# EARTHQUAKE LOSSES AS A FUNCTION OF CONSTRUCTION TYPES

by

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## SYNOPSIS

Government agencies and insurance companies must realistically estimate life hazard and potential aggregate property damage along with their geographic distributions for destructive earthquakes in any relevant region. Often it is necessary to accomplish the foregoing by a rapid and economical methodology in order to quickly resolve specific planning problems. In this regard, recent studies have produced several practical procedures which have suited a few of these needs.

Specifically, this paper discusses some of these developments regarding aggregate property damage. Government sponsored studies have improved methods for establishing aggregate total losses for maximum credible events and percentage losses as a function of construction types. Methodology and typical results are given.

## INTRODUCTION

Any study of insurance relationships among potential monetary losses, earthquake intensity-frequency parameters (or equivalent parameters), and building construction classes should be directed to at least two fundamental questions:

A. What is the expected total monetary loss or, as often stated, the aggregate probable maximum loss for all insured construction in the event of the maximum probable earthquake in the underwriting area under consideration?
B. What is the average annual loss over long periods of time in a given region for each particular construction class?

Question A is important for several reasons. For the individual insurance company, an improper evaluation could result in company insolvency. Secondly, for the insurance industry as a whole, it involves the financial capacity of the private sector to accommodate a very large increased demand for earthquake insurance should this coverage be mandated for one or more classes of construction or types of occupancy. Thirdly, for government at Federal and state levels, it involves one factor in policy decisions regarding government's role in reinsurance should the private sector be unable to absorb the demands resulting from mandation.

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The second of the aforementioned questions addressed in this paper is based on a detailed study by the authors prepared by the U. S. Geological Survey for the U. S. Department of Housing and Urban Development (in press at this writing) using the metropolitan San Francisco, California area as a case history. The computational efforts of M. McGrath and S. Hansen of the U. S. Geological Survey are gratefully acknowledged. Additionally, the advice and guidance of Theodore H. Levin of the Department of Housing and Urban Development was most helpful during the more difficult stages of this study.

## SIMULATED LOSS TECHNIQUES

Simulated loss estimation techniques have been developed in recent years. These techniques show substantial promise in reducing the large uncertainties currently present in estimating total potential loss for any event and in establishing earthquake insurance rates. In a region such as San Francisco, earthquakes have damage patterns that are related to their magnitude and the associated distribution of shaking, to length of faulting and displacement along the fault, to the geographic distribution of buildings together with the type of construction and materials used and to other measurable characteristics. Using the historical seismic record, or some other estimate of the seismicity of the area, it is possible to estimate, by class of construction, the damage and associated losses likely to occur in the future for any postulated distribution of buildings.

## BUILDING CLASSIFICATION

Classification of buildings and other structures for earthquake insurance research purposes requires a knowledge of the relative damageabilities among building types. Additionally, the number of building classes becomes a practical matter involving the levels of insurance rates. In this latter context, it is obvious that a low seismicity will produce a relatively low level of rates and it follows that the rate differential among building classes tends to be small if the overall rate levels are low. Very small rate differentials, say one mill per $100 of insured value, simply are inadequate to pay for the field inspection costs for identifying the appropriate building classes for all but the very largest valued risks. As one result, in areas where the seismicity is low, building classification systems should be simple in order to keep overhead costs within reasonable bounds. Secondly, a country having a relatively few number of construction types for most of their buildings probably will require a simplistic building classification system, even though the rates may be high due to a high seismicity.

The basic key to a successful building classification system is identifying the degree of damage control exercised by the structural system and the ease in recognizing this damage control. Damage control may exist by design on the part of the architect/engineer, or by accident of design, or by being inherent in the construction material. For example, an all-steel gasoline service station falls into the last category. It follows, then, that an appropriately written set of building classification rules will identify the damage control features and reflect them in the classes.

The following is a listing of the six basic building classes for earthquake insurance purposes in common use in United States and also used for this study. Approximately 20 building sub-classes exist within this set, but sub-classes have not been repeated below for clarity.

Class I: Wood frame construction.
Class II: All metal construction.
Class III: Steel frame construction.
Class IV: Reinforced concrete construction.
Class V: Mixed construction.
Class VI: Earthquake resistive construction having damage control features.

Classes I through V are readily identifiable by their materials of construction. Some of the sub-classes of III through V require sub-professional or professional assistance. Class VI buildings require special attention by professional structural engineers for accurate application.

## EXISTING BUILDING INVENTORY

A detailed examination was made of 20 of the most promising sources of existing building inventories in the context of one specific objective, namely, the geographic distribution of property values by specific construction class and by census tract. Data sources included land-use planning maps, property tax records, building department archives, disaster office records, and insurance sources. While insurance company files were potentially the most useful, data conversion costs would have been prohibitive.

The following methodology for building inventory was adopted since the usefulness of readily available data sources and their adaptation were impractical for purposes of this study:

First, mapping: Geographically determine the distribution of inventory of each building class on suitable maps, with the distribution relatable to census tracts.
Second, quantification: Determine the extent of the total inventory of each building class for each census tract.
Third, tabulation: Tabulate the percentages by census tract.

## MONETARY LOSS CHARACTERISTICS

Monetary losses are a function of the ground motion characteristics at a given point and the building's damage control characteristics (if any). The Modified Mercalli Intensity scale is quite useful in this regard when properly interpreted for long period effects.

For our analysis purposes, the lower intensity limit is the threshold of damage, with this threshold varying with the kind of building as well as the kind of ground motion. The upper intensity limit is determined by that intensity where ground vibration effects to buildings are overshadowed by geologic effects such as landsliding, faulting, and failures of structurally poor ground. This upper limit is normally given as Modified Mercalli Intensity IX for insurance practice. The cut-off at IX is somewhat arbitrary since vibrational effects on buildings will increase with increasing intensity, but become overshadowed by building damage due to faulting, etc.

The shapes of the characteristics curves for intensity-loss relationships are quite variable, depending upon numerous factors. The lower limit of the loss for each curve is zero at intensities within a range from MM IV to MM VI. The upper limit is at MM IX. The shape in-between is variable.

Let us next consider curves #1 and #2 in Figure 1 which show the characteristic damage patterns for certain kinds of flexible frame multi-story buildings. Both buildings are considered to be equally earthquake resistive from a design standpoint, with certain non-structural elements being the only construction variable. The lower loss vs. intensity values are represented by a flattened curved line to represent, in part, "imaginary" losses assumed by the owner/occupant. If the loss is less than 100% (i. e., no collapse), then the curve flattens out at the top. In this case, the curve flattens since increasing non-structural damage no longer requires proportionate repair costs (for example, patching and painting may cost little more between a badly cracked wall and excessively cracked wall).

One possible effect of occupancy can be seen by comparing curves #1 and #2 in Figure 1. A warehouse or manufacturing structure might have a minimal number of partitions (curve #2) while a hotel would have numerous partitions (curve #1). The vertical spread between the curves represents the difference in loss due to occupancy related construction. Significant exceptions may exist to this vertical spread between curves. For example, if the partitions are of a high value type which are subject to little damage prior to building collapse, then the two curves may essentially coincide. It should be added that these two curves are principally applicable to Class III and Class IV structures which do not have shear walls.

Curves #3 and #4 in Figure 1 have the characteristic shapes for loss to rigid unit masonry buildings, and these curves are generally applicable to Class V structures as well as some Class III and IV buildings. The beginning of the curves at low loss levels represents hairline cracks at partition-masonry wall intersections and similar kinds of minor damage. The steepness of the straight line represents brittle failure of the walls and/or roof-to-wall connections. Actually for a specific building, the straight line could be replaced by a jagged line since loss would really be a series of step functions, with each step representing another brittle failure. Numerous acceptable variants exist.

## COMPUTATIONAL RESULTS

Computation of the average annual loss by class of construction for the San Francisco, California metropolitan area required us to estimate the distribution of ground shaking likely to occur in all of the census tracts in the area considered. To compute the distribution of shaking, we made use of the historical record of earthquakes from 1800-1974 with maximum Modified Mercalli Intensities greater than or equal to VI. Existing isoseismal maps were used when available. For earthquakes for which only maximum intensities are known, theoretical isoseismal maps were developed using intensity data from well studied earthquakes with similar maximum intensities. Using the distribution of intensity in each census tract and the percent loss by class of construction, the average yearly loss was computed using the historical seismicity over four different time intervals. While the historical record is certainly incomplete for at least the smaller shocks in the 19th century, the average losses based on the period 1800-1974 and 1800-1899 are still larger than for losses computed using the seismicity in the 20th century (Table 1). This is a result of the higher seismicity in the San Francisco area in the 19th century. The implication is that earthquake losses in the San Francisco area have been low in the 20th century, particularly since 1906. Should seismicity in the San Francisco area return to pre-1907 historical levels, substantially higher losses than those experienced over the past 70 years are likely to occur. It should be clearly understood that the values given in Table 1 are not insurance rates, since these values do not include taxes and other business costs.

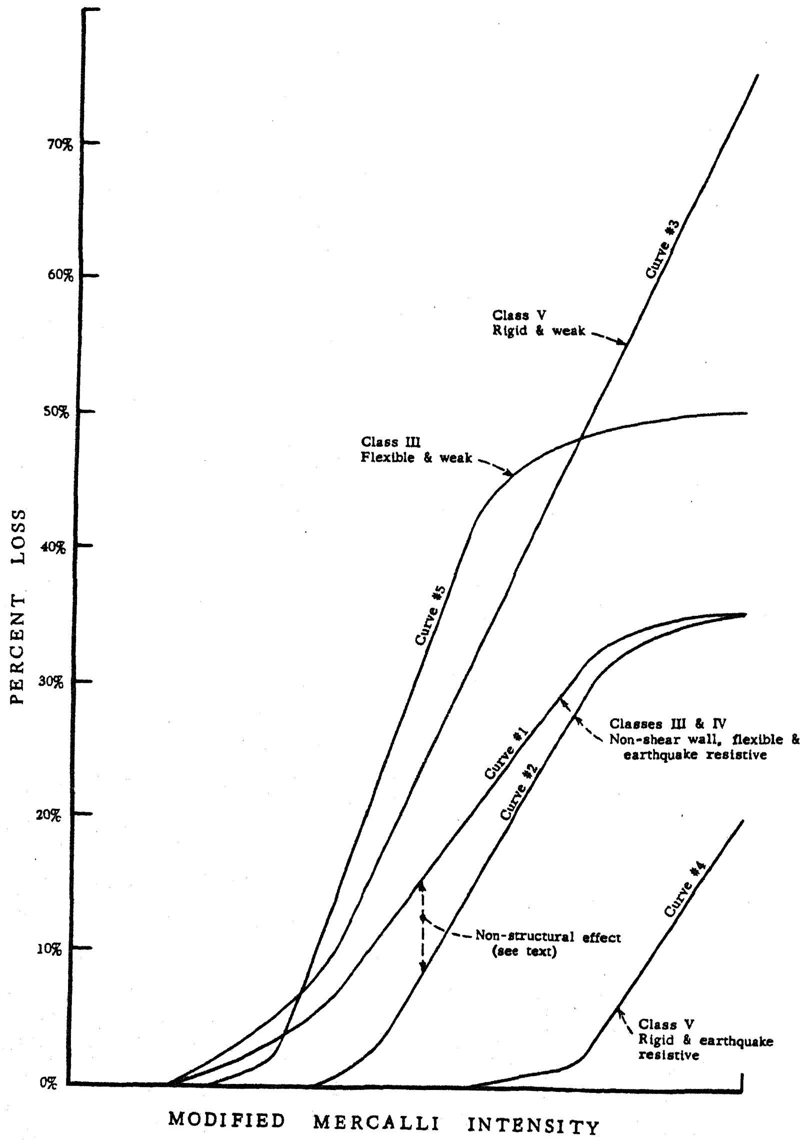


FIGURE 1. Characteristic loss patterns for selected building classes.

TABLE 1

EXAMPLES OF AVERAGE ANNUAL LOSS BY CLASS OF CONSTRUCTION

San Francisco, California, Metropolitan Area

| Selected Building Classes (Simplified Construction Description) | **Average Annual Loss in Percent of Replacement Value | | | |
|---|---|---|---|---|
| | *1800-1974 | *1800-1899 | *1900-1974 | *1907-1974 |
| All metal buildings: | | | | |
| II A - One story, all metal. | .118 | .130 | .102 | .043 |
| II B - Larger than II A. | .141 | .168 | .106 | .028 |
| Steel frame buildings: | | | | |
| III A - Steel frame carries vertical loads, reinforced concrete and/or metal deck roof and floors, reinforced concrete or reinforced masonry walls, special damage control features. | .214 | .275 | .132 | .008 |
| III B - Similar to III A, but non-reinforced masonry walls. No special damage control features. | .452 | .553 | .317 | .098 |
| III C - Includes III A and III B having intermediate damage control features. | .269 | .345 | .168 | .011 |
| III D - Steel frame with wood floors/roof. Walls are non-bearing concrete or masonry. | .452 | .553 | .317 | .098 |
| Reinforced concrete buildings: | | | | |
| IV A - Poured-in-place reinforced concrete (a) frame or (b) bearing walls or (c) mixed with steel frame having poured-in-place reinforced concrete floors, roofs, and walls. Special damage control features. | .269 | .345 | .168 | .011 |
| IV B - Similar to IV A, but non-reinforced masonry walls. No special damage control features. | .646 | .790 | .453 | .139 |
| IV C - Includes IV A and IV B having intermediate damage control features. | .374 | .482 | .231 | .014 |
| IV D - Precast concrete construction with average damage control features. | .775 | .948 | .543 | .167 |

*Time periods are inclusive.

**Values are representative and taken from families of loss-intensity curves.

## DISCUSSION

### C.T.J. Bubb (Australia)

When a community is massively damaged the level of construction costs may be much larger than before the disaster. For example, when darwin was extensively damaged by tropical cycline TRACY cost of construction of new houses was substantially greater due to the massive increase of costs, due to demands on supply of labour, materials and accomodation for labour as much of the existing housing was destroyed. Do you take this effect into account in your analysis ?

### S.A. Anagnostopoulos (U.S.A.)

Assume

1) A country does not have earthquake Insurance
2) A building of unacceptable quality collapses
3) The government may have replaced this building in the future, even if it had not collapsed during the earthquake

What quantitative description of damage should be used in this case ?

### Author's Closure

With regard to the question of Mr. Bubb, we wish to state that any methodology for computing monetary loss must be used in the context of the financial, legal, contractural, and political realities of the organizations and agencies paying the losses. Assume an extreme case for illustrative purposes, namely, that each building in a city is agreed by all concerned to be a total loss. From an insurance contractural standpoint, each owner would receive the full face value of his insurance policy. However, should the labor market or the materials market become misadjusted due to demand-supply conditions or due to consequential social adjustments, the owner would still only receive the face value of the policy. Thus, insurance oriented losses given in the paper can be considered as having a reliable basis.

To a certain degree, the Darwin experience is not applicable to the United States and probably not to a number of other countries. First, the devastated area must be remote with respect to sources of supply (labor and material). These supply problems could exist to some degree in a few American cities such as Salt Lake City, but not to a major degree in the large metropolitan areas of California where the author's studies were made. An underlying factor in the United States is the concerted efforts that the insurance companies, construction industry, and labor unions take after a disaster to stablize conditions. Past experience has shown this process works reasonably well. As a result, a computational methodology can have a firm basis. Engineers must recognize that the methodology is not transferrable if conditions in their countries are different.

If different factors are introduced, such as "social inflation", then the methodology must be modified to suit. "Social inflation" may be defined as abnormal cost increases in order to satisfy changed social needs such as replacing destroyed housing slum with much more costly improved new housing. There is no reliable way of predicting governmental policies and their resulting costs. But insurance mechanisms, be they in the public or private sectors and with the aforementioned cost controls, do allow for reliable monetary loss estimates.

With regard to the question of Mr. Anagnostopoulos, we wish to state that earthquake damage and the costs to restore structures to their original conditions are predicable, but those in excess of normal repair costs (i.e., replacing dilapitaded structure with newer better ones) is not a direct earthquake attributable cost. Indeed, these costs can occur without an earthquake, but an earthquake may become a convenient opportunity for government modernize the entire city.