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CALIFORNIA'S NEW SEISMIC HAZARDS MAPPING ACT: IMPLICATIONS FOR TECHNOLOGY AND POLICY

Abstract: The California Legislature enacted, and the Governor signed into law the Seismic Hazards Mapping Act (Chapter 1168 Statutes of 1990), requiring the delineation of seismic hazards studies zones (SHSZ's) by the Division of Mines and Geology. The new law requires the State Mining and Geology Board to develop policy, guidelines and criteria for implementation of the Act. Affected cities and counties must require, prior to approval of a project located in a SHSZ, a geotechnical report detailing the level of hazard at the site and making appropriate recommendations for mitigation. Local government must also utilize information contained in the maps in preparing the safety element of general plans, and in adopting and revising land-use planning and permitting ordinances. Finally, real estate sellers must disclose to any prospective purchaser the fact that the property is located within a SHSZ.

The Act provides for a statewide seismic hazards mapping and technical advisory program to delineate zones, with revenues from building permit fees and annual premiums from California's new mandatory earthquake insurance program. The large geographic areas and scale at which the analyses must be performed will require the use of a full-featured geographic information system having spatial, image, and geological analysis capabilities.

INTRODUCTION

The Seismic Hazards Mapping Act of 1990 mandates the California Department of Conservation's Division of Mines and Geology (CDMG) to establish a new program beginning fiscal year 1991-92, that designates special study zones for seismic hazards throughout California (Chapter 1168 Statutes of 1990; AB 3897). Implementation of this Act requires mapping large areas of California, and not only requires the development of policy, guidelines and criteria by the State, but the development of effective zone policy by local government as well. This paper highlights the public policy and technical challenges presented by this new legislation.

Background

In 1972, the Alquist-Priolo Special Studies Zone Act established a program within the CDMG to identify and zone active faults for the purpose of preventing personal injury and damage to structures caused by fault rupture during earthquakes (1). The concept of special studies zones was created following the 1971 San Fernando Earthquake, and has provided local government a means of regulating construction across active faults by providing a mechanism whereby site-specific information demonstrating the absence of fault rupture hazard must be provided as a condition for permit approval. The 1989 Loma Prieta earthquake, however, clearly indicated the need to include other seismic hazards besides fault rupture. In fact, none of the estimated $6 billion in losses from the Loma Prieta earthquake resulted from fault rupture.

Recognizing that fault rupture accounts for only a few percent of earthquake losses the California Legislature passed, and the Governor signed into law, the Seismic Hazards Mapping Act which establishes a new program to expand designation of special studies zones by CDMG to include earthquake shaking hazards. The law requires the State Geologist to:

- Compile maps identifying seismic hazards, and to submit them to the State Mining and Geology Board (SMGB) and to all affected cities, counties and state agencies for review and comment;

- Within 90 days of SMGB review, revise and provide copies of final maps to each state agency, city or county, including the county recorder having jurisdiction over lands containing an area of seismic hazard; and,

- Archive copies of the geotechnical site investigation reports required by local government and use new findings contained in these reports in the preparation of new maps and the revision of existing maps.

Ground shaking hazards account for nearly all earthquake losses, and are the principal seismic hazards to be zoned under the new law. These hazards include enhanced ground shaking, liquefaction, and seismically-induced landslides. Each of these hazards is triggered by ground shaking that emanates from a fault during an earthquake, and result from adverse ground conditions at the site. Delineation of special study zones requires assessing the geographic distribution of these adverse ground conditions. Because the analyses are complex and the data are voluminous, delineation of seismic hazard zones will require the assistance of modern information technology, which utilizes geo-referenced data bases, remote sensing, and other automated cartography.

IMPLICATIONS FOR TECHNOLOGY

While manual methods have been successfully used to locate and zone active faults over the past 15 years, the tasks required to assess ground shaking hazards are far more difficult and the geographic area to be considered in the analysis is much greater. Faults are linear features and their analyses are confined to narrow zones extending one eighth of a mile on either side of a fault. While such zones appear as narrow strips across a regional-scale map, covering the Los Angeles basin for example, ground shaking hazards must be assessed over an entire map region, with the resulting hazard zones encompassing large geographic areas. Fault mapping is typically based on interpretation of aerial photographs and limited field investigation which is a two-dimensional analysis of linear one-dimensional features. Assessment of ground shaking hazards requires analysis of a multitude of geotechnical parameters in three-dimensions (subsurface geology and topography) in order to identify boundaries of two-dimensional hazard zones to be displayed on a map. Consequently, the volume of data and complexity of analyses for mapping ground shaking hazards is orders of magnitude greater than that for fault rupture mapping.

A two-year seismic hazards mapping program feasibility study completed by CDMG prior to enactment of the enabling legislation concluded that the necessary methods and data exist, but will require modern information technology to implement over large geographic regions (2). Conventional methods of assessing ground shaking hazards developed over the past decade employ techniques that require the integration of numerous layers of spatial data, and are ideal candidates for analysis using geographic information systems (GIS). The greater Los Angeles, San Francisco, and San Diego metropolitan areas and perimeter growth regions cover nearly 6 million acres of land and include over 70 % of the State's population. Assessing seismic hazards over this region will not only require analysis and integration of existing map data, but also the creation of new maps based on the analysis of imagery and log reports for tens of thousands of engineering and hydrologic borings throughout this region.

The Product

Seismic Hazards Studies Zone (SHSZ) map sets will be published as the final output. Each SHSZ map set will be comprised of three sheets, showing special study zones for the three principle hazards: 1) enhanced ground shaking; 2) liquefaction; and, 3) seismically-induced landslides. Approximately 40 specialized overlays must be compiled and interpreted to produce each SHSZ map set.

The SHSZ map format is based on the U.S. Geological Survey 1:24,000 scale 7½ minute series quadrangle map; which covers about 60 square miles of land surface, one inch on the map represents 2,000 feet on the ground. This is the most practical map size considering the level of detail required to be shown and the extent of the area to be mapped. Because of the growing trend in local government toward using GIS technology for land-use decisions, SHSZ map sets will also be made available in digital form.

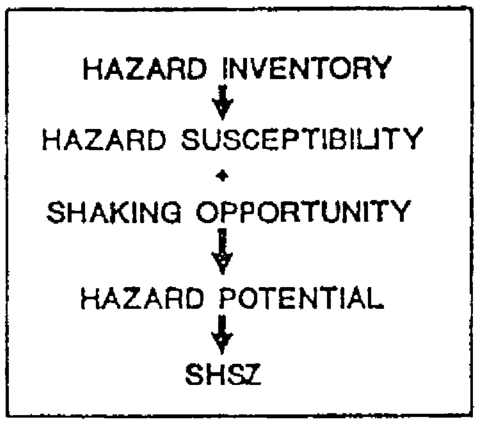
Local government will be able to compare seismic hazard zone maps with parcel maps to determine if property proposed for development falls within an area of possible seismic hazard. If so, then the developer will be required to conduct a site-specific investigation to detail the level of hazard at the site, and recommend suitable mitigation. If the property falls outside the hazard zone, then construction can proceed without special provisions to address seismic hazards. Incorrect determination of property status can have costly consequences that seriously reduce the effectiveness of the program. Determinations that incorrectly place property within a hazard zone will impose unnecessary expenses upon the developer (probably passed on to the purchaser) for site investigations.

More importantly, if properties at risk are not correctly identified because of exclusion from an inaccurately defined zone, the resulting personal injury and property loss from an inappropriately designed structure could be great in the event of an earthquake. While these unnecessary costs cannot be entirely eliminated because of the lack of detailed information available in the zoning analysis, they must not be compounded as a result of inadequate analysis capability. Failure to identify hazard zones with the highest accuracy possible given the resources and data available can render the Seismic Hazards Mapping Act ineffective.

Seismic Hazard Assessment

Figure 1 shows the five basic steps required to delineate SHSZ's. *Hazard inventory* requires locating and tabulating known hazard sites, and is the basis for recognizing the habitats of each hazard. *Hazard susceptibility* refers to the identification of hazard habitats over the remaining area being mapped, using the information acquired from the inventory. *Shaking opportunity* involves estimating the expected future ground motions over the region. *Hazard potential* is a combination of shaking opportunity and susceptibility, and reflects areas where future shaking is likely to trigger the particular hazard.

FIGURE 1
STEPS FOR DELINEATING SEISMIC HAZARDS STUDY ZONES



SHSZ's are based on hazard potential maps, and delineate areas where conditions may be present that favor the occurrence of hazards. Each step involves many complex analysis tasks for each hazard, and can result in preparation of up to 40 separate map overlays for each area zoned. An idea of the magnitude of work involved can be obtained by considering how much area must be mapped to cover just the major urban growth regions of California. The 6 million acre region mentioned previously is covered by approximately 150 U.S. Geological Survey 7 1/2 minute quadrangles at a scale of 1:24,000. This is the scale at which zone maps are to be released by the new program, and will, therefore, involve the preparation of several thousand overlays.

Automation of Seismic Hazard Mapping

Scientific and geotechnical analysis tools are required for input to the decision making process to be performed by the earth scientists. Easy-to-use interactive tools must be available for automating time consuming analysis tasks. The system must be capable of handling the storage, update and retrieval of large amounts of spatially-related geographically-registered data.

Much analysis will be based on screen displays to analyze terrain and geotechnical features, such as well-log cross sections and remotely-sensed images merged with digital elevation models. A high demand will be placed on plotting of working field maps and draft maps for review, in addition to press-ready digital tapes of map separates for outside printing. Data from many formats must be computerized or translated to create products from which analyses can be performed. Table 1 lists the type of data entry operations required to produce products suitable for analysis.

TABLE 1
DATA ENTRY AND OUTPUT

ENTRY/OUPUT	Geology	Soils	Faults	Floodways	Culture	Hydrography	Imagery	DEM	GeoTechnical
Manual Digitizing	X	X	X	X	X	X			X
Scanned Capture	X	X	X	X	X	X			X
Alpha Numeric		X							X
DLG Format					X	X			
Pixel Image	X	X					X		
Conversion In/Out	X		X	X				X	X

The geotechnical aspects of analyzing surface and subsurface features require use of technology that has up to this time been primarily used by the oil and mineral exploration industry. Table 2 lists the GIS analysis and production functions required to perform the various SHSZ mapping tasks.

Analysis of seismic hazards requires a greater than normal use of visualization tools. Many of the tasks required for mapping seismic hazards involves deductive analysis using displays of the surface of the land, and location and interpolation of well log data and geologic cross sections. The use of GIS technology allows creating computer modeled views that until recently, were impossible to create using traditional manual drafting methods. Table 3 lists the visualization and display requirements for the various mapping tasks.

FUNCTIONS/TASKS		Assess Shaking	Inventory Hazards	Analyze Stratigraphy	Analyze Slope	Analyze Imagery	Assess Susceptibility	Assess Potential	Delineate SHSZ
COORDINATE	Point Conversion	X		X					
PROJECTION	Proj. Transformation					X			
SPATIAL ANALYSIS	Raster/Vector		X				X		
	Spatial Query						X	X	X
	Zone/Proximity						X		
	Area/Theme		X				X	X	X
	Surface Approximation	X		X					
	Overlay Analysis						X	X	
STATISTICAL ANALYSIS	Univariate		X			X			
	Multivariate						X		
IMAGE ANALYSIS	Spectral Analysis					X			
	Spectral Enhancement					X			
	Raster/Vector Overlay					X			
	Temporal Analysis					X			
	Image Classification		X			X			
	Feature Extraction		X			X			
	Rectification		X			X			
TERRAIN ANALYSIS	TIN Modeling				X				
	Slope Aspect				X				
	Gradient				X				
	Cross Curvature				X				
	Down Curvature				X				
GEOLOGICAL ANALYSIS	Well Log Analysis			X					
	Well Log Correlation			X					
	Stratigraphic Modeling			X				X	
	Slope Stability Assessment							X	
	Liquifaction Assessment							X	
	Air Photo Interpretation		X						
MAP PRODUCTION	Cartographic Design	X	X				X	X	X
	Thematic Symbolization	X	X				X	X	X
	WYSIWYG Display		X				X	X	X
	Map Publication	X	X				X	X	X

TABLE 2
FUNCTIONS AND MAPPING TASKS

VISUALIZATION/DISPLAY AND TASKS		Assess Shaking	Inventory Hazards	Analyze Stratigraphy	Analyze Slope	Analyze Imagery	Assess Susceptibility	Assess Potential	Delineate SHSZ
HAZARD MAPS	Inventory		X						
	Susceptibility						X		
	Potential							X	
	Zone								X
MESH PERSPECTIVE	Standard	X		X	X				
	Isopleth-Draping	X			X			X	
	Chorpleth-Draping	X			X			X	
	Multiple/Intersecting			X			X	X	
CROSS SECTIONS	Fence Diagram			X					
	2-D Cross Section			X					
WELL LOG DISPLAY	Stratigraphic Column			X					
	Point Measurements		X	X					
	Continous Graphs	X		X					
OTHER DISPLAYS	Statistical		X				X		
	Multispectral Imagery				X	X			
	Photography		X						
	Isoplethic	X						X	
	Chorplethic		X				X	X	X
	Shaded Relief				X	X			
	Block Diagram			X					
	Vector/Raster Overlay		X			X	X		

TABLE 3
VISUALIZATION AND DISPLAY FEATURES

Based upon similar computer mapping operations, it is estimated that size of the files to be input for a standard 7½ minute quadrangle comprise about 17 mb. Table 4 lists the various data layers, or themes, and a conservative estimate for file size. Again, using similar operations as a basis for comparison, it is estimated that the output file size

TABLE 4
INPUT FOR STANDARD 7½ MINUTE QUADRANGLE

DATA THEME	DIGITAL STATUS	SIZE (mb)
Geology	Limited Area	1.0
Soil	Limted Areas	2.0
Faults	Conversion	0.5
Floodways	Conversion	1.0
Culture	All Areas	2.3
Hydrography	All Areas	0.3
Imagery	All Areas	3 0
DEM	Conversion	1.2
Geotechnical	Conversion	6.0
Input File Size (mb) For 7 1/2" Quadrangle		17.3

for a single 7½ minute quadrangle could comprise about 50 mb. Table 5 lists the various tasks, their resultant data and file size.

TABLE 5
OUTPUT FOR STANDARD 7½ MINUTE QUADRANGLE

TASK	OUTPUT DATA		
	Data	Format	Size (mb)
Shaking Opportunity	Expected Shaking	Grid	2
Hazard Inventory	Inventory (3)	Vector	3
Stratigraphic Correlation	Formation Tops (3)	Grid	6
	Thickness (2)	Grid	4
	Depth To Basement	Grid	2
	Depth To Water Table	Grid	2
Terrain Analysis	Gradient	Raster	2
	Aspect	Raster	2
	Down Curvature	Raster	2
	Cross Curvature	Raster	2
	TIN	Vector	1
Spectral Analysis	Rectified Image	Raster	3
	Spectral Ratio (3)	Raster	9
	Feature Map	Vector	1
Susceptibility Analysis	Hazard Susceptibility (3)	Vector	3
Potential Analysis	Hazard Potential (3)	Vector	3
SHSZ Delineation	SHSZ Maps (3)	Vector	3
Output File Size (mb) For 7 1/2' Quadrangle			50

Combining the input/output file sizes indicates that up to 67 mb, representing about 40 data layers, are required per 7½ minute quadrangle map sheet. Estimates of final file storage requirements must consider other factors, including retention requirements, work in various stages of progress, remakes and revisions.

The information system must serve staff in three locations, a central office in Sacramento and two field offices in San Francisco and Los Angeles. The Sacramento office has two functions -- an applications development group of earth scientists working in conjunction with a GIS support unit. Both units will be responsible for development and overall management, supporting actual mapping operations in the two field offices. Use of current distributed workstation-based technology is desirable, in order to build a foundation that can be easily modified and upgraded over time.

Authoritative estimates of earthquake risk indicate that the odds are 2:1 that a major catastrophic earthquake will strike one of California's major metropolitan areas by the year 2020. To be reasonably effective in reducing the earthquake risk to future development the new program should complete the evaluation of current rapid-growth areas well within this 30-year period, and continue evaluation of remaining land at a rate that exceeds urbanization. An opportunity exists to use information technology to provide high quality products that are consistent with mandated policy, and do so at the highest rate possible within budgetary constraints.

IMPLICATIONS FOR POLICY

The Seismic Hazards Mapping Act of 1990 provides for a State program to identify and assess seismic hazards throughout California, and to designate official seismic hazards studies zones (SHSZ's) within which conditions favorable to the occurrence of specific hazards are known or likely to occur. While the principal role of the State is to disclose the presence of the hazard to local government, awareness of these areas alone will not reduce future earthquake losses. Specific actions must be undertaken by local government, developers, and property owners to reduce the risk of future earthquakes to property located within these zones. Collectively, these actions constitute the single most important factor in determining the effectiveness of the Act in protecting the lives and property of California citizens from earthquake hazards.

Hazard mitigation is the concern of the State, local government, and the property owner, and each must understand their respective roles in the hazard reduction process. In a sense, identification of hazardous areas by the State results in a transfer of responsibility, and liability, to the jurisdiction within which the land lies, and in turn to the property owner.

Responsibilities of the State

In addition to the mandates imposed on the State Geologist, the Seismic Hazards Mapping Act requires the State Mining and Geology Board to adopt:

- Policies and criteria for local and State agencies' responsibilities in mapping seismic hazards zones;
- Guidelines and priorities for mapping seismic hazards;
- Guidelines for evaluating seismic hazards and recommending mitigation;
- Guidelines for reviewing required geotechnical reports; and,
- Procedures for waiving the requirement for a geotechnical report where studies conclude that no seismic hazard exists.

This process is currently underway, and an advisory committee of experts representing earth science, engineering, local government planning, and insurance has been formed. A workshop was held in which fifty experts in earthquake hazards exchanged ideas on methods of evaluating seismic hazards and formulating suitable mapping criteria. Participants included representatives of the U.S. Geological Survey, academia, and the geotechnical consulting and insurance industries. Working groups have been formed that will continue to provide expert advice to the SMGB during the codification process. Formal regulations will be adopted by the SMGB and approved by the State Office of Administrative Law in 1992, followed by distribution of a comprehensive report on program policies and guidelines.

Responsibility of Local Government

The Seismic Hazards Mapping Act mandates local government to:

- Require, prior to approval of a project located in a seismic hazard zone, a geotechnical report defining and delineating any seismic hazard at the site and making recommendations for mitigation as appropriate;
- Post notice of the location of newly issued maps at the offices of the county recorder, county assessor, and county planning commission within ten days of receipt;

- Utilize the policies and criteria established by the SMGB in approving proposed projects located within designated seismic hazard zones; and,

- Utilize information contained in the maps in preparing the safety element of the general plans, and in adopting and revising land-use planning and permitting ordinances.

While containing specific mandates for local government, the Act affords considerable latitude in the implementation of zone policy at the local level. This flexibility is necessary to accommodate the wide diversity of social, political, and economic climates and community objectives throughout California, and to preserve local authority over its lands. To develop effective zone policy, however, first requires a commitment by local government in the form of specific performance goals for new and existing construction.

In January 1991 an important publication was released by the California Seismic Safety Commission that clearly defines, for the first time, specific performance objectives for new and existing state buildings (3). It states that: "state buildings that kill or injure people in an earthquake pose an unacceptable risk. Buildings that are so badly damaged after an earthquake that indispensable functions cannot be restored in a timely manner also represent an unacceptable risk." Without such a decision, it is difficult to establish effective hazard mitigation policy that has a clear, unambiguous level of public safety.

We suggest that local governments should first adopt their own acceptable levels of risk for new and existing development. This is done by establishing performance objectives that will eliminate all risks that are unacceptable. When performance objectives have been met, only uncontrollable and tolerable risks remain. Only after addressing the acceptable level of risk will the commitment be found that is necessary for seismic hazard mitigation policies to successfully compete against the pressures of growth and other pressing needs of local government.

Zoning, subdivision, site development, and building regulations provide mechanisms for implementing seismic hazard countermeasures, and there are numerous examples where they are successfully being used to reduce earthquake losses. Among the most notable and best documented examples of integrating geologic information into land-use planning through regulation is the community of Portola Valley (4). Steps toward hazard mitigation for local government have been prepared (5) and exemplary programs have been identified (6). Success of the Seismic Hazards Mapping Act in reducing future earthquake losses will depend on effective hazard zone policy.

Responsibilities of Property Owners

Property owners are also affected by the Seismic Hazards Mapping Act through real estate disclosure during property transfer. Sellers of real property or the sellers agent must disclose to any prospective purchaser, prior to the sale, the fact that the property being sold is located within a seismic hazard zone. The intent is to protect the purchaser's "right to know" of any condition that could increase risk of personal loss in the transfer of property.

Finally, it will be the responsibility of property owners to comply with the seismic hazard-zone policy and regulations imposed by local government. Reputable consulting firms should be retained to perform geotechnical site investigations and recommend appropriate mitigation. When an investigation verifies a seismic hazard at the site, reputable consultants should be retained to perform the recommended structural or site improvements with quality assurance. The costs of such improvements should not be viewed as a loss, for such improvements can enhance the value of the property and make insurance more easily attainable. The quality and appropriateness of the mitigation will be the single most important factor in determining the effectiveness of the Seismic Hazard Mapping Act.

CONCLUSIONS

Under the provisions of the Seismic Hazards Mapping Act of 1990, California has the opportunity to significantly reduce personal injury and property loss caused by future earthquakes. Optimizing the effectiveness of this Act will require effective use of modern information technology and the development of effective seismic hazard zone policy. Automation of seismic hazard evaluation and mapping will permit targeting, with greater speed and accuracy, areas of high hazard potential in which hazard mitigation policies can be focussed. Policies that avoid or remediate hazardous sites and lead to appropriate design of structures are what ultimately reduce losses, which underscores the important role that local government will have in the implementation of this Act. We suggest that cities and counties must first establish an "acceptable level of risk" which will form the baseline against which to gauge the adequacy of mitigation policies. Finally, property owners and industry must comply with the intent of the Act and make necessary improvements when developing property if any reduction of future earthquake losses is to be realized. California's Seismic Hazards Mapping Act challenges government, industry, and the public to work together in making our state a better and safer place to live.

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