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# IMPLEMENTATION OF THE SEISMIC HAZARDS MAPPING ACT IN CALIFORNIA

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## SUMMARY

California passed the Seismic Hazards Mapping Act in 1990 in the aftermath of the Loma Prieta earthquake. The Act is a companion and complement to earlier legislation that addressed surface fault rupture hazards. It has the purpose of addressing protection of public safety in California from the effects of strong ground shaking, liquefaction, landslides, and other hazards caused by earthquakes. To implement the provisions of the Act, the California Geological Survey published guidelines for evaluation of seismic hazards other than surface fault rupture and for mitigation measures. The California Geological Survey is in the process of preparing and issuing 1:24,000 maps and delineating zones that may be susceptible to liquefaction and landslide hazards. The California Geological Survey established criteria to evaluate the regional seismic hazards and delineate the possible hazard zones.

Implementation of the Seismic Hazards Mapping Act has raised awareness of seismic hazards throughout California. It has also caused geotechnical engineers and engineering geologists practicing in California to become more competent in the evaluation of seismic hazards and to become more knowledgeable about mitigation methods. Similarly, the Act has caused building officials and other regulators to become knowledgeable and competent in reviewing and approving reports on the evaluation and mitigation of seismic hazards in California. This paper reports on efforts by the professional community to educate and inform practitioners and regulators in the state-of-the practice of seismic hazard evaluation. These efforts are improving the quality of the evaluations and seismic safety in California. The California experience may be a model for mitigating seismic hazards in other locations.

## INTRODUCTION

The State of California has always been in the forefront of advances in understanding and meeting the earthquake challenges that threaten the lives and livelihood of the citizens of the State. California has been a consistent leader in earthquake engineering and earth science research that has exponentially exploded in an overwhelming growth of knowledge and ability to meet the demands for public safety and

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protection of life and property. However, in the area of public policy, such advances are not easily adopted because of the pressures for growth and the desire to limit the rising costs of construction. Advances in the public policy arena generally follow a calamitous event that either elicits strong public opinion or motivates lawmakers to take action to avoid a serious lesson learned from a recent earthquake and/or to protect the public from a newly discovered hazard. California is no exception to this rule. Perhaps because of the greater frequency of earthquakes, and the greater impacts upon people and property, more pioneering public policies have been enacted into law in California than elsewhere.

## BRIEF HISTORY OF SEISMIC PUBLIC POLICY DEVELOPMENT IN CALIFORNIA

The March 10, 1933 (Magnitude 6.3) Long Beach Earthquake caused major damage to schools. It is reported that "70 schools were destroyed, 120 schools suffered major damage, and 300 schools received minor damage" according to Meehan and Jephcott [1]. Much of the construction at the time consisted of unreinforced masonry or framed construction with brick infill that is very vulnerable to earthquake forces. The Field Act was enacted on April 10, 1933, just one month after the earthquake to protect children and staff from death and injury in public school grades Kindergarten to 14, and to protect the public's investment in school buildings during and after earthquakes. The Field Act had provisions for the replacement of pre-1933 buildings; however, that process would take nearly 50 years to fulfill. The Field Act and its regulations have been updated many times since its inception, each time increasing the performance of school construction. These school facilities often become the centers for disaster relief after earthquakes.

The February 9, 1971 (Magnitude 6.6) San Fernando Earthquake rumbled through the San Fernando Valley and the Los Angeles Basin causing wide-spread damage to a large variety of structures and affecting a population of millions. Because of damage to structures caused by liquefaction, landsliding, and surface fault rupture, legislation was introduced to have the State Geologist map zones of potential seismic hazards from these effects and have regulations to mitigate such hazards. However, the final legislation was limited to surface fault rupture hazard with the passage of the Alquist-Priolo Special Studies Zone Act in 1972, which is now known as the Alquist-Priolo Earthquake Fault Zoning Act [2]. Under this Act, the State Geologist is required by law to delineate "Earthquake Fault Zones" among known active faults in California. The local governmental agencies (i.e., cities and counties) affected by the zones must regulate certain development projects within the zones. These agencies are to withhold development permits for sites within the zones until geologic investigations are performed to demonstrate that the sites are not threatened by surface displacement from future faulting.

Also in response to serious damage experienced by hospitals in the Los Angeles area during the San Fernando Earthquake, the Alquist Hospital Seismic Safety Act was passed in 1972. The Hospital Safety Act applied to construction of new hospitals and to alterations and remodeling of existing hospitals. It did not, however, apply retroactively to existing hospitals. It was the expectation that existing nonconforming buildings would be eventually replaced with new conforming buildings. The Hospital Safety Act also created the Building Safety Board (later changed to Hospital Building Safety Board or HBSB) to serve as an advisory and appeals panel to the Office of Statewide Health Planning and Development. The HBSB began to address the expected earthquake performance of hospitals that did not conform to the Alquist Act, and proposed a plan in 1983 to bring the pre-Act hospital buildings into compliance over a 30-year period. Because of the time that has lapsed since the San Fernando Earthquake, and the lack of recent earthquake activity, there was little interest by lawmakers to enact legislation to make such a plan a reality.

The October 17, 1989 (Magnitude 7.1) Loma Prieta Earthquake shook the San Francisco Bay-Monterey Bay region with more wide-reaching seismic effects, including extensive ground failures caused by liquefaction and landslides. Liquefaction affected sections of Santa Cruz, Treasure Island in San Francisco Bay, and resulted in total destruction of dozens of structures in the affluent Marina District of San Francisco. Extensive liquefaction also disrupted operations at the Port of Oakland and the Oakland International Airport, and damaged the approach roadways to the east end of the San Francisco-Oakland Bay Bridge. Prompted by the staggering losses caused by this event ($6 billion), the California State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect public safety from the effects of strong ground shaking, liquefaction, landslides, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act were based on recommendations of a previous study by Holden and Real [3], and closely resemble those of the 1972 Alquist-Priolo Earthquake Fault Zoning Act. Implementation of the Seismic Hazards Mapping Act is the principal topic of this paper.

On January 17, 1994, the Magnitude 6.7 Northridge Earthquake affected large portions of Southern California. This earthquake was one of the most costly natural disasters in United States history with 57 deaths, thousands of injuries, and economic losses exceeding $40 billion US [4]. There were 11,846 persons treated for earthquake-related injuries at hospitals in Southern California; 1,044 persons were admitted to hospitals according to Hall [5]. Affecting the ability to provide adequate healthcare services after the earthquake, there were 23 hospitals reported to have suspended some or all of their services as a result of damage from the earthquake. The California legislature quickly passed legislation in 1994, which has been known as "Senate Bill 1953" that essentially adopted the previously proposed plan to bring nonconforming hospital buildings into conformance by seismic retrofit, replacement, or abandonment by the year 2030. Senate Bill 1953 also has intermediate milestones for providing minimum life safety standards for both structural and nonstructural systems.

Although other legislation has contributed to seismic safety in California, the major advances in seismic safety policy have followed major earthquakes that have caused significant human casualties and economic loss. The June 28, 1991 (Magnitude 7.6) Landers earthquake was the largest earthquake in the United States since 1964, but failed to provoke any improvements in seismic safety policy because it occurred in a sparsely populated area, few structures were affected, and the economic losses were not great. It failed to test the adequacy of existing policy.

## REQUIREMENTS OF THE SEISMIC HAZARDS MAPPING ACT

Following the Loma Prieta Earthquake, the California Legislature realized it was necessary to identify and map seismic hazard zones in order for cities and counties in California to adequately prepare the safety element of their general plans and to encourage land use management policies and regulations to mitigate earthquake hazards in order to reduce future losses and protect public health and safety. Their remedy was to provide for a statewide seismic hazard mapping and technical advisory program to assist the cities and counties in fulfilling their responsibilities for protecting the public health and safety. The resulting legislation specifically calls for mapping the "…effects of strong ground shaking, liquefaction, landslides, or other ground failure and other seismic hazards caused by earthquakes." An amendment to the Act calls for mapping the effects of tsunamis and seiches depending on a sufficient level of funding.

The framework of the Act closely resembles the Alquist-Priolo Earthquake Fault Zoning Act, and requires the State Geologist to delineate various "seismic hazard zones." Cities and Counties, or other local permitting authority, must regulate certain development "projects" within the zones. These authorities are usually local building departments or contracted consulting firms acting on behalf of a local city or county government. These authorities must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into the development plans. The California State Mining and Geology Board (SMGB), through formation of an expert advisory committee, provided criteria for preparation of the

Seismic Hazard Zone Maps and guidelines for evaluating and mitigating seismic hazards. SMGB also prepared the necessary State regulations to implement the Act.

In summary, it is the responsibility of the California Geological Survey (formerly Division of Mines and Geology) through the authority of the State Geologist, with the guidance of the State Mining and Geology Board, to delineate the seismic hazard zones and to provide guidelines and regulations regarding the use and implementation of the Act to protect public health and safety.

The public is affected in two primary areas: transfer of real property and development of a "project." In the transfer of real property, a natural hazards disclosure clause protects the "buyers right to know" by requiring that sellers and their agents inform the buyer when the property is located within a mapped hazard zone at the time of sale. The Act does not require any further actions by the seller other than disclosure, but does affect all existing property. In the development of a "project," only new construction is affected. Cities and counties must require geotechnical reports that address the hazards and recommend appropriate mitigation measures for new "projects" within seismic hazard zones. A "project" is defined as "any subdivision of land … which contemplates the eventual construction of structures for human occupancy" or a project to build such structures. There are exemptions for single-family dwellings that are less than three stories in height and are not part of a development of 4 or more units. There are also exemptions for alterations or additions to structures that do not exceed either 50 percent of the assessed value of the structure or 50 percent of the existing floor area of the structure. A structure for human occupancy has been defined as any structure having a human occupancy rate of more than 2,000 person-hours per year.

The Seismic Hazards Mapping Act and its related regulations establish a statewide minimum public safety standard for the mitigation of earthquake hazards. "Mitigation" has been defined as those measures that are consistent with established practice and reduce seismic risk to "acceptable levels." "Acceptable level of risk" has been defined as that level that provides reasonable protection of the public safety, though it does not necessarily ensure continued structural integrity and functionality of the project. This means that the minimum level of mitigation for a project should reduce the risk of ground failure during an earthquake to a level that does not cause the collapse of buildings for human occupancy, but in most cases, not to a level of no ground failure at all.

## IMPLEMENTATION OF THE SEISMIC HAZARDS MAPPING ACT

Although the Seismic Hazards Mapping Act was enacted into law in 1990, funding for implementation was less than one-third of anticipated levels so work concentrated on the development of the required regulations, criteria and guidelines. The first Official Seismic Hazard Zone Maps showing areas of potential liquefaction and landsliding were released in 1997, and the mapping process is still in progress at the time of this writing. Seismic Hazard Zone Maps use the 1:24,000 United States Geological Survey (USGS) 7.5-minute topographic maps as a base. Accompanying each Seismic Hazard Zone Map is a Seismic Hazard Zone Report, which provides the scientific background for each map and also provides the assumptions made. Details on the methodology used to delineate zones have been published elsewhere [6].

Because of the great effort needed to produce each Seismic Hazard Zone Map, and to do the requisite research and analysis for the evaluation reports, priority was given to developing maps for the most populous areas having significant seismic risk, which are Southern California (around Los Angeles) and the San Francisco Bay area, see Figure 1.

Figure 1. Areas where initial seismic hazard maps and evaluation reports have been developed.

**Ground Shaking**

One of the important first tasks of the Seismic Hazards Mapping Act was to develop appropriate maps of ground shaking hazard. Because an assessment of future ground shaking is required to evaluate the potential for earthquake-triggered ground failure, a suite of regional ground shaking hazard maps was developed using Probabilistic Seismic Hazard Analysis (PSHA) methods [7]. Existing PSHA code was modified to account for different types of earthquake sources, variations in regional attenuation of ground motion, and fault dip, and the results included the affect of uncertainties of input parameters, including seismic sources, earthquake frequency, maximum magnitude, and seismic wave attenuation. Consensus of earth science experts was used to develop the various input parameters and the work was coordinated with the ongoing PSHA efforts of the USGS and the Southern California Earthquake Center, which has been working on national and local maps preceding this effort [8]. An example of this continuing effort is a map of peak ground acceleration developed by CGS, which is shown in Figure 2.

Using the consensus model of the fault sources and seismicity, the ground shaking levels were estimated for each of the sources included in the model using attenuation relations that related earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture. In the Seismic Hazard Zone Reports, ground-shaking levels are estimated for a 10 percent probability of being exceeded in a 50-year period for rock, soft rock, and alluvium conditions. Seismic hazard is calculated at grid points with spacing of about 5 kilometers. The ground shaking hazard map centered for the Los Angeles 7.5-minute Quadrangle with an assumed alluvium condition is shown in Figure 3.

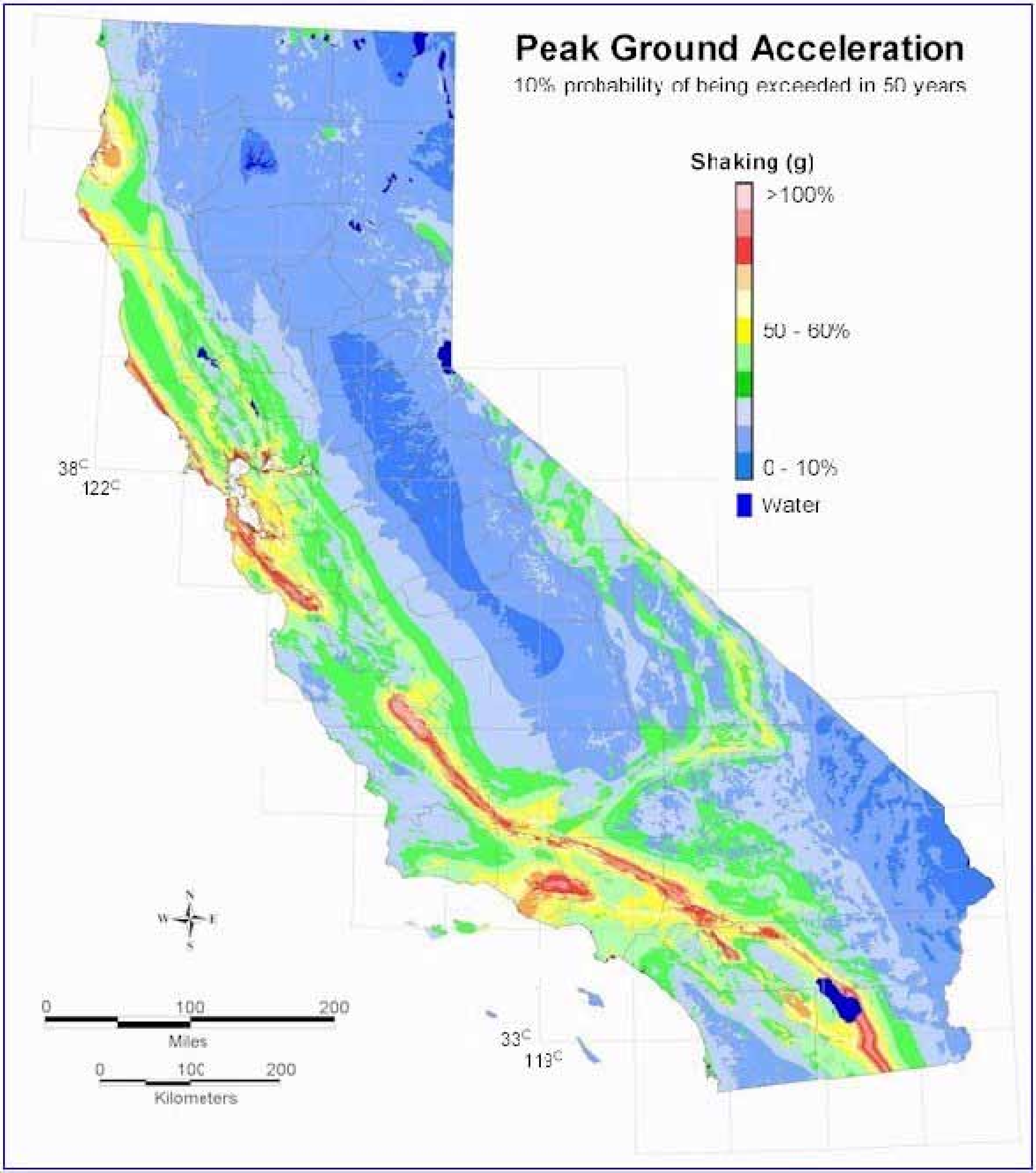


Figure 2. Earthquake shaking potential for California by the California Geological Survey [9].

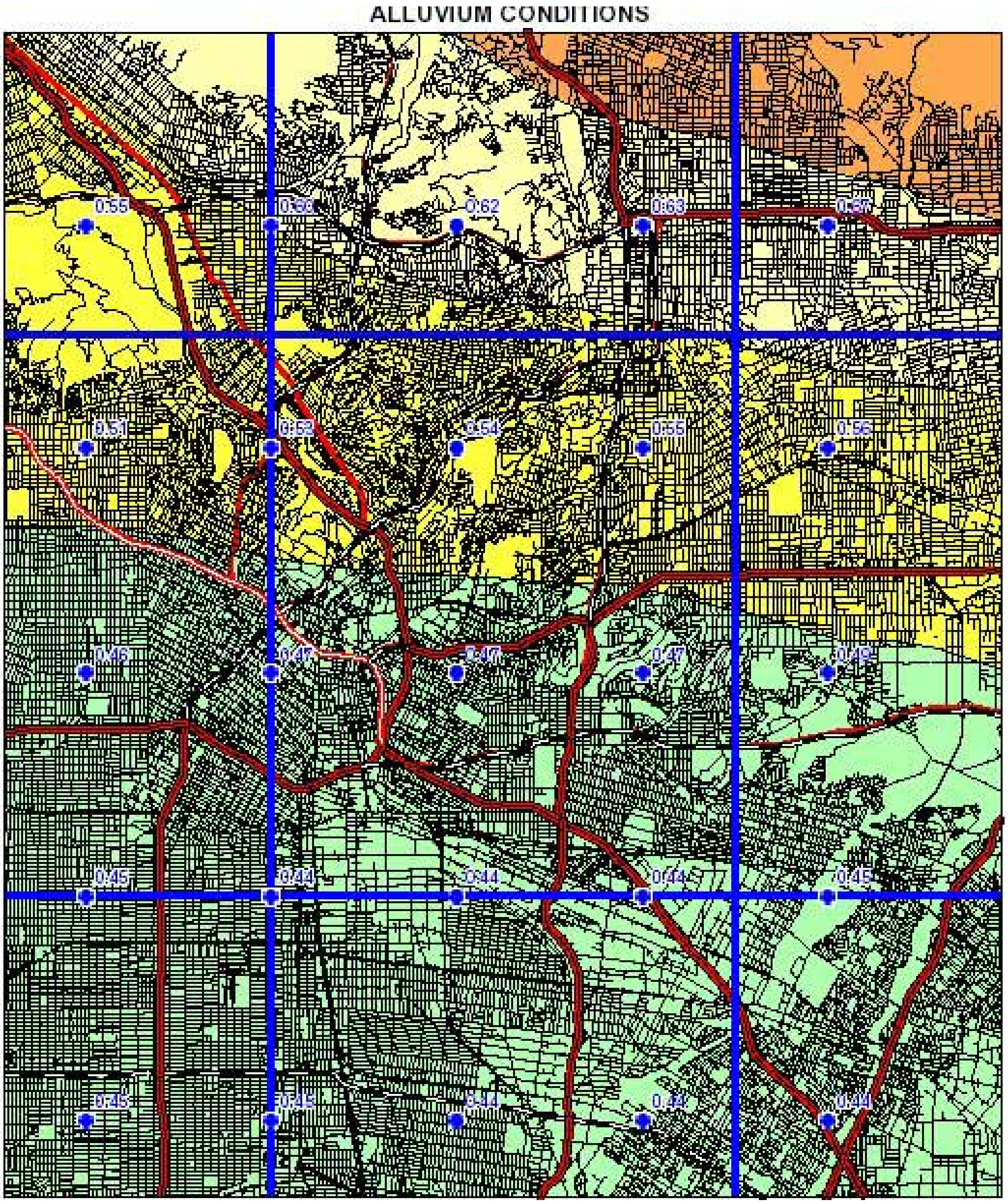


Figure 3. Ground shaking hazard map centered on the Los Angeles 7.5-minute Quadrangle for alluvium conditions and ground motions having a 10 percent probability of being exceeded in 50 years [10].

Deaggregation of the seismic hazard identifies the magnitude and distance for earthquakes that contribute most to the shaking at each grid point. Figure 4 shows the magnitude and the distance (shown in parentheses) of the earthquake that contributes most to the hazard at each 5 kilometer grid point for 10 percent probability of being exceeded in 50 years on alluvial site conditions; this is known as the predominant earthquake. This information can be used for selecting recorded ground motion time histories for evaluating ground failure.

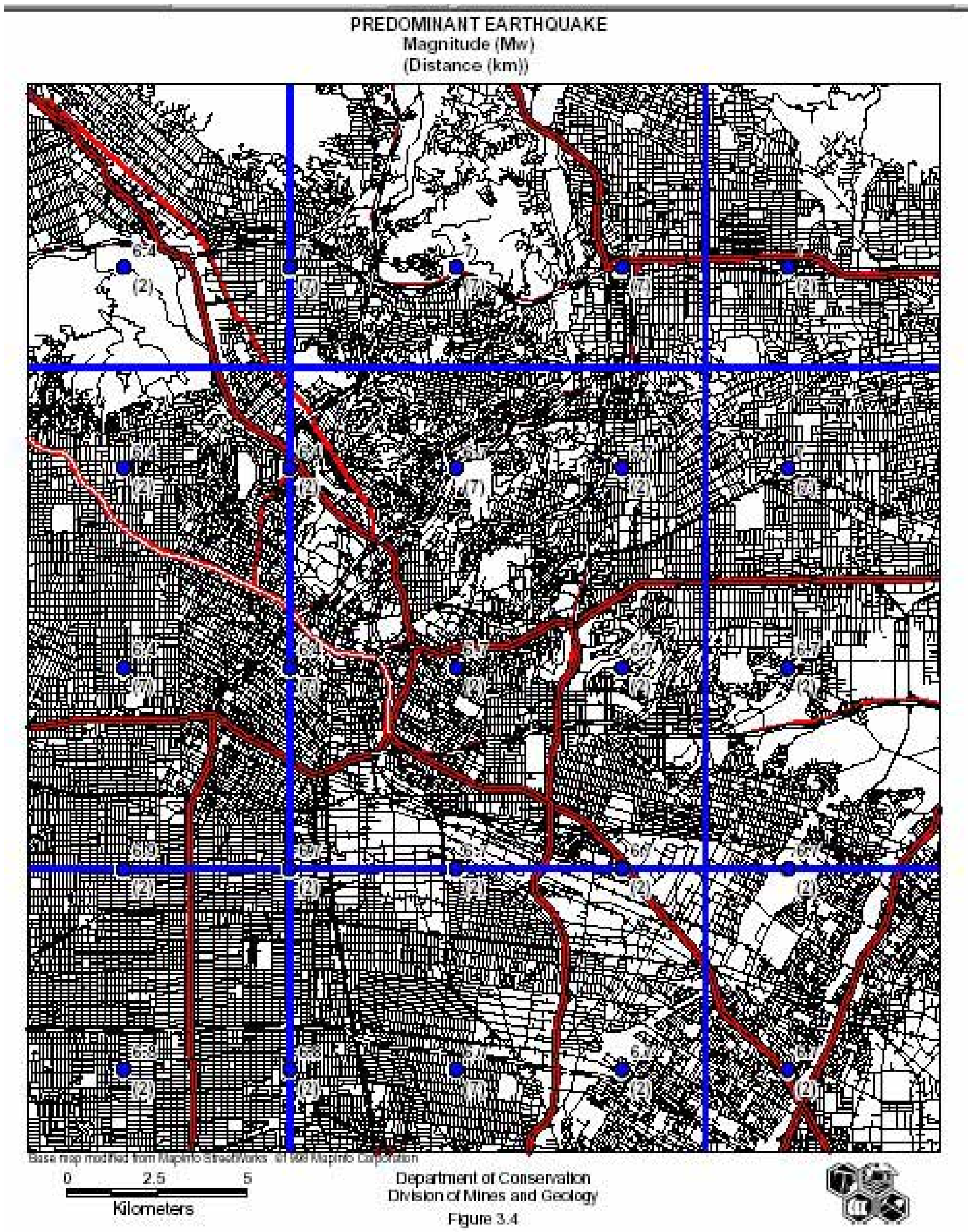


Figure 4. Predominant earthquake magnitude and distance for 10% probability of being exceeded in 50 years for alluvial site conditions in the Los Angeles 7.5-minute quadrangle [10].

**Liquefaction Hazard Zone Mapping**
The following criteria were used in developing the Liquefaction Hazard Zones in California. Liquefaction hazard zones are geographical areas meeting one or more of the following criteria listed by the California Geological Survey [11]:

1. Areas known to have experienced liquefaction during historic earthquakes.
2. All areas of uncompacted fills containing potentially liquefiable material that are saturated, nearly saturated, or may be expected to become saturated.
3. Areas where sufficient existing geotechnical data and analysis indicate that the soils are potentially liquefiable.
4. Areas where existing geotechnical data are insufficient. Liquefaction Hazard Zones should be delineated where the following criteria are met:
    a. Areas containing soil deposits of late Holocene age, where the Magnitude 7.5-weighted peak ground acceleration (for 10 percent probability of being exceeded in 50 years) is greater than 0.10 g and the historic high ground-water level is less than 40 feet below the ground surface; or
    b. Areas containing soil deposits of Holocene age (less than 11,000 years), where the Magnitude 7.5-weighted peak ground acceleration (for 10 percent probability of being exceeded in 50 years) is greater than 0.20 g and the historic high ground-water level is less than or equal to 30 feet below the ground surface; or
    c. Areas containing soil deposits of latest Pleistocene age (between 11,000 and 15,000 years), where the Magnitude 7.5-weighted peak ground acceleration (for 10 percent probability of being exceeded in 50 years) is greater than 0.30 g and the historic high ground-water level is less than or equal to 20 feet below the ground surface.

To aid in the evaluation of the liquefaction hazard, a ground-water evaluation is performed to determine the presence and extent of historic shallow ground water. Data for the evaluation is generally obtained from technical publications, geotechnical boreholes, and water-well logs. The depths to first-encountered water free of piezometric influences are plotted and hand contoured on map. The map is compared to other published maps to check against major discrepancies. The historic high ground-water levels as determined using this procedure for the Los Angeles 7.5-minute quadrangle are shown on Figure 5.

If the age and soil types of the upper soils are known, using the criteria given above, the estimated peak ground acceleration, and the historic high ground-water levels, the liquefaction hazard can be evaluated.

**Landslide Hazard Zone Mapping**
The establishment of an earthquake-induced landslide hazard zone is based on the criteria that an area meets one or more of the following conditions:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.
2. Areas identified as having past landslide movement, including both landslide deposits and source areas.
3. Areas where analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

It is recognized that it is very difficult, if not impossible, to distinguish earthquake-induced slope failures from landslides triggered by other mechanisms if the latest movement occurred prior to historic observations. Inclusion of areas meeting Criteria No. 2 may be conservative.

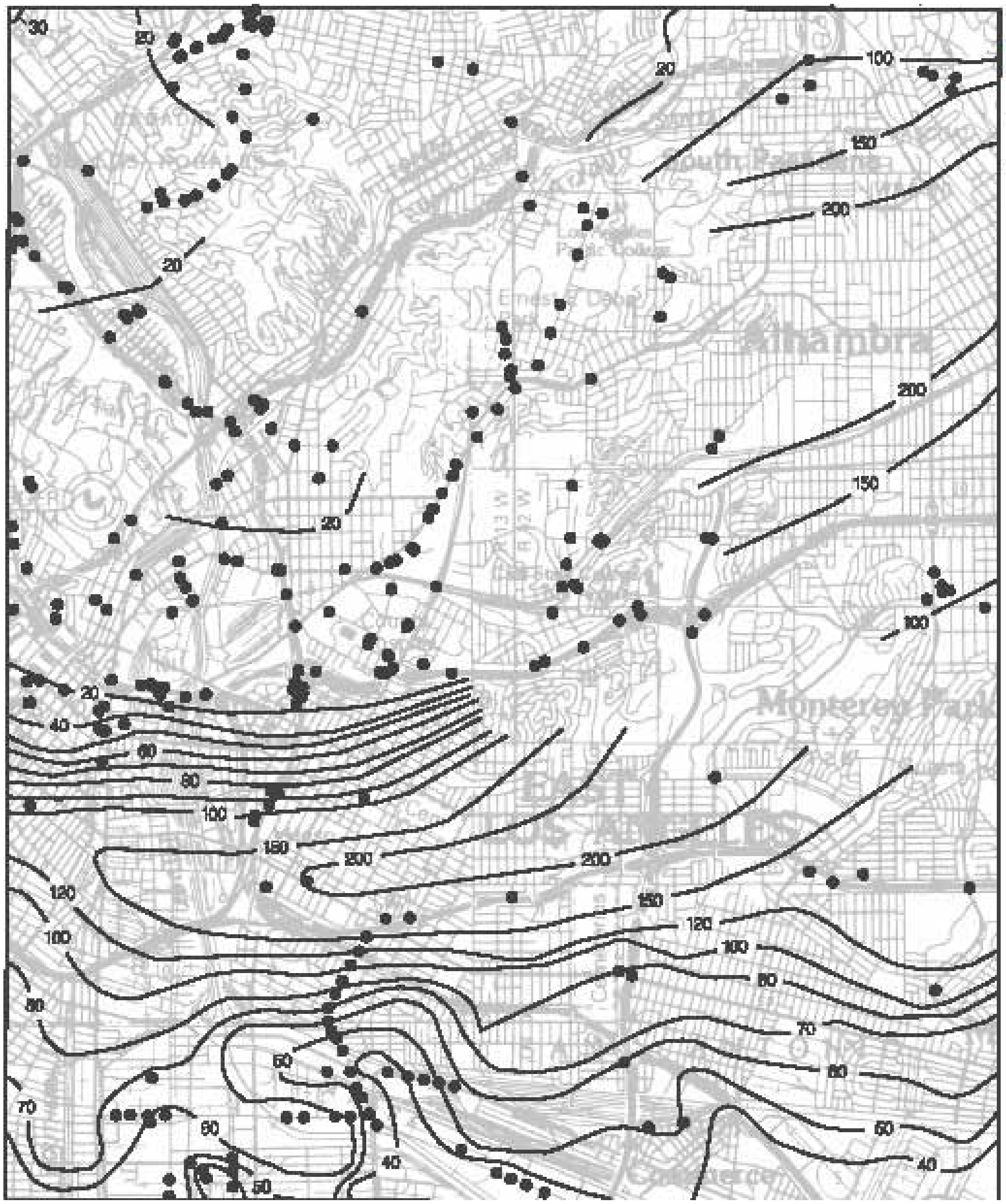

Figure 5. Estimated contours of the historic high ground-water level for the Los Angeles 7.5-minute quadrangle [10].

**Seismic Hazard Maps**

From 1997 to the present time, the California Geological Survey has released Seismic Hazard Zone Maps for most of the counties of Los Angeles, Ventura and Orange, and for portions of the San Francisco Bay area. The 7.5-minute quadrangles that have been zoned and released are shown in Figures 6 and 7 for the San Francisco Bay area and Southern California, respectively. The Seismic Hazard Zone Map for the Los Angeles 7.5-minute quadrangle is shown on Figure 8. Significant portions of the State of California remain to be evaluated and zoned for seismic hazards, including the populous area in and around San Diego.

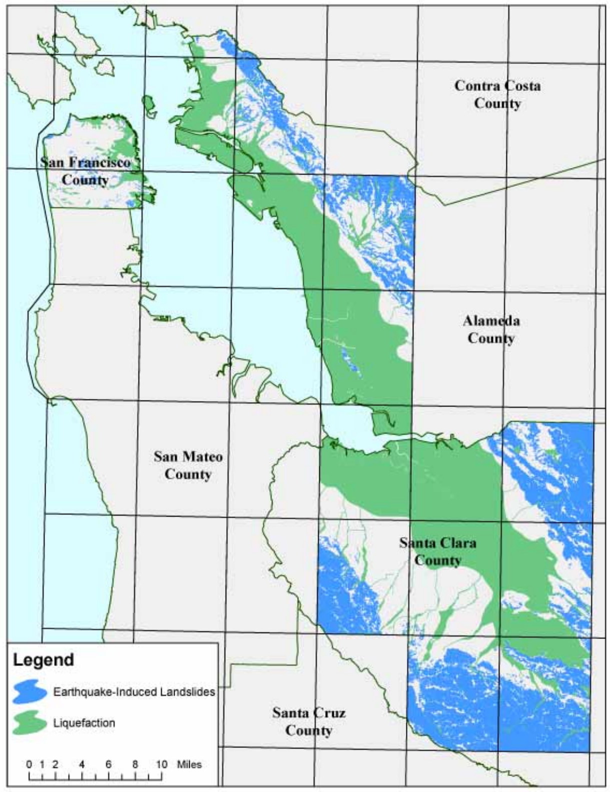


Figure 6. Map showing the 7.5-minute quadrangles that have Seismic Hazard Zone Maps in the San Francisco Bay area (as of January 2004)

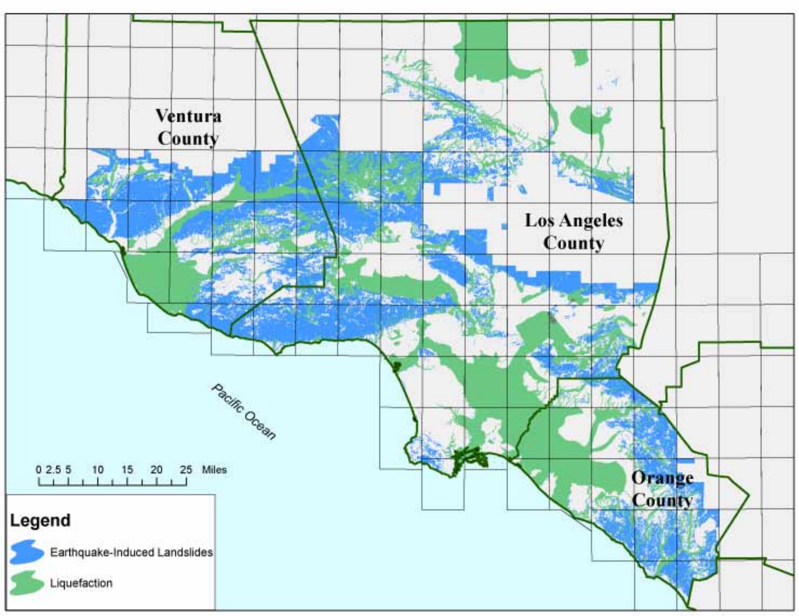


Figure 7. Map showing the 7.5-minute quadrangles that have Seismic Hazard Zone Maps in the Southern California area (as of January 2004)

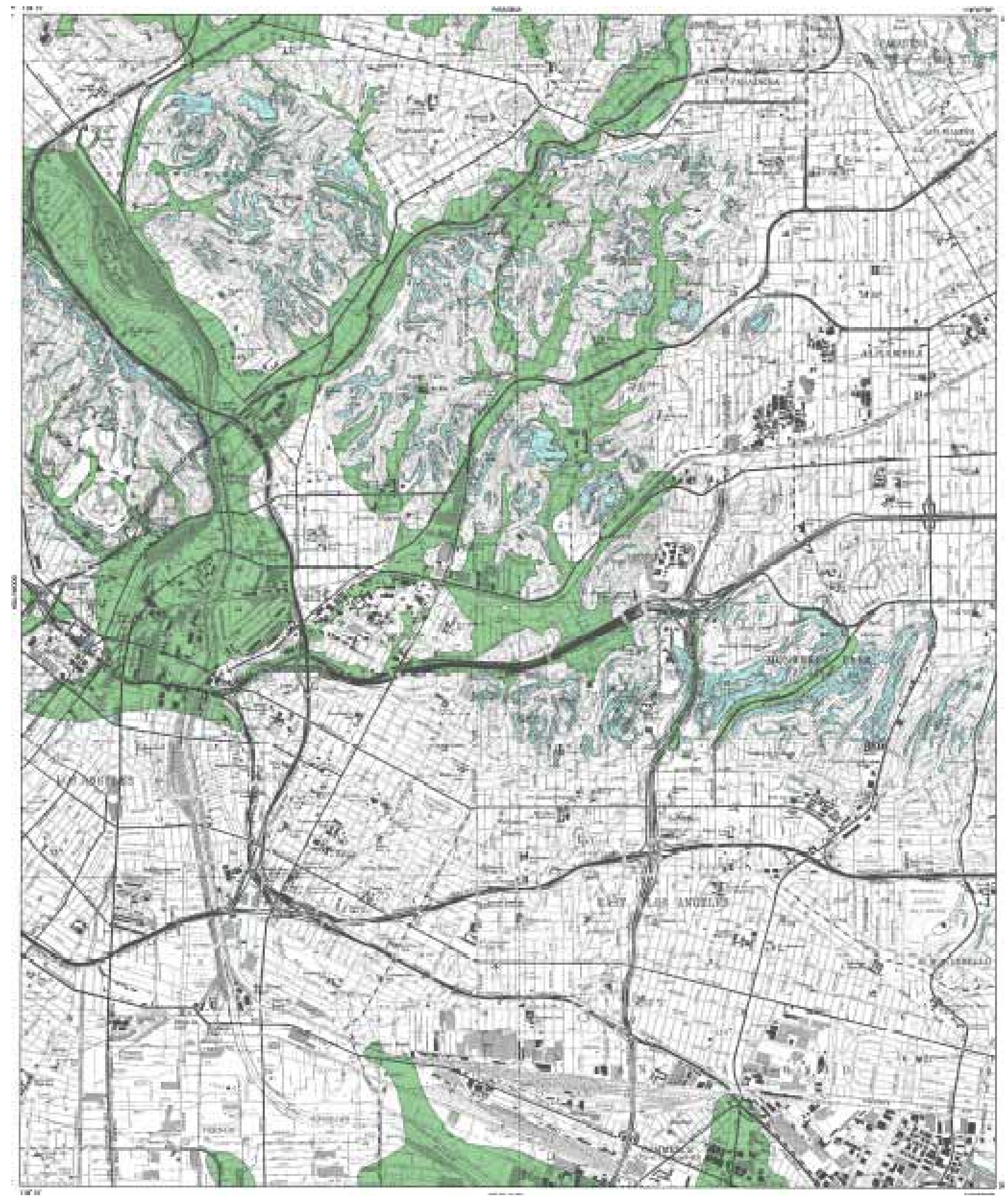

Figure 8. Seismic Hazard Map for Los Angeles 7.5-minute quadrangle with Liquefaction Hazard Zones shown in green and Landslide Hazard Zones shown in light blue [12].

**THE EFFECT UPON PRACTICE OF GEOTECHNICAL ENGINEERING IN CALIFORNIA**

With the release of the Seismic Hazard Maps beginning in 1997, a principal objective of the program was to have a more uniform and effective practice by geotechnical engineers and engineering geologists in the evaluation of seismic hazards in California. To that end, the California Geological Survey published a special report with guidelines on evaluating and mitigating seismic hazards [13]. The guidelines, known as Special Publication 117 (SP 117), were intended to be helpful to the owner/developer who is seeking approval of development projects within zones of required investigation as well as the geotechnical (or civil) engineer and engineering geologist who must investigate the site and recommend mitigation of identified hazards. The guidelines are also to provide help to the lead agency engineering geologist and/or civil engineer who must the complete the technical review, and other lead agency officials involved in the planning and development approval process. It is recognized that effective evaluation and mitigation ultimately depends on the combined professional expertise and judgment of the evaluating and reviewing professionals.

The methods and procedures outlined in the SP 117 guidelines were prepared by a working group of experts in academia, government, and geotechnical consulting industry, and are believed to be representative of quality practice at the time they were published in 1997. It is recognized that the field of seismic hazard assessment and mitigation is rapidly evolving and new methods and research will come on line quickly. The use of new methods of analysis and mitigation is not discouraged by the published guidelines.

In a real sense, the implementation of the Seismic Hazards Mapping Act in practice is one that is progressive with the release of the Seismic Hazard Maps for each USGS Quadrangle Map sheet. The evaluation of seismic hazards in areas where Seismic Hazard Maps have not been released currently depends on existing published information that may be contained in seismic safety elements for local cities and counties. It appears likely that when the official State of California Seismic Hazard Maps are issued, the mapped zones for seismic hazards will probably be larger than the areas currently designated by local seismic safety elements.

The first official Seismic Hazard Zone Maps were released for the Los Angeles area of Southern California. Local building officials from the major review agencies in Southern California felt that the guidelines given by SP 117 were still inadequate for their guidance and desired more specific recommendations to help their review personnel understand analysis techniques for the seismic hazards and to know suitable methods of mitigation for the review and approval process. More specific guidelines would also be helpful to the practicing geotechnical and engineering geological professionals to know the standards and procedures by which projects would be approved when seismic hazards are a concern.

Through the Geotechnical Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE) and with support from the Southern California Earthquake Center (SCEC) at the University of Southern California in Los Angeles, a committee of fifteen geotechnical engineers and engineering geologists was assembled to develop procedures for the implementation of SP 117 and the Seismic Hazard Mapping Act with respect to liquefaction hazard. This "implementation committee" researched and deliberated for 1½ years and published a report entitled "Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Liquefaction Hazard in California" edited by Martin and Lew [14]. Before the report was published, a draft was distributed to professional civil engineering and engineering geology community for review and comment. The implementation committee also presented two full day seminars in 1999 that were well attended on the expanded guidelines to practicing engineers and geologists who would be writing reports on evaluating and mitigating liquefaction hazards for specific projects, as well as building officials who would be reviewing and either approving or disapproving those reports.

In 1998, a second implementation committee of fifteen members was organized through the Los Angeles Section Geotechnical Group of ASCE and SCEC to deal with guidelines for the evaluation and mitigation of landslide hazards. This committee spent 3½ years of study, evaluation, and discussion to formulate guidelines on the seismic evaluation of slope stability and to present alternative methods of analysis to enhance the state-of-practice. The committee's report was edited by Blake, Hollingsworth and Stewart [15] and is entitled "Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Landslide Hazards in California." The landslide implementation committee also conducted two seminars (each of 2-day duration) on the recommendations of the committee and the contents of the report that were well attended by practicing and reviewing professionals.

The "SCEC" implementation guidelines, particularly the liquefaction guidelines, have been used by local building official agencies in California as reference documents in addition to the SP 117 document. In addition, the California Geological Survey lists these documents on its website as a useful reference to the practicing and reviewing community. The SCEC Liquefaction report has also been referenced in the "Guidelines for Evaluating Liquefaction Hazards in Nevada" prepared for the Nevada Earthquake Safety Council, and CGS is a participant in working groups assembled to advise the State of Utah on establishing a similar program, demonstrating that the impact of the Seismic Hazard Mapping Act is reaching beyond the borders of California.

There are indications that since the implementation of the Seismic Mapping Hazards Act, the state-of-practice of liquefaction and landslide hazard evaluation and mitigation has generally improved in California. Both the practice and review standards have been bolstered and the professional community is more informed about these seismic hazards than ever before.

## CONCLUSIONS

The Seismic Hazards Mapping Act has been a positive influence in improving seismic safety in California. The Act has provided for scientific and fact-based evaluation of liquefaction and landslide hazards. Although the mapping of specific USGS quadrangles still has a long way to go before the State's high earthquake risk areas are evaluated and mapped, the concentration of effort on the most populous and highest seismic risk areas of California has been a stimulus to improve seismic safety in those areas. It can be strongly argued that the practice of liquefaction and landslide hazard analyses and mitigation has been improved, and the competency of practicing and reviewing professionals has increased.

The California Seismic Hazards Mapping Act can be a model for providing increased seismic hazard awareness and seismic safety in other seismically active regions of the United States and in other countries. Implementation, however, will require a long-term investment in resources and time to properly research the seismic hazards and geologic conditions that may indicate potential for strong shaking and triggering of ground failures during earthquakes. More detailed information and products are available from the program website: http://gmw.consrv.ca.gov/shmp/.

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