USE OF GEOLOGIC AND SEISMOLOGIC INFORMATION FOR EARTHQUAKE-HAZARD REDUCTION BY PLANNERS AND DECISIONMAKERS IN SOUTHERN CALIFORNIA

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SUMMARY

Five examples illustrating the use of geologic and seismologic information in reducing the effects of earthquakes are presented. The examples include: anticipating damage to critical facilities, preparing seismic safety studies and plans, retrofitting highway bridges, regulating development in areas subject to fault rupture, and strengthening or removing unsafe masonry buildings. The collective effect of these activities is to improve the public safety, health, and welfare of individuals and their communities.

INTRODUCTION

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

ANTICIPATING DAMAGE TO CRITICAL FACILITIES

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

The California Division of Mines and Geology (CDMG) using a damage-intensity map provided by the U.S. Geological Survey (USGS), prepared a planning scenario for the Governor's Emergency Task Force on Earthquake Preparedness, assuming a repeat occurrence of the great Fort Tejon earthquake of January 9, 1857 (Ref. 1). The map is based on the method described by Evernden and others (Ref. 2), modified by using additional geologic information. The scenario assumed that a magnitude 8.3 earthquake on the southern San Andreas fault would produce: 320 km of surface rupture from Cholame Valley in northern San Luis Obispo County to near San Bernardino;

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intense shaking continuing for at least 60 sec throughout the planning area; slip on the fault, predominantly horizontal, reaching a maximum of 10 m within a zone generally less than 100 m wide; no concurrent secondary movement on other faults; and aftershocks with occasional events in the magnitude 6-7 range continuing for several weeks.

Zones roughly paralleling the postulated surface rupture along the San Andreas fault were shown on a map as isoseismal areas, that is, as areas within which the anticipated seismic intensities were comparable. Each zone was assigned an intensity rating based on the Rossi-Forel scale. This map is intended for emergency planning purposes only and is based upon the following hypothetical chain of events: the specified earthquake occurs, various localities in the planning area experience a specific type of shaking or ground failure, and certain critical facilities undergo damage while others do not.

Seven individual scenarios showing damage to critical facilities, specifically lifelines such as highways, airports, railroads, marine facilities, communication lines, water-supply and waste-disposal facilities, and electrical power, natural gas, and petroleum lines were developed (Ref. 1). The scenarios are based upon evaluation of earthquake-engineering literature, comments by numerous engineers and other public-agency officials, and judgments by the authors. The reason for formulating the assessment of the effects of the earthquake upon lifelines was to interpret a regional pattern of ground shaking and ground failure and to evaluate the resulting performance of lifeline segments throughout the Los Angeles region. For example, a communications map shows an assessment of telephone-system performance following the postulated earthquake. Other maps, for example those for water-supply and waste-disposal facilities, show the location of, and estimates of damage to, these facilities.

Each of the planning maps for the scenario is also accompanied by planning needs, for example: "Emergency planners need to identify major emergency routes that can be most readily opened immediately following the earthquake .... alternative emergency routes should be selected which are at grade, wide, not flanked by buildings which are likely to be damaged, and not likely to be obstructed by fallen powerlines or other obstructions." Each of the planning maps is also accompanied by some recommendations for further work, for example: "An inventory of commercial and amateur broadcasting capabilities should be undertaken and the resulting information employed in developing the regional emergency communications plan."

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

PREPARING SEISMIC SAFETY STUDIES AND PLANS

The California State Legislature requires that each county prepare and adopt a comprehensive, long-term general plan for the physical development of the county (Ref. 3). This general plan shall include: "A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches. The seismic safety element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, ground shaking, ground failure, and seismically induced waves."

All counties in the Los Angeles region have prepared and adopted seismic safety plans. For more than two centuries significant earthquakes have been felt or have caused damage in Santa Barbara County. Strong shaking and major damage from earthquakes occur an average of every 15 to 20 years. The county planning department used a consultative team of city and regional planners to help prepare the seismic safety plan. The county was divided into four study areas based mainly on population patterns and potential development. According to the Santa Barbara County Planning Department, geologic, soil, and seismic factors "affect the suitability of land for various uses and ... should be considered, along with other factors, in land-use planning in order to eliminate or minimize their adverse effects...." (Ref. 4).

Geologic and seismologic information was compiled and transferred to USGS 7½-minute quadrangle maps (topographic series) at a scale of 1 inch = 2,000 feet (1:24,000) for the four study areas. A reproducible mylar geologic map of the county at a scale of 1 inch = 8,000 feet (1:96,000) is on file at the county public works department. The geologic maps show the major bedrock units, surficial geologic units, faults, and folds. The hazards were evaluated and rated according to their severity by applying geologic and engineering judgments. The areal extent and severity of the hazards were shown on the topographic base maps for the study areas. The data were then transferred to 2-ha-grid base maps, and the ratings for the individual hazards were encoded to produce computerized maps. Each geologic hazard evaluated was given one of three ratings -- high, moderate, or none to low.

A composite number was then assigned to give an overall indication of the difficulty of developing any particular area, based on known geologic hazards. The department devised a system for rating geologic hazards for a given area on both an individual and collective basis -- a system that could be performed by computer. The resulting cumulative value was designated the geologic problem index (GPI). The GPI values for the four study areas were obtained by multiplying each geologic hazard by a weighting factor that takes into account the seriousness of the hazard, the difficulty of alleviating it, and the frequency of occurrence. The GPI values were then divided into five categories, ranging from low through moderate to severe. The GPI was calculated for each 2-ha cell in the computer analysis areas for each study area. The GPI was then assigned to the appropriate severity category and displayed on a computer-produced map. Thus these computer GPI maps reflect a summation of the ratings delineated on the individual geologic hazard maps.

Recommendations were then made by the Santa Barbara County Planning Department concerning land-use planning, subdivision procedures, grading codes, building codes, and land-stability insurance. One of the recommendations concerning subdivision procedures is that geologic reports should generally be required when the property contains or is near an active or potentially active fault or has a moderate to severe GPI (Ref. 4).

RETROFITTING HIGHWAY BRIDGES

The 1971 San Fernando earthquake led to a major change in the development of seismic design criteria for bridges. A senior bridge engineer in the California Department of Transportation (CALTRANS) reports that prior to the earthquake very little bridge damage was caused directly by vibrational effects (Ref. 5).

However, after this earthquake one of the problems noted was related to a design feature deliberately built into bridges and overpasses throughout the United States during the 1950s and 1960s to allow the structures to expand and contract with temperature changes. Bridge and overpass superstructures have traditionally been placed on the supporting piers and abutments without being attached, to accommodate temperature movements; the weight of the roadbed was expected to hold them in place. During the 1971 earthquake, the ends of many bridges in the San Fernando Valley fell off the abutments or hinge seats upon which they sat. CALTRANS has identified 1,133 bridges throughout the State, out of approximately 13,000, which need retrofitting. CALTRANS is now focusing on the retrofitting of the unrestrained joints of these bridges.

After the 1971 San Fernando earthquake, a map showing maximum credible ground acceleration on bedrock from future earthquakes in California was prepared by the California Division of Mines and Geology (Ref. 6). Using a set of curves relating peak ground acceleration, distance from fault rupture, and magnitude (Ref. 7), peak ground acceleration values for bedrock sites were plotted for each fault. These values were then contoured to produce a map covering all of California. This map information is combined with soil data and used as a basis for the seismic design criteria for California's bridges. More recently, probabilistic estimates of the levels of ground shaking have also been made, for example, Thenhaus and others show earthquake shaking anticipated in California coastal and outer-continental-shelf areas on a series of six maps at a scale of 1:5,000,000 (Ref. 8).

A CALTRANS bridge engineer, in discussing highway bridge retrofit, describes the various types of restrainers -- steel cables, rods, hinges, and bearing support hardware --used to tie bridge superstructures together as well as tie superstructures to substructures (Ref. 9). One type is a newly-designed hinge which has substantial cable restrainers, for example, multiple units of seven 3/4-inch cables that form a tendon inside a pipe. These restrainers allow the bridges to move in small increments; the joints may open and close to the maximum amount needed to accommodate temperature changes normally ranging from 25-76 mm. When this movement has occurred, the restrainers are designed to limit further movement and prevent collapses such as occurred during the 1971 San Fernando earthquake. However, this does not have high enough load capacity for certain superstructure configurations in highly seismic areas. As a result, CALTRANS developed a high-strength rod restrainer. A unit with four symmetrically placed 31.75-mm high-strength rods is rated at 600 kips design load.

Selection of structures for retrofit is currently based on a priority system which "takes into account the bedrock acceleration at the structure site, the estimated cost to retrofit the structure, the cost of replacement in the event of loss, the ratio of the replacement cost to the retrofit cost,

the length and availability of detours, and the average daily traffic on the main line as well as other factors which reflect the importance of the structure in the system" (Ref. 9). This rating technique ranks the structures for inclusion in the annual State transportation improvement program. To date, over half of these structures have been retrofitted at a cost of $24 million; current budget allocation will permit completion of all bridges identified as deficient by 1990.

REGULATING POTENTIAL SURFACE-FAULT-RUPTURE AREAS

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

In California, many potentially active and recently active faults have been identified and mapped. A preliminary map showing recent faulting shows the location of presently known or inferred faults in the coastal region of southern California and what is currently known about the recency of displacement along each fault (Ref. 10). The trace of an active fault cannot always be seen at the surface. Displacements do not always occur along a single fault trace; branching segments, braided, and en-echelon faults may result in wide zones of disturbance. Therefore, regulatory measures for avoiding or reducing the effects of fault rupture commonly require detailed geologic investigations to identify and evaluate all the strands of the faults.

In response to public concern and because of the availability of scientific information, the California State Legislature enacted the Alquist-Priolo Special Studies Zones Act (Ref. 11). The act provides for public safety by restricting development near or over the surface traces of active faults. In addition, the act provides for: geologic reports, approval of projects by cities and counties, exemptions for altering and adding to existing structures, disclosure of hazards by sellers and their agents, and the charging of reasonable application fees.

The California State Mining and Geology Board has prepared and adopted criteria which prohibit specific development in Special Studies Zones until a geologist, registered in California, has evaluated the geologic report that must accompany the application for development. The fault information shown on a topographic map is not sufficient to meet the requirement for a "geologic report;" cities and counties must require that the developer retain a registered geologist to evaluate the sites within the Special Studies Zones to determine if a potential hazard from any fault exists. If a city or county finds that no undue hazard exists, the geologic report may be waived with the approval of the State Geologist (Ref. 12).

The California Association of Realtors published an instruction booklet on the legal obligations of Realtors to disclose geologic hazards that relate to the use of real estate (Ref. 13). The association provides, in its real-estate purchase contract form, a place for attaching information about Special Studies Zones (Ref. 14); it has also prepared a disclosure form for Special Studies Zones which can be attached to the contract (Ref. 15). The last paragraph of this form provides a place for entering the number of days a prospective buyer has, from the time of the seller's acceptance, to make further inquiries concerning the use of the property under the Special Studies Zones Act; and provides that where inquiry discloses conditions unsatisfactory to the buyer, the buyer may cancel the contract.

STRENGTHENING OR REMOVING UNSAFE MASONRY BUILDINGS

Officials of the city of Los Angeles know that the city will be subjected to intense ground shaking when a moderate or major earthquake occurs. The seismic safety plan adopted by the Los Angeles City Council as required by the California State Legislature (Ref. 3) noted that ground shaking can result in loss of life, personal injuries, damage to property, and economic and social dislocations, but that most of this loss is preventable (Ref. 16). In 1976, the mayor of Los Angeles established a task force to "explore and evaluate the range of possible City responses to an earthquake prediction ...." Regarding unreinforced masonry buildings built before 1934, the Los Angeles City Task Force on Earthquake Prediction identified them as posing the greatest life hazard in an earthquake and recommended that "**priorities** for reinforcement, decreasing occupancy levels, or demolition should be established before we are confronted with a credible earthquake prediction" (Ref. 17).

A complete inventory of pre-1934 masonry buildings was conducted by specially trained city building inspectors in the earthquake safety division to document the nature and extent of the problem. There are at present approximately 8,000 pre-1934 unreinforced-masonry buildings in the city of Los Angeles. More than 80 percent are commercial and industrial buildings providing places of employment for an estimated 70,000 workers. About 14 percent are residential apartments and hotels containing nearly 46,000 units, housing perhaps 137,000 persons (Ref. 18). They are vulnerable to total collapse or the shedding of the outside walls under moderate to strong ground shaking, thus presenting a substantial risk to their occupants and to passersby.

After two years of deliberation, an ordinance amending the city of Los Angeles building code was formulated by the Los Angeles Earthquake Safety Study Committee and submitted to the City Council in 1979. The ordinance would reduce earthquake effects by requiring the strengthening or removal of pre-1934 buildings that have bearing walls of unreinforced masonry. The strengthening standards are not identical to those required for new construction but are especially adapted for the type of construction and typical weaknesses of these older buildings (Ref. 19).

The ordinance provides systematic procedures and standards for identifying and classifying buildings having unreinforced-masonry bearing walls -- the procedures and standards being based on the buildings' present use and occupancy. Priorities, time periods, and standards are also established under which these buildings are required to be structurally analyzed and anchored. Where analysis determines deficiencies, the ordinance requires that the buildings be strengthened or demolished. The ordinance does not apply to detached 1- or 2-story single-family dwellings and detached apartment houses containing less than five dwelling units and used solely for residential purposes.

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

An alternative compliance schedule, intended to lessen the financial and social impacts of the ordinance, gives the building owner the option of performing a portion of the remedial work within one year of notification in exchange for a longer time in which to reach full compliance. The work to be performed within a year involves the anchoring of unreinforced masonry walls to the roof and to each floor of the building with bolts and washers. As of January 8, 1983, the Los Angeles Department of Building and Safety has issued 895 orders to owners to meet the minimum seismic standards. Over 200 of the projects are using the wall-anchor alternative and are now in the automatic-time-extension period. According to the Los Angeles Earthquake Safety Study committee, compliance with the provisions of this ordinance could reduce the number of deaths within the Los Angeles city limits from 8,500 to 1,500 and the number of injured from 34,000 to 8,000 for a single future earthquake.

CONCLUDING COMMENTS

The criteria and methods used in each of the examples presented can be of value to other urban regions where similar earthquake hazards exist and where adequate scientific information is available. The adaptation to, and adoption by, other jurisdictions and users depends on similarities in public awareness, enabling legislation, targeted issues, order of priorities, community interests, and abilities of the planners and decisionmakers. Earthquake-hazard research is continuing, the information base is improving, the methods for evaluating hazards are being perfected, and new techniques are being developed. Planners and decisionmakers need to recognize these facts and use the latest information, methods, and techniques.

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