensing Division. Health Facilities Directory, July 1985, after Sedway-Cooke Associates).

Table 4.4: Community Care Facilities°

Facility	Capacity 1-6 cities	1-6 county	7-12 cities	7-12 county	13-30 cities	13-30 county	31-50 cities	31-50 county	51-80 cities	51-80 county	81-100 cities	81-100 county	100-200 cities	100-200 county	200+ cities	200+ county	TOTAL Cities	TOTAL County	TOTAL All
Group Home	317	98	14	4	8	2	17	6	12	2	4	2	2	1	--	--	374	115	489
Adult * Residential	794	275	60	24	123	49	40	11	25	10	12	4	11	3	2	1	1,067	377	1,444
Adult Day Care	1		2		34		29		17		--		10		2		95	0	95
Small Family Home	305	71	--		--		1		--		--		--		--		306	71	377
Day Care Center	3		9		561		612		579		162		260		16		2,202	0	2,202
Infant Center	--		7		12		4		5		1		--		--		29	0	29
Family Day Care Home	5,307		487		2		--		5		2		1		1		5,805	0	5,805
Residential Elderly	305	98	27	11	38	9	24	6	28	9	20	8	79	15	23	2	544	158	702
TOTAL:	7,032	542	606	39	778	60	727	23	671	21	201	14	363	19	44	3	10,422	721	11,143

Note: -- Means None or Zero
* Capacity greater than 200 included on Plate B.

° Community Care Facilities licensed by the State Department of Social Services, Los Angeles County, California (after California Department of Social Services, Licensing Division, 1985).

Table 4.5: Public Schools*

NUMBER OF PUBLIC SCHOOLS IN 1986-87:

Elementary	1,062
Junior High	227
High School	169
Continuation Schools	88
TOTAL	1,546

ENROLLMENT PUBLIC SCHOOL DISTRICTS IN 1986-87:

Kindergarten	107,395
Grade 1	110,646
Grade 2	103,276
Grade 3	100,208
Grade 4	100,433
Grade 5	98,378
Grade 6	96,014
Grade 7	95,803
Grade 8	93,077
Other Elementary	9,557
Total Elementary	914,787
Grade 9	102,723
Grade 10	114,457
Grade 11	99,420
Grade 12	71,428
Other Secondary	5,339
Total Secondary	393,367
Total Enrollment	1,308,154

The totals include L.A. Unified School District which is composed mainly of the City of Los Angeles. This district accounts for approximately 38 percent of all public schools in the county.

The totals exclude Community College Districts for which the County Office of Education does not keep enrollment figures.

* Public School Facilities of Los Angeles County (Source: California State Department of Education, Los Angeles County Board of Education, after Sedway-Cooke Associates).

private schools in Los Angeles County. The total public school population is 1.3 million. The greatest individual concentrations of students are found in the larger public high schools in the County, which may have between 3,000 and 4,000 students. The number of private schools and their total enrollment are shown in Table 4.6. The private school population is estimated at 205,000. Public and private colleges and universities are not considered to be dependent facilities, due to the age of the attendees.

Prisons

The county prison population is shown in Table 4.7. The average daily population of all Sheriffs facilities is nearly 16,900, as opposed to the board rated capacity or maximum allowable capacity, because it reflects the actual population of facilities at a given time. In major facilities, the average daily population far exceeds the board rated capacity. The total County prison population for the year 1985 was 17,389 compared to a board rated capacity of 11,800. This does not include prisoners held in City, State, and Federal facilities.

Conclusions

- There are thousands of dependent care facilities dispersed throughout the County.
- Vital manpower resources and special planning are necessary to manage evacuation of dependent populations in the event of a disaster.
- Knowledge of the location, occupancy, and structural characteristics of the dependent care facilities with respect to hazardous areas would benefit emergency response planning and rehabilitation.

Table 4.6: Private Schools*

NUMBER OF PRIVATE SCHOOLS IN 1987-88:

Elementary (K-8)	951
Secondary (9-12)	77
Combined (K-12)	214
Ungraded	29
Total	1,271

ENROLLMENT IN PRIVATE SCHOOLS 1987-88:
(includes both church-affiliated and non-affiliated)

Kindergarten	24,619
Grade 1	21,552
Grade 2	19,253
Grade 3	17,652
Grade 4	16,588
Grade 5	15,489
Grade 6	14,982
Grade 7	14,320
Grade 8	13,395
Ungrade Elementary	1,054
Total Elementary	158,904
Grade 9	12,364
Grade 10	11,724
Grade 11	11,167
Grade 12	10,826
Ungraded High School	416
Total Secondary	46,497
Total Enrollment	205,401

* Private School Facilities of Los Angeles County (Source: California State Department of Education, Los Angeles County Board of Education, after Sedway-Cooke Associates).

Table 4.7: Detention and Correctional Facilities*

STATION JAILS (Type I Facility)

Name of Facility:	Total Population (1985)
Altadena	13
Antelope Valley	17
Avalon*	4
Carson	51
City of Industry	39
Crescenta Valley	12
East of Los Angeles	33
Firestone	34
Lakewood	26
Lennox	30
Lomita	20
Lynwood	31
Malibu	17
Marina Del Rey*	2
Norwalk	34
Pico Rivera	22
San Dimas	16
Santa Clarita	25
Temple City	40
West Hollywood	41
Total	507

MAJOR FACILITIES (Type II, III, & IV Facilities)

Name of Facility:	Average Daily Population (1985)
Biscailuz Center	1,056
Biscailuz Work Furlogh	163
Central Jail	7,332
Hall of Justice	1,633
Mira Loma	636
Pitchess Maximum	1,610
Pitchess Medium	1,297
Pitchess Minimum	1,494
Sybil Brand Institute	1,681
Total	16,882

* Hold less than 24 hours

NOTE: Type I facilities usually hold persons less than 48 hours, or until court arraignment. Type II, III, and IV facilities hold pretrial and some sentenced prisoners; sentenced prisoners; and those in work furloughs and community release programs.

- Detention and Correctional Facilities run by the County Sheriff Department, Los Angeles County, California (Source: State of California Board of Corrections. Report to the Legislature, June 1986, after Sedway-Cooke Associates).

SECTION 4.5

LAND USE AND DEVELOPMENT

Figure 4.1 shows that in addition to critical facilities, land use and development are important aspects of community vulnerability. The existing and projected pattern of development, including demographic characteristics of the population and distribution of land uses (residential, industrial, commercial) determine the exposure of the community to seismic, geologic, flood, and fire hazards in the County. The Los Angeles County General Plan, adopted in 1980, recognizes such implications and has established guidelines and policies for future urban and nonurban development, based on projections of population growth, housing trends, employment, and land use capability (General Plan, 1980).

The general plan policies emphasize the "concentration of development in single and multi-purpose centers, revitalization of older urban areas, infilling of urbanized areas, creation of new regional centers as needed, and preservation of nonurban and open space uses".

Industrial and Commercial Growth

Multipurpose centers are concentrations of a variety of high intensity commercial and residential facilities and can be considered economic centers (Figure 4.3). Multipurpose centers are located throughout the urban or urbanizing areas of the County, but much of the economy of the region is within the sphere of influence of the concentration west of downtown Los Angeles (Figure 4.3). Spangle (1987) notes that this "core" is vital to the economic output of southern California, because the economy of the County is interwoven with the City of Los Angeles and other incorporated cities in this area, and in southern California. Section 4.6 details the County's economic, as well as socio-economic vulnerability to earthquake damages.

Figure 4.3 shows many of the focal areas for growth in the region. As of 1976, 124,000-acres of the County were zoned for industrial use and of these, 37,000 acres were vacant (General Plan, 1980). The 1980 General Plan also noted that some vacant land appeared unsuitable for development because of problems such as the property location relative to other land uses, infrastructure, parcel size, or site conditions. Significantly, many existing industrial facilities are old and deteriorating, the implications of which are weighed throughout this report. It has been estimated that one fourth of the industrial buildings in the County are more than 30 to 40 years old (Spangle, 1987).

Single purpose centers consist of commercial and office development or shopping centers. Many of them were constructed with the tilt-up concrete design scrutinized in the last section (Figure 4.3). Significant concentrations of light industry, commercial, and office development are growing in urbanizing

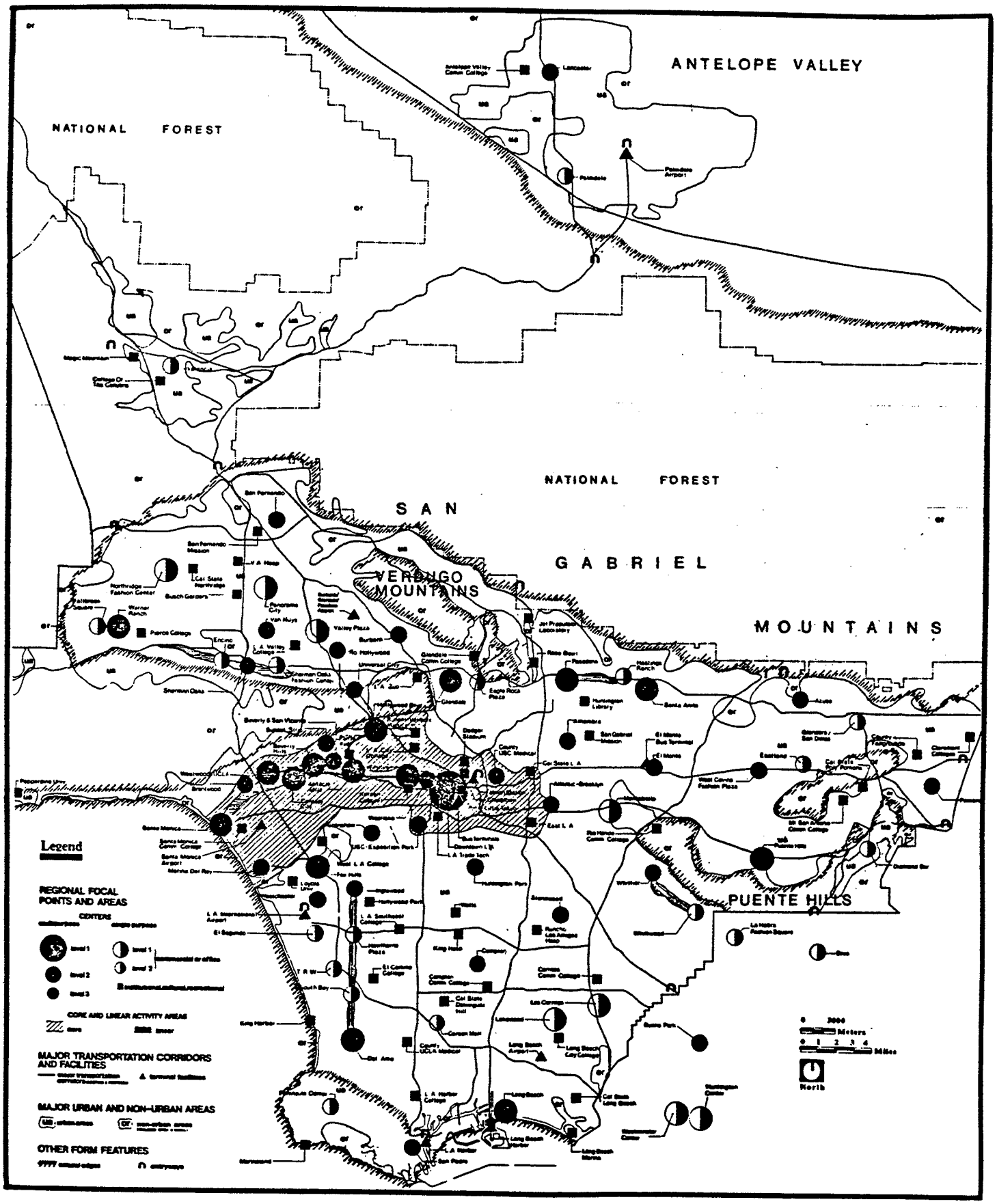


Figure 4.3: Urban form policy: (after The Los Angeles County General Plan, 1980).

areas of the County such as the Santa Clarita and Antelope Valleys, especially near Lancaster and Palmdale.

Industrial and Commercial Vulnerability

County strategy presently focuses on revitalizing and intensifying the use of older commercial and industrial areas to promote the efficient use of scarce land resources. This strategy recognizes the apparent vulnerability of older facilities to earthquake damage and the accompanying potential losses in production. Thus, needed tax revenue sources are preserved and the potential for injuries are reduced.

Pattern of Future Development

Recent Department of Regional Planning growth forecasts indicate that Los Angeles County will continue to grow in population, housing needs, employment, and urban acreage through the year 2010 (Table 4.8). Future growth of Los Angeles County is likely to be at slower rates than adjacent counties. Planned growth is expected to be accommodated by inner city areas, infilling of vacant parcels of land within existing urban land, and expansion into nonurban areas.

Areas of the County designated as primarily nonurban include the Santa Monica, Santa Susana, and Verdugo Mountains, and the foothills of the San Gabriel Mountains; the Simi, Puente, San Jose, and Palos Verdes Hills; the National Forests; and the Channel Islands.

The following areas of the County, shown in Figure 4.4, are expected to experience strong growth pressures:

- Agoura/Calabasas/Westlake
- Agua Dulce
- Acton
- Lancaster/Palmdale
- Little Rock
- Santa Clarita Valley
- Puente Hills
- Malibu/Santa Monica Mountains
- East San Gabriel Valley

According to 1985 growth projections, the County expects a net increase of 613,000 new housing units through the year 2000 (Spangle, 1987). Approximately 80 percent of this new development will be over 12 units/acre and will largely be accommodated in the above areas. This estimate includes the predicted demolition and reconstruction of 144,000 residential units in currently urbanized areas of the County, many with fire and earthquake safety problems.

Table 4.8: Growth Projection for Los Angeles County*

Planning Area	1970	1980	1990	2000	2010
Santa Clarita Valley	50,000	79,000	140,000	210,000	270,000
Antelope Valley	83,000	107,000	160,000	230,000	305,000
San Fernando	755,000	804,000	900,000	970,000	1,035,000
Burbank/Glendale	560,000	568,000	630,000	675,000	705,000
W. San Gabriel Valley	669,000	690,000	775,000	830,000	880,000
E. San Gabriel Valley	591,000	688,000	815,000	925,000	1,035,000
Malibu/Santa Monica Mts.	31,000	53,000	70,000	90,000	100,000
West	397,000	400,000	450,000	485,000	505,000
Central	1,307,000	1,431,000	1,610,000	1,745,000	1,800,000
East Central	625,000	680,000	780,000	830,000	855,000
Southeast	592,000	615,000	670,000	715,000	745,000
South	664,000	660,000	750,000	810,000	860,000
Southwest	716,000	699,000	750,000	785,000	800,000
Channel Islands	1,900	2,200	3,000	4,000	5,000
Los Angeles County	7,041,900	7,476,200	8,503,000	9,304,000	9,900,000

* Growth Projection for Los Angeles County planning areas (after County of Los Angeles Department of Regional Planning, December 1987).

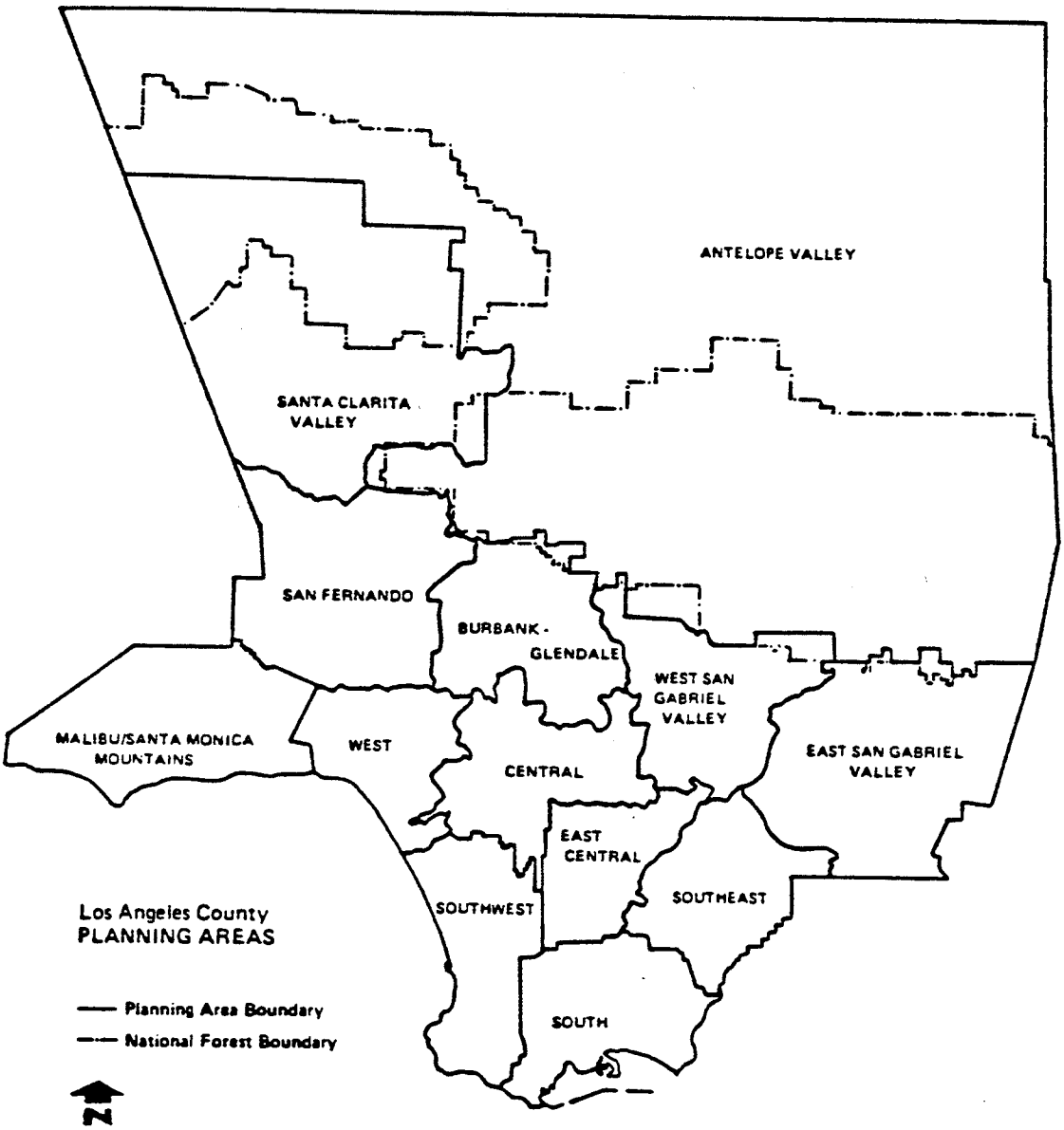


Figure 4.4: Los Angeles County planning areas (after County of Los Angeles Department of Regional Planning, December, 1987).

Development Vulnerability

The 1975 Seismic Safety Element recognized that low density residential development and low intensity land uses are less vulnerable to seismic hazards. While this is true, exposing developments to such hazards carries economic, social, and insurance implications. Residential structures are projected to account for approximately 68 percent of the total damage from a 8+ Magnitude earthquake on the San Andreas fault. Such projections can also be broadly applied to local faults. The infilling of urban development with residential and commercial development may also indirectly increase the urban fire hazard through densification of building patterns. Infilling can also increase the need for open space evacuation staging areas. Parks and green belts are utilized by the Japanese as staging areas and fire breaks.

Conclusions

- Residential structures are expected to account for 68 percent of the total damage sustained from a major earthquake in the future.
- Infilling of many urbanized areas will increase urban density and indirectly cause a potential increase in the fire hazard.
- Rapid development in the County will continue through the year 2000 and may expose much new development to seismic, geologic, fire, and flood hazards unless there is careful planning which incorporates measures and design features to mitigate these hazards.
- Vulnerability is increased in developing areas because there is either a lack of an adequate tax base for capital improvements, or there is local resistance to paying for mitigation of potential hazards.

SECTION 4.6

SOCIOECONOMIC VULNERABILITY

The economy of Los Angeles County and the surrounding metropolitan area is one of the strongest in the world. The gross regional product of the area surpasses the gross national products of all but 11 nations. The County of Los Angeles contains the regional business and financial core of this metropolitan area, the premier economic center on the eastern Pacific Ocean. Numerous public and private merchandising, industrial, utility, and banking ventures yield hundreds of billions of dollars of revenue each year (Table 4.9). Banking assets and deposits in 1984 alone amounted to roughly $130 billion. An important reason for this strong economic standing is that Los Angeles County is the nation's primary link to the growing and important Pacific Rim trade. In 1985, $50 billion in international trade passed through the Ports of Los Angeles and Long Beach. Collectively, the two ports account for 58 percent of all West Coast foreign import cargo.

It is essential for post-disaster recovery that continued economic transactions in facilities such as banks, other financial institutions, and trade facilities are ensured. Banking facilities are vulnerable to economic impact when data communication systems are disabled as a result of telephone disruption or failure of computer facilities from strong seismic shaking. Potential damage to port facilities could also have a devastating economic impact (Thiel, 1987). The extreme vulnerability of marine and port facilities is heightened by the liquefaction potential of dredged landfill.

Scawthorn and Gates (1983) assessed the potential sudden earthquake-induced economic loss to the Los Angeles area as a result of an 8+ earthquake on the San Andreas fault. The estimate was based on a modeled building inventory in the County valued at $275 billion (1982 dollars). The report projected that the economic loss from a Magnitude 8+ earthquake on the San Andreas fault could amount to approximately $4.7 billion dollars (Table 4.10). A study by the California Department of Insurance in 1985, also based on a direct loss from an 8+ earthquake on the San Andreas fault, concluded that the probable maximum loss (PML) in Los Angeles would approach $5.9 billion (in 1985 dollars) (Table 4.10) (Roth, 1986). The report by the Department of Insurance was an estimate of potential insured earthquake losses derived from an analysis of data submitted by property and casualty companies in the Los Angeles/Orange County area. Direct damages resulting from the 1989 Loma Prieta Earthquake, which displaced as many as 7,362 people, has been initially assessed at $6.5+ billion dollars (Los Angeles Times, November 5, 1989).

Table 4.9: Economy of Los Angeles County 1985-86*

INCOME SOURCE	AMOUNT IN BILLIONS OF DOLLARS
International trade volume through Los Angeles Custom District	$ 63
Revenue from major industrial firms	89
Service industries receipts	39
Total commercial bank income	83
Taxable retail sales	65
Wholesale trade sales	130
TOTAL ECONOMIC FLUX	$ 470

* Economy of Los Angeles County 1985-86 (after Los Angeles County Department of Regional Planning, 1988).

Table 4.10: Earthquake Economic Vulnerability: Los Angeles County

	SAN ANDREAS M 8 +	LOS ANGELES BASIN M 6 +
DIRECT	5.9 Billion[1]	18 Billion[2]
SOCIO-ECONOMIC	15 Billion[3]	45 Billion[4]
	20 Billion[5]	

1. *Based on losses to insured structures and contents (Roth, et. al. 1986).*
2. *Direct losses from a 6 + earthquake will be three times that of San Andreas (Spangle, 1987).*
3. *Approximated by direct/socio-economic loss ratio factor 1 to 2.5 (Thiel, 1987).*
4. *Approximated by direct/socio-economic loss ratio factor 1 to 2.5 (Spangle, 1987).*
5. *Total socio-economic loss referenced in San Andreas Scenario Earthquake report by Davis et. al. (1982).*

A study by Spangle (1987) concluded that a 6+ Magnitude earthquake near the metropolitan area of the Los Angeles Basin could cause up to three times as much direct damage to the City of Los Angeles building stock as a far-field event on the San Andreas fault. The loss estimates for the examples given so far, i.e. the Loma Prieta Earthquake, a San Andreas Earthquake, and a moderate earthquake in the metropolitan areas of Los Angeles, are based on the direct costs of replacement or repair of damaged elements of the community.

Indirect costs weigh the full economic impact of a damaging earthquake and include: 1) loss of industrial/commercial productivity, 2) adverse or destructive secondary hazards such as contamination or fire, 3) decreased market share and/or net worth (real estate values), or 4) lost markets from international or regional firms able to capitalize on temporary losses in productivity (Thiel, 1987).

Socioeconomic effects also factor in the loss equation. One factor is the failure of marginal businesses during the recovery period following a major damaging earthquake (i.e., "the Big One"). A lack of quick capital for replacement of losses, lack of earthquake insurance, or the displacement of the economically disadvantaged from collapsed or unsafe hazardous buildings substantially increase the total economic impact (Thiel, 1987). BAREPP (1987) states that a conservative factor that increases estimates of physical damages by at least 2-1/2-half times (per dollar of direct loss) might yield a more accurate description of the total impact on the regional economy. Table 4.10 shows one interpretation of the maximum probable loss from a Magnitude 8+ earthquake on the San Andreas. The total socioeconomic loss, if the 5.9 billion dollars is multiplied by the loss factor, would appear to be nearly $14 billion. However, the Department of Insurance loss estimate shown in Table 4.10 covers only insured structures and contents, and not losses from automobile, worker's compensation, and life/health insurance; and obviously not the damage involved with uninsured property losses. These factors, if taken into account, could support total socioeconomic losses of 20 billion dollars, a figure referenced by Davis et. al. (1982) in the San Andreas Fault Scenario report. If the loss estimate multiplication factor is considered for a 6 + earthquake in the Los Angeles Basin, as suggested by Spangle (1987), the total socioeconomic impact could approach $35 billion.

Population and Ethnicity

The demographic character of Los Angeles County has changed substantially since the adoption of the 1975 Seismic Safety Element. In 1990, the population is approximately 8.5 million and continues to rise. Much of the increase can be attributed to both national and international migration. Consequently, the population of Los Angeles County has become extremely diverse. Some 117,000 of Los Angeles's school children speak one of 104 languages better than English. As of 1985, more than 54 percent of the County was comprised of various ethnic minority groups. The ethnic breakdown is 46 percent nonhispanic white, 31 percent hispanic, 12 percent black, 10 percent asian, and one percent who are representatives of other ethnic groups.

The 1987 Whittier Narrows and 1989 Loma Prieta Earthquakes highlighted specific problems during all phases of post-earthquake recovery involving the multiethnic character of Los Angeles and the Bay Area regions. Problems ranged from emergency response to post-disaster assistance. Earthquake education programs must focus on the multiethnic aspects of emergency response. Another area of focus should be the development of multilingual capability within County emergency response and post-disaster recovery plans. The Los Angeles County Multi-Hazard Functional Plan for Emergency Operations has begun efforts to handle these issues (Constance Romero, 1989; personal communication).

An emerging issue is that the segment of the community most vulnerable to negative consequences of an earthquake are low income households and tenants of rented apartment units. Low income people make up the majority of the population that resides in unreinforced masonry buildings (Tierney, 1988). In the 1987 Whittier Narrows Earthquake, dislocated low income residents had difficulty finding affordable replacement housing (SSC 88-01). In addition, this segment of the population is less likely to have earthquake insurance or financial resources, such as savings, that could help in their recovery. Combined with the moral responsibility to abate hazards associated with hazardous buildings, decreasing the burden of the disaster on low income residents should also be a prime concern.

Conclusions

- A major earthquake near the metropolitan area of the Los Angeles Basin could cause up to three times as much direct damage than an event on the more distant San Andreas fault.

- Banking facilities are vulnerable to economic impact when data communication systems are disabled as a result of telephone disruption or failure of computer facilities from strong seismic shaking.

- The segment of the community most vulnerable to negative consequences of an earthquake are low income households, tenants of rented apartment units and the homeless.

- That 117,000 of Los Angeles's school children speak one of 104 languages other than English implies the need for multi-ethnic safety and language programs.

CHAPTER 5

MANAGEMENT OF FUTURE DEVELOPMENT

CHAPTER 5

MANAGEMENT OF FUTURE DEVELOPMENT

As pointed out in Chapter 4, much of the prime land in the County has been developed. In the future, development is likely to increasingly occur in areas subject to a variety of hazards. In many instances, new development is moving into areas with significant environmental constraints. Whether in active fault zones, in hillside areas prone to landsliding, on liquefiable soils, or in flood water inundation areas, proper management of future development is essential. Development can be restricted to either avoid hazardous areas or be regulated so that growth is compatible with prudent safety planning. Proper site investigation, hazard conscious project design, and hazard mitigation engineering compose prudent safety planning.

Figure 5.1 shows the County's primary regulatory tools. Their primary purpose is to protect the public health and safety. Safety is also protected as the County carries out its responsibilities under the California Environmental Quality Act (CEQA). CEQA requires that environmental constraints be considered prior to approval of significant projects. The County codes are applied to achieve the goals and policies stated in the General Plan (Figure 5.1). The County General Plan (1980) contains development policies that reflect concern for environmental impact and safety. This chapter will review the status of local regulatory tools as they are currently implemented. These include:

- County Planning and Zoning Code, Title 22;
- County Subdivision Code, Title 21; and
- County Building Code, Title 26, and County Fire Code, Title 32.

The roles of zoning ordinances, subdivision regulations, and environmental impact analysis (CEQA) will be reviewed with respect to avoidance of fault, landslide, flood, and other hazards. The issue of proper safety planning once a project is proposed will be explained in terms of components of a locally implemented safety program including project review, grading, and construction and design standards.

Zoning Code

The Zoning Code (Figure 5.1), administered by the Department of Regional Planning, prescribes permitted land uses within delineated districts or zones. Zoning Codes set forth standards and regulations pertaining to the development of land, procedures for variance from these standards, and mechanisms for zone amendments. Zoning addresses building height and setbacks, building bulk, lot coverage, density, and the types of land use activities allowed within a given zone. While zoning codes regulate acceptable land uses, the design standards in the Building and Fire Codes regulate construction practices for various types of structures.

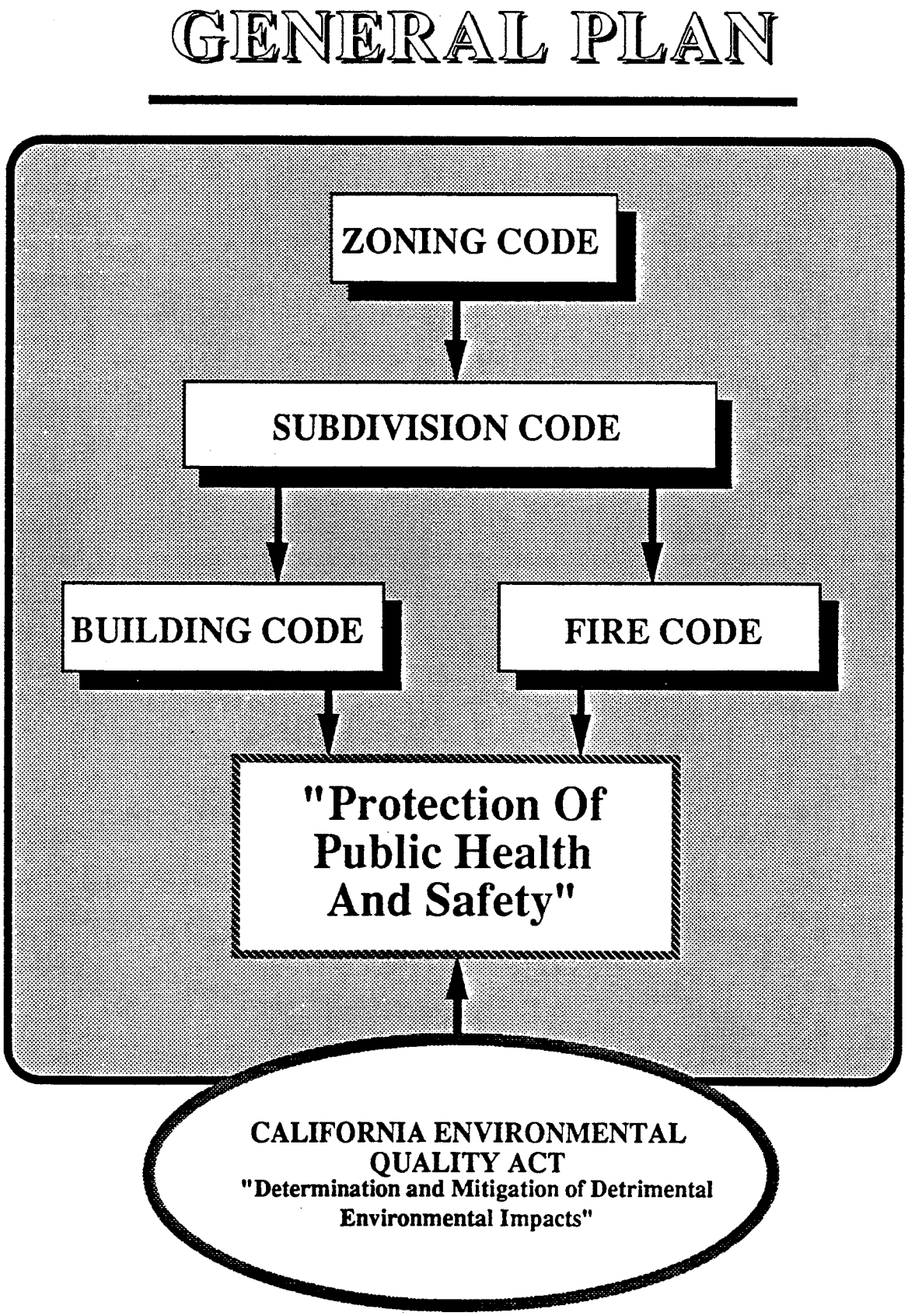


Figure 5.1: Structure of County safety regulatory programs.

The Alquist-Priolo Special Studies Zone Act (APSSZ), which pertains to construction of structures for human occupancy near active faults is a state seismic safety measure. It is implemented as part of the Building Code and therefore is not currently a County zoning regulation.

Low intensity open space zoning in high hazard areas is relevant to risk-reduction because it can reduce the exposure to hazards. Such hazardous areas can be acquired or zoned for low intensity development. Open space zoning in Los Angeles County has been applied primarily to beaches, public parks, and the National Forest.

Special Development Regulations

The location, density, and design of land development can be regulated in a variety of ways, some of which are modifications of more traditional zoning and subdivision controls. Two examples are planned unit development and cluster development. Planned unit development (PUD) is a zoning classification which permits more flexibility in combining uses and building types in the design of a single site than traditional zoning regulations. Cluster development, often a feature of PUD regulations, permits development to be concentrated on a portion of a site with the remainder designated as open space. The application to hazard reduction is that the developed portion of the site can be located and designed to avoid hazardous areas or reduce exposure to hazards. The County of Los Angeles administers a Residential Planned Development Zone; however, it does not specifically focus on seismic-geologic hazards.

Subdivision Regulations

The subdivision code regulates the division of land and site design (Figure 5.1). Carefully designed subdivisions, based on consideration of geotechnical/seismic information, can result in significantly safer development. If portions of the land are potentially hazardous, (for example, on or below steep slopes, across a fault, on unstable ground, near stream channels, or in fire prone areas), the subdivision can be designed either to avoid building in such areas, or approved subject to conditions which mitigate the hazardous conditions. Tentative parcel and tract maps in the County, where proposed in known hazardous areas, are required to have special studies addressing hazardous conditions.

The Subdivision Code, administered by the Department of Regional Planning, permits establishment of conditions for development relevant to health and safety. Conditions may include capital improvements, adequate emergency access, flood protection, fire resistive construction materials, or provisions for utility services. Subdivision conditions are set by the various agencies including such County departments as Regional Planning, Parks and Recreation, Health Services, Public Works, and the Fire Department. The fact that all aspects of a project are addressed during this process makes the Subdivision Code the nearest equivalent of a locally implemented comprehensive safety program.

Environmental Impact Analysis

The environmental review process, under the authority of the California Environmental Quality Act (CEQA), plays an important role in the implementation of Safety Element policy. The Department of Regional Planning is the lead agency for such projects as zone changes, land subdivisions, variances, conditional use permits, and general plan amendments. Various other County departments are lead agencies in preparing environmental documents for many types of public works projects. CEQA provisions require an extensive review of potentially detrimental environmental impacts of a proposed development. Similar to the subdivision review process, various County agencies have input to the process during the CEQA review. The earlier that environmental constraints are defined in the project planning phase, the better the chances for design changes that avoid potential hazards.

Concerns for water and air quality, noise and sewage thresholds are analyzed, but more relevant to the Safety Element, environmental hazards are assessed by various responsible County agencies (Figure 5.2). If significant hazards are revealed during the review, the developer has the opportunity to provide mitigation measures or to modify the project to lessen the impacts to tolerable levels. The CEQA review process, as implemented by the County, is an effective approach to hazard reduction for future development.

Building and Fire Codes

The provisions within Building and Fire Codes provide mechanisms for introducing hazard reduction measures into new development. Project design, project review, and performance standards in Los Angeles County are implemented through these codes. The codes establish the specific site investigation requirements in the investigation phase of development, identify specific departments responsible for reviewing various aspects of an application, and define the various standards by which a project will be assessed. Where development occurs in areas prone to ground failure, such as landsliding or liquefaction; or in areas vulnerable to flooding or brush fires, potential hazards must be mitigated in connection with issuance of permits. Acceptable building performance standards and capital improvement plans are also requirements of the permit process, which focus on the health, safety, and welfare of the public (Figure 5.1). In addition, fire protection standards are commonly enforced through both the Building Code and the Fire Codes.

The State of California provides mandatory guidelines for the County Building and Fire Codes, guidelines which are modified from State adopted versions of the International Congress of Building Officials (ICBO) Code and the National Fire Code. Local governments must amend their regulatory codes every three years to be in conformance with State performance requirements. Revisions may be more frequent than three years; however, local governments must abide by requirements defined in State Codes, but may adopt more stringent regulatory measures on the basis of extraordinary climatic, geographic, or topographic circumstances. This report builds the case for more stringent local safety measures.

CALIFORNIA ENVIRONMENTAL QUALITY ACT:

REVIEW PROCESS FOR HAZARDS

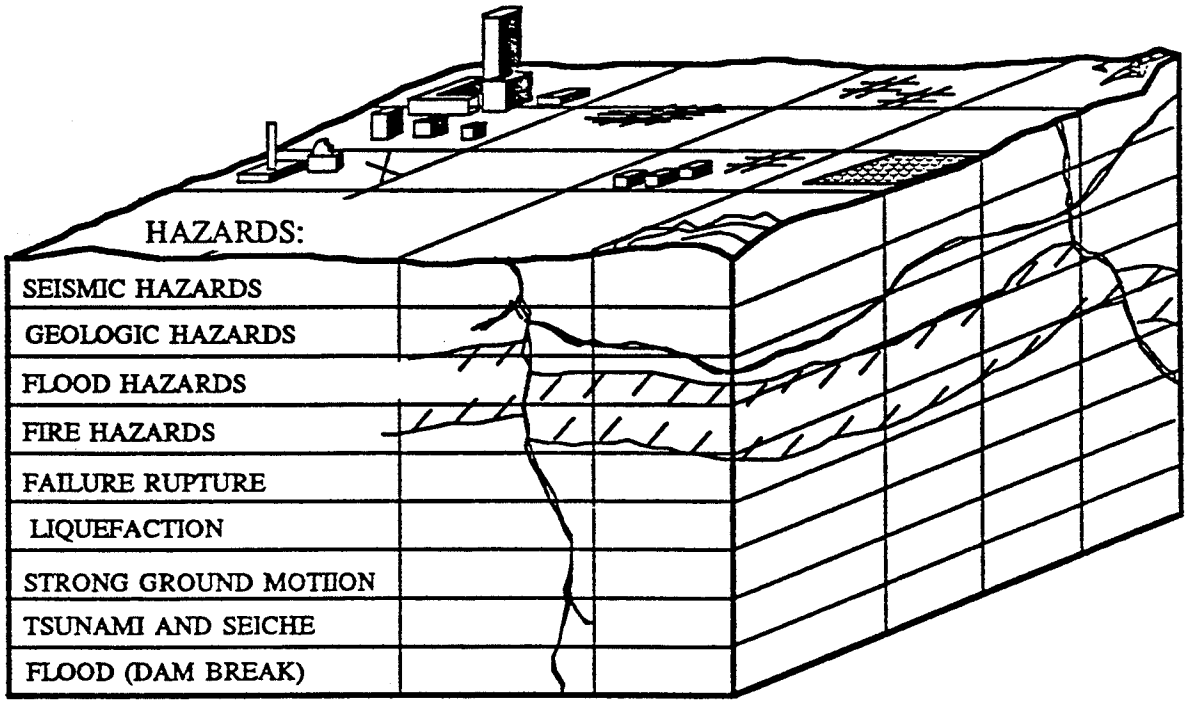


Figure 5.2: Examples of hazards addressed through the California Environmental Quality Act (CEQA) review process.

Beginning with the site investigation, project design and construction standards apply to all stages of new development. The recommendations in geotechnical, engineering geology, or flood reports are essential to proper site design and foundational stability of the new development. Project inspection is very important to ensure that the site development occurs as approved, and that building construction standards and design recommendations are fully implemented. Generally, provisions of the Building Code apply when the issuance of a building permit is required, which applies in most cases to new development. Although, enforcement of the Building Code is also effective in mitigating existing hazards in buildings undergoing substantial rehabilitation or repair, such authorization is not currently emphasized in the County Building Code.

Chapter 1 (Title, Scope, General) and Chapter 2 (Organization and Enforcement) provide the implementation framework of the County Building Code. Definitions state the circumstances where ministerial provisions of the code apply to development projects. Technical expertise in reviewing and enforcing the various chapters and sections of the County Building Code exists in various divisions and branches of the Department of Public Works (DPW) such as Building and Safety, Flood Control, and Land Development. Certain sections of these divisions play key roles in reviewing initial project proposals and performance standards during construction. The Geology and Soils Section (DPW) plays an essential role, as does the Fire Protection Section of the County Fire Department, which administers the Fire Code as well as several Chapters of the Building Code.

SECTION 5.1

SEISMIC HAZARDS

SECTION 5.1.1

STRONG GROUND MOTION

The role of predictive strong ground motion maps in urban planning is evolving. There are potential applications for such maps in land use planning, formulation of design standards, and establishment of retrofitting priorities. Avoidance of areas of high ground response is the ideal method for reducing future losses. However, given the state-of-the-art technology, the most effective seismic safety program for new development is the judicious enforcement of the seismic design provisions in the Building Code. The ICBO model building code, which is adopted by the State and County, places Los Angeles County in Seismic Zone 4. Seismic Zone 4 is a nationwide delineation of seismic risk which should not be confused with any seismic zones defined within the 1975 Seismic Safety Element. All construction and hillside grading projects must consider seismic design parameters defined for Seismic Zone 4.

Strong Ground Motion Investigation

Strong ground motion investigations involve the following process. Seismic design parameters should be defined early in the review of development projects and incorporated directly into plans for construction and design. The geotechnical consultant contracted by the developer derives the seismic design parameters for a given site for review by the Department of Public Works (DPW). The DPW checks that seismic parameters for all faults within 60 miles of the project site have been considered. Minimum seismic site parameter requirements emphasized by the State geologist (Appendix 3), as well as by the internal guidelines of DPW, consist of the following:

- Definition of the maximum probable earthquake (MPE) (the largest earthquake expected within the lifetime of the structure);
- definition of the maximum probable acceleration (MPA) (peak acceleration independent of frequency; and
- definition of the maximum probable duration of shaking and the predominant period of the site.

The emphasis of Building Codes, and hence the review emphasis of DPW, is constrained to minimum code standards. Peak acceleration (MPA) is useful as a minimum seismic design parameter because the value is readily derived and incorporated into static (or pseudostatic for slope stability) seismic analyses. Static analyses provide an economical and efficient approach to seismic design for noncritical development, i.e., development other than critical facilities. Estimating the force of an earthquake using peak acceleration is appropriate for determining hillside grading design, determining liquefaction potential, or construction design for conventional or residential development. Inasmuch as the static method does not account for the dynamic, or continuous nature of

earthquake motion, the method is somewhat approximate. Facilities which must remain standing, be operable for the health and safety of the community, or pose great risk to the public, are subject to more rigorous design criteria.

Site amplification is not considered unless the structure is critical. Significantly, as a means to reduce the risk of site amplification and damaging resonance, the 1985 County Building Code required site measurements of shear wave velocity to accurately determine site period for several types of conventional development. In Chapter 3, shear wave velocity is identified as an important parameter in ground response. The 1985 County Building Code required on-site measurement of this variable using downhole techniques because, theoretically, it allowed an accurate determination of the site period. The method was discovered to be both uneconomical and impractical for smaller projects which use only 50-foot boreholes. Measurements of shear wave velocity in an alluvial basin, in many cases, must account for the many hundreds of feet of alluvium. For this reason, the provision is now retracted and replaced with standardized factors that estimate site period.

Strong Ground Motion Mitigation: Earthquake Resistant Design

Building Code Chapter 23 "Engineering Regulations - Quality and Design of the Materials of Construction" summarizes minimum acceptable seismic design procedures. As pointed out in Chapter 4, the ICBO receives technical input from the Structural Engineers Association of California (SEAOC) through the Applied Technology Council (ATC), and develops model codes for seismic design and construction. As of 1989, County Building Code procedures for seismic design have been significantly modified and expanded with respect to seismic design, as they are after every major earthquake. The County uses dynamic analysis mainly for critical facilities having certain types of frames and structural systems and for large concrete infrastructure. Static force analyses are mainly used in the design of non-critical structures and buildings with ordinary configuration.

The codes currently adopted by the State and County have altered the conventional method of determining the **static base shear**. The base shear is the total lateral force of an earthquake that a structure must withstand. The modified static force procedure formula is now represented by the following equation:

$$V = \frac{(ZIC)}{RW} * W$$

V = total design lateral force of earthquake that must be resisted by the structural frame of a building

Z = Seismic Zone 4 (Los Angeles County)

I = importance factor; e.g., where applicable, an essential or hazardous facility with specific structural/frame systems (structures supporting or containing significant quantities of toxic or explosive substances)

C = horizontal force factor for specific structural and nonstructural components of the building and includes fundamental period of vibration of structure

RW = lateral force resisting system of the structure specifically designed to resist lateral earthquake forces

W = weight of the building

This new formula more closely approximates dynamically generated forces imposed by an earthquake and takes into consideration the toughness of the structural system used in construction. However, because peak acceleration is still used to model the force, there remains the possibility that the standardized lateral force equation may underestimate the destructive potential of an earthquake. Therefore, in the case of conventional development, such as 1- and 2-story, single-family construction and commercial buildings with certain ductility and height, minimal seismic design code requirements still are the most conservative and economical method to ensure that life safety will not be endangered by total structural collapse during a major earthquake.

Dynamic analyses is the preferred seismic design method used to impart earthquake resistance. The method models the highest peak accelerations of any given frequency of a design earthquake and incorporates this **spectra of frequencies (design spectra)** into the earthquake resistant design (Figure 5.3). The method relies upon artificially modeled or actual strong motion records to tailor the predicted site frequencies to the specific characteristics of the structure (UBC, 1988). An actual earthquake ground motion record allows the most accurate dynamic representation of how the ground once moved, and hence, how it will probably move again. The dynamic analyses model, using a sophisticated computer program, can be summarized simply as follows:

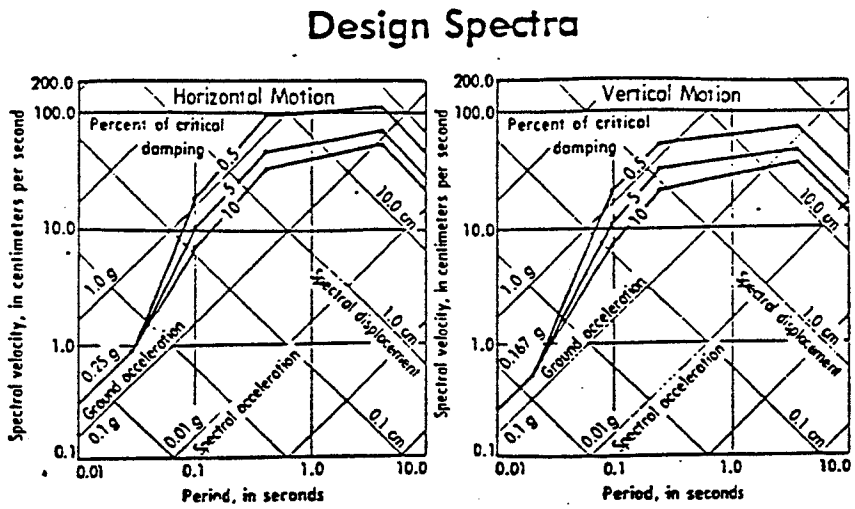
1. Select a natural frequency for a structure and assume a physical model describing how it will move during earthquake motion (a pendulum for example);

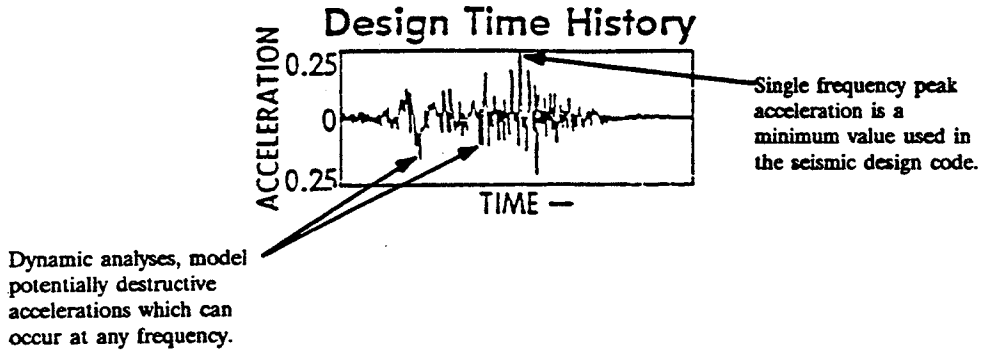
2. apply an artificial strong motion record for the single natural frequency selected and generate a maximum acceleration; and

3. apply the same process to all frequencies of interest, generate an entire artificial time history (time history is the behavior of accelerations during the earthquake), and convert this into highest accelerations for a given period (design spectra) (Figure 5.3).

The method allows the structural engineer to design for the most common earthquake frequencies. However, there is no guarantee that an earthquake will be composed of the expected frequencies. As was discussed in Chapter 3, different earthquakes, by virtue of the path of propagation, the location of the earthquake with respect to the site, or even the type of fault rupture can confound even the most sophisticated seismic design. Although strong ground motion will be unique for a given earthquake, dynamic analysis is the state-of-

CRITICAL FACILITIES, INFRASTRUCTURE, LIFELINES AND OTHER HIGH PRIORITY BUILDINGS.





PEAK ACCELERATION FOR EACH FREQUENCY - HOW TO DESIGN AGAINST DESTRUCTIVE EFFECTS OF SITE/STRUCTURE RESONANCE.

Figure 5.3: Design spectra and dynamic analyses used for earthquake-resistant design of critical facilities.

the-art method for earthquake resistant design. The California Division of Mines and Geology has indicated that local governments should not only advocate the continuation of strong ground motion instrumentation through the building code, but also a program to ensure regular maintenance and documentation for the existing network of strong motion stations. The existing system of strong motion stations, if utilized effectively, can provide a sound data set to base site frequency parameters. If on-site measurements of shear wave velocity were used for especially sensitive projects, in addition to utilizing a complete set of strong motion records, an exceptionally credible site frequency could be determined.

One significant modification of the 1988 County Building Code, especially relevant to the discussion of design vulnerabilities of potentially hazardous buildings in Chapter 4, is that dynamic analyses are now required, and apply to specific types of structures with particular framing or structural systems, including:

- Structures with heights greater than 65 feet or 5-stories; and
- structures with stiffness, weight or geometrical irregularity.

The revised code does not intend that the dynamic lateral force procedure reduce the standards for lateral forces, but seeks to strengthen the building design by establishing the correct distribution of earthquake forces. The revised code also recognizes the vulnerability of other potentially hazardous construction. There is a specific prohibition of certain types of concrete frame and bearing wall systems (e.g., certain tilt-up commercial/industrial construction techniques recently popular in southern California). As pointed out in Chapter 2, the 1987 Whittier Narrows Earthquake revealed that modified construction standards for tilt-up construction following the 1971 San Fernando Earthquake were effectively negated in some cases due to increasing popularity of complexly designed buildings. The building height and configuration complexity were increased with standards suitable only to more conventionally designed buildings. The revised Building Code now has definitions for regular and irregular design. This aspect, especially with respect to tilt-up construction, should be closely followed to prevent a similar problem from reoccurring in the future.

Enforcement of Seismic Safety Standards

The County of Los Angeles places high priority on enforcement of building and design standards for high-rises and high occupancy buildings, and has expressed support for improved State mandated site and design construction standards for all essential facilities (Safety Element, 1975). As a locally implemented safety program, the County Building Code emphasizes enforcement of the State Building Code through provisions such as "requiring new fire stations be in compliance with mandatory State requirements". Application and enforcement of UBC provisions at the local level is the primary vehicle for promoting safety and earthquake stability of buildings and structures.

That the State sets standards for essential facilities, such as fire stations, underlines the primary role of the State in the construction of other critical facilities, such as hospitals, schools, jails, most dams and many bridges. Figure 5.4 shows a list of selected facilities and structures which have been emphasized in this report. It does not represent a comprehensive list of all critical facilities, nor does it show all responsible State and/or County agencies participating in the review process. Figure 5.4 emphasizes that a number of State agencies from the State architect, to the Division of Safety of Dams, and even the State Department of Corrections may become involved in the plan review of many types of facilities. Therefore, not only are State standards imposed on certain critical facilities in the County, but State agencies accept responsibility to ensure that adequately rigorous seismic design provisions have been followed.

Figure 5.4 shows that the County is also responsible for many types of facilities and structures. This includes the construction of shopping malls, theaters, smaller dams, and County bridges. Rigorous enforcement of sometimes inconspicuous design and construction standards is essential. Design or detailing flaws can be extremely hazardous. One of the major lessons of all damaging earthquakes is that poor construction practice and quality control can result in severe structural damage or collapse.

Inspection and plan review are essential elements of locally implemented safety programs because they ensure that building code provisions have been carried out to the maximum extent possible. However, rapidly evolving building codes in California can cause confusion on the part of developers and agencies required to conform and enforce seismic design standards. To benefit from ongoing research and technological advances in seismic design in the UBC, the County must possess the technical capability to effectively review and apply new UBC provisions. Seismic design review is currently a high priority. A program in the County Five-Year Plan for Earthquake Preparedness (1987), recommends "authorization of personnel and technical capability necessary for such stringent review through the Department of Public Works". By implemenation, this requires a committment to continuing education and training by County Departments with review responsibility.

Variations in County Building Code Standards

Minor variations of the State code can be adopted at the County level, while major structural seismic design provisions are adopted directly from State and ICBO design standards. More stringent measures are limited to such aspects as roofing materials, building height, or requirements for safe treatment of nonstructural building component. County safety provisions can address the intrinsic vulnerability of life safety in any building, given the real limitations of seismic design codes, and focus on proactive hazard reduction objectives. Hazard reduction might include restrictions of window areas, a known design and architectural variable which can furnish more lateral support for walls in buildings or facilities.

Such provisions, while not major structural departures from ICBO seismic design, also lessen the possibility of broken glass in an earthquake. Fire retardant

CRITICAL FACILITIES: LOS ANGELES AND STATE OF CALIFORNIA REGULATORY RESPONSIBILITIES

HIGH RISK FACILITIES
(Hazardous Facility UBC)

- Chemical Plants°
- Manufacturing Plants° (Explosives or Flammable Materials)
- Large Dams/Reservoirs• (Height >25 ft.) (Reservoir Capacity >50-Acre ft.)
- Small Dams°

HIGH OCCUPANCY BUILDINGS
(>300 people)

- Shopping Malls°
- Theaters°
- Multi-Story Buildings°
- Commercial Facilities°
- High Rises°

ESSENTIAL FACILITIES

- Hospitals•
- Fire Stations•
- Police Stations•
- Emergency Operation Centers•

DEPENDENT CARE

- Jails•
- Prisons•
- Small Day-Care Centers°

CRITICAL TRANSPORTATION

State
- On Ramps
- Overpasses
- Bridges

County
- Roads
- Bridges
- Tunnels

CRITICAL LIFELINES

- Gas Lines*
- Waterlines*
- Electrical Transmission Lines*

° County
• State
* Public Utilities Commission

Figure 5.4: Critical facilities: Los Angeles County and State of California regulatory responsibilities. Selected facilities and responsible authorities are listed to emphasize the cooperative, and sometimes supplementary, alliance that the County and State form to ensure safe construction.

construction, numerous fire exits for evacuation, or allowances for debris along evacuation routes may also be part of locally adopted seismic safety provisions.

A Review of Other California Seismic Design Safety Programs

The Seismic Safety Commission, California building officials, and BAREPP co-sponsor extensive training programs for many Bay Area plan checkers on seismic design theory, types of construction, and retrofit technology. In addition, many plan checkers attend training seminars conducted by structural engineers to improve the seismic inspection capability of Bay Area building departments. To ensure that subtle deficiencies in code design are adequately addressed and conservatively interpreted, Sonoma County building officials are kept abreast of the latest standards and research in seismic design and construction. In so doing, a potential design problem, although not specifically identified in a current building code, can at least be addressed in the plan checking phase. The rapidly evolving three year UBC adoption program in California, necessitates this flexibility especially in the aftermath of a damaging earthquake when many new vulnerabilities become known.

Innovative designs, supported by UBC allowances for alternative designs, "based on laws of dynamics" are gaining popularity among some jurisdictions in California. One such innovation, the base isolation system, which in effect places a building foundation on rollers or ball bearings, allows the structure to move laterally with earthquake motion and dissipate energy to prevent it from being transmitted into the structure. Although base isolation has been applied mostly to tall flexible buildings, it may some day contribute an additional safeguard to extensive reinforcement of shorter, more rigid structures. A special problem posed by unusual innovations is that without having code provisions and standards to guide their use, there may be pressure to accept these techniques as suitable alternatives to code requirements. It is important that if such innovative designs are applied to structures for which the County has review responsibility, that the County be able to make rational, reasoned decisions based on in-house expertise.

Conclusions

- The State and County Building Codes are the primary mechanisms providing safety from seismic, as well as earthquake-induced fire and other life threatening building hazards. County hazard reduction code provisions can augment stringent structural design standards provided in the State Building Code.

- Seismic design plan checking is the most practical way of ensuring that new knowledge is utilized in new construction and that inadequate standards are corrected.

- All critical facilities must be designed to remain operational, functional, or able to withstand a large earthquake without excessive structural damage.

- County guidelines for utilizing the most stringent design procedures, including dynamic analyses and the importance factor (I), should be used for all critical facilities where the County has prime responsibility. Shopping malls or commercial buildings with the potential for damage, by virtue of the site geology, are one example. The survivability of structures, such as high-occupancy theaters or emergency County maintenance warehouses, is another guideline.

- Support for the program recommended in the County Five-Year Plan for Earthquake Preparedness (1987) advocating stringent enforcement of seismic building code provisions is essential to structural safety. Providing for expanded personnel and training, and encouraging knowledge and use of the latest structural design research, all supply the County with the technical capability necessary for implementing and enforcing building code provisions for maximum safety.

- Expanded use of strong motion accelerographs in Los Angeles County would allow the collection of more veritable strong motion records. Ideally, actual records, rather than synthetic records, exemplify the preferable data base for applying County Building Code provisions involving dynamic analyses. Dynamic analyses is only as good as the amount and quality of data available from strong motion instrumentation, which also requires instruments in good working condition.

SECTION 5.1.2

FAULT RUPTURE HAZARD

Project Review

The Alquist-Priolo Special Studies Zone Act (APSSZ) (Public Resources Code Section 2621 et seq.), represents the current State mandated approach to preventing development in active fault zones. Essentially, the APSSZ Act contains two requirements:

1. It prohibits the location of "developments and structures for human occupancy" across the trace of active faults; and

2. it establishes "Special Study Zones", as delineated and defined by the State geologist, within which affected cities and counties must establish special procedures for reviewing and approving applications for new building permits.

The APSSZ also grants local jurisdictions the authority to establish stricter standards than the State prescribes. The Alquist-Priolo Act only applies to residential units within large subdivisions (> 4 parcels) or when a subdivision creates more than four individual lots, as defined under the State Subdivision Act (Keene, 1986). Thus, the APSSZ Act does not specifically cover individual single-lot residential units.

Los Angeles County implements APSSZ provisions through Section 311, Title 26 of the County Building Code. Section 311 is applied to critical facilities, large subdivisions, and single-residences. By strictly applying the "human occupancy" conditions to single-lot residences, County standards are more restrictive than State requirements (Keene, 1986). Although warehouses are not covered under the APSSZ Act, commercial buildings with more than 2000 hours/year of human occupancy fall under provisions of Section 311 (Hart, 1985). An increase in occupancy of a commercial facility, the modified function of an exempt warehouse, or the redevelopment of exempt property illustrate potential problems in enforcement of Alquist-Priolo provisions during initial review stages. The value of a structure exempt from APSSZ regulations should also be considered in light of the risk of total loss from a surface rupturing earthquake.

The County requires even more stringent initial review criteria for siting or constructing hospitals, police and fire station facilities within active fault zones. The 1975 Seismic Safety Element advocated prohibiting development of dependent care facilities within 1/4 mile of an active fault. State authority may have overridden County regulatory power on this particular measure.

Fault Program Weaknesses

In terms of protecting the community from surface fault rupture hazards, Section 311 has several shortcomings. The foremost problem is that Section 311 only recognizes APSSZ defined faults. The criteria used by the State geologist to define an APSSZ fault, "sufficiently active and well defined", are inherently permissive. A potential rupture zone in coarse-grain alluvium can be easily overlooked during a typical fault investigation, since coarse alluvium may be "self-healing" after fault movement, thus concealing evidence of fault displacement. Landsliding in hillside areas can also frustrate recognition of surface fault rupture hazards using APSSZ criteria, even though arguments can be made for approaching development along their traces with caution (see Section 3.1.2). The very nature of the State Fault Evaluation Program (FER), which investigates and officially declares faults "active", also requires that mapping priorities be set on a State-wide basis. This means that many "deserving" faults, some of which are located in Los Angeles County, may not be mapped in an expedient manner. Faults included in the above categories need to be considered in the review process for new development.

Public access to completed fault studies needs to be improved. If public access were incorporated into a County fault information system, new knowledge of a fault's activity, as determined from ongoing County-wide fault investigations, could support the equivalent of a local fault evaluation program. This approach would recognize the fact that potentially active faults (Plate 1) might be proven active or even that active faults (Plate 1) might be proven inactive (pre-Holocene). This information could be readily incorporated into the initial project review phase. Such a program emphasizes the need for caution in protecting the public from surface fault rupture hazards by tracking and utilizing the most current information available.

The weakness of the County fault hazard program extends to the California Environmental Quality Act (CEQA), as implemented by the County of Los Angeles. Although recognizing the impact of other faults in the initial stages of review, current procedures only require mandatory seismic-geologic reports and statements of project feasibility for "active" faults. The problem is that these faults are not officially recognized as "active" until they have been incorporated into an Alquist-Priolo Special Studies Zone. One strategy for strengthening the appraisal of fault rupture hazards in the review process is to expand the number of faults requiring special studies based on the premise that "a fault suspected of being a fault rupture hazard is guilty until proven innocent", as discussed in Chapter 3 (Plate 1 - Fault Rupture Hazard). Another option would be to define an appropriate policy and regulations providing for standard enforcement of potentially active faults not currently recognized by the Alquist-Priolo Act.

Geotechnical Investigation for Active Faults

Enforcement of Section 311 is currently constrained by fault investigation guidelines that require a trench up to five feet to determine the existence of an active fault on the project property. In practice, the County Geologist applies this depth requirement to single-family residences, but requires larger

scale detailed mapping for large subdivisions and critical facilities. To ensure consistency of County policy with County practice, an "indefinite depth" for trenching should be supported. The following factors should be used to guide decisions regarding appropriate trench depths and the areal extent of a County fault investigation:

- Specific site characteristics; and
- the consideration of unacceptable risks.

Figure 5.5 is a proposed flow chart illustrating an proposed methodology for a fault investigation. The model could apply to any project that falls within an area suspected of being within the impact zone of an active fault i.e., a fault with a high probability of rupturing the surface. Fault investigations should at a minimum conform to the guidelines published by the CDMG (Appendix 3); however, many issues addressed within the flow chart emphasize alternatives for local implementation, such as guidelines for investigation, fault setbacks, and discretionary approval. Following a program of preliminary research, aerial photographic study, and reconnaissance field mapping, investigations should, in most cases, include a detailed subsurface investigation. When possible, trenches should be excavated deep enough to encounter older Pleistocene sediments (greater than 10,000 years).

Ideally, each fault investigation should also be guided by the specific geometry and character of faulting, site development, and other specific criteria (e.g., potential damage from strike-slip movement versus damage from thrust movement, deep alluvial fill, where detectable past movement within the Holocene units is not possible to detect). Because fault zones may be complex, knowledge of the fault orientation and width of the fault zone will dictate the lateral extent of the trenching.

If a fault is verified as active, or a potentially active fault is deemed high-risk to proposed critical facilities on-site, construction across the trace of the fault should be set back at distances approved by the Department of Public Works. In most instances, setbacks are only required for active faults. An active fault requiring a setback, as defined on the flow chart, is a fault that has either proven, probable, or unproven surface displacement within the last 10-11,000 years (see Chapter 3; Fault Rupture Hazard).

Situations and geologic conditions will vary from project to project so investigation criteria must be flexible. In some instances, the site to be investigated may be completely underlain by deep and/or coarse-grained alluvium which can hinder chances of establishing the recency of fault movement and locating the fault through normal investigation techniques. In such instances, there should be emphasis on the cooperation between the Department of Public Works and the project geologist (Figure 5.5.) If a critical facility such as a hospital, fire station, or a chemical plant is proposed, fault studies might be required offsite in areas with better stratigraphic time control (Figure 5.5). In any case, critical facility projects require more stringent investigatory procedures. Essential facilities (hospitals, police, and fire stations) are currently the only mandated structures for human occupancy subject to such

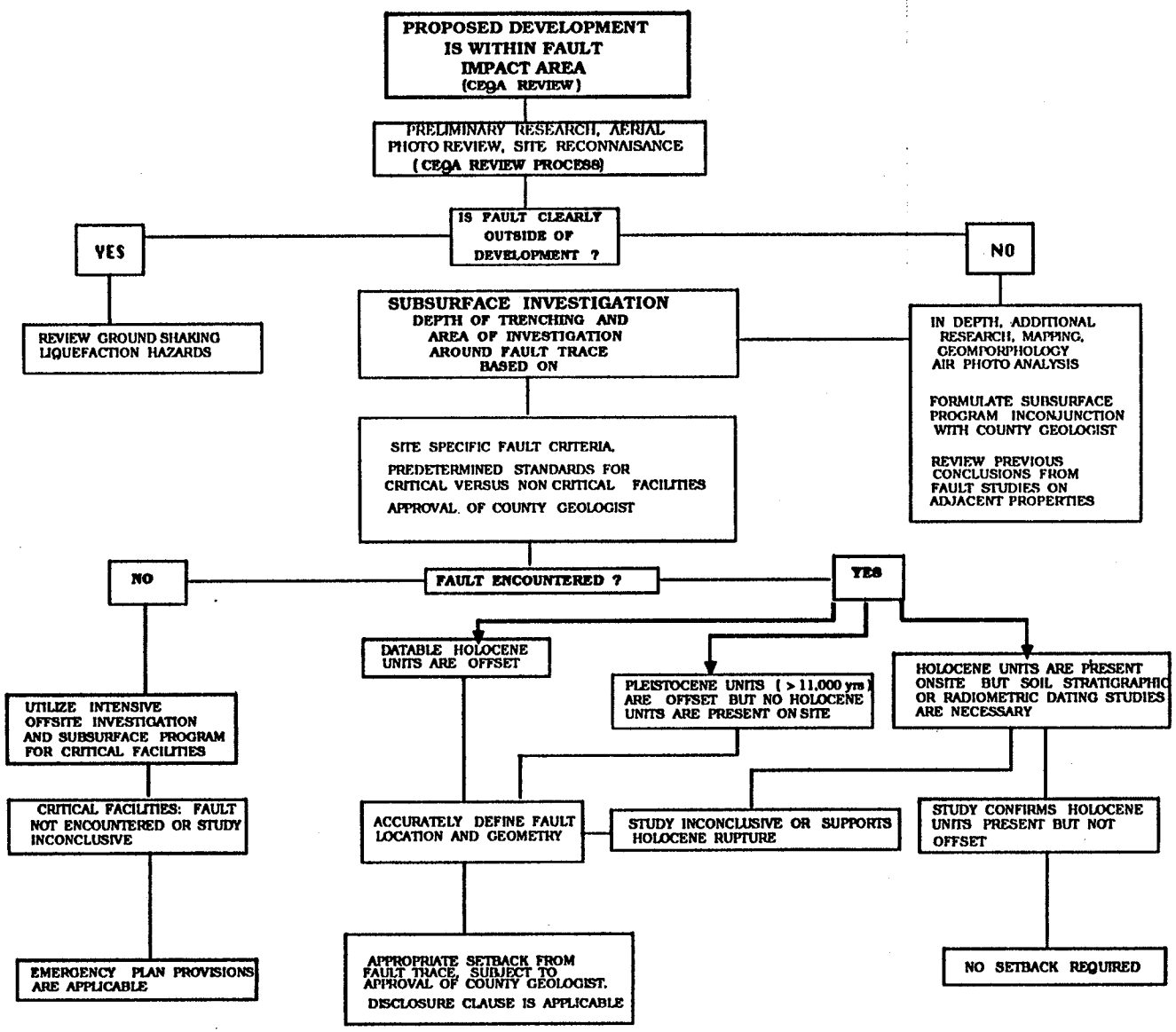


Figure 5.5: Geotechnical model for investigating active faults.

stringent investigations, as recommended in the 1975 Seismic Safety Element. In practice, large subdivisions and many other types of critical facilities are also subject to stringent investigation (Art Keene, 1989; personal communication). County guidelines for necessitating "special fault investigations" for specific types of critical facilities need to be developed to reinforce project review by the Department of Public Works.

Setting back a building from an active fault is a useful component of a seismic safety program. The setback distance can depend on the type of construction proposed. For example: "high-risk facilities" such as chemical plants, manufacturing plants utilizing volatile or explosive materials, or certain other facilities defined in Chapter 4, may need extraordinary setback distances away from an active fault. Figure 5.6 shows an example of active fault setback distances dictated in Portola Valley, California that depend on building type, occupancy, and quality of subsurface information. Criteria for such setback decisions can be either predetermined or at the discretion of a responsible County agency based on guidelines that consider risk to public safety as variable (Figure 5.6). Figure 5.6 shows an example for a strike-slip fault. Fault setback zones should also be consistent with the type of fault i.e, thrust versus strike slip.

Review of Selected Other California Fault Hazard Programs

A Riverside County Fault Safety Program designates County Fault Hazard Zones (Spangle, 1988). The faults recognized within the safety program are based on a list of active and potentially active faults located within a technical report on fault hazards in the General Plan. The special study fault zones are shown on a small scale County Seismic Hazards Map included in the General Plan; however, larger scale maps also show fault rupture, ground shaking, liquefaction, and slope instability hazards for review and planning purposes. Seismic-Geologic Community Area Maps of identified hazardous unincorporated areas of Riverside County (1:800 feet) implement APSSZ and Riverside County special studies requirements inside these zones. A special investigation requirement during fault studies includes the supervision of fault trench investigations by a County geologist. To ensure that site conditions are recorded as found, Environmental Report Sheets identifying existing geotechnical reports are kept on file with the Planning Department and logged into records of the Building and Safety Department.

San Bernardino County administers a fault rupture hazard program through the San Bernardino County Development Code. The program is implemented as a Safety Geologic (SG) Overlay and enforces the Alquist-Priolo Special Studies Zones Act. The definition of an active fault is "those delineated on the Alquist-Priolo Special Studies Zone Maps or on maps within the County General Plan". Special development standards include the following, as stated in the San Bernardino Development Code:

- "Development of all structures used for human occupancy shall take place fifty (50) feet or further from any active earthquake fault trace".

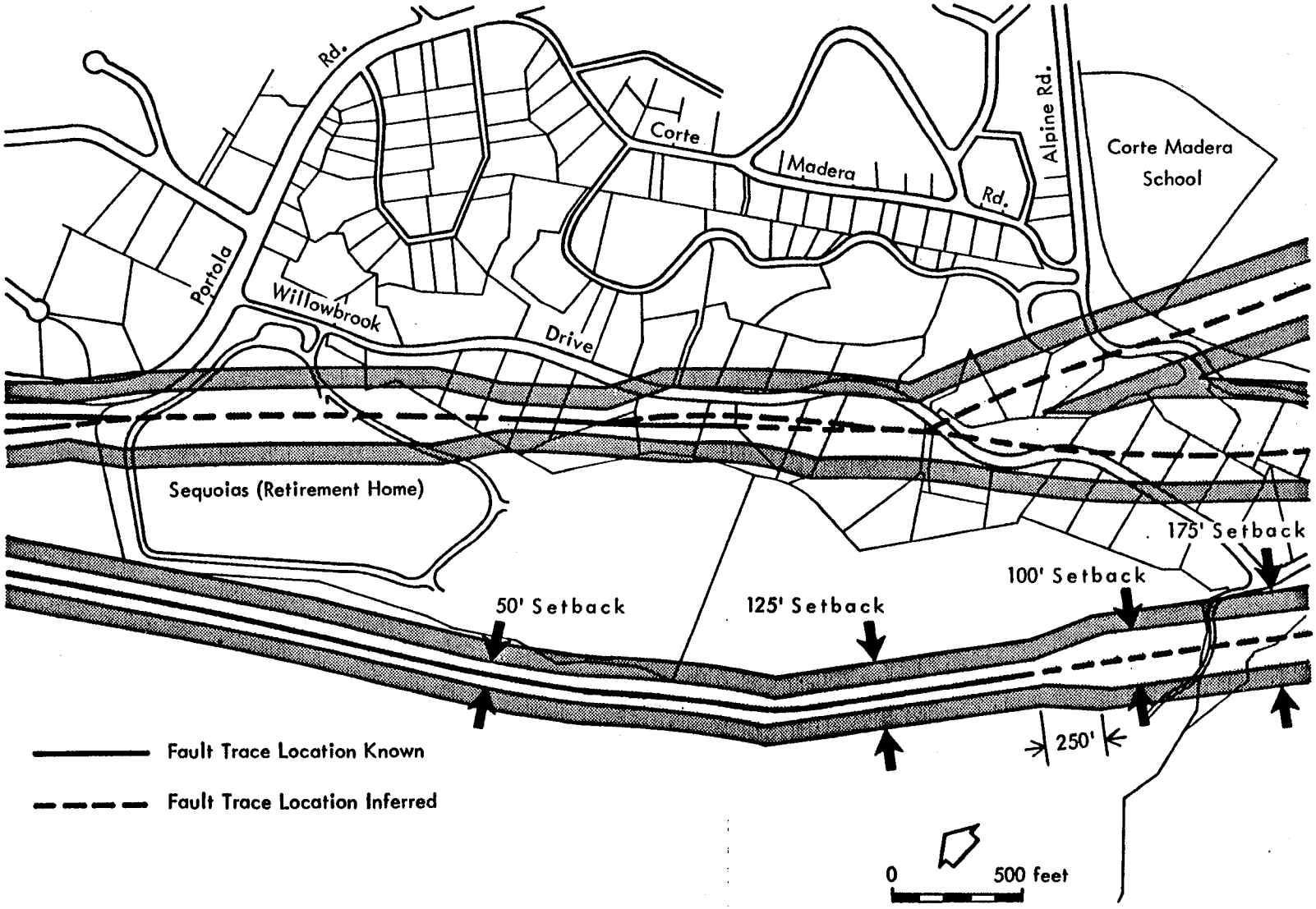


Figure 5.6: An example of varied building set backs for active faults in Portola Valley, California.

Required: 50-ft. set back for new building construction;
125-ft. set back for structures housing more than a single family;
100-ft. set back for single family residences when fault location is uncertain;
175-ft. set back for structures with larger occupancies (after Spangle, 1987).

- "Development of structures used for critical facilities shall take place one hundred and fifty feet (150) or further from any active fault traces as indicated within the County General Plan".

The citizens of San Mateo and Santa Clara Counties, recognizing the multijurisdictional character of hazards and development, have jointly created a program for acquiring hazardous land areas. The two Counties formed the Mid-Peninsula Regional Open Space District (MROSD) to lessen the economic burden of hazardous land acquisition that, in many cases, precludes this option for a single jurisdiction. The MROSD finances the purchase and management of open space lands in hazardous areas. The financing operates as an assessment district using property tax revenues, grants, and donations. Purchases to date have resulted in the acquisition of significant portions of land along the San Andreas fault.

Conclusions

- Active and potentially active fault locations shown in Plate 1 provide the framework for a County fault rupture hazard program, which could operate similar to that of Riverside County, in that certain faults may qualify for large scale, detailed fault mapping. Plate 1 may be used to help create awareness among developers proposing projects in the vicinity of active and potentially active faults, in addition to those within Alquist-Priolo Special Study Zones.

- Current use of detailed California Division of Mines and Geology Fault Maps should continue to be used during project review by the Department of Public Works. County policies and regulations, however, should not be locked into any particular map that does not have provisions for regular review and updating.

- The filing and recording aspects of fault investigations under the Riverside Fault Hazard Program might be a vehicle for amending hazard map data during future Safety Element revisions. Projects proposed on properties adjacent to areas already investigated could use this information, and thus facilitate efficiency of the environmental review. Effective, efficient, low cost review may serve as an incentive to the developer to adequately perform safety measures, thereby also reducing the need for additional inspections.

- Minimum requirements for setbacks, as illustrated in Figure 5.6 and defined in the San Bernardino Development Code are successful methods of implementing minimum standards for different types of development. Los Angeles County could benefit from such standards, especially if used in conjunction with County review of high-risk and other critical facilities.

- The scope of the current County fault hazard management efforts should continue to extend to all development for human occupancy, regardless of development size. All critical facilities should have a stringent review,

investigation, setback system, and performance standards requiring incorporation of hazard mitigation actions.

- The flow chart presented in Figure 5.5 illustrates a proper sequence for an active fault investigation in the County, and emphasizes the inferred "active" nature of a fault if an age cannot be determined.

- A district, similar to the MROSD, could acquire lands along the San Andreas, San Gabriel, Santa Susana, or Cucamonga faults, where Los Angeles County shares a boundary with an adjacent County and concerns about development along active fault segments.

- Lands in active fault zones could be acquired by State and Federal agencies to protect open space lands (Spangle, 1989; personal communication).

- Open space protection, either through zoning or property acquisition, along extremely active faults such as the San Andreas reduces the potential exposure of the public to fault rupture hazards and severe, near field strong motion.

- "Development of structures used for critical facilities shall take place one hundred and fifty feet (150) or further from any active fault traces as indicated within the County General Plan".

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SECTION 5.1.3

LIQUEFACTION AND GROUND FAILURE

Project Review

The 1975 Seismic Safety Element contained a high liquefaction potential seismic zone. High liquefaction areas were defined on the basis of shallow ground water (less than 30 feet) and proximity to an active fault (susceptible to the highest ground response). Mandatory seismic, geologic, and soils reports for the following types of development within high liquefaction potential areas were recommended (Keene, 1986):

- High cost facilities;
- high occupancy facilities;
- structures in which failures may be catastrophic; and
- subdivisions, defined as land divisions creating five or more parcels.

Linked to the high liquefaction area outlined on the seismic zone map within the 1975 Element, the purpose of the program was to identify regional areas where site-specific liquefaction studies would be necessary. For general land planning purposes this was accomplished, yet for practical purposes, the lack of map precision prevented the high liquefaction area from playing an important role in implementation. The policy emphasis of the previous element, however, did set the tone of several liquefaction-related regulations and guidelines within the County Building Code. This is especially evident in the exemption of single-family residences from special review requirements.

A map of liquefiable and potentially liquefiable areas is presented in Plate 4. As stated in Chapter 3, the map is limited by the current data base and by the fact that some localized areas of potential liquefaction cannot be depicted at such a small scale. However, Plate 4 shows cultural features presented at a convenient, practical scale, and represents the best regional information for alluvial basin areas where liquefaction could be an environmental constraint. Developments proposed in alluvial basin areas currently have no standard map to adequately assess possible constraints on proposed development from liquefaction hazards (Sudduth, 1989; personal communication).

As was stated in the discussion of fault rupture, the County should not be tied to a particular set of maps to implement future policies and regulations. Use of Plate 4 during the early impact analysis stage (CEQA), however, could prove beneficial if kept current. To remain a viable land planning tool, the map should be regularly reviewed and updated. Preparation of more detailed, larger scale mapping should be encouraged. Currently, Plate 4 does present a mechanism for promoting interdepartmental coordination. Such coordination is fundamental

during the initial CEQA review of potential liquefaction problems by the Regional Planning and Public Works Departments.

Liquefaction Investigation

Soils investigations are required for development proposals within alluvial basin areas. Prior to the 1989 County Building Code, private geotechnical consultants were given a great deal of discretion in determining an "adequate number and depth of borings" in soils investigations in alluvial basins. The lack of a performance standard in the County Building Code for the depth of liquefaction prohibited the County from confidently determining whether an area of potential liquefaction was being adequately investigated. Although consultants are still given a degree of discretion in determining site suitability, recent County Building Code revisions have defined a 35-foot ground water depth as indicative of liquefaction susceptibility. This depth of ground water definition establishes a performance standard by which the County can now require minimum 35-feet borehole explorations to examine the existence of on-site liquefaction potential. The Department of Public Works had already considered, as an internal guideline, the potential for liquefaction to be at ground water depths of 30 feet or less. The inclusion of a ground water depth in the building code makes the liquefaction evaluation and investigation review more enforceable.

The 35-foot depth borehole requirement in the County Building Code is a minimum requirement. A 50-foot borehole would be a more conservative choice for a mandatory liquefaction investigation. Based on historical data on liquefaction failures during the 1971 San Fernando earthquake and liquefaction studies in California and Japan (Earthquake-Induced Failures; Chapter 3), the range of ground water depths for liquefaction are as follows:

- Liquefiable (L) (0 to 30 feet); and
- Potentially Liquefiable (PL) (30 to 50 feet).

A common, but voluntary method of investigation in alluvial basin areas already utilized by some consultants in Los Angeles County is to drill at least one 50-foot borehole to preclude the potential for liquefaction. All consultants do not follow such procedures, which makes the designation of any mandatory borehole depth a significant improvement over current standards. An example of a model liquefaction investigation methodology supported by the National Earthquake Reduction Program is presented in Figure 5.7.

Although the County Building Code revision has not yet been adopted, the 35 foot requirement proposed in the 1989 County Building Code supports a reasonable degree of safety for most development. For certain site investigations, boreholes may need to be mandatory to depths greater than 35 feet to investigate the potential for liquefaction. Stringent investigations would be most logically jusifiable where critical facilities or other buildings that pose a threat to health and safety, are proposed in liquefaction prone areas (Figure 5.7).

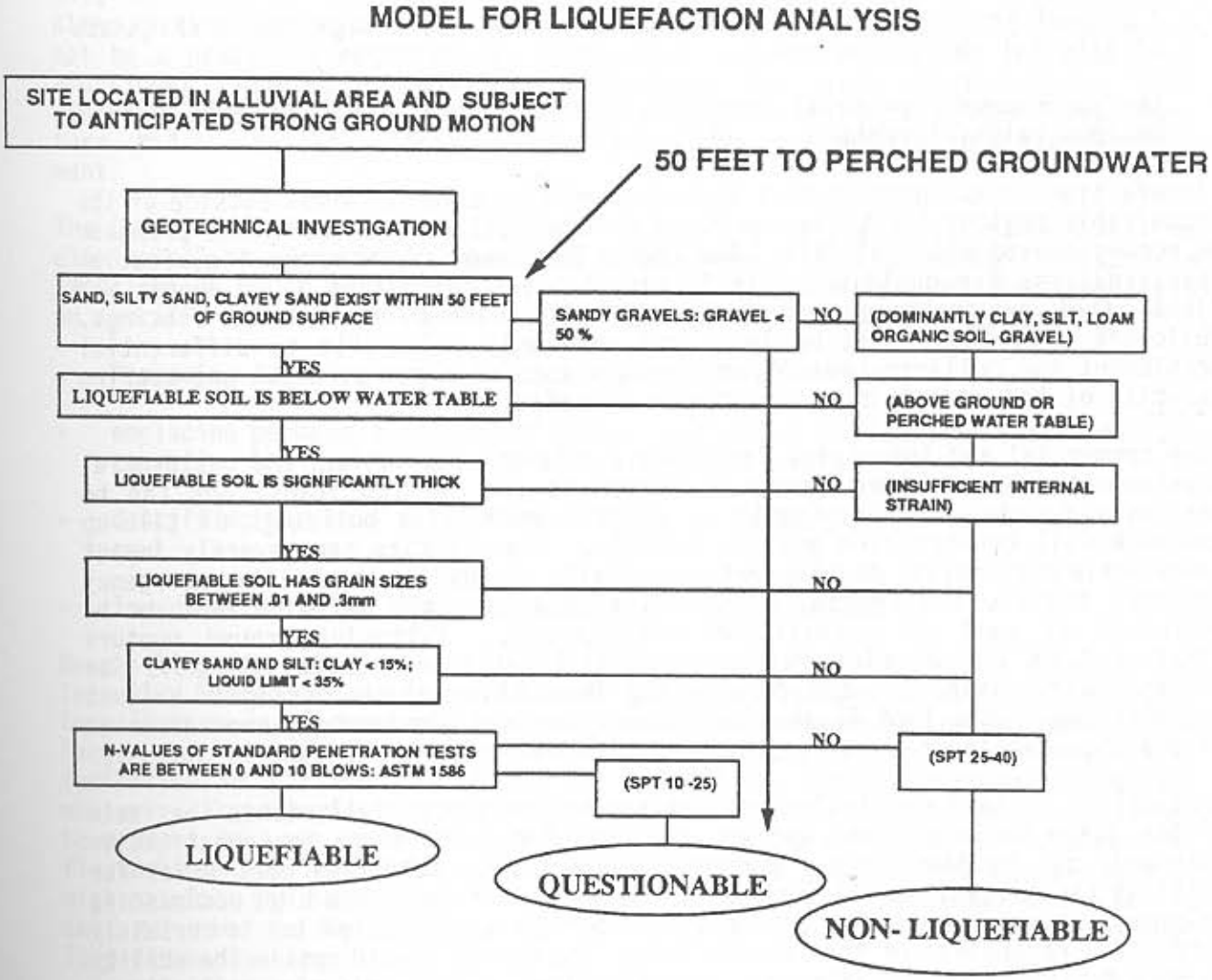

Figure 5.7: Model for liquefaction analysis; a flowchart showing guidelines for evaluating a site for liquefaction potential based on lessons learned from previous earthquakes.

Hays (1988) - Review of Information on Seismic Hazards Needed for the Earthquake-Resistant Design of Lifeline Systems in the United States; U.S Geological Survey, Open File Report ICSSCTR-10.

EERI (1986) - Lessons Learned from Earthquakes: Earthquake Engineering Research Institute Publication No. 86-02

County guidelines list two primary conditions that must exist to mandate a liquefaction investigation:

- A project is proposed within an alluvial basin or on a significant thickness of alluvial materials; and

- the development proposal involves buildings with loads in excess of a maximum weight threshold.

Liquefaction investigations must be enforceable in alluvial areas outside of the liquefiable regions identified on Plate 4, especially if a structure is proposed on nonengineered alluvial fill. The County Building Code requires liquefaction investigations for buildings with footing loads in excess of 2,000 pounds per lineal foot on continuous footings or 50,000 pounds on isolated footings. Buildings with these footing loads are extremely vulnerable to differential settlement and collapse, resulting from the loss of shear strength and bearing capacity of the underlying soils during liquefaction.

Many commercial and industrial facilities, critical facilities, and residential development may not meet County requirements for footing loads, but can be seriously damaged by liquefaction. Certain commercial buildings of tilt-up concrete wall construction are one example. Liquefaction can severely impact large scale residential development, especially evacuation capability, emergency response ingress and egress, and utility services, all of which need to be addressed as part of subdivision requirements. Extensive ground rupture attributed to liquefaction failures and fill settlement during the 1971 San Fernando Earthquake, and the devastating destruction of the Turnagain Heights neighborhood in the 1964 Alaskan Earthquake, support the need for consideration of the liquefaction hazard in subdivision review.

Critical or "vital" facilities, as defined by the State, fall within the realm of the State Building Code and are reviewed for conformance to investigation standards set by the State. However, where County authority does exist for critical facilities, and failure may be catastrophic, or where high occupancies or dependent populations are involved, a liquefaction investigation is certainly warranted, regardless of the footing load. The County should retain the ability to make decisions for liquefaction investigations on the basis of sensitivity of the project or size of the subdivision, as originally recommended in the 1975 County Safety Element.

Liquefaction Mitigation

Ideally, liquefaction mitigation could be required if shallow ground water is encountered during a soils investigation, allowing no provisions for exemption. However, in practical application, such an approach is not that simple. Sudduth (1986) indicates that the probability of total structural failure of a single-residence within an area of liquefaction (0 to 30 feet) is less than one percent, while the cost to mitigate the hazard for a single-family dwelling can be very expensive (roughly 5 to 15 percent of the house's value). County regulations, therefore, continue to stress the safety of the occupants and not

the foundational stability of individual residences due to the poor/cost benefit ratio. Builders of single-family homes may voluntarily agree to using post-tensioned or reinforced slabs at the recommendation of a consultant. Although the foundational and structural stability of an individual residence may not be a practical requirement, subdivision regulations may be the source of additional liquefaction mitigation standards for large subdivisions. Such standards would necessarily focus on protecting the utility lifeline infrastructure, and the health, safety, and welfare of the residents within the development.

The County Building Code states that "the potential for liquefaction shall be eliminated" in cases where nonexempt development is confirmed to lie within a liquefaction prone area. The Building Code, as a rule however, does not focus on specific mitigation measures or methodologies. Mitigation may include:

- Replacing existing soil with nonliquefiable material;
- emplacing permeable columns of gravel to furnish a release mechanism for the causative buildup in water pressure during liquefaction;
- densifying the soil using several types of dynamic or vibratory compaction; or
- lowering the water table by installing dewatering wells.

Deep pilings are also an option, if anchored into firm subsurface material and laterally braced for horizontal loads. Piles may be appropriate for facilities located in or near port areas while more elaborate methods may be appropriate for large subdivisions. For critical facilities, especially high-risk and essential facilities in particular, it may be prudent to apply stringent mitigation measures. For example, monitoring ground water levels with observation wells may be prudent in some cases where ground water levels are known or suspected of fluctuating (Tinsley, 1985). Land development and use practices or periods of high rainfall can cause local increases and/or potential for higher water levels that may need to be addressed, either through the building code or through long-range planning.

Review of Other California Liquefaction Hazard Programs

The Santa Clara County Baylands Plan identifies risk zones that describe differential settlement, lateral spreading, and liquefaction. The planning area was divided into risk overlay zones based on the potential for ground settlement and ground failure. The risk zones are then assigned appropriate land and building uses in the General Plan. The Plan recommends that a soils report show that any proposed development site within a risk zone must demonstrate that the zone is not at higher risk than shown on the risk zone map. Based on this recommendation, Santa Clara County has adopted an ordinance requiring geologic reports and site investigations for any subdivision on or adjacent to a potentially hazardous area identified on an official hazard (Risk Zone) Map (Spangle, et al., 1988).

To reduce liability, the County of Santa Clara also requires a signed "assumption of risk" statement from property owners who knowingly develop in areas identified as hazardous, including liquefaction prone areas. While reducing liability, the measure also promotes public knowledge through disclosure. The County of Riverside has a similar provision for disclosure. In actuality, all California jurisdictions are subject to requirements of the Real Estate Commissioner prescribing certification for on-site geologic and flood hazards. In Los Angeles County, disclosure statements for hazardous areas (Seismic Geologic and Flood) are administered through the subdivision code. However, interviews with the Department of Public Works indicates that disclosure information has not been readily available to all County agencies (Sudduth, 1987 personal communication). Such documentation could be an invaluable project review safety hazard information source. There are no provisions for reducing liability in the County disclosure program.

Conclusions

- Fault rupture and liquefaction represent the greatest localized threat to buildings and infrastructure, especially roads, underground lifelines, port facilities, and flood control protection. Strong ground motion represents the most widespread threat to these same community elements.

- To assure adequate enforcement of liquefaction regulations, detailed liquefaction site evaluation is warranted for certain industrial and commercial development (not specifically covered by foundation load requirements of the County Building Code), and for single-family residential structures more than 2-stories in height when part of land divisions creating five or more parcels.

- Critical facilities should be investigated for liquefaction potential when proposed in potentially liquefiable areas (PL), and in alluvial areas where saturation of alluvial materials may occur within 50 feet of the surface.

- Liquefaction mitigation alternatives include post-tensioned or reinforced slabs; replacement of existing soil with nonliquefiable material; densification of earth materials; installation of dewatering wells; and embedment of deep piles through liquefaction zones into stable bedrock.

- Subdivision regulations should be utilized to mitigate liquefaction hazards that threaten infrastructure in large subdivisions.

SECTION 5.2

GEOLOGIC HAZARDS

SECTION 5.2.1

LANDSLIDE AND SLOPE INSTABILITY

Project Review

To obtain an accurate interpretation of site geology during initial CEQA review, County geologists presently use USGS, CDMG or existing County geologic maps. Good quality landslide mapping coverage is currently available for only about half the County. As was noted in Chapter 3, the CDMG Landslide Hazard Identification Program is beginning to close this data gap. These maps are especially relevant because they show four principal data sets useful in the Regional Planning and Public Works review:

- Geologic mapping at 1:24,000;
- landslide inventory at 1:24,000;
- bedrock or deep-seated landslide susceptibility; and
- debris flow susceptibility.

Long-term planning options for areas having severe topographic and slope instability constraints consist of developing such areas at very low densities or utilizing them as open space. However, it is emphasized that land use allocation is not the only option. The presence of unstable slopes prone to landsliding does not preclude development, because sophisticated geotechnical engineering methods allow the development of most unstable slopes. In practice, economic constraints play an important role in controlling development in extremely rugged and unstable terrain.

Hillside and Landslide Investigation

The County should continue to encourage the requirement that all hillside and landslide investigations and grading monitoring and inspection be performed by State certified engineering geologists and geotechnical engineers (see Glossary). Hillside management guidelines are outlined in the General Plan, and enforced on slopes greater than 25 percent grade (14 degrees). Section 2907.1 of the 1985 County Building Code states that for slopes greater than 3:1 (18 degrees) all "adverse slope conditions" must be considered in the landslide investigation, including the potential for rockfalls, mudflows, and other shallow failures. The section also requires that the investigation consider the type of material and height of slope so that proper building setbacks can be determined. Among other applications, such provisions guard against rockfall hazards, a serious earthquake risk when development is located in steep, rugged terrain. The Building Code and General Plan highlight the importance of stringent site

investigation as a first step in safeguarding against future economic losses and threats to public safety.

Table 3.7 (Earthquake-Induced Slope Instability), and Table 3.8 (Rain-Induced Slope Instability) define potential shallow failure styles and identify slope angles, geologic materials, and general geographic areas vulnerable to impact. The tables suggest that careful scrutiny of development for human habitation may be warranted when proposed at the base of the following steep slopes:

- > 18 degrees: rain-induced failures; or
- > 27 degrees: earthquake-induced rockfalls.

Adequate geologic mapping and mitigation measures for such development are essential. The County requires that engineering geologic reports follow guidelines stated in Chapter 70 of the County Building Code, and that they be more stringent than the content corresponding to Chapter 70 presented in the UBC.

Landslide Mitigation

Chapter 3 reviewed a number of accepted grading practices currently required by the County. Current grading regulations are effective in mitigating natural hazards by providing a means for channeling technical information about site hazards into the development review process. Current grading and review requirements also promote identification and correction for additional site hazards discovered during grading.

County grading and design regulations are complimented by subdivision requirements that require not only mitigation of site hazards prior to development, but also:

- Standards for safeguarding the integrity of the development following construction; and
- plans for avoiding the exacerbation of potential problems caused by continued development, both on and off site.

Enforcement of grading and design practices are the key to any successful hillside management program. The lowest cost form of enforcement is voluntary compliance which reduces or avoids administrative costs. The County Building Code differs enough from the version presented in Chapter 70 of the IBCO versions in that substantial improvements in enforcement could be made merely by increased visibility of County standards. Toward that end, the County could expand and improve the availability of interpretive informational handouts to prospective developers and geotechnical consultants. An additional action would involve the development of a slope mitigation manual. The Department of Public Works is preparing a "Land Development Procedure Manual" that defines analytical procedures for use by the public. The manual will define acceptable or preferable methods for design, investigation, grading, and compaction testing; and outline procedures for site inspection and laboratory testing. This manual

could be a device to publicize characteristic provisions of the County Building Code.

Although better visibility may promote voluntary compliance, the need for stringent and diligent enforcement cannot be understated, especially with respect to illegal grading activity. Illegal grading results in poorly designed, landslide prone hillside development.

The following discussion reviews selected performance and design standards from the County Building Code, emphasizing earthquake slope stability. An important slope stability performance criteria is the "Factor of Safety". The Factor-of-Safety is the ratio of the resisting force to the driving force, so that values greater than 1.0 represent various degrees of stability. Values less than 1.0 define instability. Not considering earthquake motions (under static conditions), the Department of Public Works Safety Policy requires a minimum Factor of Safety of 1.5 against shear failure. Pseudostatic analysis is used when considering earthquake vibrations. A standard approach to seismic design of hillside grading, that is incorporated into the Building Code, is an allowable Factor of Safety of 1.1. Additional County standards for slope stability analyses are described as follows:

1. Separate calculations are performed for static and seismic conditions.

2. The pseudostatic slope stability analysis is the minimum seismic analysis accepted for design, which means that more sophisticated designs may be acceptable.

3. Conventional static methods of slope stability, based upon principles of mechanics, are used to analyze the stability of slopes under both static and pseudostatic loads.

4. The analysis includes the effect of soil weight and seepage or pore pressure, where applicable to the analysis (water saturated condition for fill).

5. Pseudostatic loads include the effect of static loads combined with a horizontal inertial force acting out of the slope and through the center of gravity of the potential sliding mass.

6. A minimum pseudostatic horizontal inertial force equal to 0.15 times the total weight of the potential sliding mass is accepted. This value is increased where the proximity to active faults and the subsoil or geologic site conditions dictate, but is left to the discretion of the private consultant(s).

7. Potential failure surfaces are composed of circles, planes or other shapes considered more appropriate to the soil and geologic site conditions.

8. The critical potential failure surface having the lowest factor of safety is considered adequate for the static case. This static surface may be assumed critical for the pseudostatic case.

9. Soil properties including unit weight and strength parameters (cohesion and friction angle) are based on conventional field and laboratory tests. The appropriate shear tests used to derive the strength characteristics, as well as the inference of present and anticipated slope conditions, are left to the discretion of the private consultant.

The above represent minimum standards for slope stability analyses for all cut and fill slopes steeper than 2:1, unless approved by the County Building official. These guidelines are not required for cut and fill slopes less than or equal to 2:1. They are largely adequate, except that cut-and-fill slopes steeper than 2:1 may require slough walls or alternative structural methods for the following reasons:

- To prevent loose earth material or debris from falling downslope and blocking roads or impacting development; and

- to prevent wedges of earth material or rock from falling down and blocking roads or damaging development.

It is currently the responsibility of the geotechnical consultant to demonstrate to the Department of Public Works that steeper cut slopes are stable. The County Building Code, however, prohibits any fill slope steeper than 2:1.

Potential Improvements in Slope Design

In the Man and Development-Induced Landsliding Section in Chapter 3, several types of slope instability problems were addressed. None of the potential problems adequately addressed seismic stability of man-made slopes and fills. Research into the effect that intense ground vibration might have on cut-and-fill developments is an ongoing effort. Engineered hillside fills have been subjected to strong earthquake motions during several recent earthquakes. The 1989 Bay Area Earthquake, in particular, may contribute useful information on hillside cut-and-fill operations, particularly the response of hillside projects designed to older codes, and, significantly, those designed to more recent stringent grading codes. What is known, is that during the 1989 earthquake, the most recently designed cut-and-fill operations appeared to perform well; however, an entire block of houses in the Inner Sunset District of San Francisco slipped downslope during, and subsequent to, the event. The following seismic design issues of hillside development remain unclear and should be the focus of further investigation:

1. Engineering procedures for evaluating the seismic ground motion of near-field local earthquakes;

2. engineering procedures for evaluating stresses within seismically loaded slopes;

3. the effect of cut-and-fill topography on ground motion patterns;

4. the impact of moisture level on response of fills to earthquake loading;

5. the earthquake performance of hillsides distressed by improper grading;

6. better definition of procedures for evaluating the expected ground water conditions during a "design earthquake" (engineering model), particularly shallow perched ground water tables;

7. better definition of probabilistic seismic slope stability analyses consistent with state-of-the-art engineering methods for defining seismic loading; and

8. potential application of Newmarkian Slope Stability Analyses to rockfalls, using slope angles, peak acceleration, and duration of shaking.

The summary above suggests that ongoing research is needed on proper slope design. On an interim basis, the minimum County standards are adequate for most development, particularly the 1.1 pseudostatic and 1.5 static seismic slope design standards. Another seismic slope design method, termed the permanent seismic deformation method by ACSE, Los Angeles County Section (1988) may provide a more realistic degree of analysis in instances where a project warrants such measures, such as in the construction of critical facilities. Such innovative methods should be addressed in the County's proposed procedure manual.

Potential Improvements in Hillside Management

The Development-Induced Landslide Section (Chapter 3) highlighted several examples where, based on historical precedent, hillside development suffered significant damage. To correct a large number of these problems, stringent hillside development measures might be adopted either in Chapter 70 or as provisions of other regulations. The following is a summary of possible approaches that should be considered in comprehensive hillside management approach:

- Conservative estimates of worst-case ground water levels in a development, including the potential effects of high rainfall, landscape irrigation, and runoff from adjacent future development;

- special conditions for development involving deep-seated, landslide complexes, including slope monitoring, either through strategically placed perched water models or slope indicators;

- incentives/disincentives for ensuring proper maintenance and regulation of artificial recharge such as landscape irrigation, septic tank density, and percolation from natural rainfall; and

- contingency planning for preventative dewatering, where it is shown to be feasible.

Review of Other California Landslide Management Programs

The regulation of development in landslide areas is a relatively common landslide management strategy, that varies somewhat depending on the long-term objectives of the local government. For example, special development regulations in the City of Portola Valley limit the number of dwellings in an area of potential sliding and encourage cluster development in nonhazardous areas (Erley and Kockelmen, 1984). Their specific reference to prohibiting roads, houses, utilities, and water tanks in landslide areas is an effective program on a city scale, but would probably not work for all of Los Angeles County.

The hillside management guidelines in the General Plan (1980) use slope angles to determine the density of development on any hillslope and advocate acceptable slope mitigation techniques. The County of San Bernardino has adopted a zoning ordinance to regulate development on active (undefined) slides, and allows for periodic amendments and updating of the official map with new landslide information.

In an approach similar to the County of Los Angeles, the City of San Diego assumes all slopes are unstable. However, a hillside overlay ordinance enforces strict hillslope standards. A simple, well-illustrated information manual is distributed to promote voluntary compliance, and covers a wide range of topics from hillslope tract design to preservation of trees and natural outcrops of rocks. More pertinent to landslide mitigation are the following:

- The size of the fill slope area to be utilized for landscaping is strictly regulated to prevent excessive watering;
- tract design for housing incorporates cluster development or low-density development depending on the specific constraints of the hillsides involved;
- road cuts are required to weave around rather than cut through topography, thus limiting large road cut faces; and
- acceptable foundation designs are promoted.

As an informational tool, the ordinance is a vehicle for disseminating the objectives of the City of San Diego to the developer. The County also possesses a similar hillside manual stating the goals of the General Plan. Such informational documents need to be readily accessible to the public.

Landslide Hazard Zoning

Under the authority of the California Public Resources Code (Division 17, commencing with Section 26500), the State can authorize the formation of Geologic Hazard Abatement Districts (GHADs). The formation of such a district requires development of a plan of control that specifies the nature and extent of the hazard; and sets forth prevention, mitigation, and other hazard reduction strategies. GHADs, acting as independent political subdivisions of the State, administered at the local level, can also be used to mitigate other natural

"movements" of the land (California Public Resources Code, Section 26570-26581). Districts are subject to local approval, as a means of financing risk-reduction measures. Geologic hazard abatement districts in California function as special assessment districts using tax revenue from affected residents.

A disadvantage of any assessment district is that, although, it promotes cooperation and significantly reduces litigation, the use of a district does not replace litigation as a means of compensation (Brown and Kockleman, 1983; California Public Resources Code Section 26574(a); West Supp. 1986). Assessment may, in some cases, facilitate litigation because the district is an organized entity and more easily targeted as a financial source.

Experience with GHADs by other California jurisdictions shows mixed results. One effective application of the act in southern California is within the Abalone Cove landslide complex of Rancho Palos Verdes. The Portuguese Bend stabilization is being funded by the City of Rancho Palos Verdes through special tax assessments, but is technically not the same methodology as that covered under the State legislation.

The Mt. Washington area, in the City of Los Angeles experienced a large landslide that destroyed six homes, and threatened five others. However, the affected residents could not convince the other residents living in the vicinity that the landslide could eventually affect their homes, as well. The majority of residents did not want to pay a special assessment fee to mitigate the landslide. The following summarizes the features of a geologic hazard abatement district, the steps involved in forming districts, the reasons for success and failure, and selected California experiences.

- **Features of a geologic hazard abatement district:**

  - Provides for funding to afford repairs and corrective actions.
  - Allows tax credits for those assessed.
  - Provides property tax credits for those impacted by a hazard.
  - Prepares a "Plan of Control" to allow proactive and coordinated response.

- **Steps in forming a geologic hazard abatement district:**

  - A geologic hazard is determined to be present.
  - The Plan of Control is prepared.
  - Minimum cost could be $100,000, which must be raised by the community.
  - Plan of control completed and distributed to all affected residents.
  - Assessment fees apportioned on the basis of calculated damage potential.
  - Vote by community on establishment of GHAD (need 51 percent of those affected).
  - Imposition or rejection of the plan of control.

- **Greatest threat to establishment of district:**

  - "This is not my problem!", i.e., disputes over who should be in a district.

- **Reasons for effective implementation of the assessment district in the Abalone Cove area:**

  - Large number of affected residents.
  - Large number of residents with little current damage, but large implicit risk.
  - Good communication and a cohesive neighborhood.

- **Reasons for failure of GHAD at Mt. Washington:**

  - Large number of potential but not obvious problems.
  - Small relative number of severely damaged homes.
  - Large number of unaffected and uninformed residents.
  - High cost of abatement relative to the perceived need.
  - Large number of moderately damaged structures which would have high fees.
  - Poor neighborhood cohesiveness. "This is not my problem, and I don't want to pay for somebody else's".

- **Northern California experiences:**

  - Abatement district concept used both before and after development.
  - Certain city regulations have interfered with specific mitigation actions.
  - Funding sources provided for repair of landslides as required.
  - Cities have acted as the repository of the monies, but homeowner association has made the decisions.
  - Cities have been responsible for needed repairs.
  - A problem of implementation has been determining how much money might be needed.
  - There are at least two known effective applications of a GHAD.

- **The San Juan Capistrano experience:**

  - Similar predevelopment ideas as in northern California.
  - Homeowners Association became the monetary repository.
  - The consultant determined that $1,000,000 would be needed over ten years.
  - Developer left initial $500,000 account, refunded over ten years, or as used.
  - Homeowners assessed a fee for a "slope stabilization fund" on their tax statements. Plan was successful due to developer contribution, and City cooperation.

The use of GHAD's is not yet widespread among the California jurisdictions. No landslide hazard abatement districts are located within unincorporated areas of Los Angeles County. Los Angeles County does, however, use assessment approaches. The County has in the past required assessment districts to finance the cost of repairs or mitigation, funded in part by property owners and common users of landslide-damaged public roads and utilities.

Unlike insurance, which helps only after landslides have occurred, assessment districts can promote regular maintenance, monitoring, and preventative actions. This is clearly desirable in mitigating landslide, mud and debris flow potential

in areas vulnerable to debris basin/flood control facility dysfunction. It may also have applications in providing slope reinforcement along designated evacuation routes which could be blocked by rock falls or other shallow failures. Such work, which would only be applicable to relatively shallow failures, is currently hampered because many of the problem areas are outside of the road right-of-way.

GHADS and other forms of assessment districts may also facilitate proactive slope monitoring of landslide complexes, including ground water monitoring and slope maintenance, as well as designating open space areas to prevent excessive development density. Another use would be to fund dewatering wells and institute other alternative slope stabilization efforts. A comprehensive landslide mitigation plan could be extremely advantageous where development is occurring on large, deep-seated landslides, especially if development is occurring on small parcels unable to finance mitigation of an entire slide mass. Such a plan must have responsible parties identified to implement mitigation or monitoring measures.

Alternative Management Measures

Several options are at the County's disposal to reduce the economic, and potentially life-threatening impact of landslide reactivation. Tax credits, property acquisition or purchase of development rights, a landslide overlay zone, assessment district, or any combination of these measures, are potentially feasible landslide management alternatives (Wolfe, et al., 1986). They are summarized as follows:

- **Tax Credits**

  Reduces the property's tax liability as long as land is left undeveloped at a very low density. Tax credit programs take a variety of forms including current use value, differed use, or as a restrictive agreement. The method provides incentives to limit development, but high property values reduce the effectiveness of the program.

- **Property Acquisition**

  Landslide areas can be managed to protect public safety, while meeting other community objectives, such as providing open space for recreation or low intensity uses. Financing options open to the County include Federal or State grants, donations, or formation of a non-profit corporation to acquire open space.

- **Landslide Overlay**

  An ordinance could be tied to a landslide inventory or a graduated landslide risk zone (e.g., high, moderate, and low). Very accurate mapping would be required to institute such an option. Open space requirements, stringent construction standards, effective slope maintenance, vegetation with low

irrigation requirements, sewage disposal options which prevent slide lubrication or low density development are relevant measures that can be linked to a landslide overlay.

Wolfe et al. (1986) has documented that if existing inappropriate uses within designated areas continue unchecked, zone variances are more likely. However, they have also suggested that if tied to economic incentives or developer liability, that program compliance and implementation are more likely.

- **Assessment District**

  A plan can be formulated to appropriate funding for alternative landslide mitigation methods, preservation of open space, or application of density restrictions and financing for acquisition of landslide areas.

Conclusions

- General Plan standards should continue to be stringently enforced for new development.

- Voluntary compliance with County Building Code standards will be encouraged by the informational and procedural manual proposed by the Department of Public Works and should be supported.

- Periodic updating of existing landslide maps (including Plate 5), as practiced by the County of San Bernardino, could improve the geologic review process.

- Potentially feasible landslide management alternatives exist in tax credits, property acquisition or purchase of development rights, landslide or hillside overlay zoning, geologic hazard abatement districts, assessment districts, or combinations of these measures.

SECTION 5.3

FLOOD AND INUNDATION HAZARDS

SECTION 5.3.1

CLEAR WATER FLOOD, MUD FLOOD, AND MUD AND DEBRIS FLOW HAZARDS

Clear Water and Mud Floods

The Federal Emergency Management Agency (FEMA) mandates that before property in flood zones can be insured, local governments must designate a flood zone management plan with minimum flood line setbacks for new development. The County, through the Department of Public Works, implements its own program and ordinance for flood zone management of clear water floods similar to that discussed in Chapter 3 (Figure 3.17 - Flood and Inundation Hazards). Clear water flood maps are used by the County to assess the potential impact of flooding on new development. The maps generated and used by the Department of Public Works are based on the "capital flood", a flood that results from a rainfall event that has the probability of occurring once in 50 years. The "capital flood" level of protection is generally more conservative than the standards used by the Federal Emergency Management Agency (FEMA) or the U.S. Army Corps of Engineers, and any project taken over by Public Works for maintenance has to meet their standards (Sree Kumar, 1990 personal communication). Flood-prone areas are updated through in-house studies and reviews by the Federal Emergency Management Agency (FEMA) for the National Insurance Program.

The focus of clear water flood mapping in the County has been on major stream channels (Table 5.1). The Department of Public Works (DPW) recognizes that many hundreds of second order drainages remain unmapped and have significant potential for high flow/flood events. Where feasible, some of these drainages have been plotted on Plate 6. Flooding in these drainages and, even some areas just outside of the clear water flood plain, are subject to mud floods. Mud floods are essentially mud-saturated clear water floods.

FEMA mapping status presented in Table 5.1 is incomplete in some areas, especially on alluvial fan areas in the Antelope Valley. As emphasized in Chapter 3, drainage patterns and hydraulics on alluvial fans are complex (Dawdy, et al 1988). Future storms in the Antelope Valley may reveal deficiencies in currently accepted flood mapping criteria. Significant modifications may include reassessment of certain 500 year flood limits and the predicted extent and severity of 100 year flooding (Dawdy, et al., 1988). The uncertainty caused by either the possible modification of existing data or insufficient data on mud floods is significant. It suggests that proposals for future development on alluvial fans, and within or adjacent to unprotected or unmanaged drainages, should continue to be carefully reviewed and investigated on a case-by-case basis (Dawdy, et al., 1988).

Table 5.1: Status of Clear Water, Mud Flood, and Mud and Debris Flow Mapping Programs.

Ongoing studies; modification of existing data and new mapping

Class of Phenomenon	Event	Location		Covered by NFIP	Status of Hazard Mapping
FLOOD	Clear Water Floods	Floodplains	Drainage Channels and Alluvial Fans	Yes	Now Mapped
	Mud Floods				Not Now Mapped
LANDSLIDES	Mud Flows	Hillslopes		No	
	Debris Flows and Other Landslides				

Data insufficient

Mud and Debris Flows

Initial Review

Table 5.1 shows that mapping of debris-laden flows is incomplete in hillside areas. The Department of Public Works has mapped certain portions of the County for mudflows and debris-laden mudflows. However, mapping is unrefined, based only on visual assessment, and the maps are currently not used. More accurate County mudflow mapping is restricted to several major canyon mouths along a portion of the San Gabriel Mountains front between Azusa and Glendora. The maps are based on empirical formulas developed from historical data on flooding along the San Gabriel Mountains frontal zone. This particular mapping procedure remains provisional until the methodology is approved by FEMA. FEMA is also in the process of finalizing a computer program designed to delineate mud and debris flow hazards. If the program is completed and approved by its 1990 target data, the Department of Public Works may review it and consider using it to map hillside areas throughout the County. In the final analysis, the status of mudflow and debris flow hazard mapping in the County appears to be dependent on the completion of FEMA's computer program.

Debris flow mapping, in particular, debris flows associated with terrain showing evidence of topographic debris flow scars, is not adequate. The forthcoming FEMA methodology may be applicable to mapping debris flow hazards in Los Angeles County; however, if based solely on hydraulic factors, the mapping may not be appropriate for showing all types of debris flow susceptibility. Hydraulic factors are useful in delineating post-hillside fire mudflow/debris flow sequences because these types of failures are more dependent on runoff factors. In contrast, geologic factors are equally important if geomorphic evidence suggests a history of debris flow susceptibility. Chapter 3 "Landslide and Slope Instability Hazards" notes that a CDMG Landslide Hazard Identification Program has developed debris flow susceptibility maps based on geomorphic evidence of scars (i.e., hollows). For planning purposes, topographic evidence of debris flow hazards may be a means of identifying additional development constraints. Significantly, Table 5.1 shows that debris flow hazards are specifically exempt from National Flood Insurance Program protection.

Investigation and Disclosure

Hydraulic studies are especially applicable to certain 100 and 500 year flood limits on alluvial fans in the Antelope Valley. Hydraulic studies are also useful in delineating post-hillside fire mudflow/debris flow sequences, because as stated earlier, these types of failures are more dependent on runoff factors. Additional hydraulic investigations are at the discretion of the Department of Public Works. Any recommended design criteria occurring as a result of these studies must be approved by the Department of Public Works; and by the Federal Emergency Management Agency, if Federal monies are used in the design and construction of the project.

Investigations for mud and debris flow hazards must also consider differing failure styles. Estimates of sediment yield must be based on sound empirical

data for debris flows associated with post hillside fire run-off, or site specific mapping for debris flows originating within hollows. The design and effective operation of flood protection features, such as debris flow basins and storm drains, depends on this data.

The County Subdivision Code contains two key provisions that relate to the disclosure of information on flood, inundation, and geologic hazards revealed during a project investigation. If a project is exposed to a hazard, a "positive declaration" must be noted on each page of the final parcel map, in which case "building restriction rights" are waived to the County. Another provision requires delineation of flood or geologic hazards on property when a subdivision creates four or less parcel units (County Subdivision Code Section 21.44.330). As stated in the section concerning liquefaction, hazard disclosure statements have not played an important role in the Department of Public Works review process because these statements are generally unavailable (Sudduth, 1989 personal communication).

Flood Hazard Project Mitigation

Land development and mitigation requirements within flood-prone areas are largely determined through the County Zoning, Subdivision, and Building Codes. "Flood Protection Districts", as defined in County Planning and Zoning Code Sections 22.44.210 - 22.44.230, are areas designated by Public Works as subject to "substantial flood hazards" from clear water floods and mudflow events. Within these specific areas, as defined on County flood maps or revealed during investigations, the following two regulations pertain:

- New buildings or structures are prohibited; and
- nonconforming structures are not to be altered, improved, or reconstructed.

Exceptions to these regulations are structural accessories to buildings or structures that are proven to not impede flows, such as parking lots and flood control structures. Additional relevant County regulations include:

- Subdivision requirements for land exposed to flood and inundation hazards are applied to lot sizes less than 40 acres (21.40.320);
- any object capable of changing stream flow or catching debris, or unanchored structures, are prohibited from channels, streams, or arroyos (County Planning and Zoning Code Section 22.52.460);
- proposed development requiring a building or grading permit is prohibited from County designated floodways (defined in Ordinance No. 1214), unless it is proven that the project does not increase the flood hazard (County Planning and Zoning Code Section 22.52.410 and County Building Code Section 308); and

- approval of flood protection must conform to applicable National Flood Insurance flood plain regulations and construction requirements (County Building Code Section 308).

In accordance with Section 21.08.075 of the County Planning and Zoning Code, all or part of a tentative tract map may be disapproved if it is determined that the development is inadequately protected from a flood hazard. "Flood Protection Districts" impose stringent standards for new development and nonconforming structures in the paths of floods and flows. County Building Code flood hazard provisions, by law, must meet, at minimum, FEMA design, regulation, and construction standards. The Department of Public Works standards are more stringent than those of FEMA. All approved new development is reviewed for conformance to Public Works and FEMA flood safety criteria.

The County may enforce more conservative regulations and standards through adoption of hydraulic formulas that improve estimates of sediment yield during heavy rains. Hydraulic formulas govern the design flood, and hence the flood protection, used for a project. Design floods are derived through the Department of Public Works. Design floods are based on the expected frequency of design storms, as deduced from historical rainfall records. An accurate deduction of the design flood increases the probability that the storage capacity and performance of flood protection features will not be exceeded.

Section 308 of the County Building Code authorizes the County of Public Works to maintain maps delineating mud and debris flow hazard boundaries. Hydraulic studies, and site specific mapping may be needed to assess the mud flood and mud and debris flow potential. In many cases, performance cannot be ensured with the highest degree of confidence unless such studies are performed. Design criteria for mud and debris flow protection is based on expected sediment transport rates and sediment volumes inferred from design storms and floods. Design standards for debris basins along the front of the San Gabriel Mountains, bordering the Los Angeles Basin, are based on historic rainfall records from the 1930's through 1955. Design standards for the Santa Clarita Valley area are based on studies on storm activity and hydrograph data through 1964. Standards for canyons in the mountains bordering the Antelope Valley reportedly exist, but have yet to be published. Continuing studies of the areas by the Department of Public Works are expected to yield effective design criteria in the future.

Different techniques used to deduce hydraulic data can produce differing estimates of sediment yields. Some private developers believe, in may instances, that County design flood standards are overly conservative. Actually, the U.S. Army Corps of Engineers employs more conservative design criteria. The County method is linked to relatively larger storm systems, but tends to average sediment yield over a longer duration. The U.S. Army Corps of Engineers model intense, shorter duration storm activity that generates larger estimates of sediment yield. Methods for estimating sediment volumes for the Santa Clarita area are being updated (Sree Kumar, 1990 personal communication).

Conclusions

- Mapping of mud flood, mudflow and debris flow inundation areas needs to be greatly improved in Los Angeles County.

- Design criteria for flood protection are most accurate along the front of the San Gabriel Mountains bordering the Los Angeles metropolitan area and in the Santa Clarita Valley area. Adequate standards are being prepared for steep canyons in mountains bordering the Antelope Valley. Standards for the Santa Monica Mountains are expected to be developed in the future based on continuing studies.

- Careful review and stringent application of design flood standards for projects proposals on alluvial fans in the Antelope Valley, and within or adjacent to unprotected or unmanaged drainages, are necessary for two reasons: 1) existing standards may be re-evaluated based on regularly updated information from site-specific investigations, improved hydraulic formulas, and the possibility that future storms may reveal greater sediment yields than current design floods; and 2) lack of a comprehensive understanding of flood hazard risk assigned to some 500 year flood plains in the Antelope Valley.

- A "mud and debris flow" mapping program that recognizes and/or incorporates the following three elements would provide the most accurate assessment of shallow, high velocity flow failures in the County: 1) hydraulic studies to model fire/flood sequences, 2) location of burnt hillside areas, and 3) geologic/geomorphic delineation of additional debris flow scars.

- Mud and debris flow hazards in some canyon drainages require additional flood/hydraulic studies to adequately assess flood and inundation potential and design proper flood mitigation. Provisions for hydraulic studies are applicable to certain 100 and 500 year flood limits on alluvial fans in the Antelope Valley.

- The County can enforce more conservative flood regulations and standards through adoption of conservative, yet scientifically documented, hydraulic formulas used to compute design criteria for flood protection. The Department of Public Works must approve any proposed methodologies before they can be used in land use decisions. The Federal Emergency Management Agency must also approve any proposed methodologies if the project requires funding from the Federal government.

- Two key provisions for disclosure of information on flood, inundation, and geologic hazards consist of: 1) a "positive declaration" on each page of the final subdivision map; and 2) delineation of flood or geologic hazards of subdivision maps. These provisions could be improved on if County agencies were involved in making hazards better known, both internally and to the public.

SECTION 5.3.2

TSUNAMI AND DAM INUNDATION HAZARDS

Dam Inundation Hazard

This section focuses on the safety of large dams, which are defined in this report as dams with crest heights greater than 15 meters (about 45 feet) as measured from the bottom to top of the dam. This places the dam under the jurisdiction of the California Division of Safety of Dams (see Chapter 3). Emphasis is extended not only to future development moving into "large dam" inundation areas, but also to existing development already settled and vulnerable to dam inundation. Existing development is covered in this section for discussion purposes only. Chapter 6 reviews preparedness and evacuation planning in dam inundation zones.

Land Use Alternatives

There are certain reservoirs/dams in Los Angeles County that have either undeveloped land, or incipient urbanization downstream in potential dam inundation areas. The Little Rock and Fairmont Reservoirs within Antelope Valley and the Pyramid and Bouquet Canyon Reservoirs are examples. The possibility that ongoing growth of the County may spread development into delineated dam inundation areas must be addressed. Presently, dams are considered during CEQA review, but no other long-term planning objectives are evident. Flood plain management, an accepted method of reducing the consequences of flooding within 100-year flood plains, can be extended to future development when proposed within a delineated dam inundation area, and even to existing properties already vulnerable to inundation (FEMA-145, 1987). However, because potential dam inundation areas often exceed the limits of the 100-year floodplain, more stringent floodplain management guidelines may be considered when siting critical facilities for which the risk of inundation is unacceptable.

If land has not yet been developed, the establishment of open space areas in potential inundation areas is the most effective alternative. Land acquisition is advocated by the Federal Emergency Management Agency (FEMA-145, 1987). This is particularly relevant to dam inundation areas in the Antelope Valley and perhaps within some mountain canyon drainages downstream from dams. "Green Belts" such as parks or golf courses provide low cost and reasonable alternatives to limiting development in inundation areas. As discussed in Chapter 3, nonstructural flood plain management is already a common practice within 100-year flood plains. Catastrophic breaching of a dam, however, may demand supplementary hazard reduction techniques (see Chapter 6).

If land is already developed, then zoning measures may be used to limit continuing development and higher population densities. Examples include the Puddingstone and San Antonio Dams. Settlement restriction is advocated by the Federal Emergency Management Agency, where practical (FEMA-145, 1987). To utilize zoning measures in dam inundation areas,risk criteria, such as intermittency of storm water storage, dam construction, and age of the facility, would need to be defined (see Chapter 7). There is currently no County program to rate the relative risk of dam inundation areas shown on Plate 6 (California Department of Water Resources, 1986). To alleviate this problem, one hazard reduction strategy might be to require disclosure and site specific safety studies based on risk factors determined directly from information supplied by the Department of Public Works or the Division of Safety of Dams. A range of safety requirements could be reserved especially for new critical facilities in dam inundation areas.

Dam Inundation Risk: Implementation

Any County program that attempts to regulate development in dam inundation areas requires that criteria be developed concerning the relative risk of dam failure. There are various possibilities that must be considered in such an assessment. They are represented by the following scenarios:

- High rainfall results in overtopping and inundation of areas downstream or uncontrolled flow of water over the dam initiates erosion and possibly the failure of an earthen dam (FEMA-145), 1987);
- structural deficiency results in catastrophic dam foundation failure;
- earthquake results in embankment failure of an earth or hydraulic fill dam or seiching inundates vulnerable areas downstream;
- site deficiencies result in landsliding or subsidence which weakens dam abutments and results in dam failure or landsliding blocks the dam spillway causing minor flooding downstream.

As will be discussed in Chapter 6, the County Department of Public Works, the California Division of Safety of Dams, and the Army Corps of Engineers implement dam safety programs to guard against such threats. Nevertheless, the County may find the development of "dam failure risk" guidelines useful in implementing regulatory measures in inundation areas. In addition to age and design, the Federal Emergency Management Agency recommends that the density of any existing urban development should also be used as criteria to assign hazard potential (FEMA-145, 1987). This may bear a useful guideline for implementing land use, flood protection, or emergency planning measures. The inundation areas prepared for the State Office of Emergency Services already show the worst case scenario for dam failures. The 1:24,000-scale mapping could be modified for regulatory purposes.

Tsunami Inundation Hazard

Many of the same arguments used in the Dam Inundation Hazard Section can be extended to tsunami inundation hazards. Open space is not often a feasible option for harbors because of their economic importance. However, land use alternatives and delineation of tsunami risk zones are appropriate objectives, especially along some portions of relatively narrow coastline areas. Table 5.2 shows that planning, building design, well planned harbor improvements, and emergency preparedness are the primary strategies for use in tsunami inundation areas. The emphasis in this section is on land use and building regulations. They are specifically aimed at reducing the potential direct and secondary impacts of tsunami flooding in potential inundation areas. See Chapter 3 (Tsunami Hazard) for background information.

Accurately delineated tsunami inundation areas can be used to implement building, fire, electrical, and plumbing and mechanical codes specifically tailored to tsunami hazard mitigation. A study by URRNSF (1988) suggests designation of flood damage control, debris reduction, and fire safety overlay zones" in high-risk areas (Table 5.2). The County Building and Fire Codes, and associated performance standards, could be designed to minimize the direct effects of a tsunami on structures directly exposed to a potential wave torrent (Table 5.2). Fire resistive construction and strict regulation of hazardous materials are also relevant hazard reduction measures. A requirement for water tight containers for storage of toxic or flammable materials directly minimizes potential secondary hazards posed by fire and contamination (Table 5.2). Hazard reduction might also include the anchoring of small buildings, liquid storage tanks, or other nonstructural items that can become potential debris (Table 5.2) (URRNSF, 1988).

Fashioning the shape and orientation of buildings can also be used to protect vulnerable buildings and structures from receiving the full brunt of the tsunami wave impact or to protect nonstructural debris such as cars, trucks, or equipment from becoming secondary hazards (Table 5.2). An example of this concept can be described in the design of a parking lot in a commercial district. The parking layout can be oriented so that strengthened structures will shield cars against dispersal by the tsunami flood. Although flood protection features have traditionally been relied on to reduce flood hazards, commercial and industrial facilities can be designed to help protect unanchored industrial equipment and materials, including storage tanks, or smaller containers storing hazardous materials.

Marina del Rey is the largest unincorporated area vulnerable to tsunami inundation that may warrant tsunami hazard reduction provisions. Flood, fire, hazardous materials, and debris reduction zones may be applicable in many smaller areas of the County along the coast. In the final analysis, risk criteria must be developed to determine the stringency of the implementation strategy, whether the risk is assumed as a worst-case scenario or based on probability. Specific considerations may include threats to life, the likelihood that an area may be inundated, the sensitivity of land uses within the area and the potential economic impact of strict regulation.

Table 5.2: Local regulatory safety measures for tsunami and other flood hazards (modified after URRNSF, 1988).

RELATIONSHIP OF TSUNAMI/FLOOD HAZARD REDUCTION CONCERNS WITH CONVENTIONAL SAFETY STRATEGY

General Safety Strategies	Tsunami Safety Concerns	Standard Administrative Program/Authority
PLANNING	Land Use Designation	Comprehensive Plan
	Land Use Density	Zoning Code
	Building Siting	Zoning Code
	Parking Layout	Subdivision Code
	Foundation Design	Building Code
BUILDING DESIGN	Strength	Building Code
	Fire Safety	Uniform Building and Fire Code
HARBOR IMPROVEMENTS	Docks and Piers	Private Owners/Gov't.
	Shore Stabilization	Private Owners/Gov't.
EMERGENCY PREPAREDNESS	Roadway Improvements	State or Local Capital Improvement Plan/ Assessment District
	Roadway Maintenance	Public Works Operating Budget/Assessment District
	Emergency Response	Sheriff/Fire/Public Works Disaster Services and other Departments.

TSUNAMI HAZARD REDUCTION OVERLAY ZONES (KODIAK, ALASKA)

Tsunami Hazard Reduction	Tsunami Overlay Zone	Safety Implementation
Flooding	Flood Damage Control	Zoning Code
Debris Reduction	Marine Safety/ Parking Amenity	Building/Zoning Code (Harbor Master)
Debris Impact Reduction	Open Space/Buffer	Building/Zoning Code
Fire Spread	Fire Safety	Zoning/Building/Fire Code
Hazardous Materials		

SELECTED PROVISIONS

- Optimal grouping of buildings to reduce force of wave impact.
- Design of special flood structures to withstand direct flood impact.
- Streamlined supports/piers to lessen resistance to floodwaters.
- Protection of foundation from scouring and increased depth of footings and embedments.
- Elevated first floors.
- Fire resistive construction.
- Special fuel line inspections.
- Stringent anchoring and containment requirements for flammable and toxic materials.

Table 5.2 outlines the objectives of local regulatory measures involved in a tsunami safety program. Aspects of tsunami safety planning outlined above can also be tailored to any inundation area, even high-risk dam inundation areas. Many existing provisions associated with the County Flood Control District could be employed in a high-risk inundation areas, such as adoption of standards for building strength or building types, elevation of first floors, or regulating hazardous materials. The goal of any flood safety program is to maintain mutually reinforcing development standards within a vulnerable area.

Conclusions

- Dam inundation and tsunami inundation areas (depicted on Plate 6) are worst-case scenarios; high-risk tsunami and dam inundation areas need to be accurately defined to implement safety measures for existing and future development.

- Zoning, Subdivision, Building and Fire Codes are existing County programs for regulating development in dam inundation areas.

- A comprehensive flood program, similar to the County flood control program, if extended to 100-year mud flood, high-risk tsunami, dam inundation areas would support greater safety for future development/redevelopment by regulating construction standards and types of development in all flood-prone areas.

- The direct impact of floods, secondary hazards caused by impact of debris, contamination from hazardous materials, and the potential for fire spread are threats to development at risk from 100-year floods, dam breaks, tsunamis or seiches.

SECTION 5.4

WILDLAND AND URBAN FIRE HAZARDS AND HAZARDOUS MATERIALS

SECTION 5.4.1

WILDLAND AND URBAN FIRE HAZARDS

The Los Angeles County Fire Department (LACFD) is responsible for preventing and suppressing fires in unincorporated areas of the County and cities that contract for fire services. Los Angeles County also has primary responsibility for the suppression of structural fires on Federal lands. The LACFD provides contract fire and emergency medical services to 47 cities in the County and maintains mutual aid or assistance pacts with several local, State, and Federal agencies. The County is the assigned fire fighting and emergency medical services entity with authority over 2,187 square miles of land valued at nearly $78 billion (LACFD, 1988). Approximately 3 million residents are served by the County Fire Department. The Department plays a key role in a variety of disaster response operations under direction of the County Sheriff, the County agency that acts as the overall disaster management coordinator in a major emergency.

During the ten year period 1977 to 1987, the population served by LACFD grew from 2.15 million to 2.6 million and the number of incidents (fire and emergency medical) rose from 110,000 to 160,000. In 1987, the LACFD responded to 11,888 fires. For that year, fire losses totaled $59.2 million, up from $36.7 million in 1983. While the long-term trend in the number of fires is downward, the dollar losses caused by fires has risen due to inflation of property values (LACFD, 1988). The downward trend in the number of fires has been attributed to the active fire prevention and protection program of LACFD.

Fire Prevention and Protection Programs

The hazards from wildland fires and from earthquake related fires are factors that must be considered in determining future land use. Disaster may be avoided if adequate attention is given to fire prevention measures in the development review and permitting process. County programs directed towards fire prevention and rehabilitation of existing development are reviewed in this chapter. Some aspects of fire safety management are also considered in Chapter 6.

This section places emphasis on selected fire prevention and protection strategies. The County programs are aimed at future development. Although not a comprehensive list of all aspects of the fire regulatory programs, it will place fire prevention measures within the context of County Zoning, Subdivision, Fire and Building Codes (including electrical, plumbing, and mechanical codes). The County adopts the State Fire Code for regulations and standards to be applied toward new development. The fire safety measures in the State Fire Code find their origin in the National Fire Code. The Fire Code, like the Building Code, is amended every three years.

Wildland Fire Hazards

To implement varied fire safety provisions, the Fire Code defines "hazardous fire areas". Fire Zones 3 and 4 denote the primary wildland fire risk areas. Fire

Zone 4 has the most stringent fire prevention measures because of the characteristics inherent to it's definition: a highly vegetated, steep, and largely inaccessible mountainous terrain. Fire Zone 4 is usually downgraded to Fire Zone 3 when large scale development encroaches into these areas and significantly reduces the fire hazard. The wildfire hazard is reduced as a result of an increase in accessibility, the designation of fire lanes, and the development of capital improvements such as water services for fire protection. Fire prevention items addressed in the Fire Code include provision of access roads, adequate road widths, and clearance of brush around structures.

Fire flow and water supply requirements are implemented as part of the County Fire and Building Codes. The County Fire Department administers distinct Water Ordinance regulations designed respectively for Fire Zones 3 and 4. Equations for computing water flow are given in Sections 20.16.030 and 20.16.040 of this ordinance. The County Fire Department has determined that an improvement is achieved by utilizing fire flow and hydrant requirements presented in Fire Prevention Regulation 8, Chapter 1, Subject 8 in lieu of the tables given in Section 20.16.060 of the Water Code.

Fire Zones 3 and 4 are also considered during impact analysis under CEQA provisions. Within high fire hazard areas, new development must show proof through certification with the County Fire Department that new development is located within a designated distance of a natural or artificial body of water for emergency fire fighting purposes (County Building Code 76, Section 307). The Water Code specifies that water storage facilities be placed to ensure gravity emergency fire flow in the event power lines are damaged. Power loss effectively renders emergency water pumps inoperable. Recent fire disasters in the County have revealed that improvements are necessary in the enforcement of this requirement. A lack of enforcement of this provision has been blamed for a wildfire disaster in the summer of 1989, a fire that resulted in the destruction of sixteen $500,000 homes (GPPRB, 1989; interdepartmental County memo).

Areas of potential ground failure, designated and implemented in the same manner as fire zones, could promote effective water utility requirements to increase fire suppression capability following an earthquake. Whether in rural or urban environments, the Water Code could be expanded to include areas of potential liquefaction, earthquake-induced slope movement or fault rupture from earthquakes. Safety measures might include redundant water pipelines, flexible polyethylene pipeline materials, or above ground pipelines easily accessible for emergency repair.

Fire Zone 4, the designation given to high brush and woodland fire areas, was created by County Ordinance 2913 in 1937. The County Forester and Fire Warden has the authority to continually review the unincorporated portions of the County and change designation from a Fire Zone 4 to a Fire Zone 3 as new urbanization expands into wildland areas. Fire resistant roofing in Fire Zone 4 has been through several regulatory reversals during the last 20 years. While Zoning Ordinance 10259 (1971) restored wood and shake shingle roofs as approved construction materials in Fire Zone 4, untreated wood shingle roofs were specifically prohibited from Fire Zone 4 in 1986.

An ordinance is presently pending, as of 1989, regarding wood and shake shingle roof coverings. The ordinance would assign specific performance standards for designated Fire Zones. A controversial point raised by the State Attorney General as an argument against implementation of provisions more stringent than the State Fire Code, is based on the following:

> "County Building Code standards must conform with the State Building Code unless, based on local climatic, geographic, or topographic considerations, there is evidence for adopting additional, more stringent standards."

Based on historical precedent and the County's vulnerability of the urban interface to wildland fire hazards, the need for such standards appears to be substantiated (see Section 3.4). This is especially true in Fire Zone 3. The County Fire Department has recommended fire retardant Class C roofs for Fire Zone 3, which is frequently impacted by fires from wildland areas.

Urban Fire Hazards

Institutional, industrial, and indoor public facilities are reviewed by the County Fire Department for compliance with Fire Code and Building Code provisions. The definition of "high-rise structure", stated as 75 feet high, is included in the Fire Code (Ordinance 86-0004, Section 2). The Building Code fire prevention provisions cover everything from fire sprinkler regulations to requirements for plumbing. The County Fire Department is responsible for fire prevention provisions within Chapters 3, 5, 10, 33, and 38 of the County Building Code. The design and construction of water utilities and peak load water requirements, items defined by the National Plumbing Code, are also the responsibility of the Fire Department. Although the Fire Department issues final recommendations and permit approval, independent contractors with technical expertise are often employed directly in the review process.

Provisions for sprinkler systems in apartment buildings above certain height and square footage thresholds are standard elements of the State Building Code. Chapter 38 of the County Building Code assigns specific occupancies for mandatory installation of sprinkler systems. At the request of the County Fire Department, additional criteria have been recently established. A requested revision for sprinkler standards in the 1989 County Building Code, recognizing occupancy and evacuation concerns, calls for mandatory sprinkler installation for buildings with three stories or 15 or more units and would include such buildings as hotels and apartments. The County has also added new guidelines that specifically designate motels with three or more units or any other facility with 20 or more guest units to install sprinkler systems.

In the case of critical facilities such as high rises, essential facilities and other definitions for high priority structures, the County adheres specifically to the standards defined in the State Building Code. The design and construction standards, as mentioned in the discussion of seismic hazards, are reviewed by a number of State agencies from the State Architect to the Department of Corrections for conformance to State mandated requirements.

Provisions for fire flows, minimum road widths and clearances around structures are applied through the Fire Code, as dictated by Zoning Ordinance provisions relating to the density and type of development. The Fire Code provisions, which enforce variable setbacks for different types of facilities, have not yet been an issue as indicated by the County Fire Department (GPPRB, 1989). However, potential improvements could be achieved through development of clearance standards based on earthquake hazards. Jaffe, et al. (1981) indicates that building setbacks, if applied on all lot lines, could encourage equalized building mass and configuration. This design has been proven to be more stable than complexly designed buildings. If applied on the lot line fronting the street, damages are more likely to be internalized within the lot, preventing the street from being blocked and leaving critical traffic corridors free from debris. The latter proposal offers a plan for development of designated evacuation routes for use during fires, hazardous material incidents, and other emergency operations.

As noted in Chapter 3, building density is also an important factor in urban fires. Fire and Zoning Code provisions for building setbacks could be applied to urban and Fire Zone 3 fire hazardous areas to prevent "branding" (the spontaneous ignition of roofing materials caused by an adjacent wildland or urban fire). Scawthorn (1987) identifies branding of roof materials as the most important factor leading to rapid urban fire spread. Branding was found to be one of the main factors causing the multiple fires in the late 1989 Wilshire Terrace fire in Westwood. Recognizing this problem, the Metropolitan area of San Francisco County has banned wood roofs in urban areas, as well as non-urban areas. The Japanese also administer performance standards requiring fire resistive structural construction in new development. As urban areas continue to "infill" and increase urban density, such standards could be important fire safety improvements in the future.

Additional ideas about improvements in fire prevention and protection, derived from interviews with personnel from the Fire Department and the Public Works Departments include:

- The high cost of fire protection for single-family tract developments could be reduced if legislation required real estate developers to participate in the cost of fire protection, especially the construction of fire stations;

- fire breaks or green belts could be better planned if they are dictated at the discretion of the Fire Department, instead of at the judgment of the builder;

- plans for redesignating older reads as fire lanes need to be reviewed by the County Department of Public Works instead of private contractors to ensure proper road standards; and

- expanded fire education programs are necessary throughout the County, and especially in high risk areas.

Conclusions

- Amending the Zoning, Building, and Fire Codes to require fire resistive construction, including treated Class C roofing material for areas identified as the potentially fire hazardous, would provide an effective regulatory program that ensures the safety of residents.

- Potential improvements in the various codes include better enforcement of the Water Code, expansion of the Water Code provisions to address earthquake ground failure, design of building setback standards based on earthquake hazard considerations, and definition of fire breaks and/or evacuation routes through application of building clearance standards.

- Designation of fire lanes and other fire road construction and performance standards should be at the discretion of the County Fire Department and the Department of Public Works.

SECTION 5.4.2

HAZARDOUS MATERIALS

Chapter 3 documented the continuing increase in the number of hazardous material incidents in the County, which could severely strain warning and evacuation plans for possibly thousands of residents. A chlorine gas release resulting from the 1987 Whittier Narrows Earthquake emphasized the potential catastrophic problem of multiple hazardous material releases. To address this problem, a variety of State and Federal legislation has been passed within the last five years governing the storage of hazardous and acutely hazardous materials (Appendix 1). California law provided the general framework for regulation of hazardous wastes by the Hazardous Waste Control Law (HWCL-1972). This has since been modified and supplemented by many additional pieces of legislation. A history of legislation is summarized below to provide a background for understanding County hazardous waste programs. The legislation includes fundamental definitions pertaining to reporting and emergency provisions of hazardous waste management programs.

The Department of Health Services (DHS) is the State's leading agency in implementing the HWCL. The HWCL defines several hazardous waste categories, including those wastes which cause increased mortality, serious irreversible illness or incapacitating reversible illness; and wastes which pose substantial hazards to human health and the environment. Wastes are determined hazardous based on toxicity, bioaccumulation, ignitibility, reactivity, and corrosivity. Extremely hazardous wastes have been defined as those wastes which cause death, disabling personal injury or serious illness. Restricted hazardous wastes form a subclass and were defined to manage land disposal. These include hazardous waste with cyanide and PCB's (polychlorinated biphenol's). Infectious wastes include laboratory and medical wastes or other wastes that may contain bacteria or viral agents. The HWCL provides for State regulation of existing hazardous waste facilities, which include "any structure, other appurtenances, and improvements on the land, used for treatment, transfer, storage, resource recovery, disposal or recycling of hazardous wastes"; and requires permits for, and inspections of, facilities involved in generation and/or treatment, storage and disposal of hazardous wastes.

The State-mandated Waters Bill (AB 2185), which took effect in 1986, requires local governments to regulate the storage of hazardous materials by businesses, and to plan for emergency response to releases of hazardous materials (Health and Safety Code, Section 25500). Hazardous materials are defined as any chemical that requires a material safety data sheet (MSDS), when stored in quantities over 10,000 pounds; or extremely hazardous substances identified in the Federal Chemical Emergency Preparedness Program, if stored above Federal threshold reporting quantities. The La Follette Bill (AB 3777) was adopted by the State in 1986, and expands the State-wide hazardous materials inventory and emergency response programs mandated by the Waters Bill for businesses handling acutely hazardous materials. Acutely hazardous materials are described as those chemicals listed on the Federal Chemical Emergency Preparedness Program List.

The Waters and La Follette Bills require businesses that store hazardous materials or wastes above State threshold limits to submit a business plan to its local administering agency. The local administering agency in the County of Los Angeles is the Fire Department. The business plan must include a list of every hazardous material and hazardous waste handled above the threshold quantities, the maximum amount of material on-site at any one time, the location of each material (typically a site map), the Standard Industrial Classification code number of the business, and a 24-hour emergency response contact. The La Follette bill also requires a general description of the processes and principal equipment involved in the handling of each acutely hazardous material (STP, 1988).

The Tanner Bill (AB 2948) created a local planning process designed to make each county capable of managing the hazardous waste generated within the county. Under this law, each county is required to prepare a County Hazardous Waste Management Plan (CHWMMP). The County Department of Public Works has completed the CHWMMP and has begun to implement it's provisions (CHWMMP, 1989). This plan includes: data regarding current hazardous waste generation; descriptions of current hazardous waste treatment facilities; feasibility of recycling or reducing hazardous waste generation; consideration of household and small generator hazardous waste; determination of the need for additional offsite hazardous waste treatment facilities; identification of facilities that can be expanded and of general areas for future disposal of hazardous wastes or criteria for selecting sites; hazardous waste management goals and policies through the year 2000; and a schedule to implement the County Hazardous Waste Management Plans.

In addition, the CHWMMP requires regional Councils of Government to prepare Regional Plans. The State Department of Health Services concurrently was required to develop a statewide hazardous waste management plan by November 1, 1989. The State drafted its plan based on County and regional plans. The schedule included finalized county plans before October 1, 1989. Each county was required to hold public hearings between January 1 and March 31, 1988 to receive comments on their draft plans.

The Superfund Amendments Reauthorization Act (SARA Title III) includes the Emergency Planning and Community Right-to-Know Act (1986). SARA mandates a program that created four distinct sets of reporting and planning requirements, each of which is built around a distinct list of toxic chemicals. SARA provides for the following:

1. The designation of a State emergency response commission, which in turn is to designate local emergency planning districts and support local emergency planning committees. Each local committee is required to prepare a district plan for emergency response to releases of "extremely hazardous substances" and submit it to the State Commission for review. The planning requirements are very similar to those in the emergency plans required by the Waters Bill (described above).

2. Definition of Federal threshold quantities for each extremely hazardous substance which would trigger a planning and release incident reporting requirements.

3. Establishment of reporting requirements covering thousands of hazardous materials for which the Federal Occupational Safety and Health Act of 1970 has required material safety data sheets (MSDS), and manufacturing facilities in SIC Codes 20 to 39 to file annual chemical inventory statements beginning March 1, 1989.

4. Requirements for annual reports from selected businesses that release "continuous" (i.e., non-accidental) emissions of 307 listed chemicals and 20 groups of chemical compounds into any environmental medium.

The Uniform Fire Code also has provisions for the regulation of hazardous substances. The 1988 edition establishes well-defined storage, secondary containment and monitoring requirements for all classes of hazardous materials, and maintains treatment requirements for any release of toxic gases. Fire Departments can require fire permits that regulate the storage and handling of compressed gases and flammable or hazardous materials. Part V of the Uniform Fire Code regulates the use and storage of hazardous substances needed in special processes, and sets standards for the handling and transportation of hazardous production materials within exit and service corridors. Part VII regulates the storage, handling and use of flammable and combustible liquids, and the manufacture, storage and transportation of highly flammable hazardous materials. Each facility subject to the Uniform Fire Code can be required to submit a Hazardous Materials Management Plan that includes all items required by the Business Plan outlined above. This includes a listing of emergency equipment, employee safety training, chemical compatibility and safety precautions (STP, 1988).

Hazardous Materials Program Implementation

In accordance with the legislation summarized above, all businesses operating "Hazardous High-Risk Facilities" within the jurisdiction of the County must prepare and maintain a Business Plan and Hazardous Materials Management Plan. The information dispensed in these plans can be used by the County Fire Department, Hazardous Material Response Units, Sheriff, paramedics and hospitals in dealing with releases of hazardous material, especially in the event of a fire or explosion.

Many businesses throughout the Los Angeles area are not providing this information to their local administering agencies, or are not complying with regulations governing the storage and use of hazardous materials. There are numerous reported cases where businesses have failed to disclose information regarding hazardous materials stored or used, or cases where businesses have filed to correct violations of safety regulations. In either case, the local administering agencies, including the County, are being forced to take legal action against these businesses in order to get them to comply. Some notable examples from within the County or incidents in adjacent Counties include the following:

- In 1987 and 1988, the Mobil Oil Corporation refinery in Torrance suffered three explosions (two in the same day) releasing hydrofluoric acid and hydrocarbon vapors resulting in one employee's death and 12 injuries. A

1,000-gallon spill of hydrofluoric acid could produce a toxic cloud lethal to all exposed within a range of five miles. Mobil typically stores an estimated 29,000 gallons of hydrofluoric acid at the plant in Torrance. Due to repeated accidents, the Torrance City Council ordered Mobil to write a risk management prevention plan in May 1988 that City officials concluded was inadequate. In 1988, the Federal Occupational Safety and Health Administration (OSHA) conducted two investigations at the plant and found four "serious violations" of Federal safety regulations in connection with the first explosion (November 1987). OSHA defines a serious violation as one "where there is substantial probability that death or serious physical harm could result." An investigation in September, 1988 of the entire plant led to 35 citations of Mobil, including 12 serious violations (Los Angeles Times, 1989).

- In 1989, five Los Angeles County companies agreed to pay fines totaling $27,000 in settlements involving allegations that they failed to comply with a State law requiring disclosure of hazardous materials on their premises. According to Deputy District Attorney David Guthman, Head of the Environmental Crimes/OSHA division of the District Attorney's office, these businesses were seen as the most flagrant violators from an original list of 94 companies that were deemed to be in noncompliance.

- In 1989, Pacific Intermediates, located in Saticoy (Ventura County), suffered a chemical fire forcing the evacuation of more than 1,500 Saticoy residents. For months previous to the chemical fire, the Ventura County Fire Department and Health Department issued warnings that the firm was in violation of laws regulating the storage, handling and disposal of hazardous materials. The initial violations were discovered only when County fire fighters and building inspectors were coincidentally exposed to a chemical in the company's storage yard during an inspection. Investigators had developed enough information to get a search warrant allowing them to get a good look inside the business, but the chemical fire occurred before the warrant was issued.

The initial inventory of businesses in the unincorporated County that use, store, or transport hazardous materials handled above threshold quantities is presently behind schedule. As of 1988, the Fire Department believed the County inventory was incomplete by as much as 60 percent. Without a complete inventory it is difficult to enforce safety measures that limit the maximum amount of material permitted on a site. Combined with the emergency response plans, these are both vital sources of information necessary for protecting the public from hazardous materials releases. The following are zoning approaches for managing hazardous materials that have been successfully implemented by selected jurisdictions in California.

- The City of Sunnyvale through Title 20 of the City Planning and Zoning Code, requires a permit for storage of hazardous waste, compliance with primary and secondary containment provisions, as defined in the ordinance, and submission of a Hazardous Materials Management Plan, as defined above. The City Fire Code also defines specific standards for hazardous waste storage containers, such as water tightness and strength.

- The Hazardous Materials Management System of Union City, in a joint effort by the Community Development Department, the Fire Department, and hazardous materials specialists, succeeded in implementing a hazardous waste industrial zone ordinance. They have replaced traditional light and heavy categories of industrial use (Standard Industrial Classification Code), with industrial zones to accommodate specific uses and permitted on-site quantities of hazardous materials. These quantities are directly incorporated into the zoning ordinance. Their Fire Code is amended to promote supplementary regulations regarding the handling, storage, and reporting of hazardous materials.

- Locally, the Los Angeles City council has given the fire Department authority to shut down businesses that do not meet current requirements to inventory and list dangerous materials that are on their private property.

The County could develop a hazardous materials zoning ordinance to ensure that performance standards are met in an expedient manner. The Regional Planning Department could support this effort by reviewing the exposure, location, and types of hazardous materials in the community through the project review process for new development; or through incorporation of retroactive provisions of the Zoning Ordinance for existing development. Retroactive measures, with adequate enforcement by the Fire Department and/or Health Services Department, could expedite the inventory and implementation of the State-mandated hazardous materials requirements.

Conclusions

- Businesses that use, store, or transport hazardous materials will continue to pose threats to public health, welfare, and safety if stringent enforcement measures are not implemented to force compliance with existing laws and regulations.

- Increased inspections are necessary to enforce compliance with existing hazardous material law and regulations and to gain the cooperation of hazardous material owners/users.

- The County would benefit from an enforceable hazardous materials ordinance (with penalties), which could define specific provisions even more stringently than defined by State and Federal laws.

- Industrial zones may be amended to provide for specific uses and permitted quantities of on-site hazardous materials.

- A comprehensive plan that coordinates community input, input from County emergency response agencies, and the businesses using hazardous materials would yield the greatest degree of assurance that the threat of hazardous materials incidents will be reduced.

CHAPTER 6

MANAGEMENT OF EXISTING DEVELOPMENT

SECTION 6.1

CRITICAL FACILITIES AND HAZARDOUS STRUCTURES

This chapter focuses on two concerns posed by existing development: the first involving the safety of selected critical facilities and potentially hazardous buildings, and the second pertaining to emergency response, as it relates to disaster response planning and other long-range objectives of the Safety Element. This section identifies and evaluates several County risk-reduction programs aimed at existing development. The organization of the discussion is as follows:

- **Critical Facilities and Infrastructure:**
  - Hospitals, dependent care facilities, facilities storing hazardous waste, high occupancy buildings (high-rises) and nonstructural hazards.
  - Lifeline systems (utilities), dams, freeway and road systems.
- **Potentially Hazardous Buildings:** County Inventory and Abatement Program
  - Future priorities for hazardous building abatement.
- **Management of Potentially Hazardous Buildings and Critical Facilities**
  - Building screening and California building safety programs.

One may note that this section follows the outline of critical facilities and infrastructure presented in Chapter 4 (Earthquake Vulnerability), a discussion that focused on concerns underscored in earthquake scenarios and other seismic hazard assessments conducted in Los Angeles County. The potential for calamitous losses in terms of deaths, injuries, social disruption and displacement in these especially sensitive categories of critical facilities also emphasizes the need for concern about them.

The purpose of the Element is to produce a safer environment and reduce the scope of disaster response through proactive long-term planning. This is accomplished by, but not limited to, prudent land use decisions and the overall strengthening of regulatory measures. This section also contributes to more effective emergency response, albeit indirectly. In this role, several aspects of existing development management will have a bearing on the following section pertaining to emergency response, disaster assessment, and disaster response planning.

SECTION 6.1.1

CRITICAL FACILITIES AND INFRASTRUCTURE

Critical Facilities

Hospitals and Dependent Care Facilities

Critical facilities can be generally defined as buildings or structures which pose extraordinary hazards to public safety if significantly damaged. For this reason, fire and law enforcement facilities, both of paramount importance in an emergency, should be located and constructed to remain functional in the event of a major earthquake. Accordingly, one objective of the County Five-Year Plan for Earthquake Preparedness (1987) was the evaluation and strengthening of County essential facilities. As explained in Chapter 4, the collapse of a hospital or dependent care facility creates an alarming potential for casualties and social disruption. This is exacerbated by the exceptional difficulties of managing persons having restricted mobility or subjected to involuntary incarceration in a disaster. For example, as documented in Table 4.5 (Chapter 4), large numbers of pre-elementary and other students (K1-K12) must be evacuated, sheltered in a safe environment, and reunited with their parents. Therefore, we limit this discussion of critical facilities to hospitals and other types of dependent care facilities.

The State and Federal governments reserve exclusive power in ensuring the seismic and fire safety of some dependent care facilities. The State's Garrison Act governs the retroactive structural safety of the public school system. Federal Agencies, such as the U.S. Health Care Financing Administration, can require remedial safety measures such as fire alarms and sprinkler systems for hospital dependent care facilities. General acute care hospitals are subject to seismic upgrading if the facility is undergoing voluntary renovation (Hospital Act). Although existing public schools and hospitals are governed by various State retroactive building regulations, many thousands of health, social care, private schools, and jail facilities listed in Tables 4.3 through 4.7 (Chapter 4), may not be governed by such programs.

For effective emergency contingency planning, it is essential to know where dependent care facilities are located and which of these facilities may have unusual structural or fire vulnerabilities. Furthermore, strengthening these buildings and retrofitting them with improved hazard reduction technology (fire suppression, etc.) would increase their survivability and reduce the potential for catastrophic injuries and fatalities. The State of California and County of Los Angeles should consider enacting mandatory retroactive regulations governing the strengthening of all critical substandard dependent care facilities, given the possibility that some are not yet comprehensively managed for safety concerns.

High-Risk Facilities

Hazardous facilities, as defined by the County Building Code, are buildings using or storing or otherwise involved with quantities of explosives or toxic chemicals above State standards. These facilities represent one type of high risk facility, as defined in the Safety Element. Hazardous facilities within County jurisdiction, that are covered by the County Fire Code, are subject to inventory by the County Fire Department Hazardous Materials Management Program. The inventory is critically important for effective emergency response to serious hazardous material incidents.

Chapter 4 concludes, based on the coincidence of major industrial zones with areas of strong ground shaking, fault rupture, and liquefaction, that many privately-owned, high-risk (hazardous) facilities are vulnerable to structural and nonstructural damage, especially if the buildings are potentially hazardous in terms of construction standards or quality. However, no structural evaluation is planned in the near future for such facilities in unincorporated areas of the County. High priority should be given to assessing the structural integrity of existing hazardous facilities, storage tanks, and other key nonstructural containment or conduit equipment as part of a critical facilities inventory. Rehabilitation and retrofit priority should be based in part on the location of the facilities relative to seismic hazard areas, such as liquefaction and fault rupture. An overall emphasis on structural safety, however, might be better extended to all areas due to the widespread potential for strong ground motion in the County.

Current regulatory measures for hazardous facilities involve not only the types and volumes of hazardous materials used or stored on the premises, but also provisions for internal emergency operation plans. The risk posed to communities near heavily industrialized zones, especially those with dependent care populations, might warrant special contingency plans. Such plans might include drills and exercises and other actions to reduce the risk associated with hazardous materials releases. Given the nature of hazardous materials releases, emergency evacuation and contingency plans should also receive more regional coordination. The development of regional plans for handling hazardous materials required under AB 2948 (a.k.a. the Tanner Bill) should emphasize the regional coordination of emergency response and contingency planning against the threat of serious hazard materials incidents.

High Occupancy Buildings and Nonstructural Hazards

Chapter 4 noted that modern high-rises are very susceptible to internal damage from interior nonstructural hazards because of the accentuated swaying in these structures. Table 7.1 (A-C) shows selected architectural, mechanical, plumbing and various other nonstructural components that might be expected to be damaged in high-rise buildings (EERI, 1984-04). Falling chairs, desks or lamps are common examples of nonstructural hazards; however, extraordinary damage may also be caused by collapsed building components such as partitions, ceilings or even floors (Table 7.1 A). Although not incorporated into the assessment tabulated in Table 7 (A-C), the failure of interior nonstructural components, such as stairways, could have severe consequences for emergency evacuation operations in

Table 6.1a: Nonstructural Hazards and Issues*

COMPONENT	ISSUE	LIFE HAZARD	ECON LOSS	FUNC-TION LOSS	STRUCT. MODIF.	DESIGN & SELECTION RESPONS-IBILITY*
ARCHITECTURAL						
APPENDAGES	Exterior Walls	●	◐	●	●	A
	Glass, Glazing	◐	◐	◐	O	A
	Veneers, Facings	◐	◐	O	O	A
	Cornices, Parapets	◐	O	O	O	A
	Ornaments	O	O	O	O	A
PARTITIONS	Fixed: General	O	◐	O	◐	A/I
	Stair Surround	◐	◐	O	O	A/I
	Elevator Shafts	O	◐	●	O	A/I
	Fire Separation	◐	◐	◐	O	A
	Mechanical Shafts	●	◐	●	◐	A
	Demountable: Rated	●	◐	◐	◐	A
	Non-Rated	O	O	◐	◐	A
	Replaceable: Rated	O	◐	◐	◐	A
	Non-Rated	O	O	O	O	A/I/O
	Operable	O	◐	O	◐	A
	Glazed	O	O	O	O	A/O
	Partial Height	O	O	O	O	A/O
CEILINGS	Fire Proofing	◐	◐	◐	O	A
	Non Fireproofing	◐	◐	◐	O	A
	Exposed Tees	◐	O	◐	O	A
	Concealed Spline	O	O	O	O	A/O
	Metal	O	◐	O	O	A/O
	Plaster	O	◐	O	O	A
FLOORS	Computer	O	●	●	O	A

STRUCT. MODIF.= structural modification

● potentially great
◐ potentially moderate
O potentially small

*A = architect
E = structural engineer
ME = mech/elec. engineer
I = interior architect
O = owner/manager

* After EERI, 1984

Table 6.1b: Nonstructural Hazards and Issues*

COMPONENT	ISSUE	LIFE HAZARD	ECON LOSS	FUNC-TION LOSS	STRUCT. MODIF.	DESIGN & SELECTION RESPONS-IBILITY*
MECHANICAL EQUIPMENT						
SOURCE	Boilers	◐	◐	◐	O	ME
	Chillers	O	◐	◐	O	ME
	Air Handlers	O	O	◐	O	ME
	Tanks	O	O	◐	◐	ME
	Heat Exchangers	◐	O	◐	O	ME
	Pressure Vessels	◐	◐	◐	O	ME
	Pumps	O	O	◐	O	ME
	Flues, Vents	O	O	◐	O	ME
	Roof Top Packages	O	O	O	O	ME
	Heat Pumps	O	O	O	O	ME
	Window Units	O	O	O	O	ME
DISTRI-BUTION	Ducts	O	O	◐	O	ME
	Pipes, Water	O	O	◐	O	ME
	Pipes, Steam	◐	O	◐	O	ME
TERMINALS	Ceiling Diffusers	◐	O	◐	O	ME
	Floor, Wall Diffusers	O	O	◐	O	ME
	Heaters, Oil	◐	O	◐	O	O
ELECTRICAL EQUIPMENT						
SOURCE	Transformers	O	◐	◐	O	ME
	Switch Gear	O	◐	◐	O	ME
	Motors, Controls	O	O	◐	O	ME
DISTRI-BUTION	Conduit	O	O	O	O	ME
	Busbars, Wireways	O	O	O	O	ME
TERMINALS	Outlets	O	O	O	O	ME
	Lighting	◐	O	◐	O	ME

STRUCT. MODIF.= structural modification

● potentially great
◐ potentially moderate
O potentially small

*A = architect
E = structural engineer
ME = mech/elec. engineer
I = interior architect
O = owner/manager

* After EERI, 1984

Table 6.1c: Nonstructural Hazards and Issues*

COMPONENT	ISSUE		LIFE HAZARD	ECON LOSS	FUNC-TION LOSS	STRUCT. MODIF.	DESIGN & SELECTION RESPONS-IBILITY*
PLUMBING							
SOURCE	Tanks		O	O	◐	◐	ME
	Pumps, Valves		O	O	◐	O	ME
DISTRI-BUTION	Pipes:	Water	O	O	◐	O	ME
		Waste	O	O	◐	O	ME
		Gas	◐	O	◐	O	ME
		Medical Services	◐	O	◐	O	ME
		Domestic Water	O	O	◐	O	ME
TERMINALS	Fixtures		O	O	O	O	ME
FIRE SUPPRESSION							
	Valves		O	O	O	O	ME
	Sprinkler Piping		O	O	◐	O	ME
	Sprinkler Heads		O	O	O	O	ME

STRUCT. MODIF.= structural modification

● potentially great
◐ potentially moderate
O potentially small

*A = architect
E = structural engineer
ME = mech/elec. engineer
I = interior architect
O = owner/manager

* After EERI, 1984

high-rise or other high occupancy facilities. This is especially critical if evacuation of dependent populations is required. Table 7.1 (B) emphasizes the vulnerability of high-rise fire suppression systems, one of the main hazard reduction systems in tall buildings.

Most nonstructural items are not analyzed by seismic engineers, but specified by subcontractors such as mechanical engineers, interior designers, or installed by the owner after purchase of the building (Table 6.1 A-C). This can be a problem as interior components respond to earthquake shaking in complex ways depending on the type of structural system or configuration of the building (EERI, 1984-04). Steps to assess nonstructural hazards, in some critical cases would require knowledge of the building's seismic response.

Los Angeles County has taken steps to evaluate and mitigate nonstructural problems in County-owned and operated buildings. In cooperation with the Southern California Earthquake Preparedness Project (SCEPP), the County has trained approximately 1,000 people to inspect for nonstructural hazards. The Department of Public Works has also made significant progress with their own facilities. How to encourage a similar approach for private buildings needs to be explored; perhaps a program similar to the Fire Department's inspections of fire hazards could be developed for seismic hazards. Local governments should consider adopting ordinances to reduce nonstructural hazards in new and existing buildings (Spangle, 1988).

Private sector organizations are aware of the potential life threats and the functional and economic losses posed by nonstructural building elements. It is very possible that owners of facilities and/or employers could be held liable for injuries caused by a failure to correct obvious nonstructural hazards. The Building Owners Managers Association (BOMA), FEMA, and the Business Industry Council for Earthquake Planning and Preparedness are forming earthquake safety groups for the evaluation of nonstructural hazards in the private sector in Los Angeles County. Another coordinated private sector program within the County is the Downtown Earthquake Preparedness Action Council (DEPEC).

Many businesses conducting vital economic transactions in high-rise buildings could be especially vulnerable to computer failure and loss of important records (Table 6.1 A-C). Recognizing this problem, the Business and Industry Council for Emergency Planning and Preparedness (BICEPP) is developing standard computer backup methods and techniques to secure computer equipment and ensure continuation of vital economic transactions. The benefits of early warning systems to various elements of the community are discussed in Section 6.2 (Emergency Response); however, it should be noted that the computer banking industry already realizes many potential applications of an automated earthquake early warning system.

Critical Infrastructure

Lifeline Systems

The County Five-Year Plan for Earthquake Preparedness (1987) recommends cooperation with private utilities to reduce the earthquake vulnerability of utility systems. The reason for the recommendation is that the Department of Public Works has no jurisdiction over most public utilities, except for smaller County Waterworks and Sewer Maintenance Districts. The County is responsible for water and sewage service in unincorporated areas with populations of less than 200 residents, otherwise the California Department of Health Services administers preparedness and performance standards.

A reevaluation of preparedness and performance programs of County waterworks and sewer maintenance districts may be warranted. Unincorporated areas of Santa Cruz, and other counties that were heavily impacted by the 1989 Bay Area (Loma Prieta) Earthquake, experienced widespread problems caused by the following:

- Severed water distribution and sewer pipelines caused by near surface fissuring and landsliding in hillside areas;
- failure of inadequate cast-iron construction; and
- lack of easily repaired or emergency back-up systems.

For protection of public health, the rapid restoration of water and sewer services is critical following a major earthquake. Segments of water and sewer systems located in earthquake hazardous areas or in areas prone to major landslides should be evaluated for proneness to damage or failure. Strengthening or relocation should be undertaken wherever these actions are feasible. In some instances, strengthening or relocation of such utilities may not be technically or economically feasible. In such situations, contingency measures should be pre-programmed for quick repair of damaged facilities. The 1989 Loma Prieta Earthquake emphasized the importance of an easily maintained, redundant, back-up system. For public safety, contingencies for emergency water supply for fire suppression are paramount, especially in isolated hillside areas.

The Public Utilities Commission, in accordance with the Public Utilities Code, is the State lead agency involved in the following:

- Establishment of safety procedures for electrical and gas utilities;
- encouraging provision of contingency communication systems for earthquake disrupted communications;
- replacement of old cast iron pipelines with new steel and plastic pipelines;
- requirement of earthquake safety features for gas and electrical utilities; and
- conversion from overhead to underground electrical systems.

The County could encourage private utility company retrofit plans by providing information on earthquake hazards. An evaluation of the susceptibility of a lifeline to ground failure damage could help assign priority to certain lifelines for closer inspection and/or upgrading. Certainly, if the County identifies particularly hazard prone areas along utility lifelines, the County may advocate a redundant back-up distribution systems for gas and electrical utilities.

Dams and Water Storage Facilities

The Department of Water Resources, Division of Safety of Dams supervises non-Federal dams and reservoirs for safety. Dams under its jurisdiction are 25 feet or more in height or have impoundment capacities of 50 acre-feet or more (61.7 decameters, see Glossary). Dams which are less than six feet high, regardless of storage capacity, or which have impoundment capacities of less than 15 acre-feet (18.5 decameters), regardless of height, are not under State jurisdiction (Department of Water Resources, 1988).

Of the approximately 100 dams and debris basins in the County under State and Federal regulations, 71 dams require inundation maps. These dams are listed in Table 3.11 in Chapter 3. Thirty-one (31) dams are owned by the County and are subject to regulation by the State Division of Safety of Dams.

The State has statutory authority to investigate dams at least every five years. The State Dam Safety Program is also responsible for issuing notices requiring maintenance or remedial work, and can revise owner operating procedures or take other actions to ensure public safety, including breaching dams when deemed necessary. Each dam owner is responsible for developing his own safety program, which is subject to review by the State. Safety programs involve vulnerability analysis, inspection, monitoring instrumentation, operating procedures, maintenance, and mitigation. Another integral component of the State Dam Safety Program is the preparation of emergency preparedness plans for each dam.

The DPW established the Review Committee on Dam Safety following the failure of the Baldwin Hills Dam in 1964. The Committee has responsibility for developing safety programs for all County-owned dams. The DPW's Planning Division is responsible for studying the seismic stability of dams. Annual field inspections are made of the 31 State regulated County-owned dams. The inspections are performed through a joint program involving DPW engineers and an engineer with the State Division of Safety of Dams. Each year the DPW submits all of its monitoring data on dam safety to the State Division of Dam Safety. The County Dam Safety Program complies with State regulations and standards.

Seismic stability analyses of County-owned dams were accelerated following the San Fernando Earthquake. As of 1989, 18 of the 31 dams, and some debris basins and other facilities have been subject to stability analyses (DPW Earthquake Stability Interim Report, 1989). These analyses have been reviewed by the State. The following is a breakdown of the current status of the County dam safety program for these 18 dams:

- Seven dams are adequate and no remedial action is necessary;

- eleven dams were initially found to have some seismic design deficiencies;
- four of the eleven dams have undergone rehabilitation through the DPW Dam Mitigation Program and have subsequently been reviewed and accepted by the State; and
- seven dams continue to have design deficiencies.

The DPW is continuing to study various alternatives for correcting the seismic deficiencies of these seven dams. The Earthquake Stability Interim Report (1989) has identified the following dams as having inadequate seismic design:

- Big Dalton
- Big Tujunga
- Devils Gate
- Puddingstone
- Santa Anita
- Sawpit
- Thompson Creek

In the interim, the County is complying with State restrictions on water impoundment for these dams. The operational procedure consists of immediately lowering the surface water elevation of each reservoir following storm activity with significant storm run-off.

Of the 31 County-owned flood control or debris basins, 13 have not been subjected to seismic stability analyses. The Department of Public Works, in agreement with the U.S. Corps of Engineers, determined seimic studies were not warranted. Some of the County debris basins are as large as the Rose Bowl. They were screened because of their short active water storage periods. They only periodically retain storm water and are designed mainly for regulating mudflows and storm debris. Because of this periodicity, the Department of Public Works does not plan to perform seismic stability analyses for 9 of these 13 debris and flood control basins under State regulation. However, they have indicated that four debris basins have the potential for significantly long storage periods, and that they will undergo seismic analyses possibly as early as 1990.

Other debris basins owned and/or operated by the County are not large enough to be regulated by the State. Some of these 160 County-owned and operated debris basins are monitored with instrumentation (wells, etc.), and all are subject to detailed inspection by County engineers at least once every three years. Seismic analyses of the nine larger debris and flood control basins under State regulation (see above) and the other 160 debris basins are not planned.

The County Waterworks Districts maintain 91 water storage tanks each with a capacity of 50 million gallons. Of the 91 storage tanks, 39 were constructed before 1971 and do not meet current seismic design standards. Catastrophic failure of these pre-1971 tanks cannot be precluded; however, 30 are located in remote areas and do not currently pose a major threat to life or property. The other nine facilities possibly pose a threat to development. They will be assigned a high priority in a retrofit program that will address these tanks possibly as early as 1990. Tanks that have deficiencies and cannot be corrected will be replaced. The locations of seismically deficient water tanks were not identified in the DPW Earthquake Stability Interim Report (1989).

Highway and Roadway Structures

The County Department of Public Works owns or is responsible for the maintenance and structural performance of some 1,436 bridges. Of these bridges, only 640 are partially or entirely within unincorporated areas of the County. Each bridge is inspected on a 2-year cycle (Earthquake Stability Interim Report, 1989). The County has corrected specific weaknesses of certain bridge structures identified as a result of the 1971 San Fernando Earthquake. The retrofitting was aimed at 225 bridges and emphasized mitigation of flaws that could cause bridge superstructures to slip off abutments or support piers. Although County bridges built after the 1971 San Fernando Earthquake have incorporated design criteria that makes them stronger than pre-1971 structures, the restraint technology used to retrofit the 225 bridges under County program are now considered inadequate on the basis of new design requirements and are targeted for review and possible mitigation where needed (Earthquake Stability Interim Report, 1989).

The DPW has identified 134 pre-1972 bridges, in addition to those mentioned above, that are similar in design to those targeted in the second phase of the Caltrans Freeway Interchange Retrofit Program (see Chapter 4). These bridges are supported by single columns that have proven vulnerable to earthquake damage. The most heavily traveled of the 134 bridges (58,000 cars/day) is in Burbank at Hollywood Way over Van Owen Street and Hollywood Way over the Southern Pacific Railroad tracks (Los Angeles Times, November 5, 1989). A total of 98 of the 134 seismically deficient bridges are within cities while 36 are partially or entirely within unincorporated areas. Currently, a safety program is directed at evaluating the 36 bridges located in the unincorporated areas, and developing a strategy for reviewing the other 98 County-maintained bridges within cities.

Caltrans utilizes geologic site variables such as the potential for fault rupture and liquefaction, and the age and structural design to determine risk factors and rate priorities to retrofit these freeway structures. Caltrans is also beginning to use California Division of Mines and Geology earthquake scenarios in their risk assessment process. While the two completed scenarios have emphasized earthquakes on the Newport-Inglewood and San Andreas Fault Systems, Plates 1 (Fault Rupture Hazard) and 4 (Liquefaction Hazards) highlight additional geologic site variables that might be considered in retrofit programs.

Conclusions

- If existing critical facilities have seismic or fire safety deficiencies they must be structurally strengthened, retrofitted with fire prevention technology, assigned less vital roles in an emergency, or replaced to reduce losses in a major earthquake or other disaster.

- Strengthening programs for all existing critical facilities such as essential, high-risk, or dependent care facilities reduce the potential for injuries and fatalities, reduce economic losses and improve the capability of County resources to respond effectively in an emergency.

- Buildings storing hazardous materials should be assessed for structural integrity, and adequacy of storage tanks and other key containment or conduit equipment.

- Contingency plans for hazardous materials incidents require improved regional coordination with other jurisdictions.

- Failure of interior nonstructural components such as stairs and elevators could have severe consequences for emergency evacuation operations especially if evacuation of dependent populations is involved.

- Reinforcement of nonstructural components is necessary for fire suppression and evacuation of critical facilities, especially in high-rise buildings. This requires knowledge of the building's seismic response.

- An evaluation of public utility lifelines and County water and sewer utilities, with respect to earthquake hazardous areas, could facilitate plans for inspection, upgrading and/or provisions for an easily repaired, or redundant back-up system, if the systems are damaged.

- The County Dam Safety Program conforms with State requirements, but as many as 12 dams and/or debris basins lack adequate mitigation against maximum credible earthquakes.

- As many as 134 County-owned bridges with single-column supports, and 225 other bridge structures may pose risks to the public and should be retrofitted.

SECTION 6.1.2

POTENTIALLY HAZARDOUS BUILDINGS

Unreinforced Masonry

Chapter 4 noted that nearly 15,000 unreinforced masonry buildings (URM's) may be located within the unincorporated and incorporated areas of the County. The majority are located in or near the central business districts of cities. There are only 274 (pre-1934) URM's in unincorporated territory. Approximately 80 percent of the 274 County URM buildings are shops, stores, restaurants, offices, and apartment houses located in the low income Firestone area south of Huntington Park or along busy commercial strips in East Los Angeles (Los Angeles Times, October 19, 1989). The DPW has indicated that these districts have the most unstable URM construction, because their brick and block walls are not tied to the floors or roofs with steel reinforcement.

The County has undertaken a seismic upgrading program for potentially hazardous buildings in unincorporated areas. In partial fulfillment of SB 547, and Government Code Section 8875, et seq., the County has established a seismic upgrading ordinance for URM's with bearing walls and has notified owners that their buildings have been identified as potentially hazardous. The ordinance does not cover single family homes and duplexes. The County has established a timetable for compliance with strengthening measures based on occupancy. Under the 1988 ordinance, implemented through Chapter 96 of the County Building Code, 77 old masonry buildings with occupancies greater than 100 persons have been assigned the earliest target date for compliance. By February 1991, rehabilitation or demolition must be accomplished unless the owners can prove the buildings are structurally sound. URM buildings with occupancies between 50 and 100 (101 buildings) are required to submit plans for rehabilitation by 1991. The owners of the remaining 96 buildings will be notified that plans and building permits will be required by at least 1994.

The City of Los Angeles seismic upgrading ordinance has had some success at compliance, using Federal block grant monies for low interest loans to finance repairs. The basic problem with current seismic upgrading ordinances is that failure to upgrade or strengthen hazardous buildings may lead to condemnation and demolition. This displaces low income tenants or building owners who are unable to find alternative low cost housing or business locations. Strategies involving the development of incentive/disincentive programs through state legislation have been unsuccessful to date. Proposals to raise local taxes in the City of Los Angeles to assist in rehabilitation have also met opposition. Given the possible evolution and/or reversal of currently unfavorable public opinion, both strategies should still be considered in the future.

Historic preservation of older URM's is also an issue. These buildings, when covered by the State Historic Building Code, have additional alternatives beyond the provisions of the County Code, including tax credits (BAREPP, 1986).

Occupancy reduction is also an option for historic buildings. Adequate strengthening provides the best assurance that the building will not be destroyed during an earthquake. It is therefore in the best interest of historic building owners to rehabilitate using the best available technology. Innovative, state-of-the-art techniques are commonly reviewed by organizations and agencies such as the Earthquake Engineering Research Institute, the Masonry Society, and the Applied Technology Council.

Future Hazardous Building Abatement Issues

A major achievement in the 14 years since the adoption of the 1975 Safety Element has been the approval of regulations providing for abatement of hazards in pre-1933 buildings. Chapter 4 indicates that although progress has been achieved, especially within the County's own URM building stock, other classes of potentially hazardous buildings should also be addressed.

The following list is a breakdown of potentially hazardous buildings, other than those with URM bearing walls, that have either structural or potential fire safety deficiencies. The list includes building and safety hazards recognized by the California Seismic Safety Commission (SSC 88-01) and identified through review of the current status of County building safety programs.

- Buildings with nonstructural URM wall infillings;
- tilt-up concrete construction (pre-1971);
- nonductile concrete frame low-rise buildings (pre-1972);
- soft-story construction (pre-1971);
- single-family residences and duplexes constructed of unreinforced masonry;
- single-family residences with unbolted foundations (pre-1952);
- mobile homes;
- dilapidated buildings of all kinds; and
- high occupancy and/or mid- to high-rise buildings with fire safety and nonstructural hazards.

There are socio-economical and political problems associated with regulating privately-owned potentially hazardous structures. Detriments to small marginal businesses and the dislocation of low income residents who occupy many of these structures are some of the problems that were mentioned earlier. With identification of potentially hazardous buildings constructed in more recent times, there may be resistance from owners with relatively modern design standards.

Although the issues above are trying, the benefits to the community include reduced future deaths, injuries, and economic losses; and a reduced burden on County emergency response resources. An abatement program also improves the chances for a smoother post-earthquake recovery, as in the example of the post-disaster housing industry. The housing crisis can only deteriorate in the aftermath of a major earthquake. Gulliver (1986) calculated that up to 22,000 permanently homeless and 37,000 temporarily homeless people could result from the loss of housing resources in the aftermath of an 8+ earthquake on the San Andreas fault. Although the study was directed at an eight County region of southern California, it suggests that the Santa Clarita, Lancaster, and Palmdale areas could be hard hit. A major earthquake within the Los Angeles metropolitan area would have even greater negative repercussions on housing.

Short-term contingencies for aid to the homeless are planned by County agencies and supported by Federal Emergency Management Agency disaster relief packages. The County, however, could bear the economic brunt of long-term housing recovery unless rehabilitation/retrofit programs improve the survivability of potentially hazardous buildings (Gulliver, 1986). Abatement programs could also reduce the County's exposure to tort claims and other liabilities that might surface in a devastating earthquake.

Conclusions

- A large number of potentially hazardous buildings, other than buildings with bearing walls, remain to be recognized by County safety programs.
- The basic problem with the URM seismic upgrading ordinances currently being administered is that the penalty for noncompliance is condemnation and demolition with attendant dislocation of residents and businesses.
- The problem of potentially hazardous buildings extends not only to potential threats to life and injury, but also to long-term recovery, since a major earthquake will only worsen the current housing crisis.

SECTION 6.1.3

MANAGEMENT OF CRITICAL FACILITIES AND POTENTIALLY HAZARDOUS BUILDINGS

The first step of a comprehensive safety program for critical facilities and potentially hazardous buildings is the preparation of an inventory, which includes information on location, age, occupancy, and structural type. The second step of such a program is to evaluate and assign the buildings within the inventory a relative risk classification for eventual rehabilitation, abatement, or other hazard reduction program. Los Angeles County has instituted a number of inventory and evaluation programs for critical facilities and certain other facilities in their building stock. These include, but are not limited to the following:

- The County Department of Public Social Services (DPSS) currently maintains a list of schools, recreation centers, and other community service centers that can be used as mass care shelters. This inventory lacks a comprehensive assessment of the structural safety and potential building vulnerability in an earthquake (Edna Bruce, 1989; personal communication).

- The Department of Public Works maintains an inventory and risk evaluation program directed at County-owned or leased buildings. The DPW data base consists of an automated building inventory with the capability to sort County-owned or leased buildings by risk category, including the date construction was completed, building function, size, and location. Buildings in the inventory are correlated with the seismic safety building code periods of pre-1933, 1933 to 1973, and post-1973, and are then categorized into six risk subdivisions: essential (emergency maintenance and response), high-risk, medium-risk, low risk, dwelling, and historical. The class of assigned risk (high-medium-low) is a function of the number of hours of occupancy, the number of employees, and the building function. The DPW inventory of County-owned or leased facilities does not consider the characteristics of the building structure in determining the risk classification.

- The Los Angeles Sheriff's Department, which is designated as the local lead agency in the event of a major disaster, maintains a critical facilities inventory. The County Sheriff has established a computer network (Landtrac) that can list and plot the addresses of many critical and essential facilities. The Sheriff's Department has confirmed that their list is incomplete for many privately-owned facilities, especially those located in incorporated areas (Blanchard, County Sheriff, 1989; personal communication). The Landtrac data base, as of 1989, consists of the following:

  - Stations and facility locations for the Sheriff, the City of Los Angeles Police Department, other incorporated law enforcement agencies, and the California Highway Patrol;

- local and State government emergency operations centers;
- County Fire Stations in unincorporated areas and in cities that have contractual fire service agreements with the County;
- public elementary schools, high schools, colleges, and universities, designated as mass care shelters;
- County-owned hospitals and some health care facilities; and
- major streets, freeways, railroads, and airports.

- The County Fire Department maintains a list of private sector, County, and other government facilities housing equipment for heavy rescue operations. They are also attempting to inventory facilities storing hazardous materials, but as indicated in Chapter 5, the facility inventory was only 40 percent complete in 1988. The inventory is aimed at nonstructural safety of containers and emergency planning. No structural evaluation is planned as part of this inventory.

Integration of the County Fire Department information, the Sheriff's Landtrac inventory, the Department of Public Works building data base, and other County and private sector emergency building data bases is a preliminary step toward developing a comprehensive inventory of critical and hazardous facilities. Some of these facilities may be potentially hazardous buildings that might be prioritized for strengthening, abatement, or hazard reduction actions. Although coordination of computer systems among County departments is necessary for an efficient inventory program, discussions with the Sheriff's Department indicate that the Sheriff's computer information system is not compatible with the Arc-Info systems used by the Departments of Public Works and Regional Planning. As both are important lead agencies for various emergency response and/or planning responsibilities, improved system compatibility could also benefit their respective planning and disaster preparedness programs.

Building Screening

Building screening is a hazard reduction technique that allows efficient identification and classification of large numbers of public and private buildings according to their structural resistance to shaking, i.e., seismic capacity. Building screening techniques are especially appropriate in Los Angeles County with its large numbers of critical facilities and potentially hazardous buildings. The method provides a risk evaluation based on a complete structural assessment, which sets it apart from the current County procedure that employs age as an indicator of structure type. A preliminary step requires development of a screening methodology to assess the structural characteristics of building stock.

The Japanese government administers a building screening program that involves the inventory and structural assessment of all existing development in certain seismically active parts of the country (NLA, 1988). The Federal Emergency

Management Agency (FEMA), through the Applied Technology Council (ATC) and members associated with the Earthquake Engineering Research Institute (EERI), have also recently developed building screening procedures, and derived methods to estimate the costs of seismic rehabilitation (FEMA 1988-154). The financial costs of an inventory and rehabilitation program require innovative measures to reduce expenses. The following discussion will describe how a building screening methodology can be implemented, as modeled after the FEMA (1988-154) and Japanese programs.

Screening existing buildings for strengthening needs consists of four steps:

- Identification of age, occupancy, and building use;
- identification of structural type;
- application of the standard methodology for characterizing seismic capacity; and
- development of criteria for urgency of strengthening or rehabilitation.

The Department of Public Works (DPW) already uses the initial steps of the screening method described above to determine the age and building occupancy of County facilities and pre-1934 URM buildings.

Identification of the structural system as either a frame or box design is part of the Federal Emergency Management Agency technique. The classification system allows a qualitative, "rapid visual" assessment of the structural toughness of buildings (FEMA, 1988-154). Unreinforced masonry, tilt-up concrete construction, and certain other types of potentially hazardous buildings defined in the last section utilize box systems. Box systems use shear walls to sustain earthquake loads, while frame systems use a steel column-beam system to resist earthquake forces and are inherently stronger. The classification as a "box" shear wall system, by itself, does not categorize a building as potentially hazardous, since construction may also employ elements of a frame system and may have an adequate redundancy of strength. A series of structural scores and modifiers, representing such features as poor building condition, building age, and plan or vertical irregularity, are compiled and used to assign a final score to each building. The final score can be used to measure the need to conduct further assessment, a task that is left to the local government. The local government must develop criteria involving the cost of safety versus the benefit of hazard reduction.

As illustrated in the building screening/structural assessment flowchart shown in Figure 6.1, the Japanese procedure incorporates additional steps to determine abatement priorities. Preliminary evaluation allows a quantitative determination of the relative strength of each building beginning with a simple ratio of seismic resistance to seismic load (Bertero, et al., 1984). If the strength ratio is found to be above the selected standard, the building is designated "satisfactory". If the strength of the building falls below the standard, or there is some uncertainty about any of the parameters used in the preliminary evaluation, the building can be screened more quantitatively. Each subsequent

SCREENING EXISTING DEVELOPMENT FOR STRENGTHENING NEEDS

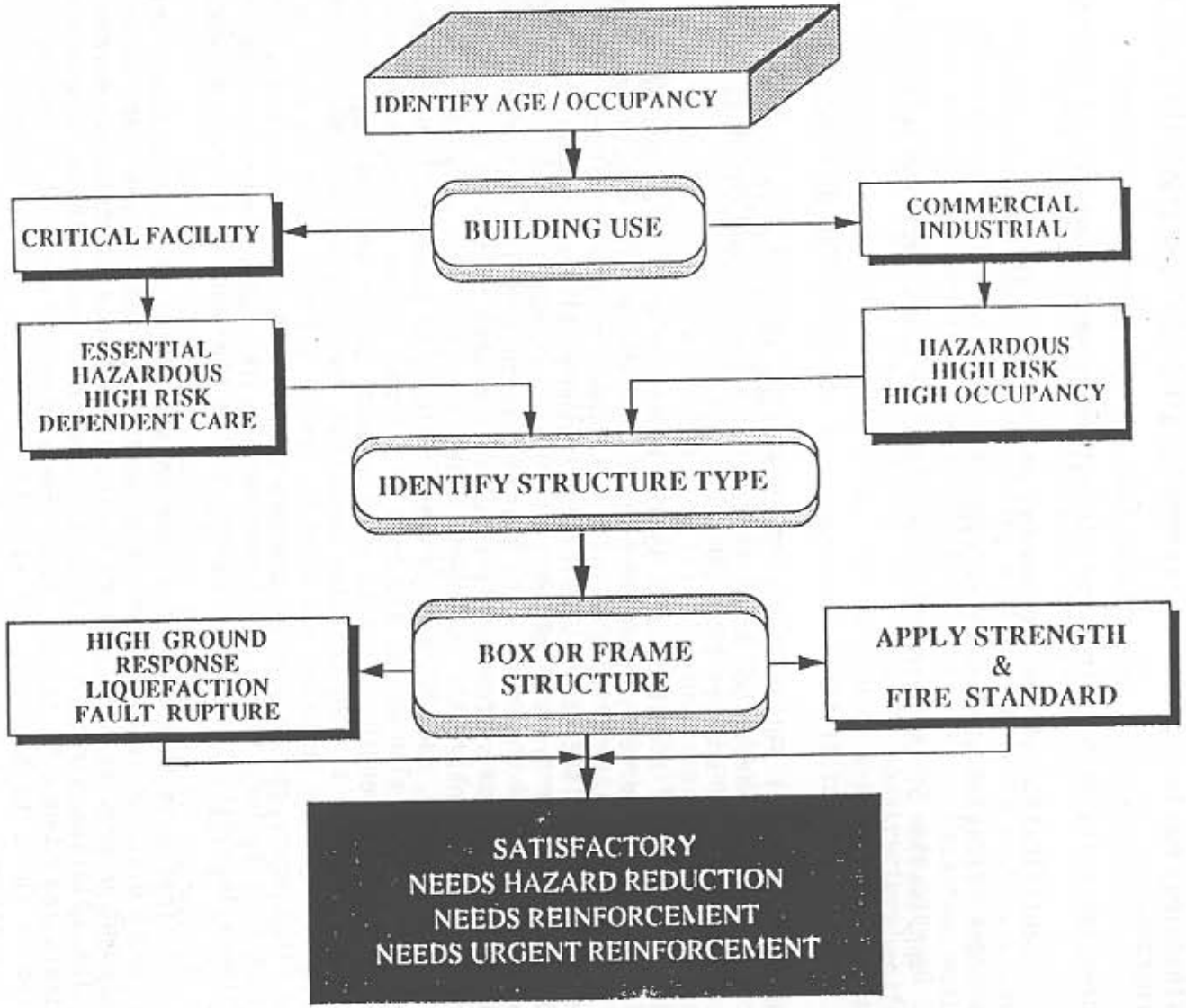

Figure 6.1: Flow chart showing a method for screening potentially hazardous buildings and critical facilities.

step in the screening process evaluates the building more rigorously. The process results in the following classification of buildings inventoried:

1. Needs minor structural or nonstructural improvements;

2. needs reinforcement;

3. urgently needs reinforcement; or

4. needs rebuilding (Bertero, et al., 1984).

In effect, a screening program determines an assigned risk for buildings with a high probability of being damaged in a future earthquake. In order to be consistent with the definition of potentially hazardous buildings (SSC, 88-01), the initial screening stage should also take into account seismic hazards, such as faulting and liquefaction (Figure 6.1). Scawthorn (1986) suggests that a preliminary safety assessment should also consider fire prevention deficiencies and recommendations for fire hazard reduction technology.

A Review of Selected California Building Safety Programs

Once the inventory, evaluation, and structural assessments are complete, a strengthening program should establish priorities and timetables for compliance, specific requirements for retrofit or hazard reduction, and other provisions. The County Five-Year Plan for Earthquake Preparedness (1987) recommends continuing analysis of various strategies, including incentives for voluntary rehabilitation of potentially hazardous buildings and critical facilities. Such programs are usually formulated on the basis of varying amortization periods, financial incentives or aggressive information campaigning.

An overview of two selected hazardous building abatement programs within California provides some useful perspectives on how to approach hazardous building abatement. The City of Santa Rosa has established procedures and criteria for the inspection of all potentially hazardous buildings and critical facilities. Their program considers occupancy, the location of the building, and structural resistance to establish priorities for abatement (rehabilitation, occupancy reduction, or demolition). A review of California programs found that the Santa Rosa program was one of the most comprehensive and stringent. Buildings failing to comply with the 1955 Uniform Building Code must be rehabilitated within one year of notice (BAREPP, 1986).

The City of Palo Alto, California administers a Seismic Hazards Identification Program (SHIP). BAREPP (1986) highlighted the following features of this plan:

- Identification and evaluation of all pre-1976 buildings;

- alternative corrective measures identified by a structural engineer;

- required rehabilitation for URM's and other types of pre-1935 buildings (dilapidated, etc.); and

- voluntary conformance with recommended mitigation measures for other buildings.

Under the SHIP program, unreinforced masonry buildings have the shortest period for abatement. Public and private pre-1935 buildings have slightly longer abatement periods. High occupancy (>300 people) pre-1976 buildings, although considered critical facilities, have the longest period of time to come into voluntary conformance. If the voluntary program proves to be ineffective, mandatory measures are to be applied (BAREPP, 1986). The scope of the program allowed provisions for voluntary conformance mainly because of community opposition to a comprehensive retrofit plan covering relatively recent development (pre-1976).

The examples given above suggest that there is a trade-off between achieving the UBC retrofitting standards and the enforceability of seismic abatement ordinances. Abatement of the pre-1955 structures addressed in the ordinance of the Santa Rosa program is mandatory, while abatement is voluntary in the Palo Alto pre-1976 ordinance. The County could utilize key years which reflect major changes in UBC seismic provisions or identify the years of post-1935 buildings that have experienced the most damage during earthquakes. In the case of nonductile, concrete frame low-rise buildings, a class of buildings which should be a target of future abatement efforts, two possibilities for retrofit priority exist:

- Mandatory retrofit priority for pre-1947 nonductile concrete frame low-rise buildings; and

- promotion of voluntary rehabilitation of pre-1972 UBC nonductile concrete frame construction, similar to the program instituted in Palo Alto. Voluntary rehabilitation could include incentives such as eliminating owner liability, tax breaks, and public recognition (BAREPP, 1986).

Although the age of the building is an important risk indicator for older deteriorated buildings, a proposed building screening program could more accurately assess the vulnerability of more recent construction and play an important role in enforcement decisions (FEMA, 1988-154). High rehabilitation priorities for critical facilities and potentially hazardous buildings could be assigned on the basis of location relative to liquefaction and fault hazards, in addition to structure, age, and occupancy.

Past precedent indicates that safety programs are often accelerated only after a major earthquake. Hazard abatement programs must be sustained to reduce long-term vulnerabilities, which can only increase as the aging and deterioration of existing development continue.

Conclusions

- Improved integration of County agency computer systems would greatly benefit the inventory of critical facilities and improve County emergency response capability and disaster preparedness programs.

- The current inventory of County-owned or leased facilities should include an assessment of the characteristics of the structure.

- "Building screening" allows efficient identification and classification of large numbers of buildings for their structural resistance to shaking.

- Emphasizing post-1933 buildings as high priority for mandatory abatement may require public financial support and additional relocation programs to reduce socioeconomic impacts.

- Voluntary rehabilitation of substandard pre-1971 UBC construction might be accomplished through economic incentives.

- Abatement programs aimed at critical facilities and potentially hazardous structure could reduce the impact of a major earthquake on County emergency operations and long-term recovery resources.

SECTION 6.2

EMERGENCY RESPONSE

The scope of the preparedness and emergency planning agenda are dealt with in detail in several County emergency management plans. Three primary County plans are:

- County Multi-Hazard Functional Plan for Emergency Operations (CMFP);
- County Five-Year Plan for Earthquake Preparedness; and
- Los Angeles County Emergency Ordinance.

The Safety Element does not attempt to duplicate these emergency plans. It provides an overall long-range policy framework for them and suggests long-range actions which may be taken to make emergency response planning and procedures more effective.

Accordingly, the Safety Element outlines a number of programs to strengthen the County's short-term emergency response capability. The main topics include:

- Greater public awareness and community and work place self-help capability;
- County disaster planning and readiness;
- critical facility emergency planning;
- interagency and interjurisdictional cooperation; and
- emergency response and urban heavy rescue.

The scope of the emergency response issues, as outlined above, will be considered in this Chapter within the context of:

- County emergency preparedness planning;
- emergency planning, response, and preparedness activities of Japan's Tokai Project, an innovative disaster planning program;
- earthquake prediction and applications of early warning technology; and
- disaster management for evacuation and urban heavy rescue.

Chapter 4 (Earthquake Vulnerability) and Section 6.1 also contain useful information relative to disaster planning and emergency response.

SECTION 6.2.1

COUNTY EMERGENCY PREPAREDNESS PLANS

The County Five-Year Plan for Earthquake Preparedness (1987) guides short-term emergency preparedness actions, including management and training of County agencies having emergency response duties. Many recommendations in the Five-Year Plan are directed toward strengthening or improving the survivability of critical facilities. Especially relevant to the Safety Element, the Five-Year Plan (1987) sets forth short-term and intermediate goals such as establishment of:

- County agency emergency operations centers;
- disaster staging areas;
- mass care shelters; and
- casualty collection centers.

The County Multi-Hazard Functional Plan (in press) details plans for the coordination of County agencies involved in activities such as damage assessment, fire suppression, search and rescue, and evacuation. Officers and employees of the County, which constitute the County Emergency Organization (CEO), are defined in the CMFP. The Multi-Hazard Functional Plan also establishes the framework for emergency mutual aid agreements with Federal, State and other local governments in the region.

The recommendations and emergency organizational structure defined in the Five-Year Plan (1987) and the CMFP are reflected in the County Emergency Ordinance and in other sections of the County Codes, which also establish the responsibilities of the main County Emergency Operation Center (EOC). The County EOC consists of several teams directly involved in coordinating County emergency activities:

1. Intelligence team which coordinates damage assessments;
2. logistics team which locates and mobilizes equipment and resources; and
3. operations team which plans the deployment of emergency personnel, equipment, and other resources.

The County Emergency Operations Center (EOC), through the Sheriff's Office, is the focus of an emergency organizational network involving city EOC's. It coordinates community action and plays a vital command role with the California Office of Emergency Services. A new state-of-the-art EOC is being planned and developed.

Coordinated disaster planning exercises are part of the County emergency preparedness program. County-wide emergency drills have involved as many as 76 cities (Constance Romero, 1989; personal communication). The purposes of these drills are to:

- Provide emergency training experience for the County Emergency Organization and city emergency services;

- test emergency communications of the County Disaster Radio Network;

- test the emergency broadcasting system and emergency power generator capability of selected private critical facilities (e.g., hospitals); and

- evaluate the effectiveness of these elements based on earthquake emergency scenarios, such as a hypothetical Magnitude 7.0 earthquake on Newport-Inglewood fault.

Many of the 86 cities in the County have some form of mutual aid agreement with County agencies for disaster emergency services. Approximately half of the cities contract for County Sheriff, Fire, and/or Public Works services and most maintain EOC's or utilize the local County Sheriff facility for this service (Constance Romero; personal communication). Many of the other 52 cities may be especially dependent on County emergency resources in the event of a major damaging earthquake. Mutual aid agreements may include law enforcement, fire suppression, evacuation, or post-disaster clean-up and safety inspection responsibilities.

Conclusions

- The County Five-Year Plan for Earthquake Preparedness (1987) guides short-term emergency preparedness objectives, while the Multi-Hazard Functional Plan establishes an organizational framework for the County Emergency Organization and a plan for mutual aid with Federal, State, and regional governments, as well as with other cities in the County.

- The County EOC guides coordination of County emergency activities such as fire suppression, search and rescue, evacuation, post-disaster safety inspections and clean-up efforts.

- The County Emergency Operations Center supports an emergency organizational network with city or Sheriff-operated EOC's, coordinates community action, and plays a vital command role in cooperation with the California Office of Emergency Services.

SECTION 6.2.2

JAPANESE MICROZONATION AND EMERGENCY PREPAREDNESS

The Japanese have pioneered the concept of microzonation, a planning concept that utilizes detailed mapping of seismic hazards to guide land use and disaster planning. Japan is also the only country in the world with a major prediction and early warning project that is integrated into its disaster preparedness planning program. An analysis of the Japanese program is instructive, since the Southern California Earthquake Preparedness Project has indicated that many of the Japanese preparedness programs may be applicable in southern California (SCEPP, 1982). In fact, many facets of their programs have already found their way into County emergency plans. Though later sections will refer specifically to Japanese efforts at earthquake prediction, early warning, and disaster management, this section will outline other components of their emergency planning strategy.

The Tokai region, located some 75 miles southwest of Tokyo, is designated an area of "intensified measures" by the Japanese government. This designation, has permitted the regional (perfectural) government to mandate and enforce certain planning and preparedness actions in the private sector (NLA, 1988). Located in an industrialized and economically developed region, the Tokai project provides several examples of disaster planning that might be adapted for use in Los Angeles County. Examples of the Japanese disaster countermeasure planning include:

- Tokai disaster planning maps (1:50,000-scale) show ground response, liquefaction, and landslide hazards and are used to coordinate emergency response and preparedness activities.

- Mitigation measures are employed to prevent earthquake-induced shallow slope failures from blocking roads that are designated as emergency response and evacuation routes, usually to and from isolated or high-risk communities. Roads are rerouted if mitigation measures are deemed unacceptable, regardless of right-of-way.

- Strengthening of lifelines and retrofitting of buildings with seismic design deficiencies is mandatory and prioritized using seismic hazard maps.

- A long-term rehabilitation program requires building construction along major evacuation routes to be fire-resistive.

- Using surtaxes, the government funds Disaster Prevention Centers (DPC) at the neighborhood level. DPC's are used to store and stockpile emergency equipment and supplies (i.e., water purifiers, emergency generators, flood lights, fire extinguishers and medical supplies).

- Local governments promote voluntary neighborhood self-help groups in a structured hazard management system involving designation of tasks to be performed by them in post-disaster situations, i.e., persons involved in light rescue, evacuation, and medical (first-aid) assistance operations.

- Strict safety and preparedness guidelines are required at "high-risk facilities" that use or store hazardous materials.

- Local governments require as many as 17,000 private companies in high-risk areas to submit emergency response plans, 84 percent of which were completed between 1980 and 1983. The plans address equipment tie downs, hazardous materials management, employee training, emergency evacuation procedures, and fire fighting.

- In the event of an "imminent" earthquake prediction, emergency response equipment and high-risk communities are moved to safe staging areas identified by using the seismic hazard maps (NLA, 1988).

Opportunities for Los Angeles County

What sets the Japanese programs apart from those in Los Angeles County are the scope of government investment, provisions for mandatory hazard reduction in the private sector, and the level of public involvement in preparedness activities and regular earthquake drills. The financial commitment to hazard reduction and disaster preparedness realized in Tokai could be difficult to duplicate in Los Angeles County. An estimated 1 billion dollars a year is spent on earthquake preparedness in the Tokai region (NLA, 1988). Unless mandated by the State, the differing priorities of the local governments in the County are a formidable challenge to implementing activities similar to those of the Tokai Project.

The feasibility of designating evacuation routes and developing programs to mitigate hazards along their path may be an urban/disaster planning measure worthy of consideration. In Japan's case, concern for hazard reduction and evacuation planning has largely evolved from the urban fire threat. The lesson for the County may be to consider targeting certain streets for fire resistive construction, given the potential for fire spread, especially those on routes located in areas of concentrated development. The Japanese actions pertaining to prevention of critical road blockages during earthquakes may be difficult to adapt to Los Angeles County because of right-of-way jurisdictional authority along most public roads. The County may consider using a Geologic Hazard Abatement District concept to prevent blockage along exiting routes that might prove vital in an emergency, such as fire lanes or access routes in mountainous areas.

The Japanese emphasis on Disaster Prevention Centers, voluntary neighborhood self-help groups, and structured hazard task management could be utilized in Los Angeles County. Preparedness action is already stressed in several jurisdictions in California. Isolated communities in the Santa Cruz Mountains have formed organized community rescue teams (Paula Shultz, 1988; personal communication, 1989). The Santa Cruz program inventories local skills, materials, and communication alternatives, and stockpiles supplies. Volunteer nonprofit community groups have begun such tasks in Los Angeles County, but are not yet widespread. The County may benefit from promoting the use of existing neighborhood watch programs to perform emergency functions (Regensburger, 1988; personal communication).

Greater emphasis on regional-scale disaster response planning may be worth exploring. Although earthquake scenarios are being used more commonly in developing County emergency plans, hazard reduction countermeasures can be also be formulated either to react to, or to reduce the impact of, several possible problems including:

- Disruption of transportation, communications, and utility systems,
- collapse of critical facilities and infrastructure, and widespread destruction of residential areas;
- impeded ingress or egress of emergency vehicles and heavy equipment by blocked roads or structural/nonstructural failures;
- fires and releases of hazardous materials; and
- catastrophic breaching of reservoirs and flooding of large areas.

Selected hazard reduction countermeasures for problems posed by existing development in Los Angeles County are illustrated in Figure 6.2. They include actions such as fire suppression, strengthening of lifelines, and evacuation planning. As required in Tokai, safety might be emphasized more in areas especially prone to liquefaction or strong ground motion. Similar to the Tokai Project, hazardous areas can also be used to guide deployment of emergency resources and to those areas displaying a greater risk of damage (Figure 6.2). As detailed later in this section, such contingency plans can benefit from knowledge of where hazardous buildings, critical facilities, or infrastructure are located (Figure 6.2).

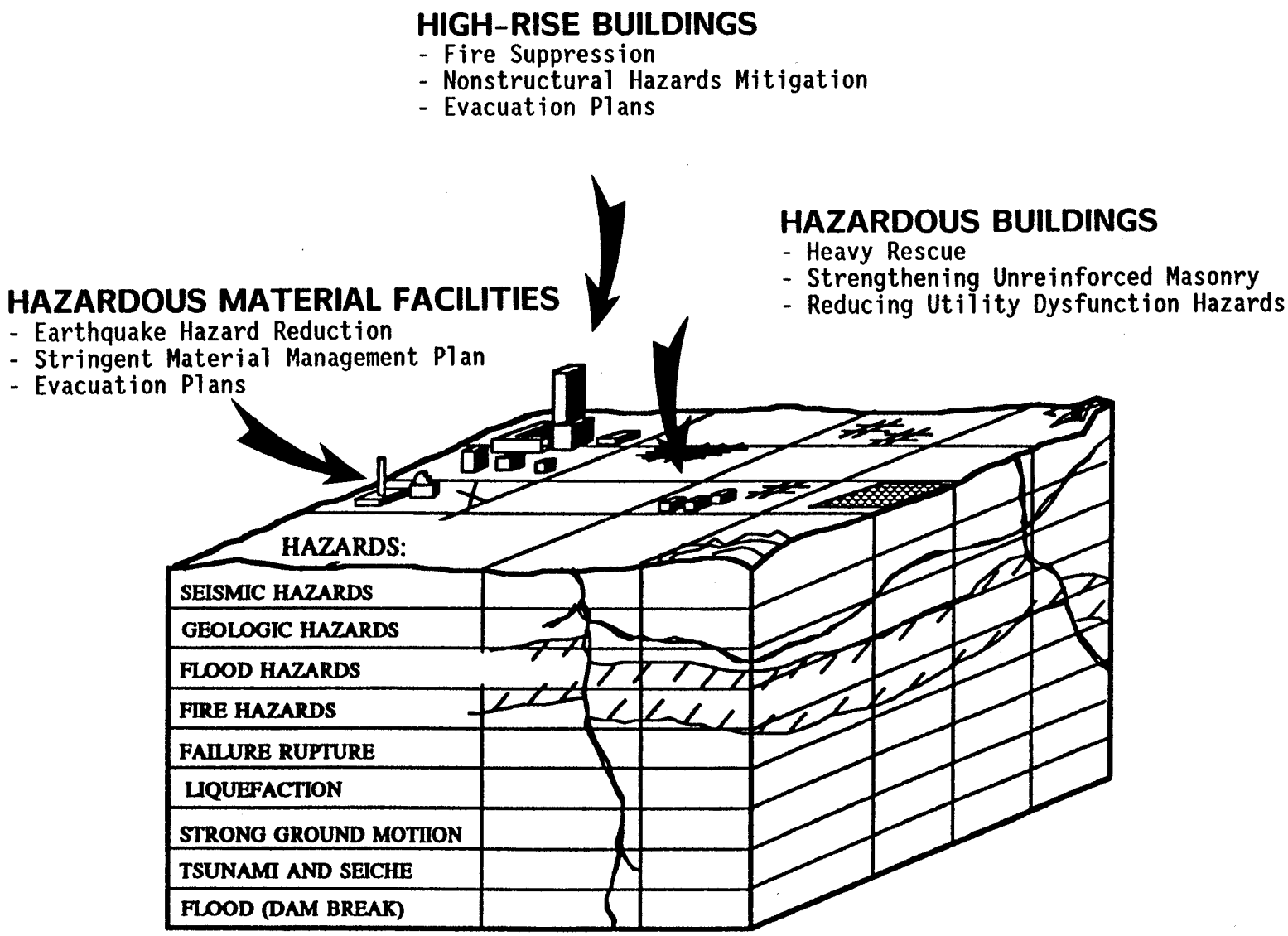

Figure 6.2: Selected hazard reduction countermeasure planning for existing development located in hazardous areas.

Conclusions

- Knowledge of the location of seismic hazards and vulnerable buildings, even if only generally known, can help initiate appropriate hazard reduction countermeasures, including structural/nonstructural strengthening, fire prevention, evacuation planning, and regional allocation of emergency response resources.

- Existing Neighborhood Watch or other community groups could be used to perform various emergency functions, a program that could reduce the burden on County emergency response and recovery resources.

- County emergency management plans need to be maintained up-to-date and improved based on new knowledge and experience.

- The system of emergency operations centers must be maintained and improved. This includes improved equipment and adequate professional staffing.

SECTION 6.2.3

EARTHQUAKE PREDICTION AND EARLY WARNING SYSTEMS

Earthquake Prediction

As mentioned in the examples of the Japanese disaster countermeasures, the Japanese government has proceeded with an operational earthquake prediction network in the Tokai region of Japan (SCEPP, 1982). The prediction effort, which is part of a broad-scale program for evacuation of cities in the region, is planned to allow enough warning time for public agencies to reduce water levels in dams and undertake other preparedness actions. One beneficial aspect of the Tokai Project is that an increased level of community consciousness has accelerated preparedness and hazard reduction programs (SCEPP, 1982). A medium-term advisory report for the 1989 Bay Area (Loma Prieta) Earthquake, although unofficial and wrong in location, has been credited with imbuing a higher level of government preparedness in the Santa Cruz and Bay Areas (Paul Flores, 1989; personal communication).

Five fundamental aspects of earthquake prediction and forecasting are presented below, as modified from Rikitake (1976), and Scawthorn and Gates (1983):

1. Long-term: years to decades (using the historical and geologic record, accumulation of strain, and seismic gaps).

2. Medium-term: less than one year to months (using accelerated crustal deformation, foreshocks and anomalous geophysical phenomena).

3. Short-term: months to days (using radon content in wells, foreshock patterns and anomalous geophysical phenomena).

4. Imminent: hours to days (using cessation of microseismicity, animal behavior, etc.)

Presently, the technology does not exist for reliable medium-, short-term and imminent predictions. Los Angeles County has, however, outlined a plan for response to a short-term earthquake prediction in the event the capability is developed. Such a prediction would be issued by the California Earthquake Prediction Council and disseminated by the Governor of California. The most accurate existing forecast for Los Angeles County is limited to a long-term prediction on the San Andreas fault. The Mojave fault segment is estimated to have a 30 percent probability of a Magnitude 7.5 earthquake in 30 years, nearly identical to the probability designated to the segment that ruptured during the 1989 Bay Area (Loma Prieta) Earthquake (Davis, 1988). The risk is estimated as a two percent annual probability, or as a recurrence of one 7.5 Magnitude earthquake every 150 years, with the last rupture occurring in 1857 (Holden, 1989).

The information needed to estimate recurrence for faults underlying the basin (i.e., buried faults) and most other active faults in the County is not yet known. Any one of the 50 or more active and potentially active faults in the County could be the future site of the next 6.5 to 7.0 Magnitude earthquake (Ziony, 1985). Increased monitoring of geophysical phenomena, foreshock patterns, and microseismicity by Cal Tech and the USGS in the Los Angeles Area might reveal precursor patterns, but would require greater government investment than currently exists. There are no comprehensive prediction efforts currently operational in Los Angeles County.

The Tokai prediction effort is based on a long-term forecast for the expected Tokai Earthquake. The prediction system operates 24-hours a day, continuously monitoring for anomalous seismic activity or geophysical phenomena with over 200 experiments or instrument arrays (SCEPP, 1982). As stated earlier, this one of-a-kind predictive effort is unique in that disaster planning is closely tied to the prediction project. Furthermore, the project applies to an area with a population of nearly six million residents, making it an extremely practical experiment (SCEPP, 1982). Some critics doubt the likelihood of success for the Tokai prediction project. However, the knowledge gained, the potential for saving thousands of lives, and the advantageous effect on earthquake awareness and preparedness among the populace are obvious merits.

In Los Angeles County, the San Andreas and Newport-Inglewood fault scenarios essentially function as long-term forecasts, especially in the sense that they promote preparedness. For the present, although the scenario earthquakes have been used to test the emergency organizational network in the County, the potential exists for improving public participation in future disaster response exercises designed for these faults.

Earthquake Early Warning

As implied above, large earthquakes pose the most challenging problem for disaster response planning. For many natural disasters, such as hurricanes or tornados, there is often sufficient time for governments to warn and evacuate people from areas especially vulnerable to the full force of the event. Precautionary actions such as shutting off gas systems, stopping sensitive industrial processes, and mobilizing of emergency resources can be initiated. For the time being, the County is vulnerable to a major earthquake with little or no warning. This increases the likelihood of casualties from primary and secondary hazards. Given this vulnerability, and the reality that reliable short-term or imminent predictions are not currently available, increasing interest has been placed on utilizing early warning systems.

Early warning options consist of the following:

- An early warning system (EWS) that detects an earthquake in proximity to it's epicenter, determines if the earthquake is large enough to be of concern, and then transmits sufficient information to issue a reliable warning. An EWS would consist of an array of seismographs and other instruments along a fault; and a radio warning relay and receiver system.

A transmitter in the epicentral area would send a signal by one of a number of potential communication networks to "out race" the earthquake shock to command centers in an affected area. Various options for the communication relay system include satellite, telephone/telegraph, microwave, or radio/television cable networks.

- A user-deployed ground motion triggering system that activates automatic shutoff valves or warnings.

Radio-Transmitted Earthquake Early Warning Systems

For a radio-transmitted EWS to be effective, an earthquake must occur at a critical distance away from the receiving system to allow adequate lead times. An earthquake occurring 50 kilometers away from the Los Angeles Basin would give lead time of about ten seconds, suggesting some potential applications for warning of the 7.5 Magnitude earthquake forecast for the Mojave fault segment of the San Andreas fault (Holden, 1989). The distance to the earthquake epicenter is not the only constraining variable that determines the feasibility a radio-transmitted early warning. The feasibility also depends on the following:

- Lead times needed by EWS users for efficient operational response;
- costs incurred from business shutdown and slowed production;
- loss of business profitability; and
- the impacts of false alarms.

To be feasible, the cost factors incurred from lead times ($\leq$ 10 seconds) must outweigh the extra damage/costs that could result from an unalerted earthquake. A survey published in the California Division of Mines and Geology Special Publication 101, noted that the majority of potential users of an EWS required response times greater than 30 seconds to efficiently utilize an early warning system. The survey reported that fire departments required as much as 120 seconds to remove apparatus from fire stations, while facilities using heavy equipment, some of which operate with hazardous materials, required 60 seconds for efficient shutdown periods. The cost-benefit ratio of utilizing an EWS cannot be fully anticipated; however, the survey data suggest an EWS for the large majority of businesses would be unfeasible. To be feasible, the cost of shutdown would have to be measured against a perceived threat to public safety, such as that posed by a catastrophic hazardous material incident (Holden, 1989).

The radio-transmitted EWS is vulnerable to false alarms. Holden (1989) has indicated a potential false alarm rate for the Mojave segment of San Andreas fault at one every six years. Japan experiences numerous false alarms within a similar system employed to automatically shut down bullet train operations. The State has studied potential liability problems of an EWS System for incorrect warnings. Citing a 1970 decision of a court case involving Connolly versus the State of California, Holden (1989) concluded that an EWS System operator may be held liable only if predicated on the basis of data gathering, evaluation, and dissemination of the forecast data that was handled in a negligent manner.

User-Deployed Automatic Alert Systems

A user-deployed system is not really an early warning system but an automatic device fitted for systems shutdown and alert. The device detects P-waves, the waves which roll ahead of the more damaging strong ground motion associated with S-waves. For potential users in a range of ten kilometers (six miles) from the epicenter, a user-deployed system is more feasible than an EWS radio-transmitted system (Holder, et al., 1989). One problem is that the device can not discriminate near field, high frequency peak ground P-wave accelerations for earthquakes in the magnitude range of 4.0 through Magnitude 7.0. Therefore, false alarm rates are higher in P-wave operated systems and can be triggered with relatively small earthquakes. The Japanese have experienced as many as three false alarms per year (Bertero, et al., 1988). The user deployed P-wave systems are feasible for facilities or potential users that can shut down or react with short warning and can tolerate high false alarm costs.

User-deployed devices are probably the most economical option for personnel and personal uses (Holden, 1989). Short warning times are useful for safety actions like moving personnel away from hazardous locations, i.e., windows or industrial processes using toxic, caustic, or explosive materials (Figure 6.3). The Japanese wire public loudspeaker systems to user-deployed systems to issue warnings and pre-recorded messages stating appropriate hazard reduction actions. They are deployed in schools, industry, and selected locations throughout the community (Bertero, et al., 1988). Several large businesses in the Los Angeles area have already installed versions of the user-deployed system including TRW, Pacific Bell, Chevron Oil, GTE, General Dynamics, and Hughes Aircraft (Los Angeles Times, November 15, 1989). Figure 6.3 shows additional uses where the system may have valuable applications in either hazard mitigation functions or protection of vital computer-based economic transactions or information (ESS, 1988). The radio-transmitted EWS and the user-deployed system are both unsuitable for evacuation purposes, due to short warning times (Holden, 1989).

User-deployed automatic gas shutoff valves have found a widespread market in the private sector, mostly for their potential in reducing the post-earthquake fire hazard. Currently, there is considerable debate about whether automatic gas shutoff systems should be required for southern California homes and businesses. The Building Seismic Safety Council, under authority of the Federal Emergency Management Agency, has suggested that "utility or service interfaces of gas, high temperature energy, and electrical power supply should be provided with shutoff devices at the building side of the interface" (ESS, 1988).

Some cities are considering ordinances that would require installation of these fire-hazard reduction devices. As reported in Chapter 4, automatic gas shutoff valves functioned adequately during the Whittier Narrows Earthquake. However, as many as 14,000 automatic valves were activated and required a week for the Southern California Gas Company to fully restore private natural gas operations (Schiff, et al., 1988). The Southern California Gas Company estimates that had gas shutoff valves been mandated at that time, as many as 100,000 units would

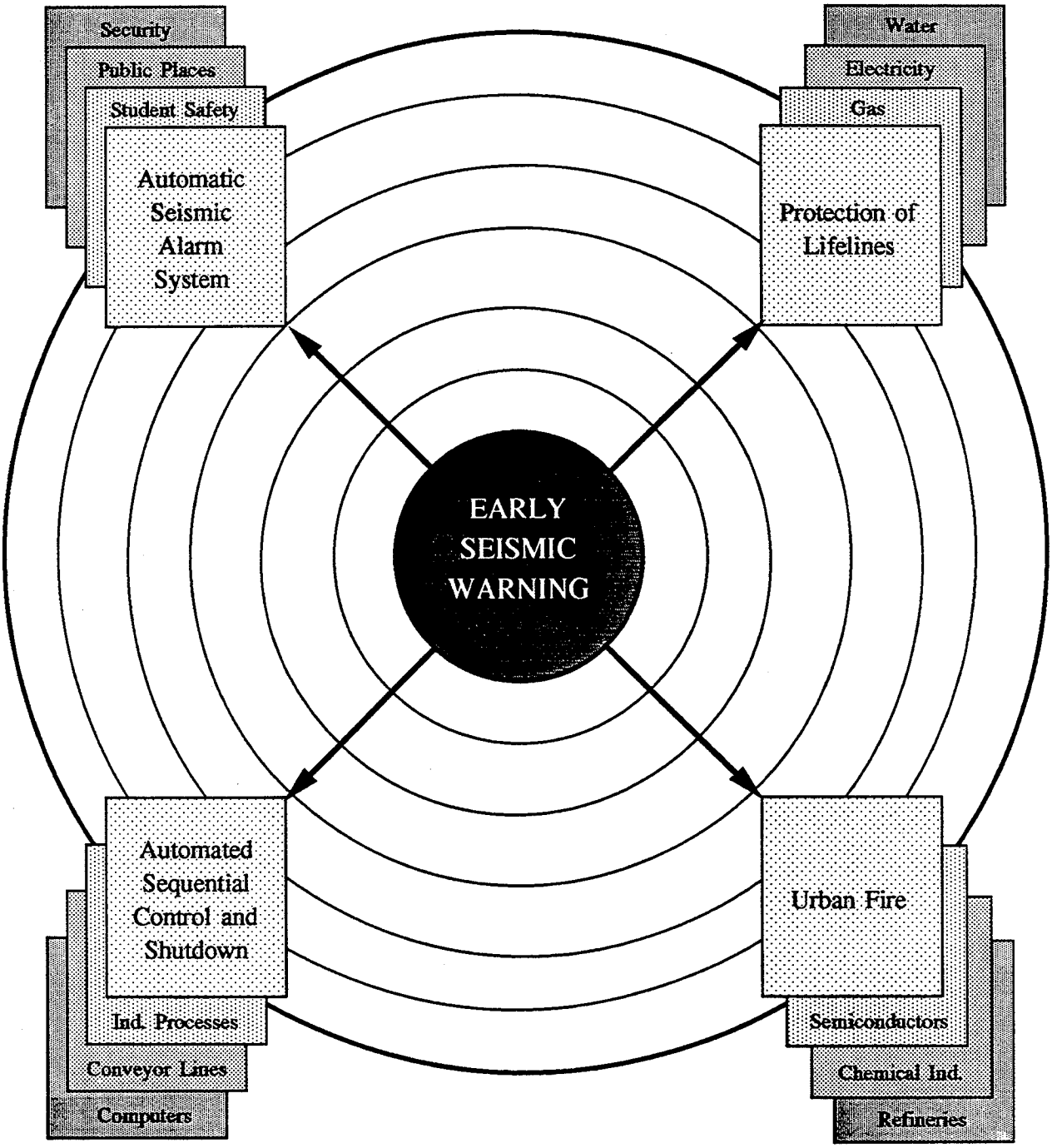

Figure 6.3: Beneficiaries of an early warning system (after ESS, 1988).

have been shut off. It is not clear at this time whether the benefits of such an ordinance would outweigh the costs incurred from the potential drain on emergency resources that would be needed to restore power in the aftermath of major earthquake. Historically, most earthquake-induced fires are caused in areas of earthquake-induced ground failures, or by inadequate restraint of residential gas utilities and hazardous electrical utilities (Scawthorn, 1986).

Tsunami Early Warning

The Alaska Warning Center (AWC) is responsible for regional tsunami warnings along the coast of southern California. Approximately 21 minutes are required between the time of detection and relay of warning. Twenty-one minutes, plus the additional time necessary for transmission of the National Warning System message to State and County emergency services and the subsequent initiation of response and preparedness action is not adequate for locally generated tsunamis.

The Tsunami Hazard Reduction Utilizing Systems Technology (THRUST) is an established pilot program developed through the U.S. Agency for International Development Office of Foreign Disaster Assistance. The general approach of the program includes pre-event emergency planning, real-time assessment, and rapid warning via the satellite communications links (Bernard, et al., 1988). The low cost (on the order of tens of thousands of dollars) Thrust System could warn Los Angeles of a tsunami generated off the coast of southern California in as little as two minutes, thus allowing longer lead times for preparedness operations.

The three components of the system are:

- Pre-tsunami preparedness, including development of a detailed emergency response plan;
- real-time local hazard assessment using seismic triggers with predetermined threshold response levels; and
- rapid dissemination of information to local officials using the Geostationary Operational Environmental Satellite.

Conclusions

- Existing technical capability to forecast long-term and short-term advisories, although not perfected, should be used to accelerate preparedness and hazard reduction programs and perform disaster exercises.

- The feasibility of requiring residential gas shutoff valves needs further study and evaluation.

- A fire-hazard reduction program aimed at earthquake-induced fires should consider the propensity for fires in older buildings, in areas of potential fault rupture or other ground failures like liquefaction or landsliding, and the high probability of fires started by damaged gas appliances.

- There are potential applications for radio-transmitted EWS or user-deployed EWS devices for businesses using hazardous materials, computer shutdowns, and personnel or personal safety alerts on loud speaker systems in schools, public places, and businesses.

- The appropriate State and Federal agencies should establish a Tokai type project in southern California to improve earthquake warning capability.

SECTION 6.2.4

DISASTER ASSESSMENT AND MANAGEMENT

In the immediate aftermath of a major earthquake, numerous decisions are made concerning evacuation, and search and rescue operations. Suspension and resumption of critical utilities, including utility services, industrial processes, and transportation services are very important. Effective evacuation and heavy rescue operations hinge not only on accurate disaster assessments but on predetermined strategies for coping with a myriad of possible contingencies. This section focuses on two specific post-disaster operations:

- Management of dam failure and hazardous materials incidents; and
- analysis of urban heavy rescue operations.

Evacuation Operations

Damage assessments of larger infrastructure such as dams and bridges are of paramount importance for guiding emergency operations. The Department of Public Works utilizes an aerial survey team to assess County dams and other critical County facilities (CMFP, 1989). The team is linked to the County Disaster Communications Network at the County EOC. Private-owners of dams and reservoirs, if governed by State regulations, must maintain internal emergency plans that include procedures for damage assessment and emergency warnings. These plans include two main elements:

1. Identification of emergency conditions threatening a dam, including criteria for warning of "failure imminent" or "failure in progress" (FEMA, 1988-145); and
2. a plan for notifying downstream communities within dam inundation zones of evacuation.

The actual evacuation warning to the public is relayed through emergency officials. In Los Angeles County, the Sheriff has lead responsibility for warning and evacuation operations (CMFP, 1989). FEMA (1987-145) advocates proactive, cooperative planning not only with disaster service officials but also with local officials in potential inundation areas, including local fire and law enforcement agencies. The inundation maps prepared for the State Office of Emergency Services would show which emergency facilities are most strategically located to receive and relay local warnings. FEMA (1987-145) suggests that dam disaster planning should provide at least the following components:

- Identification of schools, jails, and hospitals in inundation zones;
- improved public awareness;

- increased public familiarity with evacuation plans through publications and well-publicized exercises; and

- a reliable and redundant warning system for alerting responsible agencies.

The Japanese utilize well-publicized evacuation maps to prepare the public for evacuation operations (EERI, 1986). Figure 6.4 shows an example of such a map for an area at extreme risk to post-earthquake fires. This auspicious approach, which includes emergency evacuation drills, promotes better coordination between the public and emergency response officials (Bertero, et al., 1988). Such a strategy might be adapted to dam inundation zones in Los Angeles County, where there appear to be no provisions for public participation. If the need did arise, improved public awareness would be of paramount importance. Public alert systems used in Japan for earthquake warning may also have applications for evacuation in high-risk dam inundation areas.

The evacuation problems posed by hazardous materials incidents are similar to those for dams, except that in the event of major damaging earthquake, disaster assessment and evacuation would be more difficult. Due the number of potential sources of toxic materials, present County emergency plans rely on warnings from the individual facilities. This can be difficult if their communication systems are rendered inoperable by downed transmission lines or telephone oversaturation. Furthermore, toxic gases can be totally undetectable to the community and the movement of a gas plume cannot be readily predicted. This problem remains even if emergency officials are immediately notified. Regardless of these limitations, a strategy for evacuating residents would still require public participation, including identification of communities at risk, forewarning and educating these communities of County disaster plans, and developing public evacuation exercises. As with dams, conditions should be defined for the following:

1. Identification of emergency response conditions which warrant warning of "release imminent" or "release in progress", and types of chemicals involved in the release; and

2. a reliable and redundant warning system for notification of hazardous material response units and communities within impact of an unauthorized atmospheric release.

As suggested for dam inundation zones, a public alert system may also have hazard reduction applications in high-risk areas. For instance, it may be appropriate to instruct and equip the nearest population centers with gas masks. Such a requirement might be considered in areas where normal diffusion of gases would not be expected to lessen toxic concentrations or where dependent populations might be affected.

EVACUATION PLANNING

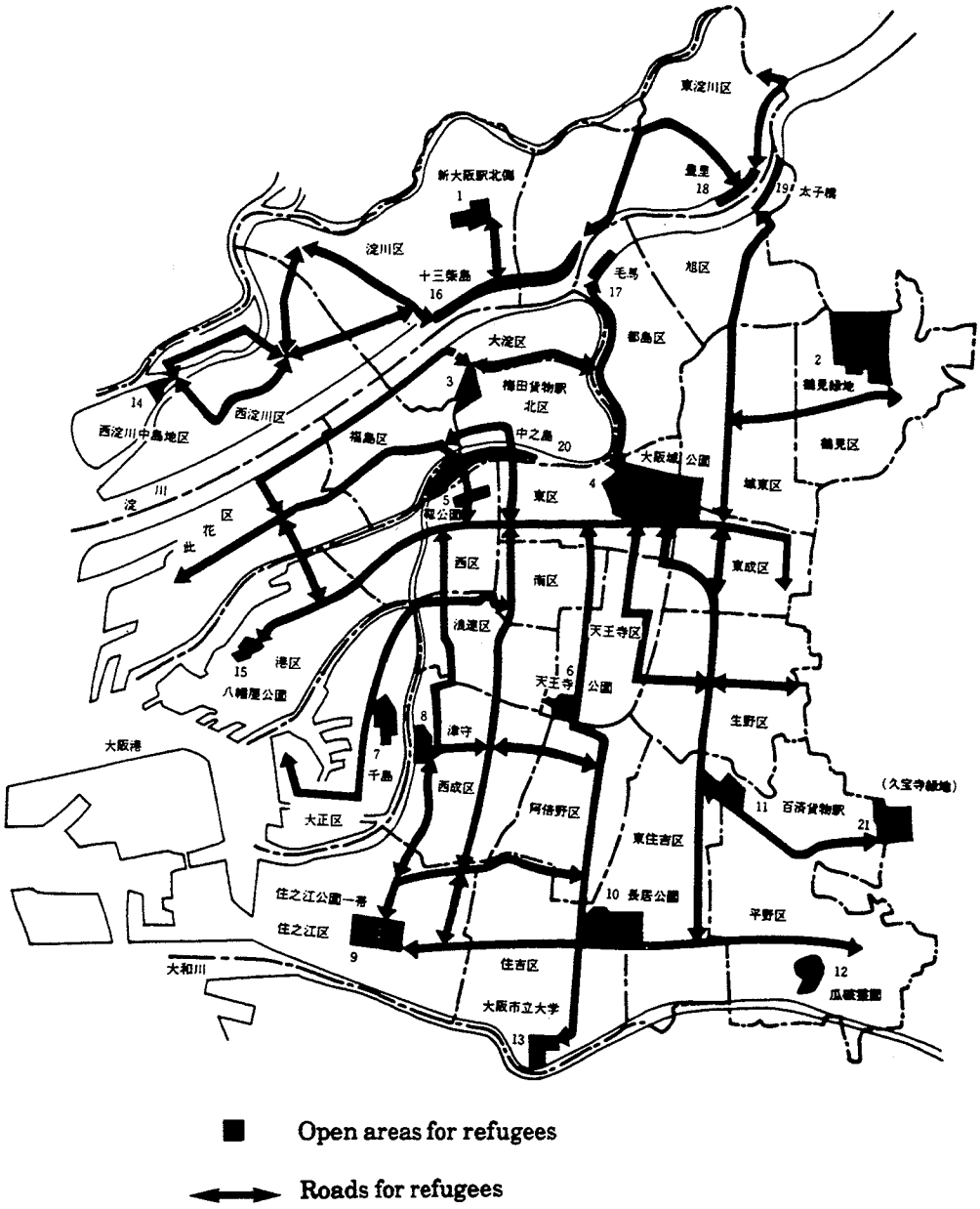

Figure 6.4: Evacuation planning: an example of a comprehensive disaster plan undertaken by the Osaka Japan City Planning Department. This plan designates large open spaces and egress roads that will be kept open top allow evacuation to from a large urban fire (after EERI, 1986)

Urban Heavy Rescue

Urban Disaster Planning

The estimated 15,000 pre-1934 unreinforced brick masonry (URM) buildings located throughout the County pose logistical problems for Urban Heavy Rescue (UHR) operations. Aggravating this problem, only 22 of the 86 cities in the County have enacted seismic upgrading ordinances for URM's. The potential for total or partial collapse of URM's to be concentrated in many of the other 64 cities can be considered a distinct possibility. Fortunately, the City of Los Angeles, which possess over half of the inventory of URM's, is implementing a seismic upgrading ordinance and maintains an intensive UHR capability. However, many other cities in the County may have little or no UHR capability and may rely on mutual aid agreements. Given the primary role of the County in disaster management, there should be a long-term emphasis on promoting hazard reducing regulatory measures in cities.

Recent and ongoing URM inventories by incorporated cities and the County provide a new opportunity for heavy rescue planning. Olson and Olson (1987) suggested that, based on existing inventories of URMs, heavy rescue operations could be planned to provide rapid emergency response to concentrations of URM's. As implied in figure 6.2 in a previous section, certain other potentially hazardous buildings and facilities and "high-risk" structures such as aged elevated highways, overpasses, underpasses and tunnels could also eventually receive special UHR priority. The very large number of building and/or structural failures possible in Los Angeles County dictates this level of urban heavy rescue planning.

Subregional Heavy Rescue Bases

Effective UHR operations involve management of an intricate balance of resources including specialized equipment, trained personnel, communications and command capability. The importance of UHR is underscored in every major damaging earthquake. The 1987 Mexico City Earthquake, the 1988 Armenian Earthquake, and most recently, the Bay Area (Loma Prieta) Earthquake, provide reminders that many earthquake casualties are not instantaneous, and that UHR equipment and personnel must be deployed in an efficient manner. In many third world countries, a lack of trained personnel, necessary heavy equipment, and poor coordination or communication have lead to inefficient rescue operations (Olson and Olson, 1987).

The 1989 Bay Area (Loma Prieta) Earthquake provides an instructive lesson in UHR planning. The earthquake verified a pattern noted by Shi-Ri (1980) which indicates that the survival rate of trapped earthquake victims drops rapidly after the first 72 hours. Another pattern confirmed in the earthquake is that the majority of victims are rescued immediately following a structural collapse by those people who happen to be in the immediate vicinity (Olson and Olson, 1987). In fact, it appears to be critically important for a UHR operation to respond much more quickly than 72 hours. The Federal Emergency Management Agency found that 41 of the 56 casualties in the 1971 San Fernando Earthquake could have been prevented if UHR deployment had arrived sooner, even though the response

time was within hours (Silvertein, 1984). An untapped resource that can save lives may be the volunteer, especially if trained in light rescue operations and first aid treatment.

During the first hours following the collapse of the Nimitz Freeway in the 1989 Loma Prieta Earthquake, many volunteers that offered their assistance were not adequately utilized because of a lack of an effective program to channel volunteer resources or people in the immediate vicinity of the collapse. Although some of the more seriously injured and inaccessible victims could not be rescued until specialized heavy equipment could arrive several hours later, a logistical UHR plan might plan to utilize on-the-scene volunteers and donated equipment in the immediate area.

A logistical plan for acquisition and maintenance of UHR resources might also benefit from a network of subregional heavy rescue bases. Inasmuch as an earthquake can affect any area of the County, a dispersed network of UHR bases would have a better chance of responding within the first critical hours after a major earthquake disaster. The basic elements necessary for development of a subregional heavy rescue system might include:

- A system of subregional UHR bases planned and coordinated with the availability of existing resources provided through County UHR contracts and/or mutual aid agreements;

- identification of vulnerable buildings and structures in a subregion that may need a higher priority for heavy rescue operations based on structural deficiencies or occupancy; and

- identification of seismic hazards, i.e., areas of high ground response, susceptibility to ground failure, and other considerations that could also be used to prioritize the distribution of heavy rescue resources.

In the County of Los Angeles, fire fighters conduct training exercises for urban search and rescue operations in a state-of-the-art collapsible building. The County is also supported by a network of mutual aid agreements with other regional governments and the military. A network of subregional heavy rescue bases could streamline these existing strengths for more efficient response. A proposed $58 million dollar EOC digital communications system to be operated by the County of Los Angeles could be utilized to coordinate such a network.

Conclusions

- Evacuation planning should include a reliable warning system to alert authorities responsible for public safety, identify dependent care populations in areas that might be effected, and provide for an aggressive public awareness campaign designed to increase the familiarity of evacuation plans through public information programs and well-publicized exercises.

- A public warning system may have applications for improving and managing evacuation operations and can alert the public to undertake personal hazard reduction actions in areas at risk from dam inundation or accidental release of toxic materials.

- There are 64 cities in Los Angeles County that have not enacted seismic upgrading ordinances.

- An inventory of hazardous buildings or structures and the locations of hazard areas could be used as the basis for developing a subregional network of UHR heavy rescue bases.

- Heavy rescue operations should be able to extricate survivors in much less than 72 hours after a disaster; however, there would be a greater assurance of survival if they are rescued within the very first hours, an objective that would benefit from a plan to use the assistance of volunteers for first aid and extrication operations, as well as donated equipment in a effective manner.

CHAPTER 7

SEISMIC HAZARD OVERLAY ZONE

AND

RELATED PROGRAMS

SECTION 7.1

SEISMIC HAZARD OVERLAY ZONE

The Los Angeles County's Five-Year Plan for Earthquake Preparedness (1987) recommended inclusion of a seismic hazard overlay zone in the Zoning Code. The following discussion responds to that recommendation by examining the overlay zone concept. It evaluates the need for a seismic hazard overlay zone, outlines provisions of such a zone, identifies potential strengths and weaknesses, and describes some alternatives for applying provisions of the zone.

A prior section on future development identified the Zoning, Subdivision, Building and Fire Codes as the primary County regulatory programs protecting public safety (Figure 5.1). A zoning overlay could maximize the potential of these existing safety programs. The seismic hazard overlay zone would cover designated hazardous areas, such as active fault zones and areas subject to liquefaction. Within designated areas, it would reinforce existing zoning.

Purpose of a Seismic Hazard Overlay Zone

Local government's responsibility to ensure public safety and the pressures to develop hazardous areas can sometimes be in conflict. Recognizing that development in hazardous areas cannot entirely be prohibited, the County is seeking ways to reduce the risks associated with development in hazardous areas. The purpose of a seismic hazard overlay zone is to enhance protection of public health and safety in seismically hazardous areas. The objectives of a zone are to:

- Increase public awareness of the risks of living in seismically hazardous areas, and of measures that can be taken to minimize those risks;
- provide for special studies and investigations which will improve site design and planning as means of reducing risks;
- Identify measures which may be applied to reduce risks; and
- identify land uses and activities which are most compatible with the hazardous conditions.

Provisions of an Overlay Zone

This section presents a brief outline of three types of provisions associated with a seismic hazard overlay zone, including compatible land uses, special studies and investigations, and possible measures to eliminate or reduce risks.

Some examples of uses which may be most compatible with a seismic hazard overlay zone are:

- Farming;
- cattle or dairy operations;
- agricultural processing and sales;
- mining, quarrying, and associated processing;
- forestry and tree farming;
- nursing stock production and sales;
- commercial outdoor recreation;
- riding academies;
- golf courses;
- hunting preserves;
- public outdoor recreation; and
- residences and caretaker dwellings associated with the above uses.

Examples of uses which require careful review and special studies include:

- Critical facilities;
- uses which may involve assembly of large numbers of people;
- large scale residential developments;
- major commercial developments; and
- major industrial developments.

Stringent review could be accomplished by requiring a conditional use permit for developments such as those listed above.

Provisions for Special Studies and Investigations

Projects for major expansion of existing development or establishment of new developments should provide sufficient information to allow decision makers to make informed decisions, and to specify measures to mitigate any significant hazards relating to a particular development. Examples of possible special studies include:

- Geological reports;
- modelling the effects of an earthquake on proposed engineered structures.
- soil studies;
- hydrologic and ground water investigations; and
- analysis of wind patterns which could disperse toxic gases from a source site.

Hazard Reduction Measures

Possible measures which may be used to minimize risks for developments located in a seismic hazard overlay zone are:

- Setbacks from known active or potentially active faults (of varying width according to use);

- occupancy restrictions;
- use of fire resistant materials, reinforced (earthquake or liquefaction resistant), or other special structural designs;
- design which minimizes nonstructural hazards;
- flexible utility connections;
- multiple means of access or evacuation, and protection of road cuts to ensure emergency ingress and egress;
- backup power and communications systems;
- strict control of hazardous materials;
- site or facility emergency response plans;
- site or facility emergency response organizations and programs, including personnel training, exercises, and drills;
- participation in local or community self help organizations;
- site emergency response equipment and supplies;
- participation in earthquake prediction, early warning, and equipment shut-off programs;
- instrumentation of the site for hazard research; and
- contribution of land or other assets for provision of improved safety infrastructure, or acquisition of open space in hazardous areas.

Some or all of these measures could be required as mitigation measures or conditions for project approval, depending on the nature of the project and the hazards identified by special studies, such as those listed earlier. Projects which cannot mitigate hazards to the satisfaction of responsible agencies should not be approved.

Strengths of an Overlay Zone

The first and perhaps most significant strength of a seismic hazard overlay concept is that it would increase the overall level of public safety by restricting development in areas subject to seismic hazards. Improved seismic safety could produce numerous desirable results, including:

- Fewer earthquake fatalities and injuries;

- lower costs to clean up buildings damaged or destroyed during an earthquake;

- less disruption of home life and business activity due to unsafe buildings, closed businesses, and quicker recovery after a disaster;

- minimization of the burden on public emergency resources such as police, fire, and medical services; and

- reduced fiscal (tax revenue) drain and burden on the County and other levels of government for disaster relief.

Second, a seismic hazard overlay zone offers flexibility. The County can address any chosen type of earthquake-related hazard. Aspects of geologic, flood and even fire-related hazards could also be included in an overlay which in many cases are coincident with and may compound earthquake hazards.

A seismic hazard overlay zone could also generate a broader data base of earthquake-related information. If geologic reports and/or investigations were required as a prerequisite to development within any overlay area, more extensive and better data regarding seismic-related hazards could be obtained. Cumulative data gathered as a result of these investigations would lead to improved safety measures.

Lastly, the implementation of a seismic hazard overlay zone would improve public awareness of hazardous areas. This is especially important for developers who, if informed of hazards to their development early in the land acquisition or project planning process, might wish to reevaluate their acquisition costs, modify the planned use of the property, and/or build safety-oriented designs into early project plans. A study by Palm (1981) indicates that previous attempts to increase public awareness through realtor disclosure programs alone had little or no effect on the private home buyer purchasing process. However, if the notice of the hazard is augmented by a zoning designation, awareness of risks by realtors, homeowners, and landowners would be improved.

Weaknesses of an Overlay Zone

The implementation and administration of a seismic hazard overlay zone involves a number of political and practical difficulties. Foremost, building restrictions set forth in an overlay zone are likely be controversial among builders, developers, and current property owners. These groups could plead that the regulation of certain lands would reduce property values and lessen their options for use or resale.

In addition, implementation of an overlay zone could, because of added building restrictions and requirements, incidentally cause short-term residential and commercial property development costs to rise within overlay areas. Short-term costs would be offset by long-term benefits associated with reduced losses involved in future disasters. However, those bearing short-term costs may not be the same people who receive the long-term benefits. Although higher costs might deter development altogether, they could also arouse adverse sentiment among existing and potential homeowners, renters, and businesses. Ultimately, there must be an evaluation of the cost benefit ratio and tradeoffs between potential rise in costs and prices and the benefits of increased public safety.

Once an overlay zone is implemented, the County might encounter costs associated with administration and enforcement. Such costs would relate not only to new building permit applications within the zone area, but also, and perhaps more significantly, to the inspection of "nonconforming" existing buildings, if such buildings were required to conform to overlay zone provisions.

Overlay Zone Approach and Location

If the County decides that the strengths of the overlay zone concept outweigh the weaknesses, then the question of how to define and constitute the zone must be resolved. At least three factors must be considered:

- The types of hazards addressed;
- the actual operation of the zone; and
- what provisions, if any, should be made for nonconforming uses.

Hazards, once identified, could be addressed individually or comprehensively. Under an individualized approach, each hazard type would have its own overlay zone; i.e., overlays for such hazards as fault rupture, landslides, liquefaction, tsunami, etc. By contrast, a comprehensive approach would subsume all hazards within a single overlay. As illustrated in Figure 7.1, individual hazards for specific areas could be identified on the zoning map under one "roof", or be mapped separately. Regulations would be prepared for each hazard and inserted into the zoning code.

On balance, a comprehensive approach is probably preferable because it would be simpler, easier to formulate, and avoids unnecessary duplication when different hazards overlap in a given area. For example, coastal areas of the County may simultaneously face risks associated with strong ground shaking, liquefaction, and tsunami hazards. In such areas, one comprehensive overlay zone would be far less cumbersome than several individual overlays.

As indicated in Chapter 5 (Management of Future Development), several jurisdictions that have developed seismic/geologic, or hazardous area overlays have also instituted large scale, standardized, mapping programs to implement the zone. Wolfe, et al., (1981) found that such mapping can partially offset the cost associated with geologic feasibility studies, since it allows developers to identify the most suitable sites (i.e., the least hazardous areas), thereby reducing the cost of extensive preliminary investigations. Nevertheless, the mapping provided in this report (1 inch = 2 miles) and other available hazard maps produced by the CDMG, USGS, or other public agencies can also be used to select potential overlay areas, but is not adequate to replace detailed site-specific studies.

In addition to delineating and mapping hazardous areas at a standardized scale, some jurisdictions have also developed additional criteria to implement overlay zones such as:

- Assigning levels of probability or risk to the various hazards; and

- establishing what levels of probability, if any, would trigger the requirements of the overlay.

The development of seismic probability factors cannot be easily accomplished in Los Angeles County due to the abundance of active and potentially active faults and, particularly, the uncertainty of earthquake recurrence for the vast majority

HAZARDOUS AREA OVERLAY

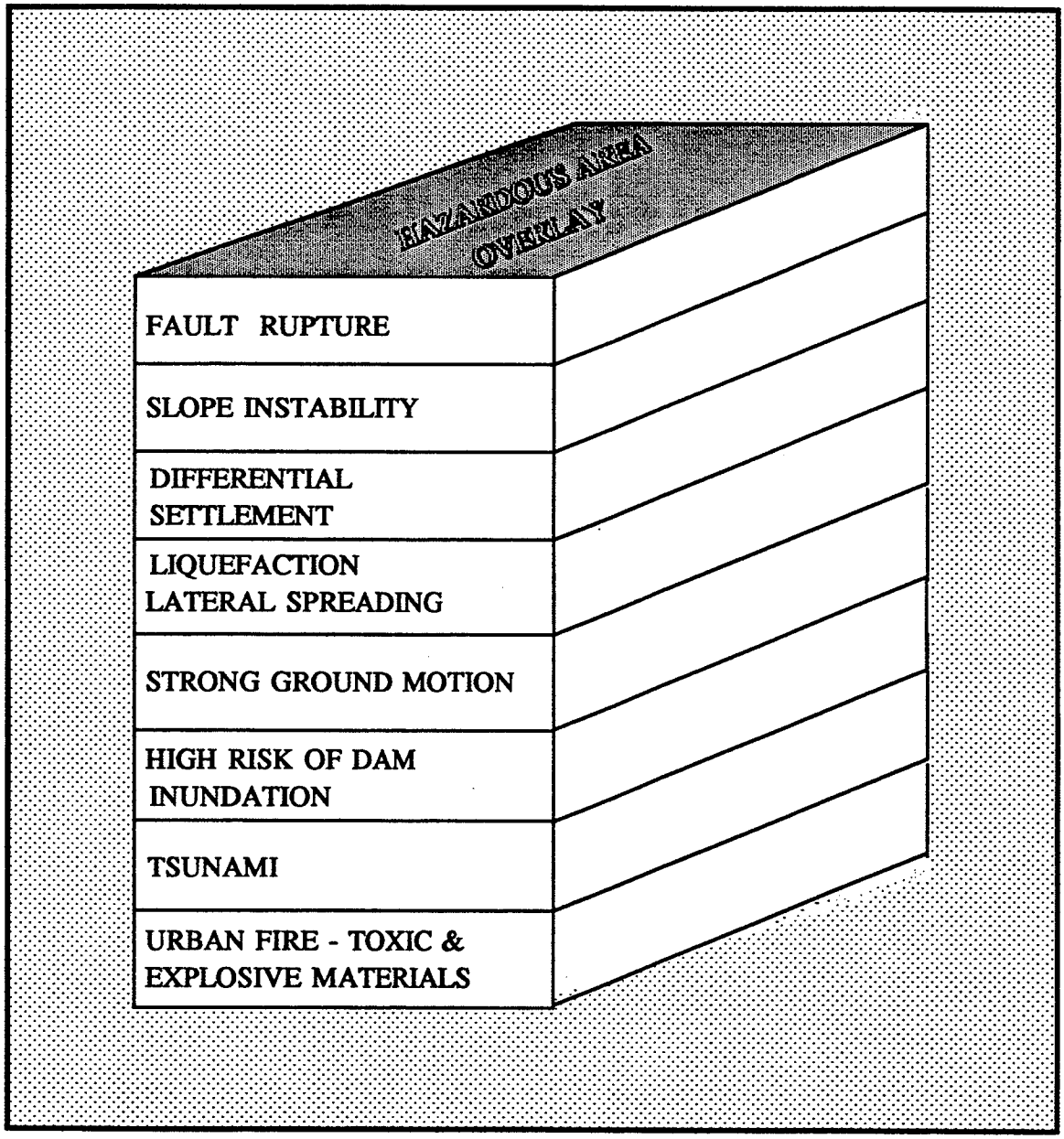

Figure 7.1: A form of the hazardous area overlay zoning concept regulating all hazards under one "roof".

of faults. Given this uncertainty, the documented presence of a seismic hazard presents the most practical alternative for implementing a seismic overlay zone in Los Angeles County.

Regarding the selection of hazards to address in an overlay, landslides are least suitable as their widely scattered locations make definition of specific overlay zones difficult. As indicated in Chapter 5, overlay areas can be applied to tsunami and dam inundation areas. However, implementation of a dam inundation overlay zoning requires assignment of relative risk of failure, which is not now available. Likewise, the lack of adequate large scale mapping of areas prone to potential tsunami inundation prevents the immediate application of overlay zoning to these hazards.

Based on the review of hazard information in Los Angeles County, fault rupture and liquefaction hazards are probably the best options for an overlay zone. First, they are the most reliably delineated seismic hazards (Plates 1 and 4). Second, based on destructive historic damage patterns observed in the 1933 Long Beach and 1971 San Fernando Earthquakes (Chapter 2), fault rupture and liquefaction pose an unequivocal threat to public safety that can be addressed by regulatory measures.

A relatively small percentage of County area would be affected by an overlay consisting of liquefaction and fault rupture hazards. Within an order of magnitude, it is estimated that about 300,000 acres or about 11 percent of the total County area are in liquefiable areas ("L" on Plate 4). About 100,000 acres are in unincorporated areas, accounting for about six percent of all unincorporated territory.

The Alquist-Priolo Special Study Zones (APSSZ) faults currently designated in Los Angeles County contain approximately 77 square miles (over 49,000 acres), which is about two percent of the total County area. Of these State recognized active faults, about 55 square miles (70 percent) are located in unincorporated County territory. Based on rough estimates using a 1/4 mile wide active fault zone, additional active faults, other than APSSZ faults account for approximately 45 square miles of County area (Plate 1). Roughly one third (15 square miles) of the additional active fault areas are located in unincorporated areas.

Overlay Zone Implementation and Administration

A seismic hazard overlay zone could be designed to operate in almost any manner desired by the County, but at a minimum should contain provisions requiring a site specific hazards report/investigation documenting site conditions, and providing a basis for regulating or mitigating the project design and location, guiding decisions concerning appropriate uses or use types, and specifying special development standards. Special development standards, designed to address seismic or related hazards to ensure safe design and construction in hazardous area developments, would be more rigorous than the development standards of the underlying zone.

SEISMIC HAZARDS OVERLAY

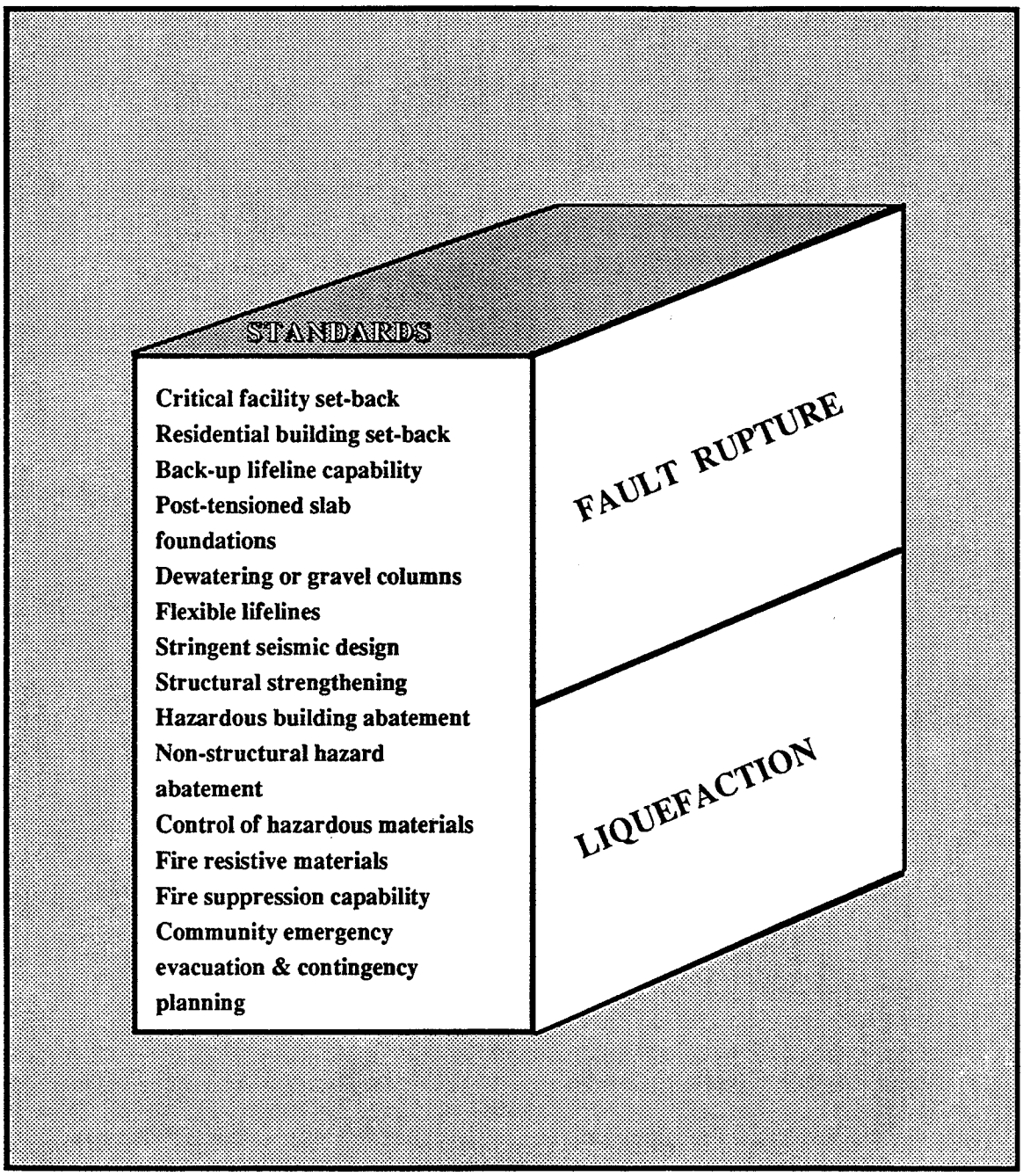

Figure 7.2: Possible "special development standards" for a hypothetical seismic hazards overlay zone.

Figure 7.2 illustrates selected regulatory alternatives within a hypothetical overlay land use "cell". The cell is designed specifically for active fault zones and/or liquefaction areas. Approved projects within the overlay cell would have to comply with appropriate development standards. The special standards would, of course, depend on the specific hazards included in the overlay cell and the nature of the proposed development. Standards, of which a select few are outlined in Figure 7.2, could be made more stringent for critical facilities than for residential development.

Application of a transferable development credits (TDC) program could help to mitigate earthquake hazards in an overlay zone. A TDC program would allow a developer to transfer development credits out of identified seismic hazard areas into areas of less risk. A developer whose lands were located in any area covered by an overlay zone would be able to transfer all or part of the proposed development to a "safer" receiving area. Safer areas should be in reasonable proximity to the subject parcels. The feasibility of a TDC system should be evaluated. The system has been used in only a few places in the country, and typically has involved only a few transfers in each case. County agencies would have to bear the burden of administering a TDC program.

An overlay zone would be implemented through a two stage process. The first stage would involve amendment of the Zoning Code to establish the basic provisions of an overlay zone. The second stage would be to amend appropriate zoning maps to apply the overlay zone to specific properties. The overlay zone concept could be initiated on a trial or pilot basis by applying it first to a limited area of a well recognized hazard area such as selected portions of the San Andreas Fault Zone.

Provision for Nonconforming Uses

If the County implements an overlay zone, a decision will be needed on whether the zone's provisions will operate retroactively, and if so, to what extent. Either of two broad options are available with respect to the existing structures that would be placed in nonconformance with any newly enacted hazards overlay zone.

Under one option, the overlay could require nonconforming structures to come into conformity within a specified amortization period. The length of the amortization period could vary according to the scale of cost or the nature of the nonconforming use. Requiring total ultimate conformity would maximize the impact of the overlay and theoretically improve safety levels within overlay areas. However, this approach could be politically unpopular and could involve high administrative costs associated with identifying nonconforming buildings and enforcing the nonconformance penalties against their owners at the appropriate future time.

Under the other option, the overlay could "grandfather" nonconforming uses or structures. Conformity would be required only if and when nonconforming structures were proposed for "substantial" renovation or nonconforming uses were curtailed.

Under a compromise option, the County would "grandfather" nonconforming uses but encourage conformity through economic incentives. Building owners doing business in the County could be offered rebates or credits against County sales and use taxes enacted under the authority of Revenue Code Section 7201 in exchange for expenditures made toward seismic rehabilitation. Or the County could implement a long-term, low-interest seismic rehabilitation loan program, as authorized by Health and Safety Code Sections 55000 to 55900. Finally, some of the "nonconforming" costs could be abated through collection of development impact fees from developers who build in hazardous areas.

Conclusions

- A seismic hazard overlay zone has several advantages, including increasing the overall level of public safety, establishing a more comprehensive seismic database; and improving public knowledge and awareness of hazardous areas.

- A seismic hazard overlay zone would probably face opposition from builders, developers, and existing property owners. It also could increase development costs, and be costly to administer and enforce.

- To be most effective, a seismic hazard overlay zone should require appropriate reports and investigations, encourage low-risk uses and discourage uses with typically high human occupancy, establish development standards to promote and ensure safe design and construction, and guide development to areas of low hazard.

- The most practical and easily implemented hazard zones to be addressed by an overlay concept are areas subject to fault rupture and liquefaction.

- The overlay zone could be implemented initially on a limited basis in a well recognized hazard area.

SECTION 7.2

COST-TRANSFERENCE PROGRAMS IN HAZARDOUS AREAS

It is inherently difficult to prevent development of hazardous areas. Local government can not dictate the level of population growth or absolutely control population distribution. Government can influence the distribution of population and the pattern of development through planning policies, regulations, and by the way it provides infrastructure for services. Population is now tending to expand into many presently undeveloped hazardous areas. Recognizing this problem, the application of cost-transference and disincentives to development in hazardous areas is explored, and means are examined by which costs may be borne by the entity generating them. The basic premise in this discussion is that costs should be borne by those necessitating them, and not by the public at large.

Channeling development to areas of lower seismic risk, especially if applied concurrently with a hazard overlay zoning strategy and open space zoning, would represent the most conservative planning approach. However, high property values in the County may make this difficult to put into practice.

The following discussion will identify various means by which the County can establish valid cost-transference programs that will act as disincentives to intensive development of very hazardous areas, investigate the feasibility of such means, and recommend implementing strategies. Four main types of cost-transference programs are reviewed:

- Impact fees;
- special study requirements (administrative/procedural);
- insurance requirements; and
- tax disincentives/incentives.

Hazard Impact Mitigation Fees

Local governments may charge hazard impact mitigation fees to offset the costs of new development. They are administered as a condition of approving the proposed development to finance the additional public services necessitated by the influx of new residents or employees attracted by the development. Though a relatively recent phenomenon, impact fees are widespread in California.

Impact fees have generally been found legal if they are reasonable in amount and relate to some "legitimate" government purpose. However, Government Code Section 66001, effective January 1, 1989, increases local agencies' burdens of justifying the imposition of impact fees. The County, in imposing impact fees and providing justification, would need to develop criteria for weighing "the reasonable economic cost" versus reducing the risk of the hazard.

Assuming the County could impose impact fees on hazardous area development, such fees need not be static. Depending on the type of development involved and its potential for burdening disaster response systems and other public services, the County could allow upward or downward adjustment of fees or outright elimination of them in appropriate cases. Adjustment of fees could be done through a formal procedure whereby interested parties could appeal the implementing agency's initial determination of the proper amount of the fee. Such a procedure would be less arbitrary and would leave fee adjustment on more solid legal ground than if there were no appeal procedure at all.

Hazard mitigation impact fees would discourage development in hazardous areas by legitimately increasing the costs of building in order to provide for improved public safety. To the extent that market conditions would not allow developers to pass the increased costs of hazardous area development on to consumers, developers would have an incentive either not to build in hazardous areas or to build in such a way as to avoid having to pay impact fees (i.e., in a way desired by the County to minimize a specific hazard). Impact fees must be shown to bear a sound relationship to the safety costs generated by the development.

Feasibility

Impact fees have been widely used in California as a means for financing the infrastructure necessitated by new development. To be defensible, they must be justified in terms of providing revenue for disaster services, emergency facilities, or infrastructure aimed at reducing the vulnerability of the development to hazards discussed in this report.

Local governments' burden of justifying the imposition of impact fees is specified in Government Code Section 66001. This section requires a local agency to show the following before it imposes impact fees on any "development project":

- The purpose of the fee;
- the use to which the fee will be put;
- a nexus between the fee's use and the type of development the fee is imposed on;
- a nexus between the fee and the burden on public facilities created by the development; and
- that the amount of the fee is reasonable.

The likely effect of impact fees as a development disincentive probably depends on two factors: legal requirements (discussed above) and market conditions. If the market will allow developers to pass their increased costs on to consumers, such projects will be no less profitable than nonhazardous area projects and impact fees will not discourage inappropriate hazardous area development. However, if the market will not support passing on of costs, impact fees could operate as a real disincentive to hazardous area development.

Special Study Requirements

By requiring thorough study and hazard mitigation by parties seeking permission to build in hazardous areas, the County could promote improved public safety and discourage high-risk development in hazardous areas. Such a strategy would effectively reduce the exposure of the community to risk. Several measures could be employed to this end:

- Geological studies;
- environmental impact reports (EIRs);
- soils studies; and
- seismic studies.

Each of these data collection or analytical requirements secondarily becomes an economic disincentive to high-risk forms of hazardous area development. More important, each can be applied to design safer forms of development. Many special study requirements are already employed by the County and these studies are key in directing public action.

Data collection requirements can also be tailored to encourage desirable hazardous area uses. For example, the County could relax or waive the requirements when developers propose uses considered "low-risk" for hazardous area parcels.

Below is a description and review of the four special study requirements.

Geologic Studies

The Alquist-Priolo Special Studies Zone Act (APSSZ) empowers local governments to require preparation of geologic reports prior to the approval of certain development projects within special zones delineated by the State geologist and implemented by the State Mining and Geology Board. In addition, the County General Plan and the subdivision and Building Code currently require geologic reports for major developments in hillside areas and in active fault zones (independent of authorization by APSSZ).

Because the APSSZ allows counties to establish stricter criteria than those of the State, Los Angeles County could expand the effective reach of the APSSZ by requiring a geologic studies for localities within a seismic hazard overlay zone. Such studies should include adequate geologic mapping of the location of faults and liquefiable sediments, the distribution of landslides and slope instability, relative landslide and debris flow susceptibility, and rockfall potential. Mitigation measures to minimize landslide and slope instability should be included in the report.

A geologic study requirement could be implemented in two ways. First, geologic reports could be mandated as a prerequisite to approval of any type of development in a hazardous area regardless of human occupancy. Second, the County could require that any EIR prepared for a proposed hazardous area project include a geologist's study/report or that all negative declarations issued on

hazardous area projects be supported by a geologist's report. The geologist's report would have to address all hazards on/or near the property as indicated on an overlay map, and recommend appropriate mitigation measures.

One feasible vehicle to trigger a geologist's study requirement would be a seismic hazard overlay zone. As a zoning action, the requirement would need to bear a reasonable relationship to the public health, safety, and welfare in order to be legal and defensible.

Environmental Impact Reports

The California Environmental Quality Act ("CEQA," Public Resources Code Section 21000, et seq.) requires preparation of an EIR for any project which has a significant environmental effect. Generally, determination of a proposed project's environmental effect in Los Angeles County follows a 3-step process:

- An initial review by the Department of Regional Planning is conducted to see if there is any possibility of environmental impact;
- if the possibility of an adverse impact exists, the project is reviewed by the appropriate departments. If the review concludes that a substantial adverse impact is unlikely, a "negative declaration" is issued allowing the project to proceed; and
- if the review identifies the possibility of a significant environmental effect, an EIR must be prepared.

The County currently uses this approach, but could employ CEQA's EIR requirement as a development disincentive by regularly mandating that any proposed project within a hazardous area would be presumed to have significant environmental effects for the purposes of CEQA. Essentially, such a presumption would have hazardous area developers seeking to rebut the presumption by preparing EIRs for their projects which provide for mitigation of hazardous conditions.

The County can require the preparation of EIRs for all hazardous area permits or rezoning if it chooses to do so. The County should employ language found in CEQA to indicate that projects proposed within hazardous areas are presumed to have "significant environmental effects" due to the existence of hazardous conditions. In order to provide an alternative to legal challenges, a procedure should be implemented which provides for appeals from the presumption that an EIR is necessary.

Soils Studies

The Subdivision Map Act (Government Code Section 66410, et seq.) expressly authorizes local agencies to require geotechnical/soils reports, prepared by a registered civil geotechnical engineer, as a condition of approval of any subdivision. Under this authority, the County could require the preparation of a soils report for a subdivision proposed in a hazardous area, regardless of the number of parcels to be created.

The preparation of a soils report could be required as a condition of securing permission for some desired activity at the discretion of the Departments of Public Works and Regional Planning. A hazard overlay zone could be used to trigger the requirement for a soils report. A soils report requirement could also be employed in the context of the Subdivision Map Act, where the express authority for soils reports is now found. This would limit application of the requirement to subdivisions as defined in the Act: "the division...of any unit or units of improved or unimproved land...for the purpose of sale, lease or financing...except for leases of agricultural land for agricultural purposes."

Seismic Studies

The County already requires studies and investigations regarding seismic hazards. First, the County requires geotechnical reports regarding the feasibility of uses in areas with the highest potential for strong ground motion (Seismic Zone 3), prior to project review. Second, the APSSZ and Section 311, Title 26 of the County Building Code, provides regulations and guidelines to protect areas from fault rupture hazard. Finally, the County Building Code requires soils investigations for proposed projects within alluvial basin areas, including a minimum 35-foot borehole sample to determine and evaluate liquefaction potential.

A seismic study requirement could include the submittal of a seismic study report to the County prior to project approval. Such a report should be prepared by a geotechnical engineer and should address the potential for strong ground motion, fault rupture, and liquefaction affecting the project site including:

- Strong ground motion discussions could include mapping of predictive ground motion areas, the extent to which destructive shaking may occur at sites located away from the fault, and analysis of engineering boreholes for noncritical buildings and structures;

- a fault rupture discussion could define a "fault investigation zone" of no less than 150 feet from the fault, and could include mapping of potentially active faults and review of other ongoing active fault studies (in addition to those recognized by APSSZ); and

- liquefaction discussions could include mandatory borehole depths of 50 feet for areas with critical and high-risk facilities.

Similar to the geologic study provisions described earlier, a seismic study investigation is most feasible if implemented via a seismic hazard overlay zone. As a zoning action, the requirement would need to bear a reasonable relationship to the public health, safety, and general welfare in order to be legal and defensible.

Insurance Requirements

Within hazardous areas, the County could reduce financial risk, create a disincentive to inappropriate development and an incentive for low risk development by requiring that all new commercial and residential buildings be insured against applicable risk(s), such as earthquakes, landslides, or other hazards. This can be justified in terms of the public necessity for quick repair of structural damage, and the reduction of public costs for emergency response and reconstruction. An insurance requirement would raise the cost of building, owning, or renting homes and commercial buildings in hazardous areas. This might discourage high-risk development in hazardous areas and encourage more suitable location elsewhere.

The Federal Emergency Management Agency actually subsidizes insurance for existing development. Insurance for existing development would need to be linked to various structural and nonstructural means for mitigating a potential hazard i.e., retrofitting potentially hazardous buildings, removing exterior parapets, tying down gas water heaters, and other similar measures.

For an insurance requirement feasibly to deter unsafe development, at least two factors should be considered. First, a means of monitoring and enforcing compliance with the requirement would be necessary, as it is unreasonable to expect widespread voluntary compliance. A monitoring program will require the County to dedicate financial resources and personnel.

Second, insofar as possible, the requirement should be applied directly to developers as opposed to purchasers, possibly by requiring developers to insure the estimated fully improved value of their projects as a condition of approval. Such a measure would serve to protect development itself rather than await the purchase of developed structures.

The Federal Emergency Management Agency is currently developing a model insurance program. Unless the model program addresses these particular problems, it is doubtful whether insurance requirements can be enforced. In addition, if the FEMA model insurance program applies to future development, it could be construed as actually providing an incentive to hazardous area development.

Tax Incentives/Disincentives

The County could use its taxing power (and advocate that the State use taxes) to discourage uses considered to be incompatible with hazardous areas, or to encourage compatible uses by influencing costs to develop and maintains them.

A County tax disincentive might involve the imposition of a special tax on new hazardous area development as a means of financing special safety services, or other structural/design risk reduction features needed in such areas. As an incentive to nonhazardous area development, the County could offer exemptions from applicable sales and use taxes to tenants or developers who devote or covenant hazardous area properties to lower risk uses.

For its part, the State might offer various tax advantages such as tax credits and lowered assessed property values, similar to those available under the Williamson Act, for open space preservation in exchange for avoidance of intensive development.

The imposition of any special County tax will require enabling legislation and the approval of two-thirds of the County's voters who vote on the issue. In addition, the special tax may not be disguised as a property tax (Government Code Section 53725).

The feasibility of a County tax incentive depends on the attitude of landowners who own developable property in hazardous and nonhazardous areas. Development of a TDC System would encourage this participation. Factors which work against the program's feasibility include its limited application (i.e., confined only to those persons affected by sales and use taxes) and the loss of tax revenue to the County.

Conclusions

- Hazard impact mitigation fees, insurance requirements, and tax incentives and disincentives offer the advantage of providing for improved safety features early in the project approval phase.
- The development of cost-transference programs in hazardous areas must have documentated evidence to assess the relationship of public safety to the need for special development procedures.
- Development disincentives are unlikely to find strong support among owners of land in hazardous areas.

CHAPTER 8

POST-EARTHQUAKE RECOVERY

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POST-EARTHQUAKE RECOVERY

A necessary component of a proactive earthquake program includes planning for long-term recovery. The risk to the socioeconomic framework of Los Angeles County described in Chapter 4 indicates that appropriate planning for post-earthquake recovery is essential. The Five-Year Plan for earthquake preparedness recommends analyses of two aspects of post-earthquake recovery: the earthquake insurance problem and post-earthquake reconstruction. Brief summaries of these subjects are provided below as an introduction to Section 8.1 (Analysis of the Earthquake Insurance Problem) and Section 8.2 (Post-Disaster Reconstruction and Recovery).

- <u>Earthquake Insurance</u>

  Currently, less than 20 percent of California homeowners pay the extra premium for earthquake coverage, even though California law requires all insurance carriers doing business in the State to offer earthquake insurance. One of the reasons for the low percentage may be the high premiums and deductibles that are almost always associated with earthquake insurance. Tentative estimates of the impact of the 1989 Loma Prieta Earthquake suggest that private insurers will pay about one billion in earthquake insurance claims (Los Angeles Times, November 1, 1989). Given this estimate, private insurers will likely be responsible for an additional 2 to 3 billion dollars in claims against fire, wrecked vehicles, medical costs and death. Estimates of Federal and State government donations are in the range of about four billion dollars, leaving as much as an additional four billion dollars in unreimbursed losses to the earthquake victims (Los Angeles Times, November 1, 1989). This does not include the costs of repairing roads, bridges, and other public infrastructure.

  In the aftermath of the Loma Prieta Earthquake, state legislators are proposing a State-guaranteed, affordable earthquake insurance plan to be offered by private insurance companies to all California homeowners. The proposed insurance plan would be similar to the flood plain insurance plan provided by the Federal government. Legislators are hoping that the passage of this legislation will increase the number of California homeowners carrying earthquake insurance from as low as eight percent to 80 or 90 percent.

  Legislation can be designed to promote a homeowner's purchase of earthquake insurance. Under one possible model, governmental funds would be provided to subsidize part or all of the high deductible associated with earthquake insurance. This is one way of alleviating the high monetary loss to property owners from a devastating earthquake, even if insured. The Federal Emergency Management Agency is developing a model insurance program that would incorporate some of the above considerations, and tie insurance rates to owner hazard reduction measures (Los Angeles Times, November 1, 1989).

Additional options for the County include advocating legislation to regulate the cost of earthquake insurance and the amount of deductible allowed. Legislation could also be supported to regulate affordable insurance rates through creation of Federal or State subsidized earthquake insurance programs. Section 8.1 will provide an analysis of the insurance problem by focusing on the feasibility of various strategies involving the Federal government and the private insurance industry. Pending State legislation will not be discussed; however, some conclusions drawn from this section may apply to any future earthquake insurance proposals, regardless of their origin.

- <u>Post-Disaster Reconstruction</u>

The tendency to immediately rebuild in hazardous areas is strong after any natural disaster. Rebuilding often involves conflict between the rights of property owners and the government's responsibility to minimize the high cost in lives and economic losses caused by natural disasters. The great Alaskan Earthquake, a gigantic 8.5 Magnitude tremor that ripped through Anchorage in 1964, devastated the city. Buildings collapsed and whole neighborhoods were destroyed as huge cracks opened and major portions of land slid away during the shaking. The residential area of Turnagain Heights was literally wiped out. In 1964, the City of Anchorage enacted stringent rebuilding provisions and outright prohibition to keep redevelopment of Turnagain Heights from occurring.

The focus of Section 8.2 will be on developing a suitable post-earthquake reconstruction program to manage problems such as those confronted by Anchorage some 25 years ago. One of the purposes is to prevent inappropriate reconstruction from occurring in areas inherently susceptible to high earthquake damage. Beyond the issues of property rights and safety, post-disaster reconstruction also highlights the issue of insurance and disaster relief. If reconstruction is allowed in hazardous areas, the public eventually foots a large share of the high cost of repairs. The County has already proven vulnerable to liability from both allowing and preventing development in areas suspeptible to landsliding and flooding, respectively, in the past decade. Disaster policy and post-earthquake reconstruction, must be carefully crafted to address these problems.

SECTION 8.1

ANALYSIS OF THE EARTHQUAKE INSURANCE PROBLEM

Two main problems beset the current system of private earthquake insurance. First, the insurance industry could suffer a devastating or even catastrophic financial loss should a major earthquake strike. Although insurance companies are expected to handle the Loma Prieta Earthquake losses, there is strong concern for a much larger earthquake that the insurance industry believes may cause as much as $50 billion dollars in damages (Franklin Nutter, personal communication; 1989). Making the problem worse, too few consumers utilize currently available earthquake insurance. These problems, in turn, could have generally undesirable social, political and economic consequences.

Potential for Catastrophic Industry Loss

Following a major quake, carriers would likely face two levels of claims: First, claims for damages directly resulting from the shaking of the earthquake, e.g., damaged and/or collapsed structures. Second, claims for such secondary effects as fire loss and damage, loss of life, personal injury, and general liability. "Second tier" claims would far outstrip claims for direct damage and pose the biggest threat to insurers.

Estimates vary as to the potential magnitude of the insurance industry's financial liability following a major earthquake; ranging from as low as $5 billion to as high as $60 billion. The higher estimates have tended to come from the industry itself and cite ineffective or nonexistent hazard reduction measures as greatly increasing their potential scope of losses.

A related problem for earthquake insurers is the industry's difficulty in preparing for the sheer size of its potential payout obligations. At least two factors contribute to this difficulty. First are the policies of the Internal Revenue Service, which treat catastrophic "reserves" set aside by insurers as "excess profits" and tax these reserves at a higher rate than other income. This treatment has effectively prevented primary insurers from building up adequate catastrophic reserves. Second, reinsurance, the other main source of funds to meet catastrophic payout obligations, is not always available and where available often comes from foreign sources. These sources, beyond the purview of U.S. regulatory authority, might prove unreliable if their time came to meet large policy obligations.

Facing obligations of potentially staggering proportions and having had inadequate means to prepare for them, the insurance industry could well find itself the biggest casualty of all following a major earthquake. This worrisome possibility takes on added significance upon consideration of it's potential repercussions.

Consequences of Catastrophic Industry Loss

Collectively, the insurance industry today plays a dominant role in the U.S. economy. A crippling blow struck to that industry could result in widespread economic dislocation affecting interests well beyond those of insurers and policy holders.

Claims from a major earthquake could leave many insurance companies, particularly smaller ones, insolvent. Not only would this leave many of the insolvent companies' employees jobless but also, on a broader scale, would force such companies to liquidate vast holdings in the nation's financial and real estate markets. The losses of the insurance industry could, much like the shock waves of an earthquake, be felt far away from their "epicenter".

On another level, the loss of insurance industry support due to catastrophic earthquake claims could result in increased reliance on Federal disaster assistance. Increased Federal reliance could severely overtax the disaster relief system, leaving taxpayers to shoulder the burden in the form of higher taxes and/or reallocations of Federal money earmarked for other purposes. Further, disaster assistance might in any event prove inadequate to fill the void left by insolvent earthquake insurers. This inadequacy could prevent victims from rebuilding homes and businesses, causing a loss of property and income tax revenues at a time when the State and Federal governments could ill afford it. Again, American taxpayers would ultimately bear the loss.

Under-Utilization of Available Coverage

Curiously, the specter of a potentially catastrophic loss has not deterred private insurers from offering earthquake insurance or, for that matter, profiting from it. That said, however, the current system suffers from under-utilization. It has recently been estimated that only 8 to 20 percent of homeowners and perhaps 50 percent of businesses in California insure themselves against earthquakes. Various reasons are offered to explain this nonparticipation.

- Insurance Costs

  Earthquake insurance policies tend to have relatively high premiums and deductibles, stemming from two main causes. First, the unpredictability of earthquakes makes setting rates or premiums difficult: earthquakes can strike at any time, with any force, and can cause any amount of damage. Second is the problem of "adverse selection" which occurs when only those persons most at risk from a particular casualty, here homeowners or businesses located in or near seismically active areas, purchase insurance against that risk; a poor spreading of the risk and consequently higher rates is the result.

- Public Awareness

  A less than zealous marketing program by the insurance industry has also contributed to the under-utilization of earthquake insurance. Particularly during "hard" market cycles, but during "soft" periods as well, insurance companies have not shown great enthusiasm in selling earthquake coverage to the public, perhaps out of fear of the potential for the catastrophic losses outlined above.

- Perceived Poor Cost-Effectiveness

  Consumers, for their part, especially homeowners, have tended to view earthquake insurance less as a prudent form of protection than as a bad investment. This attitude possibly results from a stubborn refusal to accept the probability of a "Big One", notwithstanding the many predictions to that effect, or from a feeling that money spent on earthquake insurance will never be seen again due to their fear of insurance company insolvency after the earthquake. In addition, many uninsured persons erroneously believe that Federal disaster assistance programs will provide for all of their needs following an earthquake. Many people apparently view earthquake insurance as wholly unnecessary.

Consequences of Under-Utilization

The failure of homeowners and businesses to insure themselves more widely against earthquake causes them to over-rely on governmental disaster assistance. As pointed out above, this over reliance could overtax the disaster assistance programs and threaten national taxpayers with a heavier overall burden if a major local earthquake strikes. Reliance on the State and Federal governments as the guarantors against earthquake losses has additional problems, however.

To begin with, public disaster assistance does not fully compensate disaster victims for their losses. Government disaster assistance would likely cover only a fraction of the estimated billions of dollars in direct and indirect damage from a "Big One." Without insurance to fill the breach, society as a whole would have to sustain the loss, which could have an adverse effect on the State and national economies.

Another problem with reliance on governmental disaster programs is that such programs currently offer no incentive and may even offer a disincentive for "consumers" to mitigate earthquake hazards before an earthquake hits. Taxes, unlike insurance premiums, generally do not fluctuate upward or downward according to the "risks" they go to "insure." Thus, while an insurance company might spur hazard mitigation measures through the lure of lower premiums, the State and Federal governments could face great political difficulty trying the same thing via tax credits or deductions for mitigation expenditures. Governmental disaster programs may in fact provide disincentives to hazard reduction, because currently both the initial receipt of funds and the amount received depend on the extent of the damage that one has sustained. A conscientious homeowner who prepared for an earthquake, but nonetheless suffered some minor

damage might therefore receive little or no assistance, while one who had done nothing to prepare and had accordingly lost everything could receive substantial (though not complete) compensation.

Another problem with governmental assistance lies in its systemic inequity. Government disaster programs do not treat all disasters or disaster victims equally. Presidentially-declared disasters, for example, receive more assistance than disasters not so declared. And, when disaster programs employ tax deductions as part of their assistance (as is often the case), wealthy taxpayers in higher brackets obviously benefit more than poorer ones. Finally, government disaster assistance programs are expensive, inefficient to administer and implement, and offer individuals no choice as to the amount of assistance they will receive, if any.

Taken together, the problems associated with Federal and State disaster assistance programs illustrate the undesirability of over reliance on such programs as a consequence of the general underutilization of available earthquake insurance. Proponents of a Federally-backed earthquake insurance program argue that their program would encourage utilization, and thereby decrease reliance on disaster assistance. Research on this program has been initiated by FEMA in 1988, but results are not yet available.

STRATEGIES FOR FEDERAL ACTION

Potential Federal government action in the field of earthquake insurance could take the form of nonintervention, intervention as a primary insurer, a secondary insurer (reinsure), an emergency lender and/or loan guarantor, or some combination thereof.

Nonintervention Strategy

A nonintervention strategy would have the Federal government essentially continue in its current, "traditional" role as a provider of disaster assistance, an earthquake science researcher, and a promoter of earthquake mitigation measures. Disaster assistance might be tailored to encourage earthquake preparedness. Tax incentives might be used to promote earthquake preparedness and the purchase of earthquake insurance. Federally-backed home mortgages might be made to require earthquake insurance, and other, "indirect" measures might be implemented, but the Federal government would not directly participate in the provision or promotion of earthquake insurance.

Intervention Strategies

As an alternative to nonintervention, the Federal government could involve itself directly in the provision of earthquake insurance as a primary insurer, a reinsurer, or a source of emergency loans for private insurers.

The Earthquake Project (TEP), an insurance industry consortium working for the creation of a Federally-backed earthquake insurance program, has suggested a combination of roles for the Federal government. TEP proposes the creation of a new Federal corporation, the Federal Catastrophe Insurance and Reinsurance Corporation (FCIRC) to establish two separate, but parallel earthquake insurance programs: First, a primary residential property program which would make available to homeowners, coverage against losses resulting from direct earthquake damage. Second, an excess reinsurance program through which private insurers and reinsurers could purchase high levels of excess coverage against earthquake losses not covered under the primary program.

Under both programs, premiums collected (by private insurers under the primary program, by the FCIRC itself under the reinsurance program) would be held by the FCIRC in tax exempt funds. When covered losses occurred, the funds would go to reimburse them. If losses exceeded the funds' limits, the private insurers or the FCIRC could borrow the necessary balance from the Federal government, with repayment coming from future premiums.

The FCIRC primary insurance program would encourage utilization of coverage by mandating earthquake insurance for all mortgages held or financed by any Federal agency or any institution insured by the FCIC or FSLIC in areas considered "earthquake-prone". Rates would be set according to nine "rating zones" established to reflect differences in an areas' seismic risk. The main incentive for participation in the excess insurance program would be its provision of coverage for lines of insurance related to indirect earthquake effects, e.g., fire, workers compensation, and general liability.

Insurers generally agree that a combined public-private sector scheme such as the proposed FCIRC offers the best chance of dealing with the problems affecting earthquake insurance. Theoretically, however, government involvement could be greater or lesser than envisioned under the FCIRC. The government could, for example, market and administer a program of primary earthquake insurance, or it could function exclusively as a "lender of last resort."

In the aftermath of the Loma Prieta Earthquake, a new problem with earthquake insurance has emerged. A proposed program for Federal earthquake insurance being drafted by the Federal Emergency Management Agency, although incomplete has already drawn criticism for the effect it could have on "encouraging development of hazardous areas". Critics contend that development of hazardous areas could occur "worry free" with insurance as a buffer. Therefore, it appears essential to discriminate between insurance for new development, redevelopment, and existing development in formulating a Federal insurance program. Given the shared losses of a major earthquake, there should be no incentive for development of hazardous areas that would lessen the assumed risk a new homeowner incurs by choosing to live in hazardous areas.

FEASIBILITY OF FEDERAL STRATEGIES

The chances for success of the nonintervention strategies outlined above must be evaluated on two levels. First, will they deal with the problems of potential catastrophic loss and underutilization? Second, are they feasible politically and economically?

The Catastrophic Loss Problem

- Nonintervention

  Nonintervention as a strategy could address one of the root causes of the catastrophic loss problem, the difficulty of earthquake prediction, by continuing Federal funding of earthquake research. Better earthquake data would arguably lead to more accurate risk assessments, which would allow the industry to set rates closer to expected losses than is believed the case today. However, better data could also lead to higher rates than today's and thereby exacerbate the problem of underutilization.

  On the other hand, nonintervention seems unlikely to address the other root cause of the catastrophic loss problem, the industry's inability to build up massive financial reserves. Even given better prediction and thus more accurate rate-setting than exists presently, barring a change in current tax policies, the industry would still have to liquidate vast holdings in order to meet payout obligations following a devastating earthquake. In sum, nonintervention seems likely to address only half of the catastrophic loss problem.

  Depending upon how it was crafted, a nonintervention strategy could serve either to alleviate or exacerbate the underutilization problem. A strategy which generally emphasized earthquake preparedness and specifically encouraged the purchase of earthquake insurance, perhaps by using tax and/or mortgage incentives, could foster increased use of existing, available earthquake insurance. On the other hand, a strategy which emphasized earthquake responsiveness, i.e., disaster assistance, could well exacerbate the underutilization problem because, as discussed above, the existence of disaster assistance tends not to encourage and even to discourage the purchase of earthquake insurance.

  A successful nonintervention strategy would want to emphasize earthquake preparedness over responsiveness and minimize reliance on disaster assistance programs.

- Intervention

  In contrast to nonintervention, intervention as a strategy could deal effectively with both prongs of the catastrophic loss problem. The creation of tax-free reserve funds, as envisioned in the FCIRC scheme, would allow insurers and reinsurers to build up catastrophic reserves and free them from having to liquidate their holdings to meet policy obligations. In addition,

an intervention strategy would continue to encourage research leading to improved prediction and risk assessment. Research might even expand beyond current levels in the interest of bringing insurance costs to the minimum possible.

Intervention, again using the FCIRC proposal as a model, could address underutilization in several ways. First, by requiring earthquake insurance for Federally-backed home mortgages, the FCIRC plan would directly serve homeowners, who have historically purchased far less earthquake insurance than businesses. Next, premiums and deductibles could be brought below today's levels under the FCIRC plan because of wider risk spreading, making earthquake insurance generally more attractive to purchasers. Finally, insurers, armed with more attractive rates and opportunities for substantial commission income, would have an incentive to market earthquake policies more aggressively than at present. This would hopefully increase the number of policies purchased. On the whole, an intervention strategy promises a more aggressive approach to the under-utilization problem than would a nonintervention strategy.

Political Feasibility

- Nonintervention

Because a nonintervention strategy would essentially maintain the status quo, it would likely face little or no political opposition. Political opposition, if generated, would probably revolve around the potential taxpayer expense associated with the cost of disaster assistance programs. As this potential has always existed, however, and has yet to politically stymie the Federal government's current "hands off" approach to earthquake insurance, it seems unlikely that much real opposition would exist to continuance of present policies.

- Intervention

Like any program advocating change, an intervention strategy could face political opposition. Whether opposition would actually materialize depends on the type of approach selected. Traditionally, the insurance industry has operated more or less free from the influence, much less control, of the Federal government, and therefore would be expected to oppose any Federal involvement in its business. The industry has recognized the unique problems and risks which unpredictable natural disasters such as earthquakes and volcanic eruptions pose to its interests. That the FCIRC proposal comes from an insurance industry consortium evidences this recognition. Thus, a carefully tailored intervention strategy, such as the FCIRC, which keeps Federal involvement to the minimum necessary to address the problems at hand, could skirt political opposition by, and indeed could possibly gain support from, its potentially most vocal opponent.

Opposition might also come from members of Congress opposed to expansion of public involvement in the private sector and wary of the potential costs.

However, the same arguments which convinced much of the insurance industry of the need for Federal involvement would likely be persuasive, and fiscal concerns might be met by pointing out that the FCIRC program will be largely self-supporting (beyond minimal administrative costs).

Economic (Cost) Feasibility

- Nonintervention

  Nonintervention is a cost-feasible, if cost-inefficient alternative so long as a major earthquake does not strike. The costs of earthquake research, education, and disaster assistance have so far been acceptable and would probably remain so barring disaster.

  Should a major earthquake strike, requiring the dispensation of massive amounts of disaster assistance, nonintervention could become a very expensive, even cost-infeasible strategy. Beyond the burden on taxpayers threatened by over reliance on disaster assistance following an earthquake, the inherent inefficiency and inequity of disaster assistance programs could result in many victims going uncompensated (assuming the non-purchase of earthquake insurance). Uncompensated victims will have difficulty rebuilding their homes and businesses and, therefore, paying taxes. This lost tax revenue must be considered as a major potential cost of nonintervention.

- Intervention

  Intervention under the FCIRC proposal would have start-up and administrative costs, but beyond those the program would largely support itself by relying on premiums paid by policy holders. The FCIRC would have to borrow from the Federal Treasury to meet claims in excess of funds at hand, but would use future premiums to service such loans. Thus, the current FCIRC plan appears cost-feasible. In addition, the plan would address the massive economic dislocation which could follow from insurer's having to liquidate their assets to meet massive payout obligations following an earthquake.

Conclusions

- Even though insurance companies are required to provide earthquake insurance, only an estimated 8 to 20 percent of homeowners and 50 percent of businesses insure against earthquakes, due to high deductibles and premiums, and the reluctance of insurance companies to market earthquake insurance.

- The potential exists for catastrophic loss to the insurance industry in the event of a large earthquake from claims resulting directly from the earthquake, or claims for secondary effects such as fire loss and damage, loss of life, personal injury, and general liability.

- The possible consequences of catastrophic loss to the insurance industry include economic disruption of the insurance industry in the United States, dissolution of many insurance companies, and increased reliance on governmental disaster relief funds.

- Indirect incentives for new development or redevelopment of hazardous areas should be avoided in a future earthquake insurance program.

- The FCIRC as proposed would not involve cost to the County, as its administration would be left to the corporation, and the County could benefit greatly from its creation.

- One benefit of an FCIRC program is the increased availability and utilization of earthquake insurance to lessen an earthquake victims' need to rely on Federal, State, and County disaster assistance.

- Reliance on insurance rather than public disaster funds would likely shorten the recovery period following a major earthquake, thereby minimizing the interruption of tax revenues to the County.

- The County of Los Angeles has a choice of several alternative earthquake insurance strategies. These include:

  - A State-backed program of earthquake insurance;

  - a Federally-backed program of earthquake insurance;

  - "the Earthquake Project" which would create a Federal Catastrophe Insurance and Reinsurance Corporation (FCIRC) to be implemented with cooperation of the Federal government;

  - the Federal Emergency Management Agency model earthquake insurance program; and

  - Some combination of the above.

- The County may pursue a variety of proactive strategies once an official position is taken:

  - Lobbying on behalf of Federal or State earthquake insurance legislation;

  - cooperation with the Federal Emergency Management Agency in the design of a model insurance program;

  - cooperation with insurance companies operating within Los Angeles County to support promising industry proposals; and

  - some combination of the above.

SECTION 8.2

POST-DISASTER RECONSTRUCTION AND RECOVERY

Historically, reconstruction after major disasters has been characterized by competing priorities, conflict, and substantial delay. This problem can be traced, in part, to lack of proper organization and policies designed specifically to address post-disaster issues and opportunities. Severely damaged areas, especially those resulting from a large earthquake, require special interim measures to encourage appropriate rebuilding of impacted areas. Proper management by applying a variety of actions, such as promotion of expeditious or modified application of existing building controls, which include zoning regulations and building codes, can hasten reconstruction of critical components of a damaged community, yet retain the ability to critically scrutinize potentially hazardous reconstruction. The rebuilding process may involve socially and politically controversial decisions that require expert assessment and decisive action. Pre-event preparedness for post-disaster recovery in Los Angeles County, especially for the months immediately following a major disaster, is a critical issue that must be addressed.

In preparing a draft ordinance addressing long-term recovery, two alternatives were considered. One was to define the "team" needed for effective response and provide for it to come on line with the necessary authority immediately following a major disaster. The other alternative, the one chosen for the draft ordinance below, provides for the team to be established prior to the disaster and charged with the task of preparing for an emergency in anticipation of its post-event responsibilities. This approach provides time for the team to become familiar with potential local disasters and to prepare plans and programs for post-disaster recovery.

An additional set of alternatives involves the choice of whether to design an altogether new recovery agency, or to utilize the personnel and resources of existing agencies and institutions. The approach emphasized here is the second: applying the resources of existing agencies to the problem of facilitating recovery.

The following draft ordinance outlines the proposed composition, powers and responsibilities of a "Los Angeles County Reconstruction Authority" whose principal purpose is to facilitate recovery from major earthquakes. Specifically, the principal task of the Authority will be to facilitate safe reconstruction or repair of those facilities and structures destroyed or damaged during a large seismic event. The problem of phasing from emergency conditions to "normal" activities is not dealt with in detail. This issue should be addressed by the Reconstruction Authority after evaluation of potential and actual problems in Los Angeles County.

The generic ordinance form was chosen only as a means of presenting the general subject matter that should be considered for inclusion in a legal instrument designed to establish a Reconstruction Authority for the County. Competent legal

advice and assistance from the County Counsel and interaction with the appropriate County departments would, of course, be needed in preparing an actual ordinance for adoption by the Board of Supervisors.

ARTICLE I - GENERAL PROVISIONS

It is hereby found and declared that it is necessary to create a Reconstruction Authority in the unincorporated areas of Los Angeles County to facilitate reconstruction of structures and facilities destroyed or damaged during a major earthquake; provide special procedures to expedite public and private recovery activities; guard against reconstruction which could result in future peril to life or property; encourage the improvement of the environment where new opportunities have been created by severe property damage; and enable the County of Los Angeles to cooperate more effectively with other local jurisdictions, and agencies of the State and the Federal governments during reconstruction.

It is further found that it is necessary to declare and define the duties and responsibilities of the Recovery Authority and its supporting organizations; and to provide the means whereby all elements of the community may cooperate with and assist in preparing for and participating in post-disaster recovery.

ARTICLE II - DEFINITIONS

Major Emergency: An occurrence which because of its magnitude or character is or is likely to be beyond the control of the normal services, personnel, equipment and facilities of the regularly constituted branches and departments of local government.

Activated or Activation: As used in this ordinance means placing the Recovery Authority provided for in this ordinance into post-disaster phase operation

Post-Disaster Phase: A period of time beginning with the declaration of a major emergency by the Chairman of the Board of Supervisors, or some other authorized County official, and continuing until terminated by action of the Board of Supervisors.

ARTICLE III - CREATION OF THE RECONSTRUCTION AUTHORITY

There is hereby created the Los Angeles County Reconstruction Authority composed the following members:

- Chief Administrative Officer, Chair;
- County Counsel;
- Director of Planning;
- Director of the Community Development Commission;
- Director of the Department of Public Works;
- Forester and Fire Warden;
- Sheriff;

- Director of the Department of Public Social Services;
- Director of the Department of Health Services; and
- other appropriate Los Angeles County Departments or agencies designated by the Board of Supervisors.

The Authority shall organize a damage assessment task force, composed of staff members from the County departments or other public and private organizations, with expertise in structural engineering, civil and geotechnical engineering, engineering geology, fire safety, urban planning, social services and other appropriate skills which will function under the direction of the Authority to determine the nature and extent of damage; and identify impacted areas where special reconstruction measures are needed. The task force should be set up before a major disaster and be activated to function in the post-disaster phase. The task force may be divided into two or more damage assessment teams at the discretion of the Reconstruction Authority.

During the post-disaster phase, the Authority may nominate an Advisory Committee for each Board-designated impacted area, with membership from the community at large, to be appointed by the Board of Supervisors. The Advisory Committees shall assist the Authority and the Board with development and evaluation of recovery plans and measures; assist with public outreach to increase public awareness and support of the response measures needed by individuals, businesses and government; and perform other duties as directed by the Authority.

ARTICLE IV - INSTITUTION OF EMERGENCY PROCEDURES AND REQUIREMENTS IN THE POST-DISASTER PHASE

When a major disaster, such as a large earthquake, has occurred and the Board of Supervisors has declared an emergency, the Reconstruction Authority, assisted by the damage assessment task force, shall identify and delineate those areas impacted by the disaster event where special reconstruction measures are necessary, and transmit its recommendations to the Board. The impacted areas may include the whole unincorporated County area or a portion (or portions) thereof.

As an interim measure, all normal procedures and permit requirements for building and construction activities should be suspended by the Board upon the declaration of a "major emergency" until the following conditions are met:

a. All impacted areas are identified by the Reconstruction Authority and designated by the Board; and

b. the Board of Supervisors has acted to rescind the interim suspension, based on the recommendation of the authority.

Until such conditions are met, activities related to building and construction shall be subject to the approval of the Reconstruction Authority as directed by the Board of Supervisors, unless otherwise provided for through ordinances adopted in the pre-disaster period.

ARTICLE V - OPERATIONS AND RESPONSIBILITIES

The responsibilities and authorized operations of the Reconstruction Authority are defined hereunder for the pre-disaster and post-disaster periods.

A. Pre-Disaster Phase - The Reconstruction Authority shall perform the following duties, collaborating with the appropriate County agencies:

   a. Establish procedures, rules and regulations for the conduct of Authority business including rules for the conduct of Authority meetings and related public notice requirements.

   b. Evaluate existing plans and regulations in terms of the adequacy of their provisions for recovery and reconstruction following a major disaster; and recommend improved plans, regulations, programs and action measures and for rebuilding and recovery.

   c. Prepare proposals for streamlined measures and decision making designed to expedite reconstruction and recovery of impacted areas.

   d. Organize and train the damage assessment task force.

   e. Evaluate and recommend improvements in State and Federal disaster recovery legislation and programs; and recommend improved funding support for recovery following a disaster.

   The Reconstruction Authority shall submit annual reports to the Board of Supervisors with recommendations and proposals for addressing major problems encountered.

B. Post-Disaster Phase - Upon the declaration of an emergency, the Reconstruction Authority shall give direction to and expedite rebuilding and recovery activities. The Authority shall:

   1. Activate the damage assessment task force to identify damaged areas requiring repair and reconstruction;

   2. maintain liaison with the appropriate agencies including the California Office of Emergency Services, the Federal Emergency Management Agency, cities and other counties; and collaborate with emergency response agencies in analyzing estimates of damage, casualties, need for emergency shelter, and preparation of an analysis of problems to be addressed in the various stages of recovery;

   3. establish "one-stop" branch offices, conveniently located in or near impacted areas and staffed by trained personnel from appropriate County agencies, to provide information about rebuilding, evaluate rebuilding proposals for properties damaged or destroyed in a major disaster, and to issue building permits for reconstruction proposals that comply with zoning and building regulations;

4. activate plans and preprogrammed actions to streamline regulations and facilitate rebuilding of properties damaged in a major disaster;

5. recommend to the Board of Supervisors, and other appropriate agencies, major actions for reconstruction of damaged infrastructure;

6. submit proposals to the Board of Supervisors for redevelopment projects, redesign of any previously established projects, or other special measures deemed appropriate to expedite reconstruction of heavily damaged area;

7. review the General Plan (especially the Safety Element), the Five-Year Earthquake Preparedness Plan, and other relevant pre-earthquake or predisaster plans, programs and regulations, and recommend such changes as may be appropriate because of the magnitude and concentration of damage or presence of any special hazardous conditions identified by the damage assessment task force. The Authority shall submit recommendations to the Regional Planning Commission (those relating to general plans under the Commission's jurisdiction) and the Board of Supervisors for changes in plans, regulations or policies that are necessary or desirable; and

8. coordinate with the appropriate County agencies in preparing a general program for recovery and rebuilding, and progressively implement the program, adjusting it to changing conditions and problems as necessary. The Authority shall submit the program to the Board of Supervisors for approval.

Conclusion

- The County should consider establishing a reconstruction authority to facilitate recovery from major disasters.

CHAPTER 9

RESEARCH NEEDS AND OPPORTUNITIES

CHAPTER 9

RESEARCH NEEDS AND OPPORTUNITIES

The purpose of this chapter is to identify the types of research needed to support an effective safety program for Los Angeles County. Several possible long-range research objectives have emerged through analysis and discussion of the many topics addressed in this report. Major program components can be summarized as follows:

- Support of research programs to improve knowledge of seismic, geologic, and other hazards.
- Cooperate and participate in research that will lead to the ground response microzonation of Los Angeles County.
- Advocate applied early warning and disaster prediction research.

Figure 9.1 shows the major sources of hazard reduction research. The Federal government coordinates long-term research and hazard reduction planning through a program enacted in 1977 called the National Earthquake Hazards Reduction Act (NEHRA). The U.S. Geological Survey (USGS) and the National Science Foundation (NSF) perform research on earthquake processes and seismology, while the National Bureau of Standards (NBS) plays a strong role in experimental building and structure design. The Federal Emergency Management Agency (FEMA) coordinates NEHRA programs and communicates viable hazard mitigation alternatives to State and local governments.

The 1986 California Hazard Reduction Act (CHRA) is a culmination of the State's efforts at comprehensive disaster reduction. Beginning with the formation of the Seismic Safety Commission (1974), the Southern California Earthquake Preparedness Project (1980), and the Bay Area Regional Preparedness Project (1984), the CHRA program now coordinates the actions of a number of state agencies seeking to mitigate earthquake hazards. Many objectives of the CHRA program also rely on coordination with all levels of government, as well as private sector safety activities (Figure 9.1), (Seismic Safety Commission, 1987).

Federal and State government programs have traditionally assisted local governments in safety planning by providing basic geologic and seismic mapping. More recently, however, the Los Angeles metropolitan region has received the benefit of innovative seismic hazard and disaster response mapping/planning programs (Davis, et al., 1982; Ziony, 1985; Toppozada, et al., 1988). The County can take advantage of the lessons learned from these studies by developing and utilizing hazard mapping built upon the foundation created by the Federal and State programs.

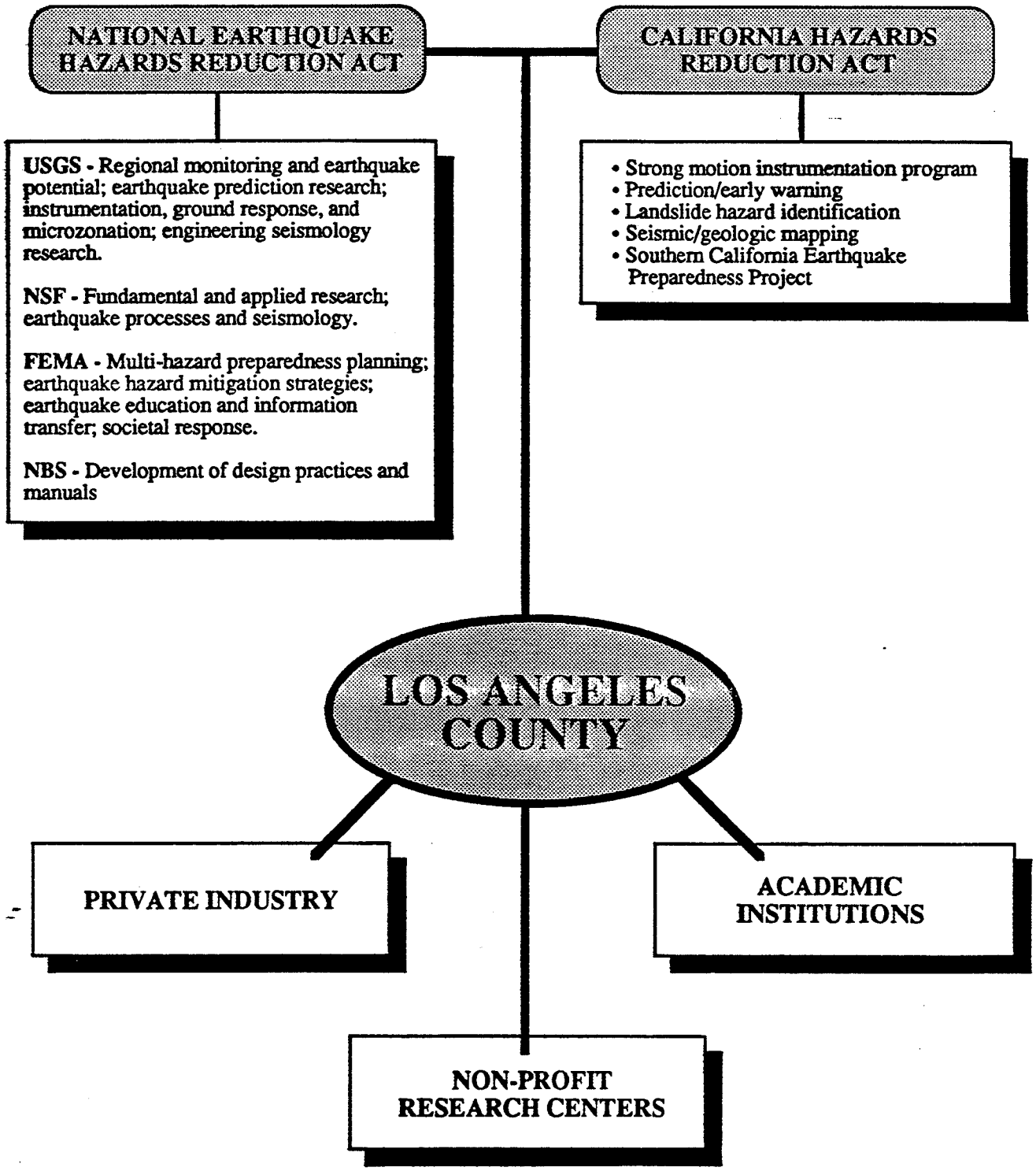

Figure 9.1: Sources for hazard reduction research for Los Angeles County.

The following tasks outline a possible County program to utilize Federal and State earth science, engineering and societal response research:

- Acquire, synthesize, and utilize Federal and State hazard reduction research;
- develop short-term and long-term research objectives based on County information needs;
- coordinate research needs and objectives with Federal and State hazard research programs; and
- encourage innovative research through public and private sector cooperation.

SECTION 9.1

GEOTECHNICAL MAPPING AND INFORMATION PROCESSING

The original 1975 Safety and Seismic Safety Elements advocated development or improvement of basic geologic mapping at 1:24,000 for certain unincorporated areas of the County. More recently, the County Five-Year Plan for Earthquake Preparedness presented a short-term goal aimed at developing seismic/geologic mapping at scales ranging from 1:12,000 and 1:24,000. Specifically, realizing the value of applying earth science information to urban and emergency planning, the recommendation advocated the development of a "County Information Management System". This capability has been referred to as microzonation. Microzonation requires the precise knowledge of the local seismology and geology, geotechnical parameters in alluvial basins, and accurate mapping of the urban environment. This section will review alternatives for improving those aspects of microzonation involving earth science.

Predictive Ground Motion

Ground motion studies are key components of a seismic hazard research program (Figure 9.2). Three fundamental limitations of the current generation of predictive ground motion maps developed for land use or disaster planning are:

- Uncertainty about the probable location of future earthquakes, especially in areas with many active and potentially active faults;
- variability in the age, detail and scale of the basic geologic/soils information, including uncertainty about variables such as basin geometry and site conditions; and
- lack of adequate information about the location and structural vulnerability of the building stock.

Probability of Earthquake Recurrence

The annual probability of recurrence of an earthquake on a particular fault is based on historical seismicity and/or probabilistic calculations derived from fault slip-rates, meaning the average rate of fault movement over periods as long as two million years (expressed in mm/gr). Faults with higher slip-rates are more prone to shorter earthquake recurrence intervals (see Appendix 2). Although the sizes of future earthquakes can be estimated from assumptions about the dimensions of faults (fault length), most of the 50 + active and potentially active fault segments in the County are not adequately characterized in terms of recurrence. Future research must emphasize improvement of slip-rate data and recurrence-interval estimates for individual faults.

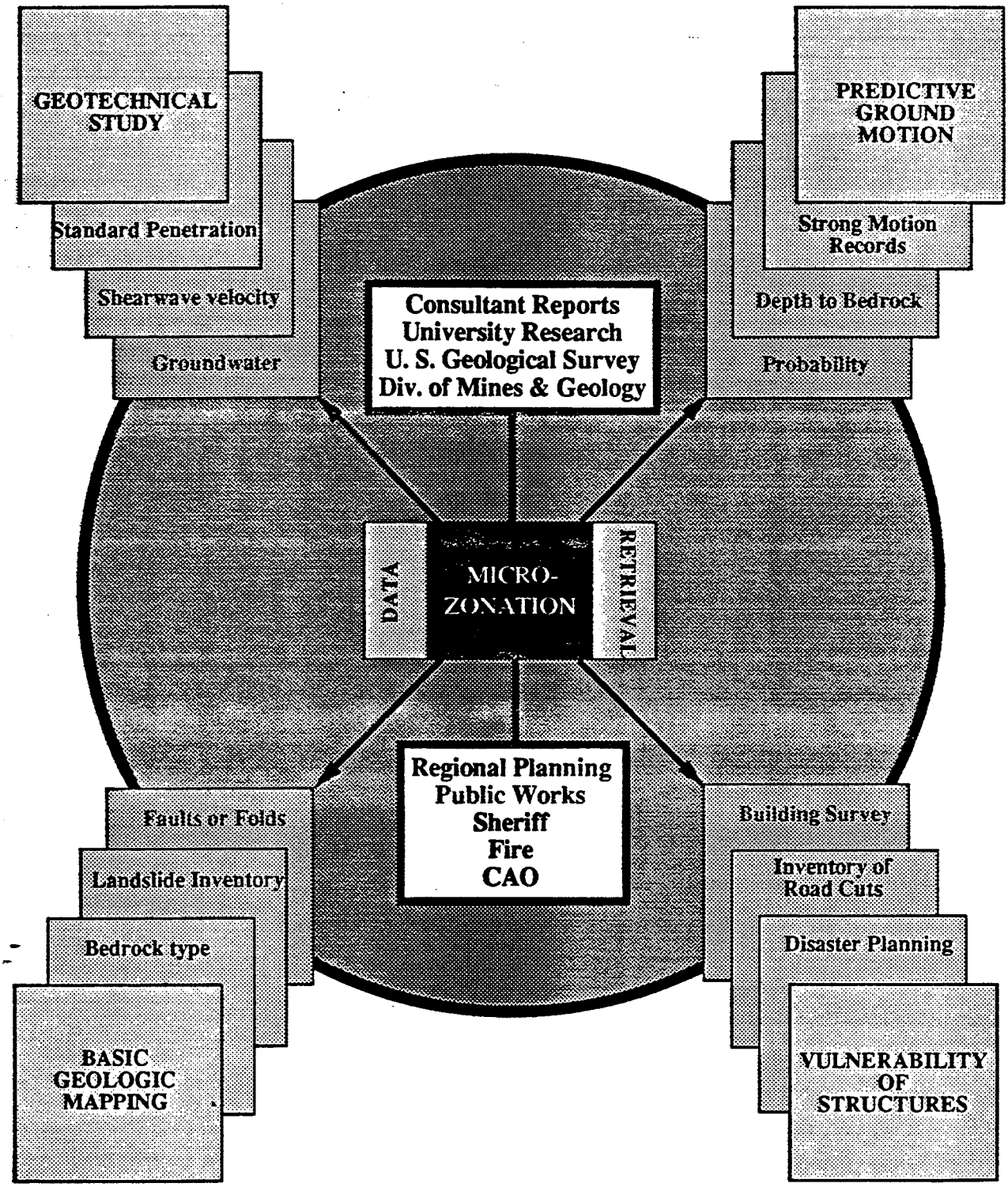

Figure 9.2: Elements involved with microzonation mapping of data and its retrieval.

Microzonation of Ground Motion

Several innovative predictive ground motion mapping techniques have been attempted by scientific researchers working in Los Angeles County. A predictive technique by Joyner and Fumal (1985) utilizes shear wave velocity. As a result of their study, it was shown that existing geotechnical information could be used to correlate mappable alluvial basin units with shear wave velocity in the Los Angeles Basin. Mapping of shear wave velocity promises the capability of regionally modeling one important variable controlling the amplification of earthquake shaking (Figure 9.2).

Rogers, et al., (1985) incorporates variables such as basin geometry, topography, and physical characteristics of the alluvium into a predictive ground motion model. The method provides a quantifiable relationship between the predominant site period and existing buildings. It allows identification of buildings with different heights that might be sensitive to particular earthquake frequencies, which as stated in Chapter 3, can severely damage structures with the same predominant periods, i.e., resonance. The "clustering method" of Rogers et al., (1985) relies heavily on ground motion recordings from either seismographs or accelerographs, the latter of which are designed to register strong motion from large, damaging earthquakes.

The seismic intensity method of Evernden and Thomson (1985) can be correlated with strong ground motion parameters for frequency bands applicable to ordinary building types. However, the method does not account for long period effects from far field earthquakes, including amplification and resonance. If the vulnerability of critical facilities and potentially hazardous buildings were better known, the accuracy of seismic intensity mapping could be significantly improved (Figure 9.2). This opportunity is discussed in Chapter 6 and in a later section.

In the event the County participates in the development of a ground microzonation mapping program in the future, shear wave velocity, accurate mapping of ground conditions, and compilation of existing seismograph and strong motion records would be necessary components (Figure 9.2). Unincorporated areas of the County would particularly benefit from such a data-intensive program since subsurface mapping of soil/sediment properties is inadequate in those areas. Additional emphasis should be on depth to bedrock, the three-dimensional geometry and structure of the Los Angeles Basin, and other alluvium-filled valleys such as Santa Clarita and Antelope Valleys (Rogers, et al., 1985).

The County already possesses a large potential geotechnical data base in existing records within the Department of Public Works. Developing this internal resource provides opportunities to:

- Establish a computer based geotechnical data retrieval system through the Department of Public Works and begin using existing records to catalog geotechnical ground conditions for easy retrieval in future microzonation studies (Figure 9.2);

- advocate an operative assemblage of seismograph stations in the County to permit accurate three-dimensional mapping of fault zones and to provide

increased resolution of site conditions for regional predictive ground motion mapping; and

- collect existing and future strong ground motion and/or seismograph records within the County and devise an information retrieval system for use in future microzonation studies (Figure 9.2).

Fault Rupture

Appendix 2 documents the latest evidence of active faulting in the County in terms of the fault rupture hazard (Plate 1). This evidence should be amended periodically to incorporate new information derived from private consultants, State and Federal governments, and Federally funded research programs (i.e., NEHRP, NSF, etc.). This new information would provide a mechanism for reclassifying potentially active faults to active, or changing the status of a potentially active fault to inactive. A data retrieval and modification system would ensure that the latest information is utilized in policy and regulatory decisions (Figure 9.2).

The data retrieval and mapping system could be located within the Department of Public Works. However, at present, there is a law which prevents breaching consultant/client confidentiality, thus private consultants cannot contribute fault study evidence to the public, unless approved by the consultant's client or submitted for recording on a Tentative Tract Map. State legislation providing for more liberal disclosure could be one means of achieving public disclosure and regular compilation of updated geologic hazard data.

Predictive Liquefaction

Shallow Ground Water

Most unincorporated areas of the County possess poor to nonexistent records of shallow perched ground water (Chapter 3). Particularly useful sources for expanding this data base include existing geotechnical data within the Department of Public Works and information held by private consultants in the geotechnical engineering field. Government agencies or environmental service consultants are also potential data sources, especially those involved with hazardous materials/ shallow ground water monitoring. An information "clearinghouse" could be established within the Department of Public Works, with special attention given to the location and depth of ground water, ground water management practices, and temporal/seasonal fluctuation of perched ground water (Figure 9.2).

Alluvial Basin Deposits

Unincorporated areas of the County lack detailed subsurface soils information. An attempt should be made to subdivide the Quaternary susceptible (Qs) unit on Plate 2 (Engineering Geologic Materials) into liquefiable and potentially

liquefiable units (Figure 9.2). Recent microzonation studies in Los Angeles and Orange Counties have demonstrated that compilations of existing borehole data, combined with strategic subsurface control (geophysical- engineering borehole, seismic refraction, etc.), allows regional interpolation of alluvial basin deposits into two and three dimensions (Ziony, 1985; Sherburne, 1985). The Standard Penetration Test (SPT) (ASTM D1586) is one tool for assessing liquefaction susceptibility (Seed, et al., 1985). A comprehensive compilation of existing and future SPT data could help delineate liquefaction prone units within areas presently designated as Quaternary (Qs) (Figure 9.2). Again, a County data retrieval and processing capability needs to be developed. This would support the capacity to provide:

- More accurate liquefaction susceptibility mapping in unincorporated areas;
- collapsible soils mapping for Antelope Valley; and
- the beginning of a data base for quantitative-predictive ground motion mapping, as Standard Penetration Test data also allows interpolation of shear wave velocity.

Recent communications with the CDMG (Mike Reichle, personal communication, 1989) indicate that they are exploring the feasibility of compiling geotechnical borehole data for this purpose. As their plans become more definitive, the County may wish to participate in establishing a central clearinghouse for data retrieval.

Liquefaction Susceptibility

Chapter 3 (Section 3.1.3.3) notes specific limitations of the liquefaction susceptibility map developed for this report (Plate 2). Because of these limitations, further liquefaction studies are needed. Although unincorporated areas of the County require basic data as outlined above, the following improvements should be incorporated into the next generation of County liquefaction hazard maps:

- An estimate of the thickness of liquefiable layers, since some units are too thin to cause internal strains large enough to affect building foundations;
- the preparation of "potential liquefaction damage" maps based on the coincidence of ground water with the variable thicknesses of susceptible alluvial units and the types of structures in liquefaction areas; and
- an estimate of "annual probabilities" of liquefaction recurrence, sometimes referred to as a liquefaction potential.

The probabilistic determination of ground motion can provide a basis for estimating the recurrence of large earthquakes on particular faults, and hence the recurrence of liquefaction. A review of Appendix 2 shows that slip rates have been identified for only a few well-studied faults, such as the San Andreas and Newport-Inglewood faults. As indicated earlier, many active and potentially active faults in and/or adjacent to the County need to be studied in greater

detail. Research of slip-rates for individual faults could eventually enable the County to utilize liquefaction probability in formulation of hazard reduction policy.

Landslides and Slope Instability

The feasibility of improving landslide susceptibility mapping should be explored by the County. A national program exists that outlines methods and costs of a local landslide mapping program (Campbell, 1985). The cost-benefit analysis and the economics of implementing such a program are provided by Berknopf, et al., (1985).

The State Landslide Hazard Identification Program (LHIP) is reconsidering the future direction of interpretive landslide mapping i.e., landslide susceptibility maps. Planning departments desire landslide susceptibility maps for general land use planning (Jene McKnight, 1989; personal communication). Although geologic investigation and grading operations eventually reveal the actual scope of hillslope constraints, land use planners find susceptibility maps helpful in preparing general plans. Some users of LHIP materials (private consultants, and geologists) desire that more effort be directed toward landslide inventory and geologic mapping than toward generating susceptibility maps (Ziony, 1989; personal communication). Because landslide susceptibility maps are only as accurate as the underlying bedrock mapping from which they are derived, first priority should be given to improved hillside/bedrock mapping.

The quality of mapping, including landslide inventory and basic geologic mapping, needs to be improved in the following County planning areas:

- Antelope Valley;
- Santa Clarita Valley; and
- Malibu/Santa Monica Mountains (see Figure 4.4).

These County planning areas above (see Figure 4.4) were chosen for a variety of reasons. They include: 1) the occurrence of rapid development, 2) the need to finalize certain preliminary USGS/CDMG landslide inventory/geologic mapping into a standardized large-scale County mapping program, and 3) the lack of adequate hazard mapping in these areas. Appendix 4 shows the reference sources used in the compilation of the Landslide Inventory (Plate 5). Additional research directions in slope instability are discussed in Chapter 5.

Tsunami

The potential economic loss to the Los Angeles Area in the event of a large tsunami warrants a more detailed analysis of tsunami risk. A better understanding of the seismic environment of the local seafloor and the geologic record is necessary for improving the perceived risk of a locally generated tsunami along

the Los Angeles coastline. The Japanese utilize the geologic record to establish estimates of the recurrence intervals of tsunamis. Recent sediments deposited along the shoreline or in coastal depressions may provide the evidence necessary to establish "tsunami risk", especially for potentially devastating local tsunamis. To date, there has been no "paleo-tsunami" research in Los Angeles County. Encouraging paleo-tsunami research would create a better understanding of tsunami risk in the County.

The tsunami inundation sections in Chapters 3 and 5 list a series of mitigation and planning methods in practice in some communities with a greater appreciation for the risk of coastal inundation. Better tsunami risk and tsunami vulnerability research in Los Angeles County would support improved tsunami safety planning. For instance, Marina del Rey might require "tsunami debris reduction zones" as in Chapter 5. Likewise, tsunami provisions may need to be incorporated in the building and fire codes. Effective safety planning, however, requires detailed (1:12,000) coastal mapping, scenario modeling of run-up, and a vulnerability assessment of land uses to tsunami flooding (see Chapter 3; Flood and Inundation).

Conclusions

- The paucity of data in the field of earthquake and tsunami recurrence probability needs to be improved to better understand the risks from earthquake related hazards.

- Shear wave velocity, accurate mapping of ground conditions, and strong motion records, are necessary components of a predictive ground motion mapping program within the County.

- A large potential microzonation data base exists within County departments, based on private and public geotechnical engineering projects, and in records of environmental and/or hazardous waste monitoring operations. This data base can be channeled into an information "clearinghouse" within a County department for use in future microzonation mapping.

- Earthquake recurrence intervals have been tentatively established for only a few of the active faults in Los Angeles County. The County should advocate further research directed at establishing earthquake recurrence intervals for all active faults.

- Improved basic geologic mapping at a standardized scale is needed for all areas of the County. Priority should be given to improved mapping in the Santa Clarita Valley, the Santa Monica Mountains and the Antelope Valley County planning areas (see Figure 4.7) in cooperation with State and Federal agencies and private non-profit organizations.

- Current predictive ground motion maps are out of date and/or too small in scale to be useful in safety management. A new generation of predictive ground motion maps is badly needed.

- Landslide inventory and landsliding susceptibility mapping is incomplete. Existing mapping was originally performed at a variety of scales and was based on differing assumptions varying with the objectives of individual researchers. The County would benefit from the availability of a comprehensive program of landslide mapping utilizing a standardized mapping scale and methodology.

- Susceptibility to liquefaction has not been comprehensively mapped in Los Angeles County. Data is most deficient outside the Los Angeles Basin in areas such as the Santa Clarita and Antelope Valleys.

SECTION 9.2

INVENTORY AND MAPPING OF CRITICAL FACILITIES AND POTENTIALLY HAZARDOUS STRUCTURES

A basic deficiency of the current safety data base is the lack of complete information on the location and nature of critical facilities and potentially hazardous structures. What is needed is detailed county-wide mapping of critical facilities and potentially hazardous buildings, at an appropriate scale (possibly 1:24,000); and a standardized County computer information management system to facilitate interdepartmental and interagency data acquisition and management. Priority should be given to unincorporated County areas; and to evaluation of the age, type of construction, occupancy (if applicable), and other relevant information related to risk assessment, hazard abatement and emergency response operations. The following facilities should be emphasized:

1. Critical Facilities

   a. Any lifeline system facility under County jurisdiction, such as energy transmission systems, major utility lines, evacuation and disaster routes, and structures storing heavy rescue and debris cleanup equipment. Accurate mapping of major energy pipelines should have a very high priority.

   b. Essential facilities that are needed in times of emergencies, such as hospitals, medical facilities, fire and police stations, emergency operation centers, and major communication centers.

   c. High-risk facilities that, if severely damaged, could cause catastrophic disasters far beyond the facility itself such as nuclear power plants, dams and other significant flood control infrastructure, freeway and road way infrastructure, and industrial plants which manufacture or store explosives, toxic materials, or petroleum products.

   d. High occupancy facilities having potential for catastrophic fatalities and crowd control problems, such as major public and private facilities used for assembly of large numbers of people, high-rise buildings and large multifamily residential complexes (greater than 500 person capacity).

   e. Dependent care facilities that house populations with special evacuation considerations, such as educational facilities for preschool, public and private schools; rehabilitation centers, prisons, and major social care facilities, including group care homes and elderly care facilities.

   f. Economic facilities whose continued operation is paramount to avoiding severe adverse economic impact, such as banking, vital record keeping and archiving, computing and data processing centers, port and airport facilities, and large industrial/commercial complexes.

2. Potentially Hazardous Structures

a. Unreinforced masonry (URM) buildings, including those with URM wall infilling.

b. Nonductile concrete frame buildings.

c. Inadequately designed pre-cast tilt-up construction.

d. Multistory buildings with soft-stories.

e. Inadequately designed structures with geometrical irregularities, including long spans and irregular shapes.

f. Mobile homes and residences not properly secured to their foundations.

g. Dilapidated buildings.

h. Buildings with interior and exterior nonstructural hazards.

i. Potentially hazardous bridges, overpasses and tunnels.

j. Potentially hazardous dams.

Since the inventory and mapping of the above facilities and structures will be expensive and time consuming, priorities would have to be established, and mapping and inventory analysis would have to be phased over a period of several years.

One approach to determining relative vulnerability of the above facilities and structures to earthquake damage would be to identify those that are located in hazardous areas, such as active fault zones and areas where there is high possibility of liquefaction using any available hazard mapping, including the 1 inch = 2 mile plates (Plates 1 and 4) depicting faults and potential for liquefaction.

Conclusions

- Inventory and mapping of critical facilities and potentially hazardous buildings are urgently needed for protecting public safety and establishing a computer-based disaster planning capability.

- An inventory and mapping program must be phased over a period of years, preferably on a schedule and based on apparent urgency or need.

SECTION 9.3

COMPUTER-BASED SAFETY AND DISASTER INFORMATION PROCESSING

Computer-Based Disaster Response Planning

An interactive computer-based mapping program is appealing because of the versatility and the benefits it could provide to long-term urban planning and disaster response operations. Computer-based disaster response planning could facilitate the following:

- Periodic improvements in the data base,
- modification of map scales to serve various purposes; and
- formulation of various contingencies for different earthquakes or other disasters.

Although in this section the focus is on disaster response planning, computer capability could also streamline the project review process and compliment long-term abatement of substandard critical facilities and hazardous structures.

Ideally, a disaster response planning program should be able to calculate seismic intensity/ground motion levels using a grid cell system suitable for a 1:12,000- to 1:24,000-scale map (Tucker, 1986). Subprograms would be able to calculate the effects of known local geologic conditions and compute the damages to selected structural types at a given seismic intensity. If no inventory or vulnerability assessments of critical facilities are available, Scawthorn and Gates (1983) demonstrated that a multivariate correlation technique can be used to model potential earthquake damage. Scawthorn and Gates (1983) state that such a technique allows estimation of building type and size on a regional scale, based on standard census and Standard Industrial Classification data. Structural deficiencies of inventoried critical facilities, information on the local geology, and knowledge of the effects of soil/structural interaction could be more easily incorporated into interactive computer programs. Specific safety planning opportunities include prediction of the following:

- Scope of damage and location of emergency response priorities in differing disaster scenarios;
- emergency response needs and evacuation routes necessary for a particular disaster scenario; and
- probable location of search and rescue priorities.

Computer based earthquake scenarios would provide the benefit of several working hypotheses, instead of putting all County efforts into one nonversatile disaster response plan (Tucker, 1986). In addition, rather than creating new maps as cultural urban information becomes outdated, or developing detailed maps for emergency response purposes, an interactive computer information system could accomplish these tasks on screen or as computer generated maps.

Tucker (1986) states that an interactive computer-based system would require the following resources:

- A moderate-sized Geographic Information System (GIS) with good graphics capability;
- a moderate-sized data base program;
- programmers and operators for hardware and software; and
- technicians to compile and/or update the inventory of hazardous structures, critical facilities, local geologic ground conditions, liquefaction susceptibility, and predictive ground motion parameters.

In terms of data acquisition, a geotechnical information "clearinghouse", advocated earlier in this chapter, could provide a mapping resolution of 1:12,000 to 1:24,000. Regarding computer requirements, as of 1990 the County Department of Regional Planning is in the process of developing a GIS capability based upon Arc-Info programs. Other County agencies are also in various stages of GIS development. The Department of Public Works has two compatible computer-based systems capable of mapping geotechnical and geologic information and the location of County-owned and leased facilities (see Chapter 6).

On the whole the County transition to GIS makes an interactive emergency information management system appear feasible. However, the computer program with the most useful information on critical facilities, the Sheriff LandTrac System, is not presently compatible with Arc-Info. Two short-term objectives should be alleviation of County agency computer incompatibility, and improvement of the critical facility and potentially hazardous structure data base, particularly for information on structural deficiencies of critical facilities.

Vulnerability Assessment

A plan for instituting a "building screening" program is outlined in Chapter 6. The main objective of the program would be to inventory and rapidly assess a building's strengthening needs (Figure 9.2). Potential benefits of a building screening program also include improved estimates of building damage mapping, specifically techniques that utilize seismic intensity. The true indicator of the damage potential, estimated by seismic intensity, is ultimately the structural integrity of the building stock. A screening approach could also assess the relative vulnerability, or risk, of selected infrastructure, such as:

- County-owned or operated dams with active storage (see Chapter 3, 5, and 6); and

- County-owned or maintained bridges and tunnels (see Chapter 6).

The hypothetical grid system presented in Figure 9.3 illustrates a procedure that has been successfully utilized in producing damage potential maps in the Bay Area (Jaffe, et al., 1981). If structurally deficient critical facilities and potentially hazardous buildings are identified, the relative vulnerability of each grid can be determined through inventory of all hazards affecting each grid (Figure 9.4). Appropriate actions for heavy rescue, emergency response routes, redundancy of lifelines, and other countermeasures could then be formulated on a grid-by-grid basis. The grid-size used in the assessment of vulnerability for emergency response would be dependent on the size of the region and the amount of cultural urban information available (Jaffe, et al., 1981).

Several advantages of the grid approach include:

- Easy manipulation of data obtained from screening structural deficiencies of the building stock into a computer format;

- identification of emergency response targets and emergency needs using defined grid areas as the basis for planning; and

- development of an automated computer-based post-earthquake damage model based on knowledge of the structural vulnerability of critical facilities within each grid (Figure 9.2).

The Association of Bay Area Governments (ABAG) effectively mapped regional earthquake damage potential for different classes of buildings, risk of dam failure, and ground failure potential using the computer-based grid system outlined above. The maps cover a seven County region at a scale of 1:250,000 and were developed through coordination with various interested jurisdictions (Jaffe, et al., 1981). Potential earthquake damage maps for an area the size of Los Angeles County require maps scales significantly greater than 1:250,000 and may benefit from similar multijurisdictional cooperation (USGS 86-401).

Conclusions

- The first step in assessing the vulnerability of critical facilities in Los Angeles County should be on a regional scale and lead to some version of a larger scale emergency information management system.

- The location, age, type, and occupancy of critical facilities and potentially hazardous structures should be included in a "first-level" regional assessment of vulnerability. Building screening and screening for the vulnerability/risk of County dams and bridges should be a goal of a County emergency management information system.

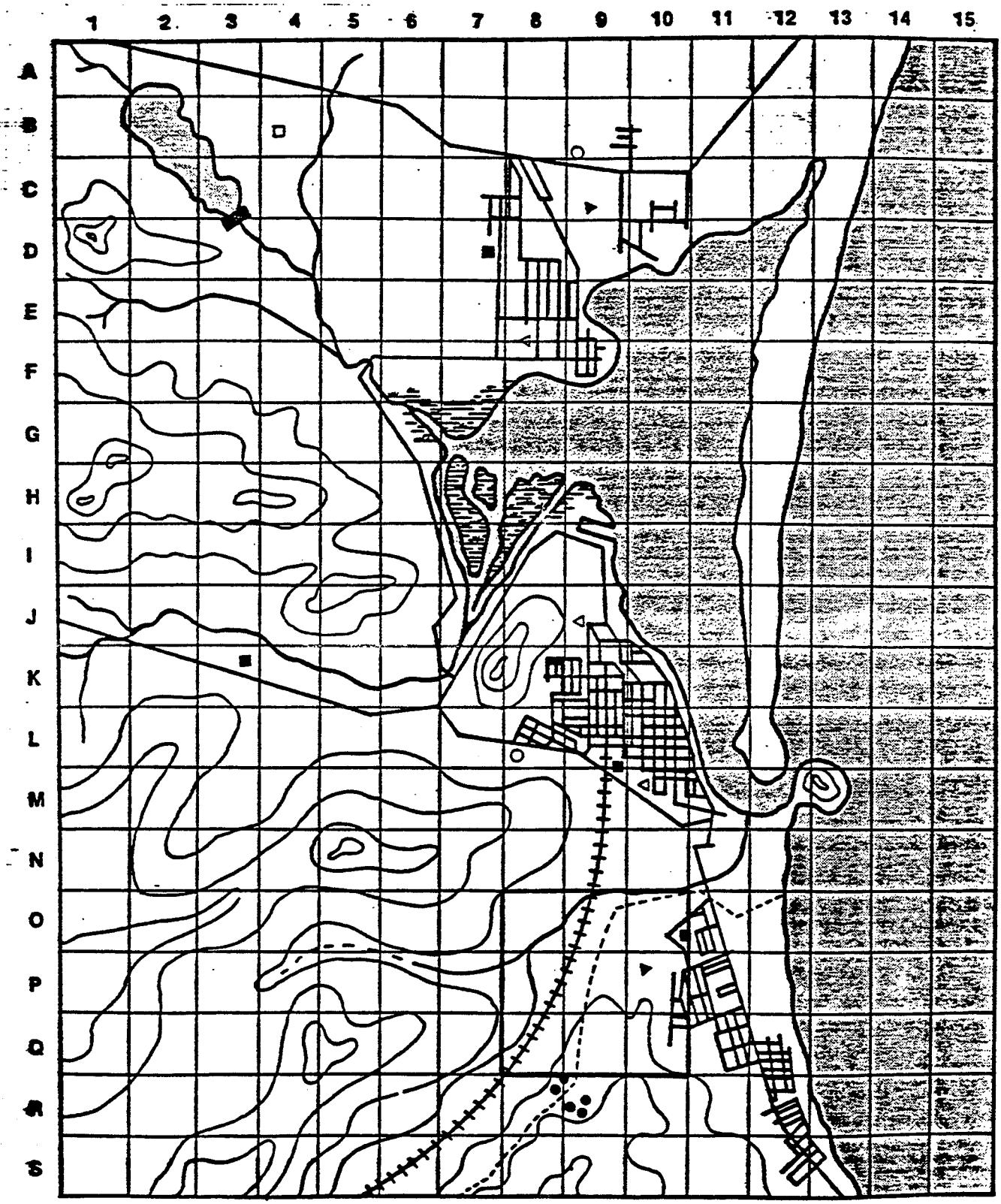

Figure 9.3: Grid analysis for a hypothetical community (after Jaffe, Butler and Thurow, 1981).

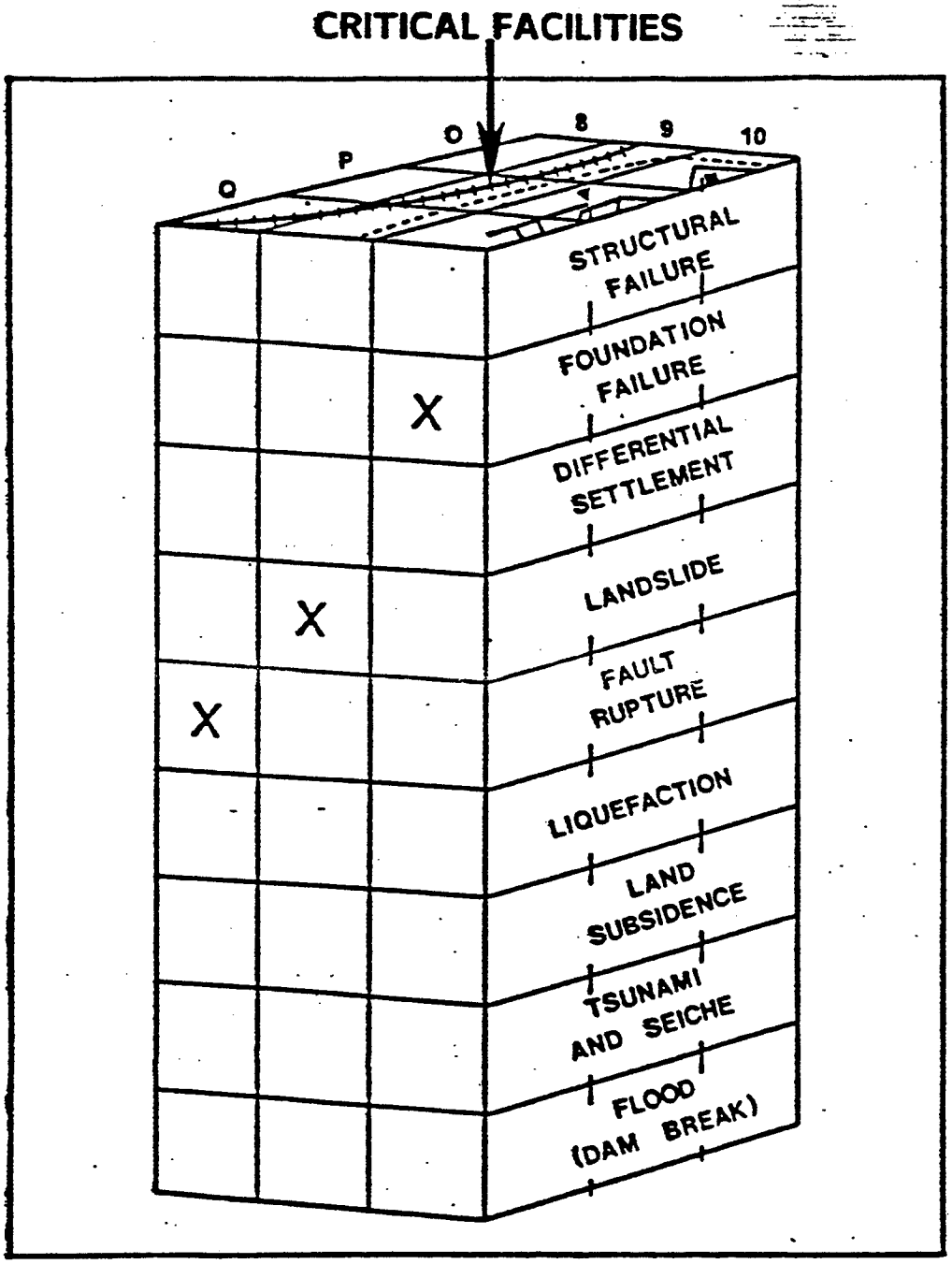

Figure 9.4: Determining phase 1 vulnerability of critical facilities from selected hazards for each grid unit area (see grids O8 thru Q10, figure 9.3). Phase 2 vulnerability considers the potential for structural failure based on the "screening" methodology presented in chapter 7 (after Jaffe, Butler and Thurow, 1981).

- Better knowledge of the regional vulnerability of critical facilities and potentially hazardous buildings could lead to a significant improvement in the predictive capability of seismic intensity mapping, a mapping technique that emphasizes structural damage potential.

- Computer assisted hazards mapping is a feasible goal in Los Angeles County. County agencies with relevant hazards data may be a primary resource of information for mapping ground conditions, shallow and perched ground water, faults, and predictive potential earthquake damage maps for emergency response.

- Even a small scale, manual inventory of critical facilities, or a detailed assessment of land use in areas identified as hazardous, could significantly improve safety by highlighting previously unknown or underestimated risks.

- A multijurisdictional cooperative potential earthquake damage mapping program would provide a feasible, low-cost alternative for developing maps at suitable scales for damage estimation and emergency response.

SECTION 9.4

PREDICTION AND HAZARD REDUCTION

Chapter 6 reviewed some inventive measures involving prediction, disaster warning, and hazard reduction currently implemented in Japan. This section emphasizes future prospects for employing applied research in earthquake prediction and innovative hazard reduction experiments in Los Angeles County.

Earthquake Prediction

As noted in Chapter 6, Japanese and United States researchers are both capable of estimating long term probabilities (years to decades) of selected major earthquakes. The forecasts, however, are limited to well-studied faults. Likewise, researchers in both countries have identified several areas where major and/or catastrophic earthquakes are expected. In California, this knowledge is limited to relatively few faults, the most notable being the San Andreas. The U.S. Geological Survey has centered experiments for earthquake prediction on the relatively isolated Parkfield segment of the San Andreas fault, while the Japanese have proceeded with an earthquake prediction experiment in a highly urbanized region. Aware that there are no proven techniques for short-term prediction, the Japanese prediction effort is carried out simultaneously with technical and societal research (SCEPP, 1982).

Los Angeles County is crossed by a number of faults, most with unknown or poorly defined recurrence intervals. In addition, some of these faults have decidedly different characteristics than the Parkfield segment of the San Andreas. Because of the County's location in such a complex seismotectonic environment, and the high risk of future damaging earthquakes, it may be advantageous for the County to be the subject of a prediction experiment similar to the Tokai Project in Japan. Even if the experiment were marginally successful, such a program could promote preparedness and hazard reduction activities in the County similar to those in Japan. As noted by SCEPP (1982), any such undertaking should not be at the expense of existing research activities, but should be in addition to existing geophysical, seismological, and technical and societal response research programs (Figure 9.1).

A Navy testing program, measuring the magnetic field in the epicentral area of the 1989 Loma Prieta Earthquake, noted fluctuations in the strength of the magnetic flux in the months and hours before the earthquake struck. Although the observation remains to be verified, the practicality of coordinating existing regional research resources, including those of the military, is evident and should not be overlooked (Figure 9.1).

Hazard Reduction

The Laboratory of Urban Safety Planning (LUSP) is one of several research organizations in Japan devoted to the disaster reduction effort. Similar to this Japanese planning group, the Southern California Earthquake Preparedness Project is directly involved with local governments in hazard reduction activities. However, the LUSP organization also conducts applied research (SCEPP, 1982). Although devoted to design alternatives for local land use planning agencies as an advising agency, they have also guided several experimental programs. One such program involved the design and construction of an apartment complex having model disaster reduction features (SCEPP, 1982). The LUSP planners took evacuation routes into consideration in the structural and architectural design of the complex. Special evacuation routes were designed to avoid reliance on internal stairwells and elevators, using roofs and exterior building components instead (SCEPP, 1982). Fire resistive blinds were designed to automatically fall over windows during a fire. Doors and other nonstructural components were designed to avoid blockage of escape routes or exits. As evident from these particular features, the Japanese are especially interested in fire safety, because they have been subjected to several earthquake fire catastrophes, one of which was responsible for many of the more than 100,000 deaths associated with the 1923 Kanto Earthquake (SCEPP, 1982). One achievement of the Japanese apartment model experiment is that several local jurisdictions and private corporations began to incorporate Laboratory of Urban Safety design features into their development.

Los Angeles County has access to private research resources, such as the Earthquake Engineering Research Institute, American Planning Association, and Urban Regional Research. Research organizations can be funded by the National Science Foundation and other State and Federal agencies to benefit local governments (Figure 9.1). In the future, Los Angeles County may wish to seek guidance from these sources on innovative hazard reduction opportunities.

Early Warning

The previous chapters have suggested several potential applications for early warning systems in Los Angeles County. The following is a summary of early warning uses which need to be closely evaluated for emergency planning.

- Earthquake: Radio-transmitted systems for the San Andreas fault provide maximum lead warning times of approximately 10 seconds. Lead times of ten seconds can be employed for some purposes. The lead times of radio-transmitted early warnings allows shut-down of some high-risk businesses or activities. Operations involving hazardous material or other activities posing an extraordinary risk to public safety can be shut-down with a greater cost-benefit ratio, relative to user-deployed systems with higher false alarm rates (Holden, 1989). The Los Angeles Metropolitan area, rather than the outlying areas of north County, would presumably be the only practical beneficiary of a radio-transmitted system.

With lead times significantly less than ten seconds and higher false alarm rates, user-deployed automatic alert systems are more feasible for personal and personnel safety (Holden, 1989). Potential applications include alerts for moving personnel or the general public away from hazardous locations: windows, industrial processes, and construction activities, etc. This version of an early warning system is more feasible for earthquakes occurring within ten kilometers of the area forewarned (see Chapter 6).

Either early warning system can be adapted to warn residents, workers, or agencies responsible for public safety to prepare for potential evacuation or hazard reduction procedures from secondary earthquake hazards. Neither system allows sufficient lead times to permit actual evacuation before or during intense ground shaking.

- Tsunami: Radio-transmitted warning of local tsunamis is a feasible, low cost option for emergency planning (Bernard, et al., 1988). The Tsunami Hazard Reduction Utilizing Systems Technology (THRUST) project can warn of an impending tsunami in two minutes. Such an alert window permits warning of a locally-formed tsunami off the southern California coastline.

- Debris & Mudflow: A U.S. Geological Survey experimental program utilizes trip wires, electric fences, and other technology to warn of impact or flood inundation. This particular technology may have potential applications in the San Gabriel and Santa Monica Mountains (see Chapter 3). Erley and Kockelman (1984) have described successful early warning applications in Billings, Montana, and Kodiak, Alaska (Spangle, 1987). The Japanese government utilizes a similar early warning system technology for volcanically-induced debris and mudflows in Sakurajima, Japan.

Conclusions

- Experiments pertaining to hazard reduction technology, if promoted in Los Angeles County, would contribute to public and private sector safety and disaster planning.

- Early warning systems for earthquakes, tsunamis, dam breaks, mud and debris, flows, and mud and clear water flooding, because of the potential improvement evacuation response times, should be seriously investigated for feasibility beginning on an experimental basis.

- Earthquake short- and medium-range prediction, although not technologically possible at present, should be encouraged, coordinated with existing research

and other geophysical operations, and integrated into disaster planning in both the private and public sectors.

- A seismic event monitoring array similar to those in Japan's Tokai region and the Parkfield area of California should be established in the Los Angeles region.

APPENDICES

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APPENDIX 1

SUMMARY OF STATE AND FEDERAL LAWS

APPENDIX 1

SUMMARY OF STATE AND FEDERAL LAWS

A synopsis of the State laws and administrative guidelines, which are applicable to updating the County's Safety Element is given in this section. A summary of Federal statutes which may be applicable to implementing the County Safety Element is also provided.

"Deering's California Codes, Annotated, 1987" (with annual supplements) is the main source for State statutes. Papers in technical journals and other safety elements were also valuable sources for identifying applicable statutes. We have not considered California tort laws (liability and immunity concerns) as they are generally beyond the scope of this task.

A search of statutes relating to the Federal Emergency Management Agency (FEMA) and Federal Codes revealed a profusion of disaster-related laws, most of them focused upon disaster preparedness and recovery. Few appear to have a direct bearing on Safety Element issues per se', but rather reinforce the objectives of the Element.

Calamities such as those which recently struck Mexico City, Whittier and San Francisco have increased the disaster awareness of the public and the State Legislature, and have been the impetus for a variety of new legislation. Early California earthquake-related legislation (e.g., 1933 Field Act) was directed at the safety of buildings while more recent legislation has focused upon facilities siting, disaster response management, and post-disaster recovery.

STATE LAWS

CONTENT OF SAFETY ELEMENT

- Government Code Section 65302(f) and 65302(i) (1971). A seismic safety element is to consist of an identification and appraisal of seismic hazards such as susceptibility to surface rupture from faulting, ground shaking, ground failure, mudflow and landslides, slope stability, and tsunamis and seiches. The safety element is a required part of the general plan.

- Government Code Section 65302(g) (General Plan Revision Law, 1984). Combines seismic safety and safety elements and adds the requirement of policies for the protection of the community. The law updates Sections 65302(f) and 65302(i) to now include seismically induced surface rupture, ground shaking, ground failure, tsunamis, seiches, dam failure, mudflow and landsliding, subsidence and other known geologic hazards, flooding, and wildland and urban fires. A safety element must include mapping of known seismic and other geologic hazards and must address evacuation routes, peak load water supply requirements, and minimum road widths and clearances around structures.

- Government Code Section 65303 (1965). The act permits the addition to the safety element of any other subject, which in the judgment of the legislative body, is related to the physical development of the City or County.

BUILDING SAFETY

- Education Code Sections 39140-156, 81130-46 (1933 Field Act). The Office of the State Architect is to ensure that public schools (Grades K through 12) and community colleges are earthquake resistant.

- Health and Safety Code Sections 19100 (1939 Riley Act). Requires local jurisdictions to set and enforce construction standards to meet minimal seismic design parameters.

- Health and Safety Code Section 15000 (1972 Hospital Seismic Safety Act). The Office of the State Architect is to ensure that hospitals are earthquake resistant.

- Public Resources Code Section 25000 (1975). The California Energy Commission is to certify power plants and review geologic hazards at their sites.

- Government Code Sections 8875-8879 (1986). Directs local governments to prepare an inventory of unsafe buildings. Cities and counties in Seismic Zone 4 (all of Los Angeles County) are required to identify potentially hazardous buildings and establish a program for their mitigation. The law is aimed at unreinforced masonry structures, but does not require retrofittings of hazardous masonry buildings. All potentially hazardous buildings and mitigation programs are to be reported to the Seismic Safety Commission by January 1, 1990.

- Education Code Section 39160 et seq. (1986). Private schools must now meet seismic design regulations.

DAM FAILURE

- Government Code Section 8589.5 (1972). Dam owners submit to the Office of Emergency Services, maps showing inundation zones caused by a catastrophic failure. The OES is to designate areas with potential loss of life, and is to review procedures for population control and for evacuation below dams in the event of a dam failure.

GEOLOGIC HAZARDS

- Public Resources Code Sections 3315-3347 (1958). Addresses repressuring of collapsed, subsided oil and gas-bearing formations.

- Public Resources Code Section 2621 et seq. (1972 Alquist-Priolo Special Studies Zones Act). The act requires the State Geologist to delineate and map special studies zones along all potentially and recently active fault traces. Cities and counties shall require, prior to approval of a project, a geologic report addressing the hazards of surface rupture from faulting. Geologic reports within an A-P zone must be submitted to the State Geologist

for review and open file compilation. As interpreted by the State Geologist, an "active" fault is one that has ruptured during "Holocene" time (the last 10,000 to 11,000 years), and that is "sufficiently active and well defined."

- Public Resources Code Section 2622 (1972). The California Division of Mines and Geology is to identify and evaluate specific geologic and seismologic hazards with respect to their impact on land use planning, and to make this information available to the public.

- Government Code Section 26500 et seq. (1979 Geologic Hazard Abatement Districts Act). Permits local property owners to establish a geologic hazard abatement district to prevent, mitigate, or otherwise control a hazard. The district is a government unit with powers of taxation, annexation, eminent domain, etc. Abatement districts have most commonly been applied to landslide impacted areas.

- Public Resources Code Section 2670 (1983 Landslide Hazard Identification Act). The State Mining and Geology Board and the State Geologist are to develop maps of landslide hazards in urban and urbanizing areas which can be used for land use planning. The act expires January 1, 1989, unless otherwise extended. Several geologic quadrangles have been completed under this program within the northern county area, and partially completed for the Puente Hills area.

- Public Resources Code Section 21000 et seq. Consider seismic and geologic setting prior to approval of most significant development projects and actions by the local Government, Environmental Assessment: California Environmental Quality Act.

EARTHQUAKE PREPAREDNESS, RESEARCH, AND RECOVERY

- Government Code Section 8550 et seq. (1970 California Emergency Services Act). The law defines various levels of emergencies and the powers of the governor with respect to the emergencies. The act also requires dam owners to submit to the Office of Emergency Services, inundation maps showing the areas of potential flooding in the event of dam failure. Such maps should be included in the safety elements per Section 65302(g).

- Public Resources Code Section 2700 et seq. (1971 Strong Motion Instrumentation Program). The act provides for the installation of strong motion instruments in hospitals, dams, bridges, schools, and power plants.

- Public Resources Code Section 2709.1 (1987). The act increases funding for the Strong Motion Instrumentation Program.

- Government Code Section 955.1 (1976). A validated earthquake or volcanic warning gives the governor sufficient basis to declare a state of emergency, but State agencies may take, or refuse to take, any action and be immune from liability.

- Public Resources Code Section 2805 et seq. (1984 California Earthquake Education Act). The act establishes the California Earthquake Education Project (CALEEP) to implement a statewide program of earthquake safety and preparedness.

- Government Code Sections 8870-8874 (1985 California Earthquake Hazards Reduction Act). The act establishes a single, overall seismic safety and hazard reduction program with elements to be carried out by State and local governments and the private sector under the guidance of the Seismic Safety Commission. The act addresses mitigation, preparedness, response and recovery. The concerns of this act, and thus State policies are focused on six areas: 1) existing development and structures that do not meet current codes; 2) the organizing and managing of mutual aid systems at and between local governments and the State; 3) new development which should meet state-of-the-art earthquake engineering and rigorous review and onsite inspection for code compliance; 4) the need for careful advance preparedness for postdisaster reconstruction to avoid short-sighted, "knee-jerk" decisions; cope with them; and 6) the need for the State to take a more active role in geological and engineering research on earthquake phenomenon.

- Public Resources Code 2800 et seq. (1985). State agencies are to join an ongoing U.S. Geological Survey program monitoring the San Andreas fault, to assess the possibility of developing an early warning system to detect seismic activity.

- Public Resources Code Section 2804.6 (1986). The Department of Conservation is to join with the U.S. Geological Survey to develop an early warning system for earthquake prediction. The department is also to evaluate the effectiveness of such a system on the San Andreas fault north of Los Angeles.

- Public Resources Code Section 2810 (1986). The act created the southern California Earthquake Preparedness Project to promote voluntary action by local governments, volunteer agencies, and private groups to address mitigation, public education, response, and recovery planning.

Toxic Waste

- Title 23, California Administrative Code, Subchapter 15, classifies solid waste and gives factors to consider when siting a waste repository, including Holocene fault setback, 100-year flood plains, tsunamis, seiches, and areas of rapid geologic change.

- Health and Safety Code Section 25159.10 et seq. (1985 Toxic Injection Well Control Act), provides State rules and regulations for toxic waste injection wells.

- Division 20, Chapters 6.5 (Tanner Bill, Roberts Bill, Katz Bill), 6.7 (Sher and Cortese Bills of the State Health and Safety Code govern the handling, storage, treatment, and disposal of hazardous waste. Prior to a natural disaster, facilities handling hazardous materials should have maintained compliance with State hazardous waste laws at their facilities.

Chapter 6.7 contains the following provisions for reporting any releases from underground tanks storing hazardous substances:

- Section 25295. Any unauthorized release from the primary containment, which the operator is able to clean up within eight hours after the release was detected or should reasonably have been detected, and which does not escape from the secondary containment, does not increase the hazard of fire or explosion, and does not cause any deterioration of the secondary containment of the underground storage tank.

- Section 25295. Any unauthorized release which escapes from the secondary containment, or from the primary containment if no secondary containment exists that increases the hazard of fire or explosion, or causes any deterioration of the secondary containment or an underground tank shall be reported by the operator to the local agency within 24 hours after the release has been detected or should have been detected. A full written report shall be transmitted by the owner or operator of the underground storage tank(s) within five working days of the occurrence of the release (Section 25295).

- Division 20, Chapter 6.95, Sections 25500 through 25520 of the State Health and Safety Code (Waters Bill) contain provisions requiring local businesses to provide business plans relating to the handling and release or threatened release of hazardous materials to the local enforcement agency. Basic information on the location, type, quantity and the health risks of hazardous materials handled, used, stored or disposed, which could be accidentally released into the environment must be provided as part of the businees plan. This requirement applies to any business (except for consumer products, Section 25503.5(b), which handles a hazardous material or a mixture containing a hazardous material, which has a quantity at any one time during the reporting year equal to or greater than, a total weight of 500 pounds, or a total volume of 55 gallons or 200 cubic feet at standard temperature and pressure for compressed gas. It also applies to railroad cars containing hazardous materials remaining at the same facility for more than 30 days.

  Business plans must include the following (not inclusive):

  - An inventory of contents and amounts of hazardous materials; and

  - emergency response plans and procedures in the event of a reportable or threatened release (including notification provisions, procedures, evacuation plans and training).

- Division 20 Chapter 6.9, Sections 25531-25541 (La Follete Bill) requires that businesses which handle specified acutely hazardous material must file a registration form including a general description of the processes and principal equipment involved in handling of the acutely hazardous materials. Some businesses will be required to submit a risk management and prevention program to prevent accidents involving acutely hazardous materials.

- Water Code, Division 7, Sections 13271 and 13272 (Porter-Cologne Water Quality Control Act) requires notification of the State Office of Emergency Services and the appropriate Regional Water Quality Control Board in the event of a discharge of a hazardous substance or sewage to the waters of the State in excess of established reportable quantities. Any person who causes or permits a discharge of over 42 gallons of oil or petroleum product to the waters of the State must notify the State Office of Emergency Services.

- Health and Safety Code Section 25180 (Proposition 65) requires a number of new restrictions on the discharge and use of two broad categories of chemicals, to be set forth in lists promulgated by the governor, and requires public notification of unauthorized discharges of hazardous materials into potential sources of drinking water.

- Title 22, California Code of Regulations provides a comprehensive "cradle to grave" regulation of hazardous wastes for the State of California.

FIRE HAZARD

- Public Resources Code Section 4117 (1965). Designates those areas of California in which the State has the primary financial responsibility of preventing and suppressing fires.

- Public Resources Code 4125 (1965). The act allows a county to adopt ordinances, rules, or regulations to provide fire prevention restrictions which are necessary to meet local conditions and which may be more stringent than State statutes.

- Public Resources Code Section 4201 (1982). Fire hazard zones are to be designated and ranked according to an expected degree of severity. The law appears to apply to lands under State responsibility (see PRC Sec. 4125).

LIABILITY AND IMMUNITY OF PUBLIC EMPLOYEES

- Government Code Section 810 et seq. (1963 California Tort Claims Act.) Addresses liabilities and immunities of public employees with specific references to earthquake prediction.

FEDERAL LAWS

- Dam Inspection, Title 33, Section 467 (1972). This statute provides for the nationwide inspection of many dams by the U.S. Corps of Engineers. The statute defines a dam as an artificial barrier greater than 25 feet in height above the natural bed of a water course, or a barrier with an impounded storage capacity of over 500 acre feet (and providing the dam is less than six feet high). Dams exempt from inspection are those under the jurisdiction of the TVA, U.S. Bureau of Reclamation, and International Boundary and Water Commission, those built under license of the Federal Power Act, and those which the Secretary of the Army determines do not pose a threat to life or property.

- Economic Recovery, Title 42, Section 3231 et seq. (1974). These statutes are intended to promote the economic recovery of a disaster stricken region after the replacement of essential facilities and administration of emergency aid is completed. The codes establish a recovery planning council and identify the eligibility and rates of interest for loans and grants.

- Disaster Relief Act, Public Law 93-288 (1974). This is a wide ranging act, which generally sets forth the guidelines, operating procedures, and responsibilities, which were subsequently adopted by FEMA upon its formation in 1979. The act adds or repeals statutes in Title 42 (Public Health and Welfare), former Title 31 (money and finance), Title 12 (banks and banking), Title 20 (education), Title 26 (internal revenue), Title 38 (veteran's benefits), Title 40 (public buildings, property, and works), and Title 48 (territories and insular possessions). The act provides for the repair and restoration of public facilities as well as for loans, grants, and temporary housing for individuals.

- Earthquake Hazards Reduction Act, Title 42, Sections 7701 et seq. (1977). The act designates FEMA as the agency to plan and coordinate a national earthquake hazards reduction program. The program's objectives are 1) to develop earthquake resistant construction techniques, 2) to develop earthquake prediction schemes, 3) to develop and promote model codes, 4) to continue public education on disasters, 5) to promote research for the mitigation of earthquake hazards, 6) find ways to ensure the availability of earthquake insurance, and 7) encourage research for the control of seismic phenomena.

- Executive Order 12148, Section 4-103(a) (1979). The order established FEMA as an agency and delegated to it the functions of the Federal Civil Defense Administration covered by Title 50-Appendix, Sections 2251-2297. Under these statutes, FEMA has the responsibility to establish and coordinate Federal policies for civil emergency planning, management, mitigation, and recovery assistance functions of the various executive agencies.

- SARA Title III mandates a new Federal program creating four distinct sets of reporting and planning requirements for toxic chemicals.

- Resource Conservation and Recovery Act (RCRA) of 1976 provides Federal "cradle to grave" regulation of hazardous wastes.

APPENDIX 2

FAULTS IN LOS ANGELES COUNTY

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FAULTS IN LOS ANGELES COUNTY

This appendix provides a summary of current technical data and professional views pertaining to surface fault rupture hazards in Los Angeles County. Table 3.2, which is keyed to this appendix, refers to fault splays to document reference sources used to compile Plate 1. Smaller, individual fault splays are not expressly mentioned in this appendix. Table 3.2 also indicates several conditionally active faults that are not covered in this review. The two fault lists do correspond for major active and potentially active faults.

Corresponding to Table 3.2, selected fault segments are included in the following discussion. The fault segments indicated may constrain the likely size of future earthquakes on these faults, particularly within the San Gabriel and Sierra Madre Fault Zones. While a tally of active faults in the County should emphasize these individual segments, individual fault splays need not be accounted for, given the low probability that a major earthquake would initiate on such a small structure.

Faults in the Santa Susana Mountains
San Fernando Valley Area

(see Chapter 3 for Activity Classification Criteria)

San Fernando Fault Zone

Classification - Historical/Active
Length - 17 km
Width - 5 km
Slip Rate - Not Reported

The San Fernando fault was not known until February 9, 1971, at which time it ruptured and caused extensive damage in the northern and eastern San Fernando Valley. The San Fernando fault is comprised of five major reverse-left-oblique en echelon strands that vary in strike from 75 degrees east of north to 70 degrees west of north. The fault dips 50 degrees north near the surface and shallows to 35 degrees north at depth. The total length is at least 17 kilometers (Ziony and Yerkes, 1985).

As illustrated on the fault map (Plate 1), the five fault segments consist of:

- Reservoir Segment: Extends from the lower Van Norman reservoir embankment eastward along the east flank of a series of low hills were it meets the Mission Wells segment.

- Mission Wells Segment: Located 1.5 kilometers east of Lower Van Norman Lake. Small south facing scarps define the trends of the fault segment. Surface cracks from the 1971 earthquake displayed left lateral offsets (USGS, 1971).

- Sylmar Segment: Well-defined zone of fractures that extends from the southern corner of Hubbard Street and Glenoaks Boulevard to south of Lopez Dam. The zone generally ranges from 75 to more than 200 meters in width (USGS, 1971).

- Tujunga Thrust: Extends along the base of the hills on the north side of Tujunga Valley eastward into Little Tujunga Canyon.

- Lake View Segment: Continuation of Tujunga segment, trends eastward along the low hills from Little Tujunga Wash to Big Tujunga Wash.

These faults were zoned within the Alquist-Priolo Special Studies Zones Act in 1976. It is generally recognized that the eastern fault segments are structurally related to the Sierra Madre Fault System; however, the structural relationship of the western segment is less well-defined. The western San Fernando segment may have structural ties to the Mission Hills fault.

Santa Susana Fault

Classification - Active
Length - 28 to 38 km
Width - 0.25 to 1.5 km
Slip Rate - 3 to 4.5 mm/yr

The Santa Susana fault dips north along the southern flank of the Santa Susana Mountains, extending eastward until it merges with the Sierra Madre Fault System (Yeats, 1987). Wesnousky (1986) and Ziony and Yerkes (1985) assign a length of 38 kilometers and 28 kilometers, respectively. The fault dips 0 to 30 degrees in the near surface resulting in a fault zone width between .25 and 1.5 kilometers (Ziony and Yerkes, 1985).

The eastern portion of the fault experienced reverse-left-oblique sympathetic rupture during the 1971 San Fernando Earthquake (Saul and Weber, 1975). This portion of the fault has been designated an Alquist-Priolo Special Studies Zones (APSSZ) fault. To the west of the APSSZ, in the Porter Ranch area, subsurface trench investigations have revealed minor faults within terrace deposits. No faulting was observed within an overlying fanglomerate that was carbon-dated as 10,010± 580 years y.b.p. (Weick and Lung, 1987). However, massive landsliding and bedding plane faulting have prevented an unequivocal determination of the age of faulting for this portion of the fault. Based on this uncertainty, and according to the criteria stated in Chapter 3 for faults adjoining APSSZ faults, the western portion of the fault is considered active.

Mission Hills Fault

Classification - Active
Length - 10 km

Width - 50 m
Slip Rate - Not Reported

The Mission Hills fault trends ENE to EW for ten kilometers along the south side of Mission Hills. The fault is expressed by young fault morphology in some instances. The width has been described as a single-strand occurring within a zone as narrow as 150 feet (Ziony and Yerkes, 1985). Smith (1978) has interpreted the age of the fault as latest Pleistocene; however, Slosson (1977) and Kowalewsky (1978) documented Holocene rupture based on evidence of bedrock thrust over Holocene-aged soil. Ziony and Jones (1989) concur with a possible Holocene Age.

Northridge Fault

Classification - Active
Length - 15 to 21 km
Width - 0.7 km
Slip Rate - Not Reported

The Northridge Hills fault consists of nine en echelon strands each with zones approximately .7 kilometers wide (Ziony and Yerkes, 1985). The strands shown on Plate 1 are drawn from several different sources and suggest the cumulative fault zone width is relatively large (Plate 1). The fault zone strikes 70 to 80 degrees west of north through the central San Fernando Valley. The style of slip is probably reverse, with a dip of 35 degrees north near the surface and 80 degrees north at depth (Ziony and Yerkes, 1985). Several aftershocks of the 1971 San Fernando Earthquake occurred coincident with the subsurface extension of the fault (Ziony and Yerkes, 1985). The fault has been described as Late Quaternary Age by many workers (Ziony, et al., 1974; Barnhardt and Slosson, 1973; Wentworth and Yerkes, 1971); however, Ziony and Yerkes (1985) have reinterpreted ground water offset data and fault physiography to suggest possible Holocene Age activity. Additional evidence of relatively recent activity is the folding and warping of Holocene and Pleistocene Age sediments exposed during trench excavations by George Larson (Jerry Treiman, 1989; personal communication). Ziony and Jones (1989) show the fault as possibly Holocene on their latest compilation.

Faults Bounding the Santa Monica Mountains

Hollywood Fault

Classification - Active
Length - 17 km
Width - Single Strand
Slip Rate - >0.3 mm/yr to <0.8 mm/yr

The Hollywood fault is mapped as a narrow strand that trends along the southern front of the Santa Monica Mountains (Ziony and Yerkes, 1985; Weber, et al., 1980). Ziony and Yerkes (1985) list the fault as having reverse or reverse oblique motion. The eastern segment of the Hollywood Fault Zone trends through

the Repetto Hills as a complex series of faults and folds within the Puente Formation. In this area, the fault and several splays are in close proximity to the Raymond fault (APSSZ) (Plate 1). Physiographic features such as scarps and inclined spurs are interpreted as evidence of Holocene movement along the eastern 17 kilometers of the Hollywood fault (Ziony and Yerkes, 1985; Weber, et al., 1980). The age of movement along the western portion of the Hollywood fault is not reported, suggesting the fault has been inactive for the last 750,000 years.

North Hollywood Fault

Classification - Active
Length - 2 km
Width - 0.5 km
Slip Rate - Not Reported

The North Hollywood fault, listed as a "possible fault in North Hollywood" by Ziony and Yerkes (1985), dips vertically along a single-strand approximately 2 km in length. This fault is but one of many ground water impediments (faults) within the San Fernando Valley; however, Weber, et al., (1980) noted that the fault formed an ENE-trending, linear break in topography on older quadrangle maps published in 1901 and 1926. Weber (1980) noted that because the south-facing physiographic lineament apparently offset youthful deposits of the Tujunga Wash, the fault may be Holocene in age.

Santa Monica Fault

Classification - Northern and Southern Strand are Potentially Active
Length - >40 km
Width - Single to Multiple Splays
Slip Rate - >0.1 mm/yr to <1.0 mm/yr

The onshore Santa Monica fault is shown as two main strands west of Century City as interpreted by Hill (1978), Weber (1980), and Crook, et al., (1983). The northern strand is approximately 40 kilometers in length, stretching between a point just north of Potrero Canyon to just east of the Los Angeles River. The northern strand is delineated by oil well data and the location of a topographic scarp near University High School (Escher and Scribner, 1972; Hill, et al., 1977). Crook and Ward (1983) concluded that the latest surface faulting episode on the Santa Monica fault is pre-Holocene based on an unfaulted 10,000 year old soil. The physiographic development of scarp features along the trace of the fault is also suggestive of a Late Quaternary Age.

The southern strand is defined by well data in the Sawtelle Oil Field and also by a ground water barrier displacing Pleistocene sediments just north of Palisades Park. The actual continuation of either of these two strands is uncertain to the west of the shoreline. Because of this uncertainty, the southern and northern strand are shown to extend into Santa Monica Bay as an offshore extension of the Santa Monica fault. The trend of the offshore Santa Monica fault is depicted differently by several workers but is shown on Plate 1 as interpreted by Clarke, et al., (1985).

Malibu Coast Fault

Classification - Active
Length - >27 km
Width - Approximately 0.5 km
Slip Rate - >0.04 mm/yr to <0.09 mm/yr

The onshore Malibu Coast fault consists of several subparallel strands trending east-west along the southern margin of the western Santa Monica Mountains. The onshore fault zone is comprised of reverse faults with dips averaging between 45 and 80 degrees to the north with zones of deformation as wide .5 kilometers (Ziony and Yerkes, 1985). Plate 1 shows the offshore portion of the Malibu Coast fault merging with the northern strand of the Santa Monica fault, as interpreted by Weber (1980) and Crook and Ward (1983).

As early as 1965, Wentworth and Yerkes (1965) reported that the fault cut terrace deposits older than 25,000 years (C-14). The State fault evaluation conducted in 1977 concluded that the Malibu Coast fault was well-defined but because no Holocene displacement had been documented, the fault was not zoned within the Alquist-Priolo Act. Such evidence has recently been reported for a portion of the fault located at the intersection of Kanan Dume Road and Pacific Coast Highway. Converse Consultants, working with Dr. Roy Schlemon, have found evidence of Holocene displacement within colluvial soils determined to be 5,000 to 6,000 years old at this location (oral communication, Greg Rzonak, 1988). Based on this evidence, the fault is shown as active on Plate 1.

Faults in the San Gabriel Valley and along the Southern Front of the San Gabriel Mountains

Cucamonga Fault Zone

Classification - Active
Length - 20 to 25 km
Width - 1 km
Slip Rate - >2.9 mm/yr to <6.4 mm/yr

The Cucamonga Fault Zone consists of one to three subparallel anastomosing strands up to one kilometer in width and measuring between 20 and 25 kilometers in length (Morton and Matti, 1987; Wesnousky, 1987; Ziony and Yerkes, 1985). As identified on Plate 1, this segment is also sometimes referred to as Sierra Madre Fault Segment E. The frontal fault zone in this area strikes about 70 degrees east of north and has moderate to steep northerly dips. Some workers confine this fault zone segment to the frontal southern margin of the San Gabriel and San Bernardino Mountains from San Antonio Canyon to the west and Lytle Creek to the east (Morton and Matti, 1987; Smith, 1977; Lamar, et al., 1973). Morton and Matti (1987) suggest, however, that because of the complex structural relations at the west end of the Cucamonga, the fault could be interpreted to extend farther west and merge with the Sierra Madre Fault System as a through-going, segmented, frontal fault system. Plate 1 reflects this interpretation.

The Cucamonga Fault Zone displays fresh-appearing scarps in the alluvial fan deposits, which prograde to the south from the mountains (Ekis, 1928; Morton, 1976). Several workers point to the young appearing scarps, measuring as high as three meters in alluvial areas, as evidence of recent activity (Fife and others, 1976; Lamar and others, 1973). In some areas between large canyons, the fault juxtaposes crystalline basement against alluvium and in other areas forms scarps as high as 23 meters in bedrock.

Just east of the Los Angeles County Line, below Cucamonga Canyon in San Bernardino, a portion of the Cucamonga fault has been designated as a APSSZ. Morton (1977) suggested that offset occurred as recently as 700 years ago along some scarp-forming splays in this area.

Morton and Matti (1987) discuss a possible segmentation scheme for the Cucamonga Fault Zone that would separate the portion of the Cucamonga fault in Los Angeles County from the segment containing the APSSZ. However, the following two reasons are given for designating the single strand of the Cucamonga in Los Angeles County as active: 1) because the proposed segmentation is not yet accepted and therefore the fault cannot be mechanically differentiated from the APSSZ segment and 2) Ziony and Yerkes (1985) indicate Holocene activity is more probable on southern strands of the frontal-fault system, which describes the portion of the Cucamonga in Los Angeles County.

<u>San Antonio Fault</u>

Classification - Active
Length - 18 km
Width - Not Reported
Slip Rate - Not Reported

The San Antonio fault is not well studied. It is a left-lateral strike slip fault interposed and oblique to the San Andreas and Sierra Madre/Cucamonga Fault Zones. On the basis of seismicity data, Hauksson (in press) has suggested that it may be a northern segment of the San Jose fault, a fault which has been associated with significant seismicity (see San Jose fault). However, it is its suspect relationship (tear fault) with the Cucamonga and the Sierra Madre faults, and reports of fault trench evidence showing left-lateral displacement of the Cucamonga fault by the San Antonio fault, that suggest the fault should be considered active; at least until detailed investigation proves otherwise.

<u>Sierra Madre Fault System</u>

Classification - Active and Potentially Active Segments
Length - 62 km
SM-A: 14 km; Active
SM-B: 17 km; Active
SM-C: 15 km; Potentially Active
SM-D: 16 km; Potentially Active

Average Width - 1 km
Average Slip Rate - <0.4 mm/yr

The Sierra Madre Fault System lies at the southern base of the San Gabriel Mountains. Ziony and Yerkes (1985) indicate that the fault system consists of one to five anastomosing strands in a zone as wide as one kilometer. This includes certain fault splays which have been A-P zoned in segment SM-A (see Table 3.2). The fault system has a reverse sense of slip and forms a complex zone with four identified sections (designated as A, B, C, and D). Each section consists of a mechanically coherent salient (Crook, et al., 1987). These sections extend: 1) from Mount Wilson to Big Tujunga Canyon (SM-A: 14 kilometers), 2) from Big Tujunga Canyon to Arroyo Seco (SM-B: 17 kilometers), 3) from the Arroyo Seco to Monrovia Canyon (SM-C: 15 kilometers), and 4) from Monrovia Canyon to Big Dalton Canyon (SM-D: 16 kilometers). Crook, et al., (1987) estimate a maximum credible earthquake of magnitude (M_L) 7 for any one of these segments, and an average recurrence interval between major shocks longer than 5,000 years.

The fault segments in numerous places have juxtaposed basement bedrock over alluvium and dip northerly below the steep topographic front of the San Gabriel Mountains. Barriers to ground water flow have been cited as evidence of alluvial-buried faults of the Sierra Madre Fault System (Proctor and Kalin, 1965; Shelton, 1955). Offset Holocene deposits are reported along SM-A and SM-B and have been designated as APSSZ faults. In compliance with criteria defined in Chapter 3, the mechanically distinct segments SM-A and SM-B are designated active. Note that the APSSZ segment (SM-B) shown on Plate 1 is correctly identified as a segment of the Sierra Madre fault and not as the Mount Lukens Thrust, as described by Smith, 1978.

The Duarte fault trends northwestward along the San Gabriel front subparallel to SM-C. The fault appears to splay basin-ward from the Sierra Madre Fault System in a complex area of faulting that also involves the Raymond fault (Crook, et al., 1987). Ziony and Yerkes (1985) describe the Duarte as a reverse fault consisting of 1 to 2 subparallel strands locally in a zone as wide as 1.5 kilometers. The fault has a length of about 14 kilometers and is presumed to dip steeply to the northeast. The presence of offset Holocene age sediments along the northern strand near Azusa (Crook, et al., 1987) and the apparent mechanical relationship to the Raymond fault implies that the fault can be designated as active. Sierra Madre Segments SM-C and SM-D, however, are designated potentially, because of the lack of evidence for Holocene displacement along these distinct salients.

Clamshell-Sawpit Fault Zone

Classification - Potentially Active
Length - 13 km
Width - 1 km
Slip Rate - Not Reported

The Sawpit-Clamshell Fault Zone branches northeastward from the Sierra Madre Fault System and trends up Sawpit and Clamshell Canyons in the area north of

Monrovia. These faults have been mapped by Dibble (1958) and Morton (1973), who identify the faults as a one kilometer wide zone of subparallel faults. The faults dip northerly to northeasterly with an apparent thrust or reverse sense of slip. Morton (1973) identifies one location at the mouth of Santa Anita Canyon where basement is thrust over alluvium. Ziony and Yerkes (1985) and Ziony and Jones (1989) designate the fault as Late Quaternary, hence it is defined on Plate 1 as potentially active.

Mount Lukens Thrust

Classification - Potentially Active
Length - 7 km
Width - .5 km
Slip Rate - Not Reported

The Mount Lukens Thrust fault trends northwest across the south flank of the San Gabriel Mountains, between Big Rock Canyon and the Angeles Crest Highway. The fault dips steeply to the south and is located about one kilometer north of the Sierra Madre fault. Smith (1978) incorrectly identified the Mount Lukens Thrust as a portion of the Sierra Madre fault (SM-B), a portion that was eventually zoned APSSZ. Plate 1 shows the Mount Lukens Thrust as identified by Crook, et al., (1987). Because of the apparent mechanical similarity between the two faults, the Mount Lukens Thrust is designated potentially active.

Raymond Fault Zone

Classification - Active
Length - 22 km
Width - 0.4 km
Slip Rate - 0.1 to 0.2 mm/yr

The Raymond fault consists of one to three strands which diverge from the Sierra Madre fault zone in the area of Monrovia and trend to South Pasadena. Ziony and Yerkes (1985) indicate that the sense of movement on the fault is reverse-left-oblique. Crook, et al., (1987) have presented a detailed description of numerous physiographic features which attest to the fault's recent activity. The most impressive feature is the nearly continuous fault scarp between Monrovia Canyon and Arroyo Seco. The fault displaces recent alluvium and forms a significant ground water barrier which has been the subject of several previous studies. Numerous trench studies and radiometric dating of exposed sediments has allowed definition of five major seismic events in the last 36,000 to 155,000 years B.P., and an additional three events which cannot be dated precisely in the last 29,000 years (Crook, et al., 1987). Crook, et al., (1987) infer an average recurrence interval of 3,000 years, with an average vertical displacement of 0.4 m per event. A maximum credible earthquake of M_L6-3/4 can reasonably be assumed if the entire 22 kilometer length of the fault were to break. Crook, et al., (1987) have also recognized a scarp feature in alluvium on the south side of the Raymond fault in the South Pasadena area. This fault, named the York Boulevard fault lies outside of the Alquist-Priolo Zone, but due to its close proximity is identified as active.

Faults within the San Gabriel Mountains

San Gabriel Fault

Classification - Active and Potentially Active Segments
SG-A: 24 km; Potentially Active
SG-B: 35 km; Active
SG-C: 17 km; Potentially Active
SG-D: 54 km; Activity Uncertain
Length - 130 km
Average Width - 0.5 km
Average Slip Rate - 5.0 mm/yr

The San Gabriel fault is reported by Ziony and Yerkes (1985) to consist of a zone of en echelon strands striking 45 to 65 degrees west of north with dips between 50 to 80 degrees toward the north. The fault displays a complex sense of movement that appears to change from one section of the fault to another. (Stitt, 1986). The San Gabriel fault has been divided by various workers into a number of different segmentation schemes (Ehlig, 1973; Weber, 1979; Ziony and Yerkes, 1985; Stitt, 1986; Wesnousky, 1987). For the purposes of this report, the San Gabriel fault is divided into four segments in Los Angeles County. Segments SG-A, SG-B, SG-C, and SG-D shown on Plate 1 possess some similarities with the other proposed schemes, but are also defined by geologic evidence along the length of the fault for the recency of faulting.

Recent exploratory subsurface work near Castaic indicates that a portion of the SG-B segment (Plate 1) cuts Holocene alluvium dated by radiocarbon methods as 8140 ± B.P., 777 ± 60 years B.P., and 3500 ± 250 years B.P. (Cotton, 1986). The State has therefore designated a ten kilometer portion of the San Gabriel fault that includes this site as an APSSZ fault. Stitt (1986) has stated that the segment of the San Gabriel fault to the northwest is apparently not Late Quaternary because the fault is buried by the Plio-Pleistocene Hungry Valley Formation. However, Roquemore, 1989 (personal communication) has submitted evidence for Holocene movement in the Violin Canyon area to the State fault evaluation program in apparent contradiction to Stitt's (1986) interpretation. In light of this evidence, the active segment of the San Gabriel fault (SG-B) is extended to Violin Canyon, and the segment to the northwest (SG-A) is considered potentially active so as to stimulate special study. Ziony and Jones (1989) concur with this interpretation.

Segment SG-B is arbitrarily extended to the southeast until the San Gabriel splits into the Dillon and Demille fault (SG-C). Weber (1979) notes that the evidence for the recency of faulting becomes less clear-cut at this point. The geomorphic and stratigraphic evidence documented by Weber (1979) still suggests Late Quaternary movement.

SG-C is interpreted to extend to Big Tujunga Canyon where the San Gabriel fault splits into a prominent northern and southern branch, the latter which is shown on Plate 1 as the Vasquez fault (Crook, et al., 1987). The northern strand of the San Gabriel fault (SG-D) is not considered Late Quaternary by Ziony and Yerkes (1985); however, the Vasquez fault is considered potentially active

because of the following: 1) the apparent geometrical and mechanical relationship with the Sierra Madre Fault Zone, 2) the geomorphic and stratigraphic evidence stated by Weber (1979) and 3) basement rock is thrust over alluvium at some localities (Smith, 1978). The two different traces of the Vasquez fault shown on Plate 1 is due to the fault being mapped differently by Smith (1978) and Weber (1979).

Holser Fault

Classification - Active
Length - 19 km
Width - .5 km to 1.5 km
Slip Rate - Not Reported

The Holser fault is a south dipping reverse fault consisting of several closely spaced strands that strike from 80 degrees east of north to 70 degrees west of north (Ziony and Yerkes, 1985; Winterer and Durham, 1962). The fault zone is as much as 1.5 kilometers wide along its western portion (Plate 1). The portion of the fault transecting Los Angeles County is approximately 13 kilometers long. Ziony and Yerkes (1985) list offset stratigraphy and physiography as clear evidence of Late Quaternary movement. The Holser fault is shown as active on Plate 1 for the following reasons: 1) the Holser fault is associated with known active faults, accommodating the north-south shortening between the San Cayetano and Santa Susana faults in a complex zone of south-dipping reverse faults (Yeats, 1987; Yeats et al., 1985; Ziony and Jones, 1989; Smith, 1977); 2) the Holser fault intersects an APSSZ fault (Chapter 3); and 3) geomorphic evidence (i.e., drainage control of several streams including Piru Creek) supports a Holocene, or at least Late Quaternary age for the Holser fault (Yeats et al, 1985). Although no Holocene deposits are known, to date, to be displaced by the Holser fault (Allan Seward, 1990 personal communication), no published trenching program has conclusively shown the Holser Fault Zone to be inactive. Trenching across the Alquist-Priolo segment of the San Gabriel fault may have indirectly proven that the Holser fault is active, since the San Gabriel fault may be a reactivated tear fault in the Holser Thrust System (Tom Rockwell, 1990 personal communication).

Santa Felicia Fault

Classification - Potentially Active
Length - 8 km
Width - .2 km
Slip Rate - Not Reported

The Santa Felicia fault is one of several short fault segments north of and subparallel to the Holser fault. The sense of motion and geometry are not known; however, Ziony and Jones (1989) include the fault on their map of Late Quaternary faults.

Del Valle Fault

Classification - Potentially Active
Length - 4 km
Width - .5 km
Slip Rate - Not Reported

The Del Valle fault is one of several short fault segments south of, and subparallel to, the Holser fault. Ziony and Yerkes (1989) have included the fault on their map of Late Quaternary faults.

Clearwater Fault

Classification - Potentially Active
Length - 33 km
Width - Not Reported
Slip Rate - Not Reported

The Clearwater fault consists of a complex zone of faulting characterized by east-west trending (N80W), north-dipping steeply-inclined faults and presumably younger, low-angle faults (Ziony and Yerkes, 1985). Steeply-dipping portions measure 70 to 80 degrees while low angle faults measure between 25 to 40 degrees. Los Angeles County conducted an investigation of the fault in 1965 and concluded that the Clearwater fault is primarily a dip slip fault, with little evidence of strike-slip movement (Smith, 1977; Los Angeles County, 1965). The Los Angeles County (1965) study concluded that the fault zone contains older reverse faults that do not cut Pleistocene terrace deposits and younger thrust faults, which do cut the terrace deposits. Ziony and Yerkes (1985) list the Late Quaternary portion of the fault as possibly reverse.

The portion of the Clearwater fault near Bouquet Reservoir and the northeastern end of the San Francisquito fault in the Sleepy Valley quadrangle was once zoned under the APSSZ Act (Smith, 1977). Plate 1 shows that presently only the easternmost portion of the Clearwater fault is designated as an APSSZ fault. Ziony and Yerkes (1985) and Ziony and Jones (1989) suggest that the Late Quaternary portion of the fault is approximately 14 kilometers in length, extending from the Bouquet Reservoir westward. Plate 1 shows that the entire length of the fault extends westward some 50 kilometers to the Ventura County line from its intersection with the San Andreas fault. Plate 1 also shows that the portion interpreted as Late Quaternary in this report is 33 kilometers in length. This length is in agreement with Wesnousky (1987) who concludes that the fault is capable of a maximum credible earthquake of 6.9 Magnitude.

Faults in the Los Angeles Basin Areas

Cabrillo Fault

Classification - Active
Length - 18 km
Width - .3 km to 1.0 km
Slip Rate - Not Reported

The Cabrillo fault consists of several en echelon strands striking 20 to 25 degrees west of north and dipping 50 to 75 degrees (Ziony and Yerkes, 1985). The onshore portion of the fault lies on the Palos Verdes Peninsula and extends offshore into the San Pedro Bay. Dames and Moore and MESA[2] (1983) have mapped the fault offshore as a zone of two 1.2 meters high "scarps" in Late Quaternary sediment that shows evidence of offset Holocene stratigraphy. Ziony and Yerkes (1985) and Ziony and Jones (1989) agree with this interpretation and support an active designation for the offshore portion.

Recent subsurface work in the Silverspur graben area on the Palos Verdes Peninsula by Lockwood-Singh and Dr. Roy Schlemon has shown that a fault probably correlative with the Cabrillo fault offsets probable Pleistocene Age colluvial and lacustrine soils. The onshore portion of the fault, however, is shown as active on Plate 1 because the Holocene displacement on the offshore portion suggests that more study is warranted. Schlemon (1984) found no young geomorphic evidence for the fault in this area but stratigraphic evidence may exist elsewhere.

Charnock Fault

Classification - Potentially Active
Length - >10 km
Width - Not Reported
Slip Rate - Not Reported

The Charnock fault is identified as a ground water barrier by Poland, et al., (1959) and Castle (1960). They noted that the fault appeared to cut upper Pleistocene terrace deposits and the lower portion of the San Pedro Formation. Smith (1978), Ziony and Yerkes (1985), and Ziony and Jones (1989) have confirmed displacement of Late Quaternary strata. The sense of movement on the fault is not well established but the east side of the fault has apparently moved up along a presumed vertical dip (Smith, 1978).

Overland Fault

Classification - Potentially Active
Length - >10 km
Width - Not Reported
Slip Rate - Not Reported

As with the Charnock fault, the Overland fault is an inferred fault that cuts Late Pleistocene deposits. The fault is inferred on the basis of a probable ground water barrier (Poland, et al., 1959). The west side of the fault has moved down and, thus, a graben appears to be present between the Overland and Charnock faults. Poland, et al., (1959) indicates that the fault displaces earliest Holocene to pre-Holocene deposits. However, Ziony, et al., (1974) note that the alluvium is not cut by the fault, an interpretation that is in agreement with more recent work by Ziony and Jones (1989).

Palos Verdes Fault Zone

Classification - Active
Length - >77 km
San Pedro Bay Segment: >30 km
Onshore Segment: 17 km
Santa Monica Bay Segment: 30 km
Width - 1 - 4 km
Slip Rate - >0.02 mm/yr to <0.7 mm/yr

The portion of the Palos Verdes Fault Zone in Los Angeles County can be discussed in terms of three separate segments: 1) the San Pedro Bay segment, 2) the onshore segment, and 3) the Santa Monica Bay segment (Ziony and Yerkes, 1985). All segments are believed to possess reverse right oblique or reverse motion (Ziony and Yerkes, 1987). The San Pedro Bay segment is characterized as a complex zone of en echelon faults with evidence of offset Holocene stratigraphy (Fischer, et al., 1987). Fischer and others (1987) state that the eastern faults of the zone displace seismic reflectors or horizons that represent Holocene surficial sediments.

The onshore segment of the Palos Verdes Fault Zone is depicted by Ziony and Jones (1989) as Late Quaternary; however, Woodward and Clyde (1983) point to several factors that suggest Holocene displacements have occurred along the Palos Verdes Peninsula. These factors include the extensive deformation of the 120,000 year old terrace and apparent Holocene folding of the Gaffy anticline, a probable drag feature related to movement on the Palos Verdes fault. Plate 1 shows this portion of the fault as active despite the lack of unequivocal evidence for Holocene displacement.

The Santa Monica Bay segment is inferred to be a Late Quaternary feature by Ziony and Yerkes, (1985); however, increased seismicity in this offshore area, especially that associated with the longest, single coherent strand in Santa Monica Bay, suggests that this segment is active.

Newport-Inglewood Fault Zone

Classification - Active
Length - 43 km (Los Angeles County)
Width - Not Reported
Slip Rate - >0.1 mm/yr to <6.0 mm/yr

The trace of the Newport-Inglewood Fault Zone (NIFZ) is marked by a series of low-lying hills including the Cheviot Hills, Baldwin Hills, Rosecrans Hills, Dominquez Hills, Signal Hill, and Reservoir Hill. These hills are sites of oil fields in which faulted anticlines form structural traps. The fault zone consists of a set of left stepping, discontinuous faults indicating a through-going right-lateral strike-strike-slip fault at depth. Harding (1973) indicates that the NIFZ is a nearly-vertical, right-lateral strike-slip fault at depth. The fault zone is covered under the APSSZ Act.

Five separate en echelon faults comprise the zone in the County of Los Angeles. These faults are as follows: from north to south (Ziony and Yerkes, 1985).

Inglewood: Northwest-trending fault with stratigraphic evidence of Late Quaternary movement and recent physiographic features. Normal to normal-right-oblique sense of movement. Possible source of 1920 earthquake.

Potrero: Northwest trending fault with normal to normal-right-oblique sense of movement with Late Quaternary physiographic features and ground water impediments along trace in Late Quaternary alluvial deposits (Poland and others, 1959). Numerous small earthquakes nearby.

Avalon-Compton: Northwest-trending, vertical fault which experienced movement in 1941 and 1944. Has reverse-right-oblique sense of movement and Late Quaternary physiographic features and ground water impediments (Poland and others, 1959).

Cherry-Hill: Northwest-trending near vertical fault with reverse-right-oblique sense of movement. Late Quaternary activity evidenced by offset stratigraphy, physiographic features, and ground water impediments. Numerous small earthquakes east of trace.

Reservoir Hill-Seal Beach: Northwest-trending, near vertical fault with normal-right-oblique or right-lateral strike-slip sense of movement. Late Quaternary activity is evidenced by offset stratigraphy, physiographic features, and ground water impediments. Numerous small earthquakes east of trace.

Norwalk Fault

Classification - Potentially Active
Length - >14 km
Width - Single Strand
Slip Rate - Not Reported

The Norwalk fault strikes 65 to 85 degrees to the northwest and dips steeply to the northeast. The fault is noted as the possible source of a damaging earthquake (M_L 4.7) occurring in 1929 (Ziony and Yerkes, 1985). There is an

ongoing debate regarding the importance of this fault as newly emerging evidence of seismogenic low angle thrust faults underlying the Los Angeles Basin evolves. Given this uncertainty, the 1929 earthquake may not have been associated with the Norwalk fault, but might have occurred on a subsurface ramp structure related to buried thrust faults. The evidence cited for Late Quaternary activity is based on relatively young fault physiography along the trace of the fault (Ziony and Yerkes, 1985).

Los Alamitos Fault

Classification - Potentially Active
Length - 12 km
Width - Single Strand
Slip Rate - Los Alamitos

The Los Alamitos fault is shown on Plate 1 as striking parallel to the Newport-Inglewood fault zone. Ziony and Jones (1989) show the fault as potentially active. In light of evolving concepts of faulting within the Los Angeles Basin, the fault could be either an upward verging ramp of a lower "buried thrust" or an inward segment of the Newport-Inglewood Fault Zone.

Faults in East Los Angeles County

Indian Hill

Classification - Potentially Active
Length - 9 km
Width - Single Strand
Slip Rate - Not Reported

The Indian Hill fault strikes east-west and is believed to be a single strand with a length of approximately nine kilometers. The California Division of Water Resources (1970) noted that the ground water barrier formed by the Indian Hill fault offsets alluvium of Late Pleistocene Age. Cramer and Harrington (1984) have recently concurred with this interpretation. The offset trace in the Indian Hill fault as shown in Plate 1 may not be real. The offset may be caused by the two disagreeing map locations given by CDWR (1970) for the eastern segment and Shelton (1955) for the western segment.

Chino Fault

Classification - Potentially Active
Length - 28 km
Width - Not Reported
Slip Rate - <0.2 mm/yr

At the northern end of the Santa Ana Mountains, the Elsinore fault splits into the Chino fault and the Whittier fault. The Chino fault is shown as having

Holocene displacement by Wentworth, et al., (1970). The Chino fault does not extend into Los Angeles County and, therefore, is not considered a ground rupture hazard, but should be considered a seismogenic source along with the Elsinore and Whittier faults.

Central Avenue Fault

Classification - Potentially Active
Length - 8 km
Width - Single Strand
Slip Rate - Not Reported

The Central Avenue fault is believed to be a single strand striking subparallel to the Chino fault. The length of the fault is approximately eight kilometers and has not been traced more than a few kilometers into the County. Ziony, et al., (1974) stated that the Central Avenue fault has experienced fault displacement of Quaternary and Holocene Age. Because there is no surface expression of the fault and the evidence of Holocene displacement is not conclusive, the fault is assigned an age of Late Quaternary (Ziony and Yerkes, 1985).

Walnut Creek Fault

Classification - Potentially Active
Length - 17 km
Width - Not Reported
Slip Rate - Not Reported

Smith (1977) states that the only reference made of this fault is by the California Department of Water Resources (1966). Their discussion (Page 47) of the fault is as follows:

> "The Walnut Creek fault trends northeast through the alluvium northwest of the San Jose Hills. The existence of the fault is suggested by a few water level differences across the fault, and petroleum exploration data substantiate the fault at depth."

No information is available that indicates the shallowness of the water barrier. In terms of the activity of the fault, Smith (1977) did report that there are some possible relationships between the distribution of epicenters and the fault location. The fault is interpreted to have been active in the Late Quaternary, because of its apparent geometrical and possibly mechanical relationship with the Indian Hill fault to the east.

San Jose Fault

Classification - Potentially Active
Length - 14 km
Width - Not Reported
Slip Rate - Not Reported

The San Jose fault consists of a single strand that strikes variably northeast through the San Jose Hills (Ziony and Yerkes, 1985). Harshman (1933) reports that the fault dips steeply, 80 to 85 degrees northward and has a reverse sense of movement with the north side up. Eckiss (1928) states that the fault, which displaces upper Miocene sedimentary and volcanic rock as much as 2,700 feet vertically, has a very young physiographic expression with notched spurs along an eroded scarp. The California Department of Water Resources (1970, Page 10) documented a 100 m vertical offset in older subsurface alluvium, however, they found no evidence for offset Holocene alluvial deposits. Smith (1978) interpreted the available data at the time as indicating that the fault was probably more active during Late Pleistocene time.

Hauksson (in press), upon analysis of the seismicity data produced by the 1988 and 1990 Upland Earthquake sequence, established that the San Jose fault is seismically active, and concludes that the San Jose fault was responsible for the M_L = 4.6 (1988) and M_L = 5.2 (1990) tremors that shook eastern Los Angeles County, as well as hundreds of aftershocks. A critical conclusion from this analysis is that a significant length of the fault appears to be locked, and may be the origin of a magnitude 6.0 to 6.5 earthquake. Although the fault is seismically active and may produce strong ground motion, it remains unclear whether this fault has surface rupture potential.

Whittier Fault Zone

Classification - Active
Length - >40 km
Width - 1.2 km
Slip Rate - 1.7 mm/yr to 2.5 mm/yr (Rockwell, et al., 1988).

The Whittier fault zone consists of 1 to 3 subparallel strands in a zone as wide as 1.2 km. The length of the Whittier fault to the point where it merges with the Elsinore Fault Zone is approximately 45 kilometers; however, Wesnousky (1987) has recently defined a longer Whittier segment (74 km). The 14 kilometer length within Los Angeles County strikes 65 to 85 degrees to the northwest and dips 65 to 80 degrees to the north. The sense of movement on the Whittier fault is believed to be reverse right oblique (Ziony and Yerkes, 1985), or nearly pure right slip (Gath and Rockwell, in press).

Evidence of offset Holocene stratigraphy northwest of Brea Canyon in Orange County is recognized by Ziony and Jones (1989); however, these workers interpret the northwesternmost portion of the Whittier fault in Los Angeles County as Late Quaternary. Gath, et al., (1988) and Leighton, et al., (1987) have uncovered evidence of offset Holocene stratigraphy four kilometers east of the City of Whittier in Arroyo San Miguel near Colima Boulevard. Based on these trench

studies, Plate 1 shows the fault as active along its entire length in Los Angeles County.

Faults Bounding the Verdugo-San Rafael Mountains

San Rafael Fault

Classification - Potentially Active
Length - 6 km
Width - .2 km
Slip Rate - Not Reported

The San Rafael fault is a steeply dipping fault with an unresolved type of offset. The fault is not structurally connected to, but forms the last leg of the Verdugo, Eagle Rock, San Raphael Fault System. The fault separates basement rock on the east from conglomerate-breccia of the Topanga Formation on the west. To the north, the fault apparently dies out as a series of disjointed strands (Weber, et al., 1980). To the south, the fault is expressed as low areas and lineaments across terrace deposits. The fact that the fault displaces terrace deposits suggests a Late Quaternary Age. Although the fault trends toward and apparently intersects the APSSZ-zoned Raymond fault, the fault is not considered active under the criteria developed in Chapter 3. This decision is based on the uncertain mechanics of the San Rafael fault, as well as the covered nature of the southeast end of the fault.

Verdugo Fault

Classification - Active
Length - 21 km
Width - 0.5 to 1.0 km
Slip Rate - Not Reported

The Verdugo fault trends northward along the west flank of the Verdugo Mountains and separates a Precambrian Age basement complex on the east from alluvial and sedimentary Tertiary strata on the west. The fault consists of multiple strands in a zone 0.5 to 1.0 kilometers in width as evidenced by southwest facing scarps in alluvium in the Burbank area (Ziony and Yerkes, 1985; Weber, et al., 1980). The fault apparently dips 45 to 60 degrees to the northeast and forms ground water cascades in the alluvium north of the terminus of the Verdugo Mountains. On the north, the fault may curve westward and join the Mission Hills fault. To the southeast of the Verdugo Mountains, the fault becomes less well defined and shallows in dip as it trends through Verdugo wash where it apparently connects with the Eagle Rock fault. Ground water cascades and surface scarps are evidence of recent activity along the fault (Weber, et al., 1980).

Eagle Rock Fault

Classification - Potentially Active
Length - 5 km
Width - 0.3 km
Slip Rate - Not Reported

The Eagle Rock fault appears to consist of a single strand, five kilometers long. The fault appears to be a distinct segment lying between the Verdugo fault to the northwest and the San Rafael fault to the southeast. Ziony and Jones (1989) show the fault as Late Quaternary based on offset Late Quaternary stratigraphy and fault physiography.

Faults of the Antelope Valley Area

San Andreas Fault Zone

Classification - Historical/Active
Length - Mojave Segment 120 km
Width - 0.3 to 1.5 km (4 km locally)
Slip Rate - 30.0 mm/yr

The San Andreas fault extends from northwest to southeast across the County of Los Angeles. Numerous fault related geomorphic features such as linear troughs are present over much of its length. The sense of displacement on the fault is right-lateral strike-slip and most faults within the zone are vertical (Ziony and Yerkes, 1985). The California Division of Mines and Geology has completed a multi-year study of the San Andreas fault through which detailed maps of the fault zone and the geologic units they affect have been compiled (Barrows, 1979; Beeby, 1979; Kahle, 1980; Barrows, et al., 1985).

Activity along the San Andreas Fault Zone has been recorded during historic events including the Magnitude 7.1, 1989 Loma Prieta Earthquake, the 1906 Magnitude 8 Earthquake in San Francisco, and the 1857 Magnitude 7.9 Fort Tejon event. The segment in Los Angeles County is one of eight discrete fault segments, each segment exhibiting a unique character and return period for damaging earthquakes along strike of the more than 1,000 kilometer long fault. The 1857 event is believed to have ruptured the section in Los Angeles County. Offset stratigraphy of Holocene deposits provides evidence that rupture occurs on the San Andreas at Pallet Creek on the average of every 145 to 200 years (Seih, 1984). This work has given rise to an assessment that the Mojave Segment stands a 30 percent chance of being the origin of a 7.5 Magnitude earthquake by the year 2018 (Davis, et al., 1988).

Llano Fault

Classification - Active
Length - >6 km
Width - Not Reported
Slip Rate - Not Reported

The Llano fault is located west of Victorville in the Mojave Desert (Plate 1). The fault strikes 65 degrees west of north along a single-strand with a presumed dip to the southwest (Ziony and Yerkes, 1985). The reverse fault shows evidence of Holocene monoclinal folding and is shown as active by Ziony and Jones (1989).

Mirage Valley

Classification - Potentially Active
Length - 30 km
Width - Highly Irregular
Slip Rate - Not Reported

The Mirage Valley fault consists of several en echelon strands, each 1 to 7 kilometers long (Ziony and Yerkes, 1985). The fault zone measures up to three kilometers wide in some areas. The main strand strikes 40 to 50 degrees west of north. This fault is presumed to be vertical with a total length of approximately 30 kilometers. The fault is thought to have a right-lateral strike-slip sense of movement. Ziony and Yerkes (1985) report that the fault is Late Quaternary in age based on unfaulted Holocene alluvial fan deposits overlying the fault in some localities.

Principal Offshore Faults

Santa Cruz-Santa Catalina Ridge Fault Zone

Classification - Potentially Active
Length - >120 km
Width - 4 km
Slip Rate - Not Reported

The Santa Cruz-Catalina Seafloor escarpment forms a zone of en echelon fault strands as wide as four kilometers. The faults strike approximately 50 to 60 degrees west of north. The length of individual strands is between 5 to 40 kilometers and the length of the entire zone is at least 120 kilometers (Ziony and Yerkes, 1985). This fault may have been the source of the 1981 Santa Barbara Island earthquakes (M_L 5.2) and aftershocks.

San Pedro Basin Fault Zone

Classification - Potentially Active
Length - 70 km

Width - 5 km
Slip Rate - Not Reported

The San Pedro Basin Fault Zone is located approximately 20 kilometers offshore of the Palos Verdes Peninsula where it trends 35 to 50 degrees west of north toward Point Dume. The fault zone consists of a series of separate left stepping en echelon strands in a zone as wide as five kilometers (Ziony and Yerkes, 1985). Most of the individual strands are 4 to 12 kilometers off the shore of Los Angeles. The sense of displacement on the presumed vertical faults is right-lateral strike-slip to reverse-right-oblique. Numerous small earthquakes have occurred near and east of the fault trace (Hilemand, et al., 1973). Clarke, et al., (1985) and Ziony and Jones (1989) report that the individual strands shown on Plate 1 are known to cut Late Pleistocene marine strata.

Redondo Canyon

Classification - Active
Length - 13 km
Width - Not Reported
Slip Rate - Not Reported

The Redondo fault is presumed to be a single strand which strikes 80 to 85 degrees east of north as it trends offshore from a point just north of the Palos Verdes Peninsula down Redondo Canyon. The fault length is approximately 13 kilometers and the dip is unknown. Scattered small earthquakes have occurred near the fault trace.

Anacapa-Dume Fault

Classification - Potentially Active
Length - 45 km
Width - Not Reported
Slip Rate - Not Reported

The Anacapa fault is presumed to consist of a single strand in its western portion and multiple strands to the east and is approximately 45 km in length. The fault strikes northwest to northeast and is inferred to dip moderately north (Ziony and Yerkes, 1985). The sense of displacement on the fault is reverse based on focal mechanism solutions. The epicentral locations and focal mechanism solution for the 1973 Point Mugu earthquake (M5.3) and the aftershocks suggest the Anacapa fault may have been responsible. Hauksson and Salvidar (1989), however, have recently established a much more complex transitional compressional regime under the Santa Monica Bay that may account for much of the seismicity in the area. According to Hauksson and Salvidar (1989), the Anacapa fault and Dume-Whittier Thrust and fold belt extend under the bay at depths of 11 to 16 kilometers.

Clarke, et al., (1985) indicate that along much of the length of the Anacapa fault in Los Angeles County younger deposits are absent. However, there is general agreement that the Anacapa Dume fault is potentially active (Ziony and

Jones, 1989; Ziony and Yerkes, 1985; Yerkes and Lee, 1979). Plate 1 shows the eastern segment of the Anacapa Dume fault as potentially active but shows the western segment that curves into the Santa Monica fault as active. This designation is based on work by Clarke, et al., (1985) that reports Holocene sediments cut by the fault in this area.

Santa Rosa Island (Not shown on Plate 1)

Classification - Potentially Active
Length - 72 km
Width - Not Reported
Slip Rate - Not Reported

The Santa Rosa Island fault consists of a single arcuate strand that strikes 50 degrees west of north at the western end and 60 degrees east of north at the eastern end. The fault is approximately 72 km in length and has an unknown dip (Ziony and Yerkes, 1985). This fault was the probable source of the April 1, 1945, earthquake (M_L 5.4). The sense of movement on the fault is reverse left oblique. Physiographic features and offset stratigraphy indicate a Late Quaternary Age.

Santa Cruz Island (Not shown on Plate 1)

Classification - Potentially Active
Length - 68 km
Width - 0.5 km
Slip Rate - >0.2 mm/yr to <0.9 mm/yr

The Santa Cruz Island fault is approximately 68 km long and consists of one to three en echelon strands in a zone up to 0.5 kilometers wide. The fault strikes 70 to 80 degrees west of north and dips 70 to 75 degrees toward the north (Ziony and Yerkes, 1985). There is generally a lack of small earthquakes on the fault but it may have been responsible for the 1973 ML 5.0 earthquake near Anacapa Island. The sense of displacement along the Santa Cruz Island fault is somewhat controversial. The fault has been described by Ziony and Yerkes (1985) as having reverse left oblique slip with offset stratigraphy and physiographic features indicating a Late Quaternary Age. McLean, et al., (1976) have suggested possible major right lateral strike-slip faulting along the East Santa Cruz Basin Fault System. The Santa Cruz Island fault may be a subaerially exposed segment of this fault system.

APPENDIX 3

CALIFORNIA DIVISION OF MINES AND GEOLOGY

HAZARD INVESTIGATION GUIDELINES

FAULT INVESTIGATION

GEOLOGIC AND SEISMIC INVESTIGATION

AND ENVIRONMENTAL IMPACT GUIDELINES

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

DMG NOTE 42

GUIDELINES TO GEOLOGIC/SEISMIC REPORTS

The following guidelines are taken from "Geology and earthquake hazards: Planners guide to the seismic safety element" prepared by Grading Codes Advisory Board and Building Code Committee of the Southern California Section, Association of Engineering Geologists, July, 1973. They are reprinted here courtesy of the Association of Engineering Geologists.

I. *Introduction*

This is a suggested guide or format for the seismic section of engineering geologic reports. These reports may be prepared for projects ranging in size from a single lot to a master plan for large acreage, in scope from a single family residence to large engineered structures, and from sites located on an active fault to sites a substantial distance from the nearest known active fault. Because of this wide variation, the order, format, and scope should be flexible and tailored to the seismic and geologic conditions, and intended land use. The following suggested format is intended to be relatively complete, and not all items would be applicable to small projects or low risk sites. In addition, some items would be covered in separate reports by soil engineers, seismologists, or structural engineers.

II. *The Investigation*

A. *Regional Review*

A review of the seismic or earthquake history of the region should establish the relationship of the site to known faults and epicenters. This would be based primarily on review of existing maps and technical literature and would include:

1. Major earthquakes during historic time and epicenter locations and magnitudes, near the site.

2. Location of any major or regional fault traces affecting the site being investigated, and a discussion of the tectonic mechanics and other relationships of significance to the proposed construction.

B. *Site Investigation*

A review of the geologic conditions at or near the site that might indicate recent fault or seismic activity. The degree of detail of the study should be compatible with the type of development and geologic complexity. The investigation should include the following:

1. Location and chronology of local faults and the amount and type of displacement estimated from historic records and stratigraphic relationships. Features normally related to activity such as sag ponds, alignment of springs, offset bedding, disrupted drainage systems, offset ridges, faceted spurs, dissected alluvial fans, scarps, alignment of landslides, and vegetation patterns, to name a few, should be shown on the geologic map and discussed in the report.

2. Locations and chronology of other earthquake induced features caused by lurching, settlement, liquefaction, etc. Evidence of these features should be included with the following:
   a. Map showing location relative to proposed construction.
   b. Description of the features as to length, width and depth of disturbed zone.
   c. Estimation of the amount of disturbance relative to bedrock and surficial materials.

3. Distribution, depth, thickness and nature of the various unconsolidated earth materials, including ground water, which may affect the seismic response and damage potential at the site, should be adequately described.

C. *Methods of Site Investigation*

1. Surface investigation

   a. Geologic mapping.
   b. Study of aerial photographs.
   c. Review of local ground water data such as water level fluctuation, ground water barriers or anomalies indicating possible faults.

2. Subsurface investigation

   a. Trenching across any known active faults and suspicious zones to determine location and recency of movement, width of disturbance, physical condition of fault zone materials, type of displacement, and geometry.

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b. Exploratory borings to determine depth of unconsolidated materials and ground water, and to verify fault–plane geometry. In conjunction with the soil engineering studies, obtain samples of soil and bedrock material for laboratory testing.
c. Geophysical surveys which may indicate types of materials and their physical properties, ground water conditions, and fault displacements.

III. *Conclusions and Recommendations*

At the completion of the data accumulating phase of the study, all of the pertinent information is utilized in forming conclusions of potential hazard relative to the intended land use or development. Many of these conclusions will be revealed in conjunction with the soil engineering study.

A. *Surface Rupture Along Faults*

1. Age, type of surface displacement, and amount of reasonable anticipated future displacements of any faults within or immediately adjacent to the site.

2. Definition of any areas of high risk.

3. Recommended building restrictions or use–limitations within any designated high risk area.

B. *Secondary Ground Effects*

1. Estimated magnitude and distance of all relevant earthquakes.

2. Lurching and shallow ground rupture.

3. Liquefaction of sediments and soils.

4. Settlement of soils.

5. Potential for earthquake-induced landslide.

IV. *Presentation of Data*

Visual aids are desirable in depicting the data and ma include:

A. *General data*

1. Geologic map of regional and/or local faults.

2. Map(s) of earthquake epicenters.

3. Fault strain and/or creep map.

B. *Local or site data*

1. Geologic map.

2. Geologic cross–sections illustrating displacement and/or rupture.

3. Local fault pattern and mechanics relative to existing and proposed ground surface.

4. Geophysical survey data.

5. Logs of exploratory trenches and borings.

V. *Other Essential Data*

A. *Sources of data*

1. Reference material listed in bibliography.

2. Maps and other source data referenced.

3. Compiled data, maps, plates included or re renced.

B. *Vital support data*

1. Maximum credible earthquake.

2. Maximum probable earthquake.

3. Maximum expected bedrock acceleration.

C. *Signature and license number of geologist registerec California*

GUIDELINES FOR GEOLOGIC/SEISMIC CONSIDERATIONS IN ENVIRONMENTAL IMPACT REPORTS

The following guidelines were prepared by the Division of Mines and Geology with the cooperation of the State Water Resources Control Board to assist those who prepare and review environmental impact reports.

These guidelines will expedite the environmental review process by identifying the potential geologic problems and by providing a recognition of data needed for design analysis and mitigating measures. All statements should be documented by reference to material (including specific page and chart numbers) available to the public. Other statements should be considered as opinions and so stated.

1. CHECKLIST OF GEOLOGIC PROBLEMS FOR ENVIRONMENTAL IMPACT REPORTS

GEOLOGIC PROBLEMS		Could the project or geologic event cause environmental problems?			Is this conclusion documented in attached reports?	
PROBLEM	ACTIVITY CAUSING PROBLEM	NO	YES	ENVIRONMENTAL PROBLEMS	NO	YES
EARTHQUAKE DAMAGE	Fault Movement					
	Liquefaction					
	Landslides					
	Differential Compaction/ Seismic Settlement					
	Ground Rupture					
	Ground Shaking					
	Tsunami					
	Seiches					
	Flooding Due to Failure of Dams and Levees					
LOSS OF MINERAL RESOURCES	Loss of Access					
	Deposits Covered by Changed Land-Use Conditions					
	Zoning Restrictions					
WASTE DISPOSAL PROBLEMS	Change in Groundwater Level					
	Disposal of Excavated Material					
	Percolation of Waste Material					
SLOPE AND/OR FOUNDATION INSTABILITY	Landslides and Mudflows					
	Unstable Cut and Fill Slopes					
	Collapsible and Expansive Soil					
	Trench-Wall Stability					
EROSION, SEDIMENTATION, FLOODING	Erosion of Graded Areas					
	Alteration of Runoff					
	Unprotected Drainage Ways					
	Increased Impervious Surfaces					
LAND SUBSIDENCE	Extraction of Groundwater, Gas, Oil, Geothermal Energy					
	Hydrocompaction, Peat Oxidation					
VOLCANIC HAZARDS	Lava Flow					
	Ash Fall					

(over)

For a list of geologic maps and reports available from the California Division of Mines and Geology, write to the California Division of Mines and Geology, P O Box 2980, Sacramento, CA 95812, or visit our District offices in SACRAMENTO, 2815 "O" Street, (916) 445-5716; SAN FRANCISCO, Room 2022, Ferry Building, (415) 557-0633; LOS ANGELES, Room 1065, 107 South Broadway, (213) 620-3560.

CHECKLIST OF GEOTECHNICAL HAZARDS AND POTENTIAL MITIGATION MEASURES (MODIFIED FROM CDMG NOTE 46)

GEOLOGIC PROBLEMS		DEGREE OF HAZARD OR PROBLEM				POSSIBLE MITIGATION MEASURES		
PROBLEM	ACTIVITY CAUSING PROBLEM	NONE	SLIGHT	MODERATE	SEVERE	CODE CONFORMANCE	CODE CONFORMANCE AND SPECIAL WORK*	ADVANCE PLANNING, AVOIDANCE, RESTRICTIONS
EARTHQUAKE DAMAGE	FAULT MOVEMENT	X	X			X		
	LIQUIFACTION		X	X			X	
	LANDSLIDES		X	X			X	X
	DIFFERENTIAL COMPACTION/ SEISMIC SETTLEMENT	X	X			X		
	GROUND RUPTURE	X				X		
	GROUND SHAKING		X	X		X	X	
	TSUNAMI	X				N/A		
	SEICHES	X				X		
	FLOODING (DAM OR LEVEE FAILURE)	X	X			X		X
LOSS OF MINERAL RESOURCES	LOSS OF ACCESS	X				N/A		
	DEPOSITS COVERED BY CHANGED LAND USE	X				N/A		
	ZONING RESTRICTIONS	X				N/A		
WASTE DISPOSAL PROBLEMS	CHANGE IN GROUNDWATER LEVEL		X			X		
	DISPOSAL OF EXACAVATED MATERIAL		X	X	X		X	X
	PERCOLATION OF WASTE MATERIAL	X				X		
SLOPE AND/OR FOUNDATION INSTABILITY	LANDSLIDES AND MUDFLOWS		X	X			X	X
	UNSTABLE CUT AND FILL SLOPES	X	X			X		
	COLLAPSIBLE AND EXPANSIVE SOIL		X	X	X	X		
	TRENCH-WALL STABILITY		X	X	X	X		
EROSION, SEDIMENTATION FLOODING	EROSION OF GRADED AREAS		X			X		
	ALTERATION OF RUNOFF		X			X		
	UNPROTECTED DRAINAGE WAYS		X			X		
	INCREASED IMPERVIOUS SURFACES		X	X		X		
LAND SUBSIDENCE	EXTRACTION OF GROUNDWATER, GAS, OIL, GEOTHERMAL ENERGY	X				X		
	HYDROCOMPACTION, PEAT OXIDATION	X				X		
VOLCANIC HAZARDS	LAVA FLOW	X				X		
	ASH FLOW	X				X		

*"SPECIAL WORK" CAN INCLUDE ADDITIONAL INVESTIGATION, SPECIAL SITE PREPARATION, OR SPECIAL FOUNDATIONS.

3. Surface observations, including mapping of geologic and soil units and structures, geomorphic features, springs, deformation of manmade structures due to fault creep, both on and beyond the site.
4. Subsurface investigations
   a. Trenching and other extensive excavations to permit detailed and direct observation of continuously exposed geologic units and features that must be carefully logged (see Taylor and Cluff, 1973).
   b. Borings and test pits to permit collection of data on geologic units and ground water at specific locations. Data points must be sufficient in number and adequately spaced to permit valid correlations and interpretations.
5. Geophysical investigations. These are indirect methods that require a knowledge of specific geologic conditions for reliable interpretations. They should seldom, if ever, be employed alone without knowledge of the geology. Geophysical methods alone *never* prove the absence of a fault nor do they identify the recency of activity. The types of equipment and techniques used should be described.
   a. Seismic refraction
   b. Magnetic intensity
   c. Other (e.g., electrical resistivity, seismic reflection, ground penetrating radar, gravity)
6. Other methods should be included when special conditions permit, or requirements for critical structures demand, a more intensive investigation.
   a. Aerial reconnaissance overflights.
   b. Geodetic and strain measurements, microseismicity monitoring, or other monitoring techniques.
   c. Radiometric analysis (^{14}C, K-Ar), stratigraphic correlation (fossils, mineralogy), soil profile development, paleomagnetism (magnetostratigraphy), or other age-dating techniques to identify the age of faulted or unfaulted units or surfaces.

E. Conclusions
1. Location and existence (or absence) of hazardous faults on or adjacent to the site.
2. Type of faults and nature of anticipated offset, including sense and magnitude of displacement, if possible.
3. Probability of or relative potential for future surface displacement. The likelihood of future ground rupture seldom can be stated mathematically, but may be stated in semiquantitative terms such as low, moderate, or high, or in terms of slip rates determined for specific fault segments.
4. Degree of confidence in and limitations of data and conclusions.

F. Recommendations
1. Set-back distances from hazardous faults, if appropriate. State and local law may dictate minimum standards (see Hart, 1985, appendix B).
2. Need for additional studies.
3. Risk evaluations relative to the proposed development—opinions are acceptable. But remember that the ultimate decision as to whether the risk is acceptable lies with the governing body.

II. References

A. Literature and records cited or reviewed; citations should be complete.
B. Aerial photographs or images interpreted—list type, date, scale, source, and index numbers.
C. Other sources of information, including well records, personal communications, and other data sources.

III. Illustrations—these are essential to the understanding of the report and to reduce the length of text.
A. Location map—identify site locality, significant faults, geographic features, regional geology, seismic epicenters, and other pertinent data; 1:24,000 scale is recommended.
B. Site development map—show site boundaries, existing and proposed structures, graded areas, streets, exploratory trenches, borings, geophysical traverses, and other data; recommended scale is 1 inch equals 200 feet, or larger.
C. Geologic map—shows distribution of geologic units (if more than one), faults and other structures, geomorphic features, aerial photo lineaments, and springs; on topographic map 1:24,000 scale or larger; can be combined with III(A) or III(B).
D. Geologic cross-sections, if needed to provide 3-dimensional picture.
E. Logs of exploratory trenches, and borings—show details of observed features and conditions; should not be generalized or diagrammatic. Trench logs should show topographic profile and geologic structure at a 1:1 horizontal to vertical scale.
F. Geophysical data and geologic interpretations.

IV. Appendix: Supporting data not included above (e.g. water well data).

V. Authentication: Signature and registration number of investigating geologist.

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Wallace, R.E., 1977, Profiles and ages of young fault scarps, north-central Nevada: Geological Society of America Bulletin, v. 88, p. 1267-1281.

CALIFORNIA DEPARTMENT OF CONSERVATION
DIVISION OF MINES AND GEOLOGY

DMG NOTE 49

GUIDELINES FOR EVALUATING THE HAZARD OF SURFACE FAULT RUPTURE

These guidelines are to assist geologists who investigate faults relative to the hazard of primary surface rupture. Subsequent to the passage of the Alquist-Priolo Special Studies Zones Act (1972), it became apparent that many fault investigations conducted in California were incomplete or otherwise inadequate for the purpose of evaluating the potential of surface fault rupture. It was further apparent that statewide standards for investigating faults would be beneficial.

The investigation of sites for the possible hazard of surface fault rupture is a deceptively difficult geologic task. Many active faults are complex, consisting of multiple breaks. Yet the evidence for identifying active fault traces is generally subtle or obscure and the distinction between recently active and long-inactive faults may be difficult to make. Once a structure is sited astride an active fault, the resulting fault-rupture hazard cannot be mitigated unless the structure is relocated, whereas when a structure is placed on a landslide, the hazard from landsliding often can be mitigated. Further, it is impractical from an economic, engineering, and architectural point of view to design a structure to withstand serious damage under the stress of surface fault rupture. Thus, the evaluation of a site for the hazard of surface fault rupture is a difficult and delicate procedure.

Because of the complexity of evaluating surface and near surface faults and because of the infinite variety of site conditions, no single investigative method will be the best, or even useful, at all sites. Nonetheless, certain investigative methods are more helpful than others in locating faults and evaluating the recency of activity.

The evaluation of a given site with regard to the potential hazard of surface fault rupture is based extensively on the concepts of *recency* and *recurrence* of faulting along existing faults. In a general way, the more recent the faulting the greater the probability for future faulting (Allen, 1975). Stated another way, faults of known historic activity during the last 200 years, as a class, have a greater probability for future activity than faults classified as Holocene age (last 11,000 years) and a much greater probability of future activity than faults classified as Quaternary age (last two million years). However, it should be kept in mind that certain faults have recurrent activity measured in tens or hundreds of years, whereas other faults may be inactive for thousands of years before being reactivated. Other faults may be characterized by creep-type rupture. The magnitude, sense, and nature of fault rupture also vary for different faults or even along different segments of the same fault. Even so, future faulting generally is expected to recur along pre-existing faults (Bonilla, 1970, p. 68). The development of a new fault or reactivation of a long-inactive fault is relatively uncommon and generally need not be a concern in site development.

As a practical matter, fault investigations should be directed at the problem of locating existing faults and then attempting to evaluate the recency of their activity. It is pointed out that data are obtained both from the site and outside the site area. The most direct method of evaluating recency is to observe (in a trench or road cut) the youngest geologic unit faulted and the oldest unit that is not faulted. Recently active faults may also be identified by direct observation of young, fault-related geomorphic (i.e. topographic) features in the field, on aerial photographs, or on remotely obtained images. Other indirect and more interpretive methods are identified in the outline below. Some of these methods are discussed in Slemmons (1977), Bonilla (1982), Wallace (1977), Taylor and Cluff (1973), Sherard and others (1974), Hatheway and Leighton (1979), and the National Research Council (1986), but no comprehensive manual on the subject of fault investigation and evaluation exists at this time. Many other useful references exist and are listed in the bibliographies of the references cited here.

The following annotated outline provides guidelines for a comprehensive fault investigation that may be applied to any project site, large or small. Fault investigations may be conducted in conjunction with other geotechnical investigations [see DMG Notes 42 (formerly 37) and 44]. Although not all investigative techniques need to be or can be employed in evaluating a given site, the outline provides a checklist for preparing complete and well-documented reports. Since most reports on fault investigations are filed with and reviewed by local or state government agencies, it is necessary that the reports be adequately documented and carefully written to facilitate that review. The importance of the review process is emphasized here, because it is the reviewer who must evaluate the adequacy of reports, interpret or set standards where they are unclear, and advise the governing agency as to their acceptability (Hart and Williams, 1978).

The scope of the investigation is dependent not only on complexity and economics of a project, but also on the level of risk acceptable for the proposed structure or development (Joint Committee on Seismic Safety, 1974, p. 9). Obviously, a more detailed investigation should be made for hospitals, high-rise buildings, and other critical or sensitive structures than for low-density structures such as wood-frame dwellings that are comparatively safe. The conclusions drawn from any given set of data, however, must be consistent and unbiased. Recommendations must be clearly separated from conclusions, since recommendations are not totally dependent on geologic factors. The final decision as to whether, or how, a given project should be developed lies in the hands of the owner and the governing body that must review and approve the project.

Suggested Outline for Geologic Reports on Faults

The following subjects should be addressed, or at least considered, in any geologic report on faults. Some of the investigative methods listed below should be carried out well beyond the site being investigated. However, it is not expected that all of the methods identified would be used in a single investigation.

I. Text

A. Purpose and scope of investigation
B. Geologic setting
C. Site description and conditions. Include information on geologic units, graded and filled areas, vegetation, existing structures, and other factors that may affect the choice of investigative methods and the interpretation of data.
D. Methods of investigation
   1. Review of published and unpublished literature and records concerning geologic units, faults, ground-water barriers, and other factors.
   2. Stereoscopic interpretation of aerial photographs and other remotely sensed images to detect fault-related topography, vegetation and soil contrasts, and other lineaments of possible fault origin.

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II. CHECKLIST OF GEOLOGIC REPORT ELEMENTS

REPORT ELEMENTS	YES	NO
A. General Elements Present		
Description and map of project.		
Description and map of site.		
Description and map of pertinent off-site areas.		
B. Geologic Element (refer to checklist)		
Are all the geologic problems mentioned?		
Are all the geologic problems adequately described?		
C. Mitigating Measures		
Are mitigating measures necessary?		
Is sufficient geologic information provided for the proper design of mitigating measures?		
Will the failure of mitigating measures cause an irreversible environmental impact?		
D. Alternatives		
Are alternatives necessary to reduce or prevent the irreversible environmental impact mentioned?		
Is sufficient geologic information provided for the proper consideration of alternatives?		
Are all the possible alternatives adequately described?		
E. Implementation of the Project		
Is the geologic report signed by a registered geologist?*		
Does the report provide the necessary regulations and performance criteria to implement the project?		

*Required for interpretive geologic information.

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IV. PUBLIC AGENCIES WITH GEOLOGIC DATA

Source	Data Available			
	Seismicity	Geology	Ground Water	Soils
Libraries and Geology and Engineering Departments of California Universities	X	X	X	X
California Institute of Technology	X			
California Division of Mines and Geology (Sacramento, San Francisco, Los Angeles, CA)	X	X		
California Department of Water Resources (Sacramento, CA)		X		X
California Department of Transportation (District Offices)				X
County Soil & Water Conservation Districts				X
County Engineer and Departments of Building and Safety	X	X		X
County Highway Department				X
County Flood Control District				X
U.S. Geological Survey (Menlo Park, CA)		X		
U.S. Corps of Engineers (District Engineer)		X		
U.S. Bureau of Reclamation (Regional Offices)		X		
U.S. Soil Conservation Service and Forest Service				X

APPENDIX 4

REFERENCE SOURCES FOR ENGINEERING GEOLOGY MATERIALS AND LANDSLIDE INVENTORY

APPENDIX 4

REFERENCE SOURCES FOR ENGINEERING GEOLOGY MATERIALS - PLATE 2

Government Agencies - Contributors to Professional Paper 1360 US

California Department of Water Resources, Southern District
California Department of Transportation, Division of Structures, SAC
California Division of Oil and Gas, Long Beach
City of Los Angeles Department of Building and Safety
City of Los Angeles Department of Water and Power
County of Los Angeles Department of County Engineer (Geologic Section)
Department of Facilities (Agriculture)
Department of Public Works (Soil Division)
Department of Flood Control District
    Materials Engineer and Water Conservation
    Ground Water Studies and Operations Section
Department of Roads
Southern California Rapid Transit District (RTD)
Metropolitan Water District of Southern California
U.S. Army Corp of Engineers (LA)

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Oakshott (1958)

Rogers (1967)

Olmstead (1958)

Shelton (1955)

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Dibblee (1960a)

Dibblee (1960b)

APPENDIX 4 (Continued)

LANDSLIDE INVENTORY REFERENCES - PLATE 5

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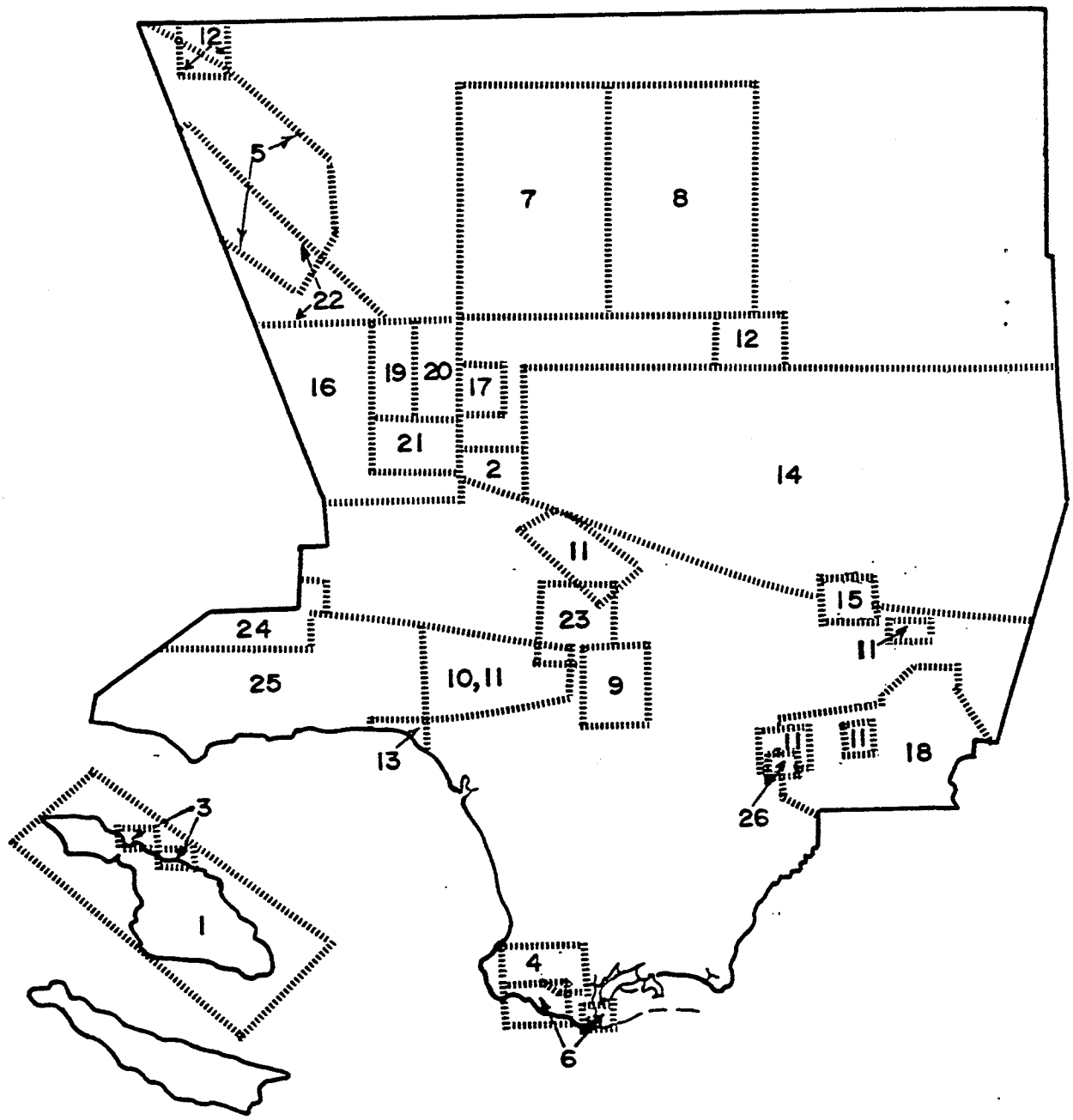
3. Cann (1985)
4. Cleveland (1976)
5. Crowell, et al., (1982)
6. Dibblee (1960a)
7. Dibblee (1960b)
8. Ehlig and Keene (1985)
9. Hsu (1982)
10. Krohn (1987)
11. Leighton (1966)
12. Los Angeles County (1973)
13. McGill (1973)
14. Morton and Streitz (1964)
15. Morton (1973)
16. Morton (1976b)
17. Saul (1983)
18. Tan (1989)
19. Treiman (1986a)
20. Treiman (1986b)
21. Treiman (1987)
22. Weber (1979a)
23. Weber (1979b)
24. Weber (1984)
25. Weber and Willis (1983)
26. Yerkes (1960)

APPENDIX 4 (Continued)

LANDSLIDE INVENTORY REFERENCES - PLATE 5



APPENDIX 5

GENERAL DESCRIPTION OF LANDSLIDE TYPES

GLOSSARY

GLOSSARY

This glossary is intended for the convenience of users of the technical background report. A more precise glossary of terms is located in the Safety Element. The Safety Element Glossary is used to support policies and programs in the Safety Element and takes precedent over this glossary if terms appear in both.

Abatement - The reduction or elimination of a hazardous condition, including but not limited to strengthening, occupancy restrictions, or demolition.

Active fault - A fault that shows evidence of, or is suspected of having experienced surface displacement within the last 11,000 years. An active fault is considered to have the highest potential for future surface rupture.

Accelerograph - An instrument used to record very large earthquakes.

Aftershocks - Earthquakes that follow a main larger earthquake, most commonly smaller than the mainshock.

Alluvium - Surficial sediments of poorly consolidated, gravels, sand, silts, and clays deposited by flowing water.

Arson Fire - A fire deliberately set in a structure.

BAREPP - Bay Area Regional Earthquake Preparedness Project.

Bedrock - Designates hard rock that is in its natural intact position and underlies soil or other unconsolidated surficial material.

Branding - The wind transport of burning debris outward from a fire. The debris can be carried a mile or more ahead of a fire.

Catastrophic Earthquake - A great earthquake, generally near Magnitude 8.0 or greater, capable of widespread tremendous damage in epicentral area accompanied by localized severe damage 100's of miles from earthquake source.

Collapsible Soils - Typically found in arid environments and associated with Holocene-aged or slightly older deposits on alluvial fans, collapsible soils undergo settlement when exposed to development practices such as construction and artificial irrigation.

Conditionally Active Fault - A fault showing evidence of movement in the Quaternary but greater than 750,000 years ago (considered only for certain critical facilities).

Conflagration - A large fire, usually in excess of 1,000-acres that advances along a front.

Coseismic Rupture - Rupture occurring during an earthquake.

Critical Facilities - The definition of critical facilities in the glossary of the Safety Element takes precedent. The following are categories of critical facilities referenced in this report:

a. Any lifeline system facility under County jurisdiction whose operations are essential at times of emergencies, such as energy transmission systems, major utility lines, evacuation and disaster routes, and warehouses storing heavy rescue and debris cleanup equipment;

b. essential facilities that are needed in times of emergencies, such as medical facilities, fire and police stations, emergency operation centers, and communication centers;

c. high-risk facilities that, if severely damaged, could cause catastrophic casualties or disasters far beyond the facility itself, such as nuclear power plants, dams and flood control infrastructure, freeway-to-freeway interchanges and bridges, and industrial plants which manufacture or store explosives, toxic materials, or petroleum products;

d. high occupancy facilities having potential for catastrophic fatalities and crowd control problems such as high-rise buildings, large assembly public and private facilities and large multifamily residential complexes;

e. dependent care facilities that house populations with special evacuation considerations, such as educational facilities for preschool, public and private schools, rehabilitation centers, prisons, and major social care facilities, including group care homes and elderly care facilities; and

f. economic facilities whose continued operation is paramount to avoiding severe economic impact, such as banking, vital record keeping, archiving activities, airport and port facilities, and large industrial/commercial complexes.

Debris - Debris may be used to specify surficial material in which 20 to 80 percent of the fragments are greater than 2 mm (.08 inches) and the remaining fragments less than 2 mm.

Debris Flow - Rapidly moving earth flow with 50 percent rock fragments coarser than 2 mm in size (Varnes, 1978).

Deformation - A general term for the process of folding, faulting, shearing, compression, or extension of rocks.

Dekameters (Dam) - Unit of dam storage capacity where 1 Dam^3 is equal to .8 acre-feet. An acre-foot is the volume of an acre of area that is one foot in thickness.

Design Flood - The flood magnitude for which a specific project was designed.

Differential Settlement - Nonuniform settlement; the uneven lowering of different parts of an engineering structure, often resulting in damage to the structure. Sometimes included with liquefaction as ground failure phenomenon.

Dynamic Analyses - A complex earthquake-resistant engineering design technique (UBC - used for critical facilities) capable of modeling the entire frequency spectra, or composition, of ground motion. The method is used to evaluate the stability of a site or structure by considering the motion from any source on mass, such as that dynamic motion produced by machinery or a seismic event.

Earth Flow - Imperceptibly slow moving surficial material in which 80 percent or more of the fragments are smaller than 2 mm, including a range of rock and mineral fragments.

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

EERI - Earthquake Engineering Research Institute.

Emergency Operations Center - A room or building equipped and staffed to monitor and direct the response to an emergency situation.

Engineering Geologist - A geologist who is certified by the state as qualified to apply geologic data, principles, and interpretation to naturally occurring earth materials so that geologic factors affecting planning, design, construction, and maintenance of civil engineering works are properly recognized and used. An engineering geologist is particularly needed to conduct investigations, often with geotechnical engineers, of sites with potential ground failure hazards.

ESS - Earthquake Safety Systems.

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

Fault Line - A scarp that has been produced by differential erosion along an old fault line, sometimes synonymous with fault trace.

Fault Plane Solution - A model of the sense and orientation of the generating fault displacement.

Fault Slip Rate - The average long-term movement of a fault as (and measured in cm/year) determined from geologic evidence.

FEMA - Federal Emergency Management Agency.

Fire Storm - A large fire that stays in one place and has cyclonic attributes such as strong in-rushing winds and a grossly rotational motion.

Fuel loading - Management of onsite volumes of combustible material, usually vegetation.

Frequency Composition - The range of frequencies as measured at a site, including high frequency earthquake ground motion (greater than 1 Hz) and lower frequency energy (less than 1 Hz).

Geotechnical Engineer - A licensed Civil Engineer who is also certified by the state as qualified for the investigation and engineering evaluation of earth materials and their interaction with earth retention systems, structural foundations, and other civil engineering works.

Ground Failure - Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.

Ground Rupture - Displacement of the earth's surface as a result of fault movement associated with an earthquake.

Hollows - bowl-shaped geomorphic scars located at the top of swales and serve as source areas for certain types of debris flows.

Imbricate - A stacked sequence of overlapping; subsurface faults.

Incendiary Fire - A fire deliberately set in grass, brush, or woodland areas.

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

Isoseismal Area - An area composed of points of equal earthquake intensity on the earth's surface.

Large Fire - A fire that is out of control at first arrival.

Lateral Force - The force of the horizontal side-to-side motion on the earth surface as measured on a particular mass; either a building or structure.

Lateral Spread - Shallow angle slope failure caused by liquefaction of a subsurface layer; very large displacement.

Levee - An artificial embankment of earth fill, built along the bank of a water coarse or an arm of the sea in design to protect land from inundation.

Lifeline System - Linear conduits or corridors for the delivery of services or movement of people and information (e.g., pipelines, telephones, freeways, railroads)

Liquefaction - Changing of soils (unconsolidated alluvium) from a solid state to weaker state unable to support structures; where the material behaves similar to a liquid as a consequence of earthquake shaking.

Magnitude - A measure of the size of an earthquake, as determined by measurements from seismographic records.

Major Earthquake - Capable of widespread, heavy damage up to 50+ miles from epicenter; generally near Magnitude Range 6.5 to 7.0 or greater, but can be less, depending on rupture mechanism, depth of earthquake, and location relative to urban center, etc.

Maximum Probable Earthquake - Refers to the design size of an earthquake used in probabilistic design analysis. The design earthquake is used to assess the maximum ground motion that can be expected within a certain period of time; for example, within a 30 year or 100 year period, depending on the purpose, lifetime, or importance of the proposed construction. The more critical the facility, the longer the time period considered.

Melange - Persuasively sheared and weakened rock.

Microzonation - The detailed mapping of various seismic hazards for use in urban and disaster planning.

Moderate Earthquake - Capable of causing considerable to severe damage, generally in the range of Magnitude 5.0 to 6.0 (Modified Mercalli Intensity <VI), but highly dependent on rupture mechanism, depth of earthquake, and location relative to urban center, etc.

Mudflood - Refers to a flood in which the water carries heavy loads of sediment (as much as 50 percent by volume) including coarse debris. Mudfloods typically occur in drainage channels and on alluvial fans adjacent to mountainous regions, although they may occur on floodplains as well.

Mud Flow - Wet earth flow containing 50 percent fragments smaller than 2 mm (Varnes, 1978).

Near-Field Earthquake - Used to describe a local earthquake within approximately a few fault zone widths of fault which is characterized by high frequency waveforms that are destructive to above-ground utilities and short period structures (less than about two or three stories).

Nonductile - Refers to concrete construction using columns and beams with insufficient steel reinforcing, making a structure brittle and prone to collapse during earthquakes.

Nonstructural Flood Management - Where flood plains are reserved for ground water spreading basins, recreational uses, agricultural and open space uses, and public service facilities or other development able to tolerate occasional flooding.

Parapet - The portion of any wall which extends above the roof line, or a wall that serves as a guard at the edge of a balcony or roof.

Piling - Used to pin a structure to stable bedrock below using long piles emplaced through an unstable zone of potential ground failure; commonly utilized for landslide and liquefaction mitigation.

Peak Acceleration - The greatest amplitude of acceleration measured across a record left on an accelerogram.

Potentially Active Fault - A fault showing evidence of movement within the last 750,000 years but before 11,000 years ago and is capable of generating damaging earthquakes.

Project - A development application involving zone changes, variances, conditional use permits, tentative parcel maps, tentative tract maps, and plan amendments.

Power Intertie - Terminal facilities in a lifeline network system, such as water and sewage pumping stations, electrical power substations, and power generating facilities.

Pseudostatic - A simplified engineering analyses of the stability of a site or structure that translates earthquake ground motion into a static force in performing stability calculations.

Reinforced Masonry - Masonry construction with steel reinforcement.

Resonance - Amplification of ground motion frequencies within bands matching the natural frequency of a structure and often causing partial or complete structural collapse; effects may demonstrate minor damage to single-story residential structures while adjacent 3- or 4-story buildings may collapse because of corresponding frequencies, or vice-versa.

Response Spectra - The range of potentially damaging frequencies of a given earthquake applied to a specific site and for a particular building or structure.

Rock Avalanche - Rapidly moving and large volume debris fall (wet or dry).

SCEPP - Southern California Earthquake Preparedness Project.

Seismic Capacity - The measure of resistance of a structure to strong earthquake shaking, or seismic loading as commonly used when applying lateral forces to a structure.

Seismogenic - Capable of producing earthquake activity.

Seismology - The study of earthquakes.

Seismic Risk - Given the location and magnitude of future earthquakes in a region, and a means for specifying the return period for each fault, the cumulative risk for a site to experience a certain level of ground shaking in a given period of time can be ascertained. Expressed as a probability for design and planning considerations, seismic risk factors depend on the type of development. ATC 3-06 (1978) recommends that a 10 percent chance of exceeding a design ground motion in 50 years (.002 percent probability of exceedance), which is equivalent to a 500 year return interval, be used for the design of critical structures such as lifelines, dams, and bridges. A 50 or 100 year return period, which is equivalent to a .01 percent probability of exceedance, is recommended for regional planning purposes or noncritical structures.

Soft-Story Construction - A structure that has at least one story, often the ground level, with significantly less rigidity or strength than other floors in the structure during seismic loading, e.g., apartment dwellings with garages on the lower floor, etc.

SSC - Seismic Safety Commission.

Standard Cone Penetrometer - A engineering borehole measurement, which among other applications, is able to translate penetration resistance (as gauged from a narrow cylindrical instrument of standard weight dropped from a standard height) of unconsolidated earth materials into a measure of liquefaction susceptibility.

Standard Project Flood - As used by the U.S. Corps of Engineers, a flood that may be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographic areas in which the drainage is located.

Storage Capacity - Is measured in acre-feet and decameters, including dead storage.

Stike-Slip Fault - A fault with a vertical to subvertical fault surface in three dimensions that displays evidence of horizontal and opposite displacement.

Structural Engineer - A licensed Civil Engineer certified by the State as qualified to design and supervise the construction of engineered structures.

Tilt-up Wall - A poured concrete-and-steel-reinforced wall raised or lifted into place and tied to other walls, and the roof and floor.

Total Freeboard - The vertical distance in feet and meters from the dam crest to the lowest point of the spillway control section (excluding flashboards and gates).

Trench Plate Boundary - Subduction of one crustal plate under another at line of convergence.

Tsunami Runup - The height of the tsunami wave as it crosses mean low-low water (MLLW) at shoreline.

URRNSF - Urban Regional Research for the Natural Science Foundation.

Veneer - A covering layer of material for walls, which is attached to the wall, but not bounded adquately so as to act with it during earthquake shaking.

Water Table - The upper surface of ground water saturation of pores and fractures in rock or surficial earth materials.

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REFERENCES

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