

EARTHQUAKE DISASTER PREPAREDNESS: ENGINEERING ASPECTS OF PLANNING

by

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SYNOPSIS

Techniques are summarized which provide realistic estimates of the number of probable deaths and injuries after a postulated earthquake. Additionally, the need is pointed out to determine losses to medical resources (such as hospitals) and other vital public necessities (such as utilities). Methods are also summarized which relate to the determination of monetary losses by class of construction. Case histories of California cities and the State of California are given.

INTRODUCTION

It is becoming increasingly clear that available resources of any nation are not sufficient to take care of all the pressing priorities established by that country, and usually earthquake hazard reduction is only one of these pressing needs in seismic areas. As pressures of population growth and high density urbanization accelerate throughout the world, assessment of seismic risk becomes a critical variable to be evaluated in terms of government and private commitment to disaster preparedness programs. Consequently, earthquake vulnerability analyses of existing urban areas as a preparedness effort for the inevitable future are useful.

Pre-earthquake hazard reduction programs which are intended to restrict the hazard to some acceptable level are necessary public policies, but these programs normally do not eliminate the hazard. In addition, post-earthquake recovery through insurance programs or through government (or private) aid and grants requires pre-disaster information on the probable extent of potential losses; this is particularly true for insurance programs which require financial reserves. It follows, then, that earthquake disaster planning in its broad sense is vital to both public and private sectors.

In the past, adequate statistics on potential casualties and property losses have not been available to private executives or public administrators and consequently have not allowed for realistic appraisal of resources prior to the event. The purpose of this paper is to summarize some of the engineering approaches which are being developed to solve these problems. Within this context, methodologies have been evolved to evaluate earthquake risk on an

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objective basis so that assignment of priorities may be realistically approached.

A reliable planning basis requires the evaluation of two aspects of the seismic hazard:

1. Determination of the recurrence interval of various magnitude earthquakes and their geographic distribution on some basis related to either (a) damage ("intensity") or (b) to some type of seismic force criteria.
2. Determination of the resulting casualty and damage patterns (including monetary losses for certain uses).

This paper is limited to the second of the two aspects stated above. California and particularly the metropolitan San Francisco region are used as examples of case histories, but the general concepts and methodologies are applicable elsewhere.

Some investigators have used variants of earthquake spectrums instead of isoseismal maps. These methods using spectrums have substantial promise but they presently seem to offer excessive procedural complications with as yet little or no improvement in output quality. As a result, isoseismal maps currently are the best basis for applied work, with suitable modifications for long period effects at comparatively large distances from seismic energy sources. Past disasters provide the best foundation for present methodologies used in estimating the potential number of deaths and injuries in the event of a postulated earthquake.

EARTHQUAKE CASUALTIES

Casualty statistics gathered after past disasters provide the best foundation for methodologies used in estimating the potential number of deaths and injuries in the event of a postulated earthquake. It is vital to carefully identify these statistics with respect to time of day, building age and construction types, occupancy, earthquake intensities (or force criteria), and other relevant parameters. For a particular earthquake, casualty figures can be determined in terms of deaths per 100,000 population (death ratio); injury ratios may be similarly stated or given as a multiple of the death ratio. In addition, it is desirable to correlate building period (sometimes simplified to building height or to the number of stories) with expected predominant ground motion (i. e. , such as short period vs. long period).

Experience data do not exist for all desired categories, and therefore extensive judgment and interpretation are required in most instances. For one example, heart attack deaths may or may not be included in or identified by the historic record. As a second example, some data will include only "serious" injuries without defining "serious". Thirdly, one or two collapses can dominate the data, such as the collapsed Veterans Administration Hospital buildings

in the 1971 San Fernando, California shock, and these data can greatly distort the death ratio if extrapolated to other situations without modification.

Post-earthquake planning must not only consider deaths, but care of injured and the communities' vital needs. Specifically, any planning must determine (a) demands on medical resources (i. e. , direct deaths and injuries), (b) post-earthquake medical resources (i. e. , remaining serviceable hospitals, health manpower, medical supplies, ambulances, etc.), and (c) effects on immediate and vital public needs (i. e. , communications, transportation, utilities, fire fighting facilities, etc.). With the foregoing realistically quantified, it is then possible for public and private organizations to plan for the potential emergency.

San Francisco Case History -- Casualties Excluding Dam Failure

A study sponsored by the United States Federal Government through its Office of Emergency Preparedness (Ref. 1) covered the topics discussed in the previous paragraph as well as other subjects; the resulting report is henceforth referred to as the OEP Study. Each topic required two steps: (a) selective data collection on as nearly compatible bases as reasonable, and (b) analysis of the data.

Data collection:

The primary task involving data collection was to define and delimit the "environmental fabric" of the 9 county San Francisco region to insure complete coverage within a matrix compatible with the analysis phase which followed. Accordingly, significant functions and services found in or provided by the communities in the study area were first determined and later categorized for relevance to the study as a means of obtaining a measure of their performance relative to (a) effects and demands on resources, and (b) effects and demands on immediate and vital public needs.

A multitude of data was readily available, but generally on non-compatible bases. Although the sources of data provided some commonality, each source had limitations. For example, air photographs did not show underground facilities or building heights, existing maps were outdated, records were in many cases incomplete, and statistics compiled for other purposes included unuseable data. Accordingly, data collection required numerous site inspections and personal interviews. The following data was collected for each category wherever possible:

Location	Geologic hazards	Cost or value
Construction	Earthquake bracing	Type of facility
Height of structure	Year built	Foundation type
Area or size	Materials	Exits
Site conditions	Occupancy	Accessibility

The complexity and magnitude of the problems encountered during the data collection phase were significant. The study area covered 7,000 square miles and had a total population of over 4,600,000 inhabitants. Within the congested zones there were 1,900 buildings 4 stories or higher which required documentation. To determine casualties, population shifts with respect to the times of day for the postulated earthquakes were determined. Population figures were also approached in relation to the geologic hazards. The original or historic margins of marshlands surrounding the San Francisco Bay Area were related to current topography, recent land use developments, and population distribution. In turn, this information was related to probable effects on utility services, surface communications, manpower resources, accessibility to freeways, and relationships to overpasses.

Specific categories established for detailed data collection included:

Major hospitals	Public utilities	Mercantile facilities
Medical supplies	Health manpower	Industrial
Blood banks	Clinical laboratories	Transportation
Public structures	Nursing homes	High-rise buildings
Schools	Ambulance services	Dwellings
Communications	Reservoirs & dams	Fire

Data analysis:

The tens of thousands of buildings and other structures involved in the OEP Study precluded a detailed analysis of any specific structure. As a result, evaluation by building class for each intensity was the practical approach. Building classifications included materials of construction, height (i. e. , period approximation), and earthquake resistive design characteristics.

Space requirements do not allow a detailed review of the OEP Study, but several aspects may be of general interest and value. Table 1 is a listing of deaths and injuries per 100,000 population for selected United States earthquakes. Earthquakes with life losses less than 8 were excluded from the listing, and the 1872 Owens Valley earthquake was omitted since construction types were not relevant. Quite possibly the cut-off figure should have been much higher than 8 since the data for Tehachapi in the 1952 Kern County earthquake are so few as to be questionable when used for extrapolation. The inclusion of the 1949 Puget Sound earthquake can be misleading unless it is understood that Puget Sound earthquakes have much deeper focal depths than do those in California; as a result, the damage and life loss patterns are distinctly different and judgment is required for usage. Similar problems exist when applying data abstracted from the Charleston shock of 1886. As has been previously stated, the influence of a single major collapse can strongly affect the losses per 100,000 population; see, for example, the variations in Table 1 with respect to the 1971 shock in San Fernando.

Statistics from earthquakes in other countries were rarely significant since construction types were not relevant, with the principal exception being the 1967 Venezuelan earthquake. For an example of non-usable data, the death of 70% of the population in Dasht-e-Bayez, Iran in the 1968 earthquake was useless for the OEP Study since construction was adobe or mud wall; this may be compared with the negligible life loss in wood frame dwellings in the 1971 San Fernando shock (Ref. 2, p. 23).

Table 1 is a useful guideline when used with judgment and in context with the time of day, construction classification, and appropriate intensities such as shown in Figure 1. In the OEP Study, magnitude 8.3, 7, and 6 earthquakes were postulated on each of the two major faults, namely San Andreas and Hayward. Theoretic isoseismal maps were developed, damage patterns by class of construction and by intensity were established, and casualties determined. The 8.3 magnitude shock represents the maximum credible shock which will be a rare occurrence (being the same magnitude as the 1906 San Francisco shock); the 7 magnitude shock represents a destructive event requiring Federal Government assistance and is an event which is relatively frequent in California; the 6 magnitude shock represents an event which local and state governments are expected to cope with, except for Federal financial aid. Expected casualties, in summary form and exclusive of dam failure, were as follows for maximum credible earthquakes:

<u>Fault</u>	<u>Time of Day</u>	<u>Deaths</u>	<u>Hospitalized Injuries</u>
San Andreas fault	2:30 a. m.	2,850	10,800
	2:00 p. m.	9,460	34,400
	4:30 p. m.	10,360	40,360
Hayward fault	2:30 a. m.	3,120	11,600
	2:00 p. m.	7,200	28,500
	4:30 p. m.	6,650	24,900

Non-hospitalized injury data are difficult to quantify since there is no way of accurately totaling non-reported injuries. However, based on fragmentary data, a ratio of hospitalized injuries to non-hospitalized injuries of 1 to 30 was reasonable for the 1971 San Fernando earthquake, and this ratio may well be appropriate for planning purposes in United States. Deaths and injuries stated above must be considered in the context of the total population of the study area which is over 4,600,000. Thus, even under the most unfavorable circumstances, the probable life loss is about 0.2%.

Life support facilities such as electric power, water systems, oil lines, transportation, and others were found to be particularly susceptible to damage from the relatively smaller Hayward fault; these facilities cross the fault and unfortunately lack earthquake loss control features at present.

San Francisco Case History -- Dams

Potential casualties from dam failure pose a quite different kind of problem from that caused by building collapse. The collapse of even a single large building results in life loss which is insignificant compared to a catastrophic dam failure. As a result, dams in California for many years have been subject to a rigorous design check and field analysis by the state government. On the other hand, the near catastrophic failure of the state government approved Lower San Fernando Dam in the 1971 San Fernando earthquake showed that a significant hazard remains for at least some existing hydraulic fill dams.

There are 226 significant water storage dams in the San Francisco area. Of these, three major dams, located only a few miles from the Hayward fault, are of the hydraulic fill type and currently suspect. The downstream population of these three dams is about 200,000 persons. (At this writing, one reservoir has been partially emptied and the others are being investigated; this situation is a transient one since repairs or dewatering will result if the dams are indeed found to be hazardous.) It is evident from the foregoing that the greatest potential life hazard in many parts of the world may not be from falling buildings but from dam failure.

Implementation

At this writing, the United States Government through its Office of Emergency Preparedness (OEP) is developing plans for a realistic response to a major earthquake disaster in the San Francisco Bay Area. The State of California's Office of Emergency Services, as well as local government and private agencies, are also deeply involved in this effort. The result will be a plan which will substantially save lives and allow a quicker economic recovery than past records indicate. These efforts will hopefully serve as the model for other areas.

PROPERTY DAMAGE

Space limitations preclude a discussion of the somewhat complex methodologies developed to determine damage patterns for various classes of construction for each intensity; the cited references must be examined for this. However, some comment on the monetary aspects may be of value.

There has been virtually no consistency in the methods used to gather monetary loss statistics after an earthquake. Various organizations which have compiled statistics usually do it without regard to the various types of loss definitions, often being unaware of these definitions. As a result, most loss data published in engineering and scientific reports after an earthquake require major interpretative efforts to be useful in other studies.

First, consider the "personal" vs. "impersonal" viewpoints on loss and how each affects the loss statistics. Suppose, for example, a wood frame dwelling suffers minor plaster cracking but no structural damage. This would

become a \$25 "personal" loss if the homeowner pays for the paint and makes his own repairs for \$25 out-of-pocket costs with no outside labor used. If, however, the loss is covered by insurance or a government grant is obtained, the loss becomes "impersonal" from the homeowner's standpoint since others must pay; commercial painters would probably make the repairs for what might reasonably cost \$250, or ten times the "personal" loss. Given the case of about 300,000 wood frame dwelling units in the strongly shaken area of the 1971 San Fernando shock, one could reasonably estimate that perhaps 25% of the dwellings had damage as described above. The difference between "personal" and "impersonal" loss viewpoints would aggregate about \$17,000,000. In a great earthquake, the sum could be many multiples of \$17,000,000. From a government and insurance standpoint, the "impersonal" loss viewpoint is normally the realistic approach and is the one required for most studies.

"Impersonal" losses may be one of several kinds, with two of these requiring special attention. Specifically, dollar losses can be determined on the basis of replacement cost or on the basis of actual cash value (or appraised value), with the differences between these two being significant in some cases. For example, a study of the 1952 Kern County, California earthquake by McClure (Ref. 3, p. 1-7) showed that the actual cash value of buildings in Bakersfield at the time of the 1952 shocks was 36% of the replacement value of these buildings. To the extent that the 36% is applicable elsewhere, damaged structures requiring replacement would have a real loss three times their pre-earthquake value since they couldn't be rebuilt for their depreciated values.

Authorities responsible for a system of government grants, or other types of non-reimbursable aid, need only determine the losses from the maximum credible earthquake and examine them for potential budget problems and their possible political implications. An insurance program, however, requires a significantly broader study in order to determine rates which will be adequate for the potential losses. The traditional property insurance method of comparing insurance premiums with losses as a basis for establishing rates is of little value (Ref. 4, Appendix A, p. 20).

Simulated loss estimation techniques have been developed in recent years which show promise in reducing the substantial uncertainties in establishing earthquake insurance rates (Ref. 4 and 5). It is of value to briefly examine these simulated loss estimation techniques.

California Case History

In a particular region such as San Francisco, earthquakes have damage patterns that are related to the earthquake magnitude, length of fault displacement, geographic damage distribution throughout the area by class of construction, and other measurable characteristics. Using these relationships (Ref. 4), one may examine the seismic history back to 1810 and from this history it is possible to reconstruct the damage and losses for any postulated distribution

of buildings by construction class. The total losses for the entire historic record can be developed by summation.

Let us next examine the hypothetical case of damage to wood frame dwellings based on the assumption that all presently existing wood frame dwellings have been in existence for the entire recorded seismic history of the San Francisco region. While absurd in one sense, it also becomes the basis for practical insurance studies. For any particular historic earthquake, it is possible to determine the geographic distribution of dwelling damage and to sum it up to determine the aggregate loss for the event. In the actual study, dwelling losses were established for the various construction components (i. e. , wall finishes, veneers, chimneys, etc.) for each earthquake intensity for each census tract, and the results summed. By extending this process to the entire historic record, the summation of all losses based on today's construction could be determined. The results of this summation, using 1968 values, are as follows for wood frame dwellings on the basis of replacement values or "impersonal" repair costs:

(a) Maximum credible earthquake in San Francisco area	\$1. 2 billion
(b) Maximum credible earthquake in Los Angeles area:	
San Andreas fault	\$1 billion est.
Inglewood-Newport fault	\$2 billion est.
(c) Entire state, for 157 year period	\$10. 3 billion

These techniques have been partially tested after the 1969 Santa Rosa (California) earthquake and after the 1971 San Fernando (California) earthquake, and correlations look good.

The senior author of this paper extended the foregoing calculations to determine average annual losses as a percentage of replacement values (or "impersonal" repair costs), as follows:

Metropolitan San Francisco	0. 11%
Metropolitan Los Angeles	0. 07%
Entire state, disregarding seismic zones	0. 07%

In the event that the first 5% of the dwelling loss would be excluded (i. e. , including non-structural damage such as repainting and plaster patching) the average annual losses would become:

Metropolitan San Francisco	0. 06%
Metropolitan Los Angeles	0. 04%
Entire state, disregarding seismic zones	0. 04%

Obviously, the foregoing results look only to the past. A great earthquake would, of course, result in a major increase in the percentages. The foregoing

TABLE 1
DEATH AND INJURY RATIOS
Selected United States Earthquakes

Earthquake	Date	Time of Occurrence	Deaths per 100,000 Population	Injuries per 100,000 Population
Charleston, S. C.	Aug. 31, 1886	9:51 p. m.	45 outright; 113 total	-
San Francisco, Calif.	April 18, 1906	5:12 a. m.	-	-
San Francisco			124	104 serious
Santa Rosa			116	69 serious
San Jose			80	38 serious
Santa Barbara, Calif.	June 29, 1925	6:42 a. m.	45	119
Long Beach, Calif.	March 10, 1933	5:54 p. m.	26	1,300
Imperial Valley, Calif.	May 18, 1940	8:37 p. m.	18	40 serious
Puget Sound, Wash.	April 13, 1949	11:56 p. m.	1	-
Kern County, Calif.	July 21, 1952	4:52 a. m.	-	-
Tehachapi			500	-
Bakersfield, Calif.	Aug. 22, 1952	3:41 p. m.	3	47
Alaska	March 27, 1964	5:36 p. m.	-	-
Anchorage			9	315
San Fernando, Calif.	Feb. 9, 1971	6:01 a. m.	see below	180 serious
Excl. Vet. Adm. Hosp.			12	-
Incl. Vet. Adm. Hosp.			64	-

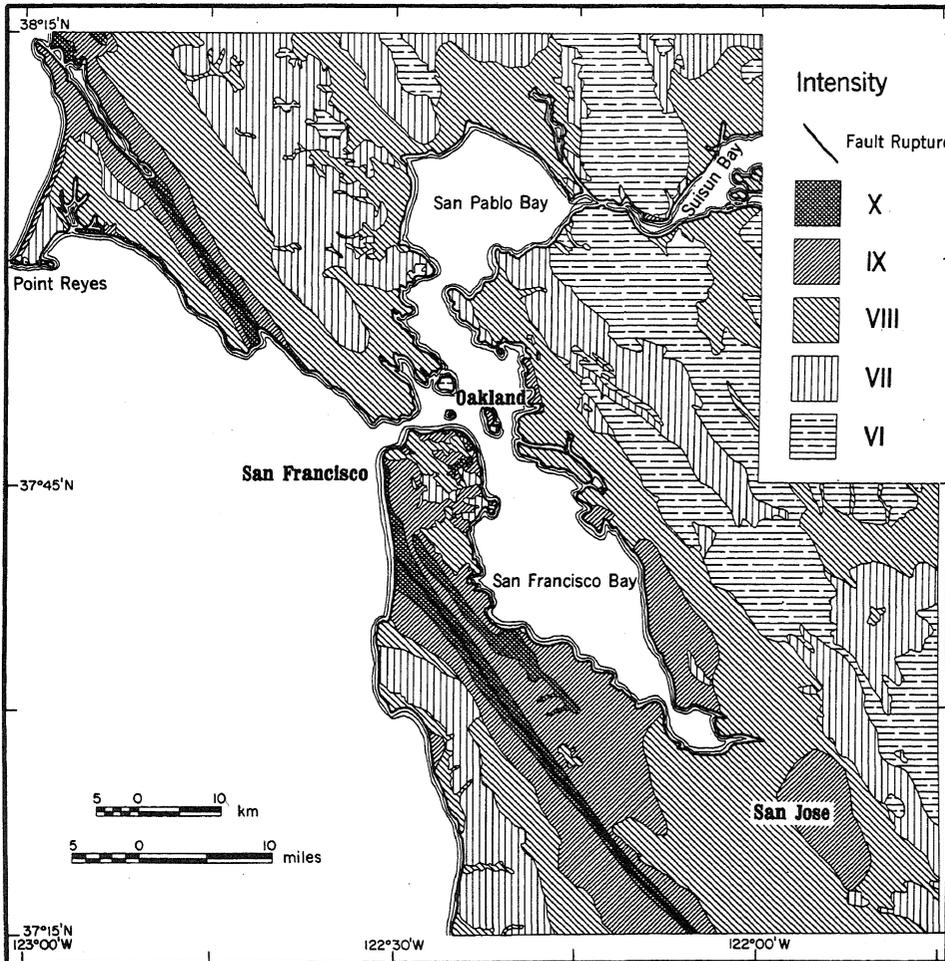


FIGURE 1.
Intensity distribution for M = 8.3 on San Andreas fault.