EARTHQUAKE DISASTER RESPONSE PLANNING: AN ENGINEERING OVERVIEW

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INTRODUCTION

In the United States, one increasingly important role for engineers, along with related earth scientists, is to give substantial assistance in the formulation of public policy as it relates to earthquake hazard reduction. Foremost at this writing are the efforts by engineers, scientists, and others found in "Meeting the Earthquake Challenge", being the final report to the Legislature of the State of California by its Joint Committee on Seismic Safety (reference 1). Enacted legislation has broken new ground in public policy, with some examples as they affect engineering mentioned in later sections of this paper (reference 2).

In recent years in the United States, and particularly within the State of California, there has been a growing awareness and concern over the interrelated and multifaceted aspects of the problems arising from a great earthquake in a large metropolitan area. The loss of a community's lifelines, such as the failure of public utilities, communications, and transportation can compound the community's problems from building damage in ways which did not exist prior to the development of today's complex technological infrastructures.

In response, disaster oriented public agencies have shown increasing interest in identifying the probable dimensions of the future disaster and what pre-planned steps can be taken to minimize the hazards. Clearly, tearing down or strengthening all non-earthquake resistive or partially-earthquake-resistive structures is not often the answer from the standpoint of available economic resources. Even if adequate funds existed today, the rapidly changing state-of-the-art of earthquake resistive design would make many of today's best seismic designs legally "unsafe" in a few years. Lastly, "perfect" safety cannot be achieved with today's technology. Obviously, this leads to an element of risk, or to a level of acceptable risk which is inherent in designs at present.

The American public official involved in disaster preparedness programs is now beginning to examine his problems from three viewpoints:

1. Life Safety: This quite rightly is the highest priority and one to which building codes give their principal attention.

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2. Property Damage: American building codes generally do not require damage control features in building design. However, the U.S. Federal Government, which has heavily subsidized public and private reconstruction after recent earthquake disasters, is beginning to make significant public policy changes in this regard.
3. Functional Impairment: Post-earthquake problems are seriously increased if vital public needs such as hospitals become non-functioning due to elevator outages, etc. even though remaining "safe". Recently enacted law in California requires new hospitals and hospital additions to be designed in a manner which keeps them functional insofar as the state-of-the-art allows (reference 2).

The scope of this paper is restricted to an engineering overview of earthquake disaster response planning as it relates to engineering and changing public policy.

Disaster response planning may be viewed from two distinctly different viewpoints:

1. Planning for after-the-event efforts, such as rescue, restoration of utilities, etc. Engineering input is required when determining the amount, kind and extent of expected damage to buildings, dams, and other man-made facilities. Part B of this paper briefly examines the current American progress, with emphasis on methodology concepts.
2. Planning for pre-earthquake hazard reduction, such as the strengthening or razing of hazardous structures. Part C of this paper summarizes one current effort to establish priorities for strengthening or razing structures.

The potential monetary loss from a large disaster and also the average annual loss from all earthquakes over long periods of time are becoming increasingly important with respect to the two viewpoints expressed above. Part D to this paper discusses current progress from an insurance viewpoint.

To keep this paper within reasonable limits, the subject areas have been confined to a few among those discussed in the "Selected Bibliography" and those which are believed to have greater relevance to other nations. Henceforth, the Los Angeles study will refer to reference 4 while the San Francisco study will refer to reference 3.

PART A - SEISMIC CONSIDERATIONS

Any earthquake disaster response

planning requires information on the potential magnitude and locations of the upper limit earthquake which can be reasonably expected. Secondly, the geographic distribution and variations of the seismic wave trains must be understood in terms of potential damage. Underlying any methodology for mass application to buildings are the economics which require simplistic approaches as compared to that for a specific building design.

The following paragraphs are a brief summary of a few of the criteria and procedures found in references 3 and 4, and are stated here to give context to Parts B, C, and D.

The Postulated Earthquake(s)

The postulated earthquake, or earthquakes, for disaster preparedness planning is that earthquake which results in the greatest aggregate loss of life, property damage, and functional impairments in the study area. Isoseismal maps (or other maps accomplishing the same objectives) are required for each postulated event. As a result, a very strong earthquake on a comparatively small fault within a highly populated area may be more serious than a great earthquake on a great fault located near the city. (It should therefore be noted that the postulated earthquake from a disaster preparedness planning standpoint may be quite different from the "design" earthquake for a specific building.).

For example, the San Andreas fault in California has often been termed California's master fault due to its capability of having the largest earthquake in terms of Richter magnitude, amount of fault displacement, and length of fault rupture. This title of "master fault" is enhanced by its proximity to both Los Angeles and to San Francisco. However, the geologically and seismologically lesser Hayward fault (in metropolitan Oakland) and the Newport-Inglewood fault in metropolitan Los Angeles have the potential for greater aggregate disaster effects than does the San Andreas fault (references 3 and 4).

Often more than one postulated earthquake must be used. For example, one shock may rupture a dam but have only moderate aggregate effect on buildings while a differently located shock could reverse this pattern. In the cases of the San Francisco and Los Angeles planning studies, quite different but equally useful results came from the study of more than one postulated earthquake location. Finally, the selection of postulated earthquakes requires the combined inputs of seismologists, geologists, and engineers.

Isoseismals or Geographic Distribution of Ground Motions

The geographic distribution of ground motions is a function of the magnitude and focal depth of the postulated earthquake(s), the intervening geology between the causative fault and the specific site, and local surficial conditions as may be expressed by micro-regionalization maps or by soil data. Mathematical models have been developed which can portray the surface motions at a

particular site and the structure's response. However, the economics of the situation does not allow a detailed dynamic analysis of the many tens of thousands of buildings in the study area, particularly when detailed knowledge of the structures' response characteristics have not been compiled. Neither do these procedures allow the simple analysis of the mechanical-electrical systems which, if they fail, seriously impair the functional capabilities of an otherwise "safe" building.

Alternately, and apparently feasible, are maps which would be the equivalent of an isoseismal map but which show spectra; however, to date they have not been extensively used as far as the author knows.

The simplest model, but the most criticized and most maligned model, is a theoretical isoseismal map patterned after current practice. Its flaws, such as inadequate representation of long period effects, are well known and the deficiencies perhaps need not be listed. Its principal virtue for past earthquakes is that it represents in summary form what actually happened in the earthquake -- any mathematical model of any type should be tested against it and the mathematical model changed in the event of disagreement.

Theoretic isoseismal maps can be readily constructed for a given seismic regime; figure 1 is one such example. Obviously, long period effects are missing and map scale does not allow micro-regionalization. Friedman (reference 5) has developed similar computer models which print out isoseismal maps. Other models exist.

To this point, the engineering input has been no more than moderate. However, it is vital for the engineer to understand the limitations of the seismic and geologic input by others. The middle range Modified Mercalli intensities are essentially descriptions of degrees of vibrational effects on buildings, but Intensities X, XI, and XII are principally related to geologic effects. In American earthquakes, perhaps 95% or more of the damage and other effects have been due to ground vibration and not due to geologic effects. For example, far less than 1% of the buildings in either Los Angeles or San Francisco lie astride an active fault where Intensity XII has occurred along the break, but perhaps IX no more than a few feet away. Major landslides occur with or without an accompanying earthquake; while Intensity XII may occur in the landslide area, vibrational intensity may be no more than VI. Thus, the engineer must carefully re-examine very high intensities, separating out vibration damage from geologic problems. In any event, good judgment and understanding are vital in the use of isoseismal maps and micro-regionalization maps.

PART B - DAMAGE ANALYSIS METHODOLOGY: A REVIEW OF CONCEPTS

This section of this paper contains a brief description of several of the more important concepts used to determine some aspects of the potential aggregate damage for selected postulated earthquakes in

metropolitan Los Angeles and metropolitan San Francisco Bay Area. Additional details on these concepts and methodologies, plus other methodologies, may be found in references 3 and 4.*

Any methodology must develop a relatively simple relationship between Intensity (or other parameter) and damage, or preferably Intensity as it relates to functional capability. (For short-term disaster response, functional capability is preferred since a "safe" building may be a significant liability if non-functioning.) One such relationship is given in Table 1 and it is useful when examining the inventories of tens of thousands of older structures of low to middle value. Table 1 applies only to southern California construction. This table includes multistory buildings, but these buildings would be eliminated whenever more specific data were available. It is important to note that the Intensities higher than IX were not included; as has been discussed, these higher Intensities usually reflect geologic effects rather than vibrational effects and therefore these higher Intensity effects must be considered independently.

Deaths and injuries, as well as the effectiveness of disaster response, are functions of time of day as well as seasons of the year. Deaths and injuries for the Los Angeles and San Francisco studies were determined for 3 times of day for each postulated earthquake as follows:

1. 2.30 a.m., when the greatest proportion of the population would be at home in bed (normally in safe wood frame dwelling in California).
2. 2.00 p.m., when the greatest proportion of the population would be away from home, and
3. 4.30 p.m., the beginning of the commute rush hour.

Damage to structures and their facilities was also considered in terms of time of the day when relevant. The season of the year, namely wet or dry season, was considered when pertinent (for examples, landslide during the wet season and conflagration potential in the windy dry season).

Potential Losses to Local Medical Resources

Planning for appropriate disaster response requires a responsible estimate of the potential losses to local medical resources. Among others, the planner needs potential loss information on major hospitals, health manpower (doctors, nurses, etc.), medical supplies, bloodbank stocks, local stockpiles of reserve medical facilities, non-hospital clinical laboratories, and ambulances (automobile and helicopter). The degree of analysis is a function of the importance; for example, the damage analysis for hospitals is in much greater detail than that indicated by Table 1. The following are examples of some of the methodologies.

Hospitals: Hospital requirements increase

* Copies of these reports have been placed on file with The New Zealand Society for Earthquake Engineering.

after a disastrous earthquake but experience shows that due to damage some hospitals become a liability to the community rather than an asset. This has been recognized in recent California law which requires that new (not existing) hospitals be designed in a manner so that they will remain functional insofar as the state-of-the-art permits. Specifically, the California Legislature stated (in addition to the technical details of the legislation):

It is the intent of the Legislature that hospitals, which house patients having less than the capacity of normal healthy persons to protect themselves, and which must be completely functional to perform all necessary services to the public after a disaster, shall be designed and constructed to resist, insofar as practicable, the forces generated by earthquake

It should be noted that this legislation does not require the hospital to remain damage free, rather that it remain functional. Obviously, new structural design criteria are being evolved as well as criteria for mechanical and electrical equipment.

Table 2 is a compilation of information on potential losses and is applicable only to the metropolitan Los Angeles area; it is based on the typical earthquake resistant hospital built in that area from 1955 to 1970. It should be evident that Table 2 does not apply to hospitals being built under the new laws and that the tabulated values will be on the high side for them; it should also be evident that older hospitals, such as those with non-reinforced brick bearing walls having sand-lime mortar, are far more hazardous. Table 2 applies as an average to 10 or more hospitals, and gross error may occur if applied to a single facility.

In order to estimate the total number of hospital casualties, including the loss to medical personnel, data must be compiled similar to those shown in Table 3. Based on tables such as Tables 2 and 3, plus similar information on hospitals not covered by Table 2, the total losses can be readily computed.

Examples of Other Local Medical Resource Losses: Based on data from 90 locations after the 1971 San Fernando earthquake, retail drug stores and pharmacies which did not collapse suffered losses as shown in Table 4; these data should be reasonably applicable elsewhere.

Non-hospital clinical laboratories which are not in collapsed buildings may become non-functional when laboratory equipment (including microscopes) are thrown on the floor and the failure of electric power results in loss of refrigeration (see Table 5 for California type losses).

Ambulance services in California are housed in all kinds of structures, or ambulances may be parked outside. It is evident, then, that the losses to this type of medical resource are functions of

building collapse when ambulances are stored indoors, debris falling on ambulances when parked outdoors, and debris on the streets which blocks egress. Field surveys are normally required to determine these factors.

Demands on Medical Resources

Deaths and Injuries, Excluding Dam Failure:

Probably having the poorest confidence limits and being least transferrable is the methodology for estimating deaths and injuries, particularly the numerical coefficients. This is because disastrous earthquakes striking large numbers of earthquake resistive structures are so few and data are extremely sparse. On the other hand, quite reliable data exist in large amounts for those countries with many hundreds of years' experience with traditional heavy unit masonry construction. However, as these traditional collapse-hazard types are phased out by modern earthquake resistive types, these countries will be faced with the problems of inadequate information.

This paper discusses only deaths due to vibrational damage. Many regions will have specialized kinds of problems, such as tsunami (Japan, Alaska, Hawaii, Chile) or major landslide (1970 Peru with 25,000 to 30,000 deaths), and these must be included in the overall study.

There have been 27 American earthquakes having sufficient relevance to current California construction to have warranted examination in detail. Most significant of these are listed in Table 6. Excluded was the 1872 Owens Valley earthquake in which 23 persons were killed in Lone Pine, California, out of a population of 250 to 300; this exclusion was based on non-relevant construction, i.e., adobe and stone houses, usually without any kind of mortar.

The published back-up materials for these 27 earthquakes are not as strong with respect to deaths and injury information as those for buildings and other property damage. Heart attack deaths may or may not be included, and the text leaves the matter unclear in most cases. Injuries leading to deaths may be included under injuries or under deaths. What constitutes the dividing line between "serious injury" and "injury" is rarely stated in reports, and the given data are often incomplete. Whether or not emotional cases were included is usually not stated, although some of these cases would have required medical attention.

Table 6 includes a listing of deaths and injuries per 100,000 population for the selected American earthquakes. Earthquakes with life losses less than 8 were excluded from the listing, and the 1872 Owens Valley earthquake was omitted for reasons already stated. Quite possibly the cut-off figure should be much larger than 8 since the data for Tehachapi in the 1952 Kern County earthquake are so few as to be seriously questioned when used for extrapolation. The inclusion of the 1949 Puget Sound earthquake is also of reduced value when applied to California since 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. Similar variations apply for the Charleston shock of 1886. Also, the effect of a single major collapse can strongly affect the losses per 100,000 population; see, for example, the variations in Table 6 upon inclusion of the deaths at the Veterans Administration Hospital from the 1971 San Fernando shock.

Table 6 is a useful guideline when applied with judgment and in the context of the time of day, appropriate comparative construction, and appropriate Modified Mercalli intensities. It must be clearly understood that direct usage of Table 6 information is not possible without consideration of the foregoing qualifications.

For realistic usage, the deaths and injury ratios in Table 6 must be modified on the basis of a hazard evaluation of the construction types found in the study area. In turn, these modified ratios must be multiplied by the daytime and also the night-time populations in the areas being examined.

Data on multistory construction (by number of buildings, by floor area, and by story height groupings) should be gathered. For the Los Angeles study, the selected construction types of multistory buildings were:

Concrete,
Steel frame,
Brick, and
Mixed construction.

The basic data source was the Sanborn maps which in the past have been used principally by the insurance industry.

The favourable effects of the so-called "Parapet Ordinance" of the City of Los Angeles were substantial in the Los Angeles hazard evaluation. This 1949 ordinance requires the strengthening and/or removal of hazardous parapets and appendages to buildings over public ways, with these hazardous features normally being unreinforced brick masonry. The Los Angeles Department of Building and Safety -- Conservation Bureau estimates that 22,000 pre-1933 constructed buildings exist which will require or have required attention; of these 22,000 in excess of 17,000 have received parapet correction, or 77%. It may be recalled that the lower intensities usually prevail over greater areas than do the higher intensities and that unit masonry parapets and appendages are the most common failure in these lower intensities. Under these circumstances, similar corrective work in other older cities would substantially reduce the number of potential casualties without creating undue economic hardships in most cases.

The detailed application of the methodology may be found in references 3 and 4, and need not be repeated here since much of it is non-transferrable. However, it might be useful to note that the ratio of hospitalized injuries to deaths was found to be 4 to 1 while non-hospitalized injuries

to deaths was found to be 30 to 1.

Deaths, Injuries, and Homeless from Dam Failures:

The potentially catastrophic nature of dam failure for those dams having large downstream populations cannot be overlooked. Indeed, the potential life loss from this source may be substantially greater than that from building collapse. Also, dams may be relatively more common than often believed; for example, the 1972 earthquake hazard study of the metropolitan San Francisco area listed 226 dams (reference 3).

The number of casualties is a function of the exposed population (day-time vs. night-time populations) and the assumed type of dam failure. For one example of the magnitude of the problem in the San Francisco Bay Area in 1972, the failure of the complex consisting of the Upper San Leandro Reservoir which drains into the Chabot Reservoir would have reasonably resulted in the following:

	<u>Day</u>	<u>Night</u>
* Maximum possible individuals exposed	86,000	109,000
Maximum possible deaths	50,000	52,000
Estimated probable deaths	30,000	35,000

* Potential homeless.

(Since the foregoing was written in 1972, steps have been taken to strengthen the facilities to the current state-of-the-art of dam design.)

It is evident from the foregoing that a much more detailed engineering analysis is warranted for individual dams than for individual buildings. However, psychological block is often encountered when assuming a dam failure for planning purposes. Certainly, no designer of a dam would conceive of a structure which he thought to be even possibly unsafe. A good professional often has the feeling that his dam is "perfectly" safe and that any significant element of uncertainty is intolerable. However, the catastrophic near-failure of the "safe" Lower San Fernando Dam in the 1971 San Fernando earthquake is one evidence to the contrary; this event resulted in a complete review by the State of the California of the earthquake design criteria for dams and upgrading of these criteria and dams where necessary. Additionally, the fact that dams are not necessarily perfectly safe has been legally acknowledged in a State of California Legislative Act approved in 1972. Pertinent parts of this act are as follows:

(a) Inundation maps showing the areas of potential flooding in the event of sudden or total failure of any dam, the partial or total failure of which the Office of Emergency Services determines, after consultation with the Department of Water Resources, would result in death or personal injury, shall be prepared and submitted as provided in this subdivision.....

(b) Based upon a review of inundation maps

submitted pursuant to subdivision (a), the Office of Emergency Services shall designate areas within which death or personal injury would, in its determination, result from the partial or total failure of a dam. The appropriate public safety agencies of any city, county, or city and county, the territory of which includes such an area, shall adopt emergency procedures for the evacuation and control of populated areas below such dams.

Methodologies for inundation area determination in current use, among others, are "Procedures for the Determination of Inundation Maps Showing Areas of Potential Flooding in the Event of Sudden or Total Failure of Any Dam" (Los Angeles County Flood Control District, Hydraulic Division) and "Determination of Dam Break Inundation Area, Earth Dams", (City of Los Angeles, Department of Water and Power). The use of the foregoing methodologies, or others, cannot avoid the need for substantial judgment when determining the number of deaths in the inundated areas.

Effects on Immediate and Vital Public Needs

The disaster response planner must have some knowledge of the potential damage to non-medical facilities which are needed to keep a community functioning. In this regard, the engineering input is of major importance. In particular, the probable damage patterns to public buildings, including schools, must be known. Normally, schools in California for the first 12 years education are geographically distributed in relation to population, have some minimal type of mass feeding facilities, and can be adopted for mass housing.

Additionally, damage patterns to a community's lifelines must be examined (public utilities, communications, transportation, etc.). Estimates are required of the potential homeless population. Lastly and certainly not least, fire following earthquake must be examined. Engineering assessments are required for all of the foregoing.

Much of the discussion in previous sections of this report are also applicable here. However, the methods for determining potential damage to underground pipelines may be of interest.

Damage to Underground Pipelines: Metropolitan Los Angeles as an Example

Methodologies for determining the number and extent of underground pipeline breaks or outages have weaknesses due to the lack of adequately recorded experience data. However, the amount of experience gained from the 1971 San Fernando earthquake provided a reasonable basis for studies elsewhere in the metropolitan Los Angeles (reference 4).

Causes of earthquake damage to utility distribution and collection systems, particularly to those below ground, can be considered in two parts: (1) those due to ground shaking, and (2) those due to differential ground movement such as surface faulting, landslides, subsidence, etc.

Considering ground shaking, it can be assumed that the extent of damage is a function of the ground motion, including its duration. Based on 1971 San Fernando experience (reference 6), it was evident that the majority of ground vibration damage to underground utility collection and distribution systems was due to Intensity IX (and greater). Estimates of damage due to ground shaking can then be made by comparing the relative urban areas affected by Intensity IX (and greater) ground motion in the San Fernando earthquake with the postulated earthquakes. This analysis is based on the assumption that the utility distribution and collection systems are uniformly distributed in the urban portions of the study areas in the same manner as the Intensity IX zones affected by the San Fernando earthquake. The obvious limitations to this method include the lack of complete information of the type of materials used for the lines, line deterioration, workmanship, and localized surficial geology. Indeed, many water line outages will be due to pressure surges finding weak spots in old deteriorated lines; the result is immediate damage instead of what otherwise would be maintenance problems spread over a long period of time. In any event, the outages would be real at a time of great need.

Based on isoseismal maps of the 1971 San Fernando earthquake and with consideration to the distribution and degree of damage, it was determined that an urban area of about 12 square miles was affected by Intensity IX (and greater). There were about 380 breaks in natural gas mains and services in this 12 square mile area; it was estimated that about 10% of these, or 38 breaks, were caused by ground shaking and the remainder (342) by permanent ground differential displacements (reference 6). For one example of use of these data, a postulated magnitude 7.5 event on the Newport-Inglewood fault would result in Intensity IX and greater over 200 square miles of the urban area of Orange County. The number of breaks in natural gas mains and services in Orange County may then be estimated as follows:

Number of breaks per square mile
due to vibration = $38/12 = 3.167$

Number of main and service breaks
in Orange County = $3.167 \times 200 = 633$, say 630.

The previously mentioned 10% and 90% distribution of pipeline breaks was based on the observation that the zone of deformation caused by surface faulting along the San Fernando thrust fault was extremely wide, ranging from a few hundred feet to over a few thousand feet. This large disturbed zone was due to the geometry of the faulting and the amount of displacement. On the other hand, the width of such a zone for strike-slip faults, such as the Newport-Inglewood and San Andreas, would often be less than 50 feet -- this must be considered in the calculations for these kinds of faults.

An approximation of the influence of permanent ground displacement can be made by computing equivalent hazard areas. An

equivalent hazard area is defined as the sum of the following:

- A. Length of surface faulting times 0.25 mile wide zone.
- B. For metropolitan Los Angeles, 10% of urban landslide area in Intensity IX.
- C. For metropolitan Los Angeles, 50% of structurally poor ground in urban areas in Intensity IX.

Fortunately, reasonably adequate maps exist for metropolitan Los Angeles which define the potential landslide areas and the structurally poor ground areas. However, the percentages given in "B" and "C", above, are judgment figures. The following is an application of this method for natural gas mains and services in Orange County in the event of a magnitude 7.5 event on the Newport-Inglewood fault:

Breaks due to differential ground movement
= $(20 \text{ sq. mi.}) \times \frac{342 \text{ breaks}}{12 \text{ sq. mi.}} = 570 \text{ breaks}$

where 20 sq. mi. is the Equivalent Hazard Area for Orange County and 12 sq. mi. for San Fernando (coincidentally the same number as that for the heavily hit urban area of San Fernando).

The total estimated number of breaks in mains and services would be $630 + 570 = 1200$.

Magnitude of the Problems

Table 7 is a summary statement of the magnitude of the disaster potential for two regions having a high degree of earthquake resistive construction. On a percentage basis, the number of probable deaths is low, but 20,000 deaths plus 80,000 hospitalized injuries is not negligible by any means. It should be added that deaths due to dam failure have not been included in Table 7 since, at this writing, the most hazardous dams have been dewatered and/or are being strengthened.

PART C - PRIORITIES FOR STRENGTHENING BUILDINGS

It is self-evident that the adequate strengthening of non-earthquake resistive buildings will save more lives than will superb rescue efforts brought about by excellent disaster response planning. On the other hand, the monetary resources available to policy makers must be allocated among many great needs which usually exceed these resources.

This type of problem is currently being faced by the University of California; their solution may have widespread applicability. The Chancellor's Seismic Review Board (Berkeley campus) and the Berkeley campus consulting engineer have developed a methodology for establishing the relative hazard among the seismically deficient campus buildings. Their concepts may be obtained from the following extract from their "Interim Report of the Chancellor's Seismic Review Board", January, 14, 1974 (Karl V. Steinbrugge, chairman; Frank E. McClure, consultant):

..... Seismic hazard may be considered from three viewpoints: (1) Life safety, (2) Property damage, and (3) Functional impairment (loss of utilities, elevators, etc.). These three viewpoints are related; for example, it is property damage which causes life loss. However, the relative significance of each of the three viewpoints varies from case to case. For example, extensive and costly nonstructural partition damage is not a significant cause for severe injury; on the other hand, the falling of one brick over an exit produces a significant injury hazard.

..... after extensive review of its task, the Board chose life safety as its highest priority. The board recognized that the cost of reconstruction to correct seismic deficiencies could be considerably reduced by including only those items related to life safety, without major consideration to property damage and functional impairment. The Board was unanimous that in the reconstruction of buildings there be equivalent compliance with code on those items affecting life safety; however, on those items affecting primarily property damage and functional impairment the extent of reconstruction be in keeping with policy established by the University administration.

The recommended procedure includes some built-in flexibilities in order to accommodate the other requirements which are necessary to keep a university functioning during reconstruction.

Specifically, a priority based on a "Benefit-Cost" relationship was developed and may be expressed by the following equation:

$$(BCR) = \frac{(LSR)^* (ECO)^* - (LSR)^{**} (ECO)^{**}}{(\text{Reconstruction cost})}$$

* denotes prior to reconstruction
** denotes after reconstruction

where:

BCR: Benefit-Cost Ratio, being the number of postulated lives saved per reconstruction dollar.

LSR: Life-Safety Ratio, being the postulated number of fatalities per 10,000 for a particular structure for the criterion earthquake.

ECO: Equivalent Continuous Occupancy, being the theoretical number of persons continuously occupying the structure to give the equivalence of actual varying use.

The methodology expressed by the foregoing equation allows a priority listing of structures for reconstruction based on the greatest life saving potential for a given amount of money. It allows for alternates such as the demolition of a building and its replacement.

The methodology does not require a dollar value to be placed on life.

Further, by changing the occupancy load, the reconstruction priority can be changed, and administrators may do this if they wish. For an extreme example, a classroom structure may be changed to a storage or other facility having a small occupant load, thereby changing its relative risk and changing its reconstruction priority

(end of quotation)

PART D - POSTSCRIPT ON MONETARY LOSS

Existing Compiled Loss Data

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 have any use.

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 could 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 labour). If, however, the loss is covered by insurance, 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 author's calculations show that 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.

"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, earthquakes by McClure (reference 7) showed that the actual cash value of wood frame dwellings 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 dwellings requiring replacement would have a real loss three times their pre-earthquake value since they could not be rebuilt for their depreciated values.

Simulated Loss Estimation Techniques

Simulated loss estimation techniques have been developed in recent years, with

these techniques showing substantial promise in reducing the large uncertainties currently present in estimating total potential loss for any future seismic event and in establishing earthquake insurance rates. Studies to date have been with respect to 1 to 4 family wood frame dwellings in the San Francisco Bay Area, and the author has contributed to most of these studies (principally reference 8).

In a particular region such as San Francisco, earthquakes have damage patterns that are related to earthquake magnitude, to length of fault displacement, to geographic damage distribution throughout the area by class of construction, and to other measurable characteristics. Using these relationships, one may examine the seismic history of metropolitan San Francisco back to 1810. 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. In other words, the total monetary loss for any class of construction and for any geographic distribution can be computed for any given earthquake in metropolitan San Francisco. It then follows that the total loss for all earthquakes listed in the historic record can be determined.

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 earthquake 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 (reference 8), 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 continuing this process for the entire historic record, the summation of all losses based on today's construction could be determined. The result of these 1968 calculations, updated by the author to 1973 values, are as follows for wood frame dwellings on the basis of replacement value:

(a) Maximum credible earthquake in metropolitan San Francisco	\$1,800 million
(b) Maximum credible earthquake in metropolitan Los Angeles area:	
San Andreas fault	\$1,500 million est.
Inglewood-Newport fault	\$3,000 million est.

Note: "Metropolitan area includes heavily shaken as well as moderately shaken area, and includes cities well over 100 miles from heaviest shaken areas.

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 author extended the foregoing calculations to determine average annual losses as a rate related to replacement values, as follows (for wood frame dwellings):

	Cents/\$100 (No Insurance Deductible)
Metropolitan San Francisco	0.11
Metropolitan Los Angeles	0.07
Entire state, disregarding seismic zones	0.07

Note: Above are based on 1968 calculations; updating to 1975 would not create significant changes.

These numerical values are the equivalent of the "burning ratio" and are not insurance rates. To the above values must be added the cost of doing business plus a factor for the possibility of a great earthquake occurring at any time.

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

	Cents/\$100 (5% Deductible)
Metropolitan San Francisco	0.06
Metropolitan Los Angeles	0.04
Entire state, disregarding seismic zones	0.04

Note: Above are based on 1968 calculations; updating to 1975 would not create significant changes.

As has been stated, the foregoing results look only to the past. A great earthquake would, of course, result in a major increase in the average annual losses.

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TABLE 1.
ESTIMATED PERCENTAGES OF BUILDINGS RENDERED NON-FUNCTIONAL DUE TO EARTHQUAKE DAMAGE

Contents not included

*Damage Susceptibility Factor	Modified Mercalli Intensity (MM)				Brief Typical Building Description
	VI	VII	VIII	IX	
1	0%	5%	7%	10%	Small area one and two story all metal and wood frame with many partitions. Small area concrete box type with few wall openings and concrete floor and roof.
2	0%	8%	15%	20%	Large area metal and wood frame with few partitions. One and two story earthquake resistant with masonry walls, wood and metal deck floors and roof. Steel frame multistory, earthquake resistant with shear walls or bracing. Steel towers.
3	5%	15%	30%	50%	One story tilt-up with wood roof. Multi-story earthquake resistant, moment frames. Masonry bearing wall multistory.
4	10%	20%	40%	75%	Old non-earthquake resistant multistory.
5	15%	40%	75%	100%	Old un-reinforced masonry bearing wall buildings with wood floors and roof.

Descriptions and percentages apply to typical construction in southern California. Application to other areas must be determined by competent earthquake engineers.

*Damage Susceptibility Factor (DSF) of 1 is least damageable while 5 is worst.

TABLE 2

HOSPITAL DEATHS, INJURIES, AND DAMAGE

Applicable to southern California;
see also text for limitations

	Modified Mercalli Intensity				
	<u>Under VII</u>	<u>VII</u>	<u>VIII</u>	<u>IX</u>	<u>Over IX</u>
Death:					
Doctors	0%	0%	0.67%	2%	3%
Patients	0%	0%	1%	3%	5%
Staff, nurses, outpatients, visitors	0%	0%	0.67%	2%	3%
Bedside visitors	0%	0%	0.5 %	1.5%	2%
Injuries:					
Doctors	0%	4%	8%	15%	20%
Patients	0%	5%	10%	20%	30%
Staff, nurses, outpatients, visitors	0%	4%	8%	15%	20%
Bedside visitors	0%	4%	6%	10%	15%
Impairments affecting beds (percentage of):					
Total bed loss (all causes)	0%	5%	20%	50%	80%
Restricted access	0%	0%	5%	10%	25%
Communication loss	0%	0%	0%	20%	60%
Elevator outage	0%	10%	30%	70%	95%
Auxiliary power outage	0%	0%	2%	30%	70%
Outside utility outage	0%	5%	10%	25%	80%
Inside utility outage	0%	2%	10%	20%	80%
Heat outage	0%	0%	10%	50%	90%
Water outage	0%	0%	3%	30%	80%
Sewer outage	0%	0%	15%	60%	90%
Natural gas outage	0%	0%	20%	20%	90%
Electric power outage	0%	0%	5%	20%	90%
Medical supplies	0%	5%	50%	75%	90%

- Notes:
1. Impairment losses are non-cumulative.
 2. See text for limitations.

TABLE 3
HOSPITAL OCCUPANCY FACTORS
Applicable to California in 1973

	Time of Day		
	2.00 p.m.	4.30 p.m.	2.30 a.m.
Number of nurses on duty per bed	0.55	0.52	0.20
Number of other staff on duty per bed	0.59	0.45	0.13
Number of outpatients per bed	0.06	0.06	0
Number of bedside visitors per bed	0.29	0.29	0
Number of doctors on duty per bed	0.11	0.06	0.013
Percentage bed occupancy (of total beds)	86%	86%	86%

TABLE 4
DAMAGE TO RETAIL DRUG STOCKS
For non-collapsed buildings

<u>Intensity</u>	<u>Drug Stock Losses</u>
IX	23%
VIII	12%
VII	7%

TABLE 5
NON-FUNCTIONING CLINICAL LABORATORIES
(non-hospital locations in California)

<u>Intensity</u>	<u>Percent Non-Functional</u>
VI	0%
VII	20%
VIII	40%
IX	80%

TABLE 6
DEATH AND INJURY RATIOS
Selected United States Earthquakes

<u>Earthquake</u>	<u>Date</u>	<u>Time of Occurrence</u>	<u>Deaths per 100,000 Population</u>	<u>100,000 Population</u>
Charleston, South Carolina	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.	-	180 serious
Excl. Vet. Adm. Hosp.			12	-
Incl. Vet. Adm. Hosp.			64	-

TABLE 7
COMPARISON OF SOME PRINCIPAL FINDINGS
OF SAN FRANCISCO AND LOS ANGELES
EARTHQUAKE DISASTER STUDIES
(from references 3 and 4)

<u>Item</u>	Metropolitan San Francisco (9 counties)		Metropolitan Los Angeles (Los Angeles and Orange counties)	
	<u>San Andreas Fault</u>	<u>Hayward Fault</u>	<u>San Andreas Fault</u>	<u>Newport-Inglewood Fault</u>
Population	4,600,000	4,600,000	10,100,000	10,100,000
Deaths, excl. dams				
2.30 a.m.	2,900	3,100	2,800	4,100
2.00 p.m.	9,500	7,200	11,300	18,800
4.30 p.m.	10,400	6,700	12,400	20,800
Homeless (long term)	33,200	48,200	46,000	182,000
Hospital bed loss (major hospitals)	18,000	16,200	7,500	13,300

FIGURE 1: TYPICAL ISOSEISMAL MAP USED IN EARTHQUAKE DISASTER PREPAREDNESS STUDIES (REFERENCE 3, FIGURE5).