DETERMINING MONETARY LOSSES AND CASUALTIES FOR USE IN EARTHQUAKE MITIGATION AND DISASTER RESPONSE PLANNING

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SUMMARY

Estimates of the number of potential casualties and aggregate monetary losses are vital for selecting the most effective hazard mitigation measures as well as for post-earthquake disaster response planning. These are also very important in earthquake insurance. Major factors in these estimates are the casualty and monetary loss data by class of building construction, the appropriate building inventories, and the relevant geophysical parameters such as magnitude, focal depth, and probable recurrance intervals. This paper presents a summary of some of these major factors which have been applied to a number of seismic regions. Also summarized are the current advances in these methodologies. The loss estimation methods are intended for evaluating hundreds of buildings, or for a city, or for the entire shaken area. The algorithms given herein are not a substitute for site-specific investigations.

INTRODUCTION

The term "loss ratio" as used in this paper is defined as the mean percentage value of the monetary loss to a particular class of construction in the event of the maximum probable earthquake for buildings in the vicinity of the faulting. In California, the maximum probable earthquake is assumed to be magnitude 8.25 for the purposes of this paper. "Life-safety ratio" is the equivalent term to "loss ratio" for casualty estimates. Firm alluvial soil is assumed for building foundations, except where otherwise microzoned. An impersonal loss definition is used for monetary losses, namely, losses paid by the government or insurance company rather than by the owners or occupants. A parallel term to loss ratio used in earthquake insurance practice is "probable maximum loss (PML) which is defined in the same manner, except that 90% of the buildings will have losses not exceeding the PML. Transfer functions between loss ratio and PML can be easily developed.

Casualty life-safety ratios and monetary loss ratios by class of building construction along with relevant geophysical parameters constitute two of the most important inputs for quantifying casualties and monetary losses. These

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ratios have commonalities throughout the world wherever similar construction is found. When these ratios are multiplied by the building inventories or population at risk, the results are the mean aggregate monetary losses and casualties.

Effective use of these ratios requires a careful examination of all of the other input parameters. These major inputs are:

1. A suitable building classification system.
2. Compilation of a building inventory and an inventory of population at risk in and adjacent to the buildings.
3. Selection of appropriate geophysical parameters, such as: magnitude, focal depth, fault rupture length, and probability of occurrence.
4. Appropriate loss ratios and life-safety ratios which have been carefully defined for intended uses and which include the damaging effects of long period ground motion.

The most costly aspect of applying the loss estimation algorithms is obtaining suitable inventories of buildings and populations at risk. Normally, appropriate inventories do not exist. Suitable building inventories must be divided into construction classes by damage vulnerability and must be segregated into small areas. It is also necessary to know story height (or an equivalent parameter for estimating long period effects), age, monetary values, and population at risk within these structures as a function of time of day. Provisions for local microzonation can be included when the individual areas are as small as a postal ZIP or census tract.

Area-specific hazards may also exist, such as hazardous upstream dams and fire following earthquake conditions. These are usually examined separately and the results added to those found by the general methodology.

Despite their importance, economics dictates that monetary loss ratios and casualty life-safety ratios must be developed in the context of cost-effective inventory methods. The entire process has been computerized using postal ZIPs for certain uses and census tracts for other uses.

BUILDING CLASSIFICATION SYSTEMS AND INVENTORIES

Excluding region-specific instances such as landslides and dam failures, life loss and monetary loss come from the failure of man-made structures such as buildings. It is therefore desirable to obtain building inventories based on a single classification system which is useable for developing casualty figures and monetary losses.

Every effort should be made to examine existing inventories for their applicability. The geographic distribution of buildings in the inventory must be known; unit areas in the United States may be postal ZIPs, census tracts, city blocks, political boundaries, or other small areas for which suitable inventories exist. The inventoried buildings must also be classed according to their relative vulnerabilities. Except for dwellings, it is usually incorrect to substitute occupancy inventories for construction class inventories. For example, a mercantile occupancy may be of wood frame construction (minimal vulnerability), or of non-earthquake-resistive unit masonry (highest vulnerability), or of anything between. The usual inventory prepared by or for governmental sources such as tax assessors and land use planners often emphasizes occupancy, and therefore these inventories are usually inappropriate. Property insurance inventories held by private insurance companies are excellent resources; they are limited by not being commonly available and not necessarily including all privately owned buildings. Public buildings are usually not included. Federal, state, and local government inventories of their structures (owned or leased) are usually inadequate.

Building inventories may be adapted from various existing specialty inventories such as those prepared for real estate purposes. When suitable ones are not available as is the common case, field inspections by knowledgeable persons such as former building officials have been successful. These inspection may be supplemented (but not supplanted) by low-altitude air photography. Very important occupancy types, such as hospitals and fire stations, often require special inspections. These inspections may include a brief examination of the construction drawings, but normally do not include a mathematical analysis by engineers. (While desirable to obtain these dynamic analyses, costs have been prohibitive when hundreds of major structures have been involved.)

Table 1 is a summary description of a practical building classification system using construction materials. This table is based on experience gained over the past decade from the preparation of numerous vulnerability studies for governmental use in the United States. It also follows earthquake insurance practice. Experience has shown that not all earthquake resistive buildings can be placed into equivalent Classes 1 through 5, and Class 6 is therefore provided for these specialty cases. Each study area has regional construction variants which require minor revisions or interpretations to Table 1. It will be noted that Table 1 allows for further subdivision of Class 1C, if desired. Variants of the classification system are used by the private property insurance companies and by the California Department of Insurance. Only a summary description of a building classification system is given here, and Ref. 1 should be examined for further information on various classification systems.

ALTERNATIVE TO EARTHQUAKE INTENSITY

The authors have developed algorithms which minimize the use of intensity scales. Continued development of data for these algorithms will eventually bypass the use of intensity scales. In time, this change is expected to significantly improve the quality of the loss estimates.

The common approach to monetary loss estimates has been to group all kinds of damage, geologic effects, as well as human reactions into earthquake intensities, usually Modified Mercalli intensities. These commingled earthquake effects which include casualties and monetary losses are given as site or locality intensities. After plotting these intensities on a map, isoseismal lines are drawn which separate intensity grades. The isoseismal maps, or intensity-loss curves derived therefrom, can then relate intensity grades to casualties and/or monetary losses. Using an appropriate building inventory, the calculation of aggregate losses is readily achieved for any postulated seismic event using isoseismal maps (Ref. 2 and 3).

There are significant error potentials using these methods since intensity data on casualties and damage (and thereby monetary loss) are commingled with other earthquake effects which often are not compatible. There is no assurance that monetary losses and casualties were the principal determinants when the site or regional intensity was established. The next step in this customary methodology is the reverse of the foregoing; the generalized intensities shown on the isoseismal maps are interpreted to obtain casualty and monetary loss information. Clearly, mixing incompatible data to obtain an intensity and then reversing the process may be a significant source of interpretational error.

The authors are minimizing this error potential through the use of distance-loss algorithms whenever the source data permit. Site-specific or region-specific monetary loss data or damage information is directly used or interpreted to provide the basis for distance-loss curves, thereby bypassing the intermediate determination of intensity. This does not presently eliminate the use of conventional isoseismal maps in the absence of building damage information. Summarizing, the algorithms are distance-loss relationships obtained directly from loss experience whenever known; intensity information becomes a secondary source in many situations.

DISTANCE - LOSS RELATIONSHIPS

Geophysical Parameters

Figure 1 is a diagrammatic crossection through the earth showing the model for the distance-loss relationships. A line source is assumed for the origin of the seismic energy. The assumed focal depth is that which is common for earthquakes in the region under study, being 10 km for California.

The earthquake magnitude may be selected on the basis of the most probable for a given recurrence interval. More often, however, the maximum probable earthquake is selected by governmental response planners to be in a "fail safe" position. It is also not an uncommon position for private financial organizations to take a similar position. Epicenters are assumed to be located at the rupture midpoint, and usually located to maximize losses.

The length of the fault rupture along the line source in Figure 1 may be approximated by using any one of the equations developed by various authorities (Ref. 4, 5, and 6). The length of rupture approximation may greatly vary, depending upon the user's choice among the the equations given in the references. The use of some of these equations may create a problem when simulating an earthquake on faults such as the San Andreas, San Fernando, or White Wolf. In these cases, the surface traces of past events have been well-mapped and the earthquake magnitudes are well-known. The rupture equations in the references may give results which are substantially different from those observed in past earthquakes. The authors tend to prefer past experience on the fault under consideration as the basis for estimating future rupture lengths. Special equations were developed for these cases. Depending upon the chosen equation, there can be significant differences in the shape and size of the shaken area. In turn, the aggregate monetary losses and total number of casualties may vary significantly.

Distance - Monetary Loss Curves

Certain aspects of the characteristic shape of the distance-loss curves shown in Figure 2 require explanation. It has been stated by a number of careful observers after many American earthquakes that damage near the surface trace of the fault was not significantly different from that a few miles away when the structure was subjected only to ground shaking (and not from faulting or landsliding). The atlas to the thorough and classic Carnegie report on the 1906 San Francisco earthquake (Ref. 7) is often cited to the contrary, but see Louderback's observations in Ref. 8. It is also presumed that uniform soil conditions existed beneath all buildings for this uniform intensity. This observation of uniform damage is consistent with the model shown in Figure 1. However, one must also examine instrumental records from special instrumental arrays distributed at right angles to the fault. See, for example, the Parkfield earthquake of 1966 (Ref. 9) and the Imperial County earthquake of 1979 (Ref. 10). Little damage differential was noted among the few wood frame dwellings found near the strong motion instruments in the Imperial County earthquake. Tentatively, the portion of the distance-loss curve marked "A" is flat and represents observation-- certainly more investigation is necessary before this can be accepted as final.

The portion of the distance-loss curve marked "B" approaches the threshold of damage. This threshold varies with the building class as well as the kind of ground motion. Reported effects often include "imaginary" damage; imaginary damage is that which the owner/occupant believes to have occurred during the shock, but in fact it did not occur (or may have only partially occurred). It is most difficult for other than trained persons to distinguish between new and existing cracks; too often, cracks appear to be new to the untrained eye despite cobwebs or paint within the crack. When using the impersonal loss definition, the owner/tenant view is normally accepted. On that basis, the aggregate monetary losses become very inflated from the costs of patching pre-earthquake cracks and repainting many thousands of houses. The "B" portion of the curves will therefore vary with the definition of loss.

Long period effects are principally found as damage to high-rise buildings located at relatively long distances from the fault rupture. Human observation as well as seismographic records show that the short-period motions in the energy release region of an earthquake are damped and dispersed quickly, leaving the longer period motions dominant at large distances. Generally speaking, the greater the distance, the longer the ground motion period. At these greater distances, mostly the taller buildings with longer natural periods are adversely effected. Thus we can see the difficulty of assigning intensities to the multistory buildings in Anchorage after the 1964 Alaskan earthquake or after the 1967 Caracas earthquake. In each case, the "collapse hazard" types of one story buildings survived without damage but high-rise buildings were damaged (Refs. 11 and 12).

Figure 2 shows a family of characteristic distance-loss curves. From left to right, each curve represents a longer natural period of buildings. Computed or observed natural periods are not always available, and approximations based on story height are practical alternatives. Attenuation of seismic energy as a function of distance is a regional characteristic and therefore separate sets of curves are required for other seismic environments such as Puget Sound and eastern United States. Loss ratios at the fault trace for each building class listed in Table 1 are given in Table 2. Space does not allow a full presentation of the distance-loss algorithms, including consideration for long period effects.

Casualty Life-Safety Ratio

Life-safety ratio is used to estimate the number of deaths and injuries to persons within or adjacent to buildings. Its principal use to date has been to establish priorities for the strengthening or reconstruction of State of California buildings (Ref. 13). Its use can be expanded to follow the methods for distance-monetary loss curves discussed above.

For Table 3, the life-safety ratio is defined as the number of fatalities per 10,000 building occupants in the heaviest shaken areas of a great earthquake, being magnitude 8.25 in California. In Table 3, "large areas" implies auditoriums and other high occupancy loads.

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TABLE 1
SIMPLE IDENTIFICATION OF BUILDING CONSTRUCTION CLASSIFICATIONS

Building Construct. Class	Summary Description	Story Height Limit	Major Special Conditions
Wood Frame			
1A	1 to 4 family dwellings	-	Any height and area
1B	Mobile homes	-	
1C	Other habitational	2	
1C	Small non-habitational	3	Non-dwellings to 3,000 sq.ft.
1C	Wood frame -- other	-	Any height and area
All-Metal			
2A	Small	1	Up to 20,000 sq. ft. area
2B	Large	-	Any height and area
Steel Frame			
3A	Superior***	-	EQ resistive with damage control
3B	Ordinary	-	Poured R/C floors and roof**
3C	Other	-	Wood, metal, or precast R/C floors
Reinforced Concrete			
4A	Superior***	-	Superior EQ resistive with D/C**
4B	Ordinary	-	Poured R/C floors and roof**
4C	Precast, incl. lift slabs	-	Structural precast R/C, lift slabs
4D	Other	-	Wood or metal floors and roof
Mixed Construction			
5A	Reinforced concrete walls***	-	Superior earthquake resistive
5B	Non-reinforced walls*	-	Ordinary non-EQ resistive*
5C	Non-reinforced walls	-	Hollow masonry, adobe, tile
6	Special EQ resistive***	-	Special design for D/C

*Excluding hollow tile, hollow concrete block, hollow masonry, and adobe.
**Roof may be of any material if building is over 3 stories.
***Engineering review of existing inventories is recommended.
Abbreviations: EQ - earthquake; D/C - damage control; R/C - reinforced concrete

TABLE 2
MONETARY LOSS RATIOS

Class	Loss Ratio%	Class	Loss Ratio%
1A	8	4A	15
1B	10	4B	22.5
1C	9	4C	32.5
2A	7	4D	30
2B	9	5A	20
3A	12.5	5B	100
3B	15	5C	100
3C	20	6	varies

TABLE 3
LIFE SAFETY RATIOS

Class	Summary Description of Building Class	Life Safety Ratios: Earthquake Resistive Buildings (Non-ductile Concrete)	Ductile Concrete	Life Safety Ratios: Non-EQ Resistive Buildings
1A	1 to 4 family wood frame dwellings	2		4
1B	Mobile homes	2		4
1C	Large wood frame	5		10
2A	All-metal -- small	2		4
2B	All-metal -- large	8		15
3A	Steel frame, superior -- small area	5		10
	-- large area	25		50
3AB	Steel frame, intermediate -- small area	10		25
	-- large area	--		1500
3B	Steel frame, ordinary -- small area	15		40
	-- large area	--		1500
3C	Steel frame, other -- small area	25		50
	-- large area	--		1500
		Non-ductile Concrete	Ductile Concrete	
4A	Reinf. conc., superior -- small area	50	25	100
	-- large area	75	50	200
4AB	Reinf. conc., intermediate -- small area	200	50	500
	-- large area	1000	200	2500
4B	Reinf. conc., ordinary -- small area	300	75	1000
	-- large area	1000	200	2500
4C	Reinf. conc., precast	500	75	1500
4D	Reinf. conc., other	800	100	2000
5A	Mixed construction -- small, such as dwellings	10		200
	-- superior tilt-up	15		800
	-- ordinary tilt-up	20		1000
	-- other	40		2000
5B	Mixed constr., unreinforced masonry	--		4000
5C	Mixed constr., adobe, hollow tile	--		5000

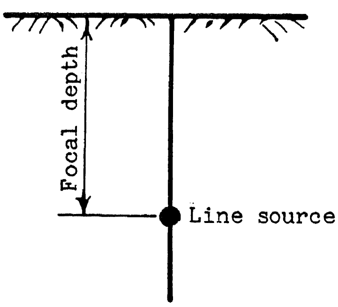

FIGURE 1

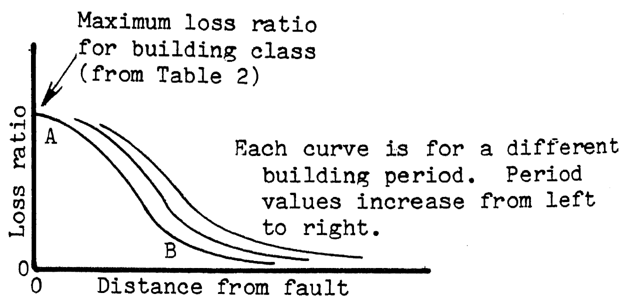

FIGURE 2