THE BENEFITS AND COSTS OF SEISMIC BUILDING CODES[1]

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Introduction

Perhaps the most developed institutional structure for employing earthquake hazards information is use of building codes. Communities in earthquake prone areas typically adopt the provisions of the Uniform Building Code pertaining to earthquake resistant structures. Such building codes have been developed in great part on the basis of ground shaking information. Thus, one of the principal benefits of earthquake hazard mitigation programs is embodied in building codes which reduce property damage and risk to human life from earthquakes.

In estimating benefits of any program which reduces risk to human life, great care must be taken in relating dollar values to safety. Thus, our first task undertaken in the next section is to explain just how safety programs can be valued in terms of *a priori* measures of the value households place on reduced risk to life. Note then, that economists try to obtain information on how individuals value their own safety, i.e., how much they are willing to pay to live and work under safer conditions, not how much a particular person's life is worth in dollar terms, an objectionable and now discarded concept.

Section 3, building on Section 2, then develops the economic theoretical basis for assessing the benefits and costs of building codes including reduced property losses. Economic analysis is based on expectations. Thus, for example, if the odds of an event which would destroy five percent of the real estate in Los Angeles County are one in one hundred per year, then annual expected losses are $E(L) = 1/100 \cdot .05 \cdot$ (value of real estate in L.A. County).[2] If building codes would reduce damage by 10 percent then annual benefits of building codes (from this source) would be $.1 \cdot E(L)$.

Calculations of the sort described in Section 3 are impossible without some estimate of probability of, at least, major events in the study area, Los Angeles County. It is the purpose of Section 4 to examine the available evidence on event probabilities and likely damages to structures. New evidence on the history of the San Andreas fault is employed to provide data for an analysis using statistical failure theory. This analysis suggests that the annual odds of a large event may now be about 1.2 percent. It is argued that, in terms of expected levels of ground shaking, a large event on the San Andreas in southern California is now the dominant fraction of the overall earthquake risk in Los Angeles County.

The probability analysis of Section 4 is then applied in Sections 5 and 6 in order to quantify the benefits of building codes. These sections present preliminary order of magnitude estimates of the annualized expected benefits of reduced damage to structures and increased safety, respectively, from current building codes. These estimates are made for Los Angeles County only to demonstrate the methodology, using a great number of simplifying assumptions, relying mainly on the NOAA study of 1973 [NOAA, 1973]. However, our preliminary benefit results, when compared to costs which are developed in Section 7, suggest that the net benefits of building codes may be substantial and that current codes probably can be justified on the basis of benefit-cost analysis. Section 8 contains qualifications and a summary of our results.

Valuing Safety

The benefits associated with reduced loss of life can be defined as the value to individuals of reducing risk of death from an earthquake. Mishan [1971] was the first to note--at least in the context of benefit-cost analysis--that benefits of reduced risk could be defined independently of any notion of the "value of life". Rather, individuals require compensation to accept small risks voluntarily and such compensation can be observed and analyzed using econometric modeling in market situations--e.g., riskier jobs pay higher wages--and applied as a measure of the benefits of reduced risk (see for example, Thaler and Rosen [1975], and Schulze and Kneese [forthcoming]).

Thus, Mishan distinguished between the concept of the marginal value of safety, which is perhaps ethically acceptable, and earlier efforts to value human life based on lost productivity which have now been universally rejected by economists both on theoretical and ethical grounds. Thaler and Rosen made the initial estimates of the value of safety as determined from wage differentials between jobs varying in the level of job associated with risk of death. Unfortunately, however, their study dealt with a high risk class of individuals. The Thaler and Rosen estimate suggests that in current dollars a small reduction in risk over a large number of individuals which saves one life is worth about $340,000. In another study, Blomquist [1977] examines seat belt use and suggests that the figure might be $260,000. However, this estimate may be biased downward because individuals seem to have biased perceptions of risk which involve an element of personal control such as driving an automobile. Finally, Smith and Deyak [1975], based on work relating industrial wages to job related risk, have suggested that for a more typical population and for job related risks the figure may be about one million dollars. Clearly the marginal value of safety is not precisely known, and perhaps will never be since attitudes and risk preferences presumably can change over time, between groups, and can even vary in different situations. However, these estimates provide a range of values with which to make order of magnitude estimates of the marginal value of safety. Detailed studies can reveal the value of reduced risk in special circumstances such as hazard mitigation.

The theoretical basis of the marginal value of safety concept can be shown briefly as follows: assume that an individual has a utility function $U(W)$, where utility is an increasing function of wealth, W. If the risk of death in any period is, Π, expected utility in that period is $(1-\Pi)U(W)$. If we hold expected utility constant, we have $(1-\Pi)U(W)$ = constant, and the total differential of this equation is:

$$(1) \qquad -U(W)d\Pi + (1-\Pi)U'(W)dW = 0$$

where the prime denotes differentiation. Holding utility constant then implies that the increase in wealth or income necessary to offset an increase in risk is:

$$(2) \qquad dW/d\Pi = U/(U'(1-\Pi)).$$

This is the compensating variation measure of the cost to an individual attributable to an increased risk of death or the marginal value of safety.[3]

Methodological Basis for Valuing Building Codes

Focusing on reduced property losses and on safety benefits resulting from building codes, we can derive the individual's willingness to pay for codes by using the following notation:

Let P_E = annual probability of a large earthquake;

Π° = initial risk of death for the individual;

R = additional risk of death if a large earthquake occurs;

W = individual's wealth;

L = losses in the individual's wealth (property losses) if an earthquake occurs;

C = index of the stringency of earthquake resistive building codes;

U = utility, a strictly concave function of wealth;

and $E(U)$ = expected utility.

The individual is assumed to maximize expected utility which is

$$(3) \qquad E(U) = (1-P_E)(1-\Pi^\circ)U(W) + P_E(1-\Pi^\circ-R)U(W-L)$$

or the sum of expected utility if no event occurs $(1-P_E)(1-\Pi^\circ)U(W)$ plus expected utility if an event does occur $P_E(1-\Pi^\circ-R)U(W-L)$. Note in the latter state of the world, risk of death is increased by R and wealth is decreased by L, property losses. Codes will presumably reduce both property losses and risk of earthquake related death, so it is plausible to assume that R and L are both decreasing functions of C, $R(C)$ and $L(C)$ respectively where $R'(C), L'(C) < 0$. Taking P_E and Π° and $E(U)$ as fixed, we can obtain a compensating variation measure of the willingness to pay for codes by totally differentiating Eq. (3) and solving for dW/dC where we assume $R = R(C)$ and $L = L(C)$. This yields:

$$(4)\quad \frac{dW}{dC} = P_E\left\{\underbrace{\left[\frac{U}{P_E(1-\pi^\circ-R)U' + (1-P_E)(1-\pi^\circ)\bar{U}'}\right]}_{(a)}\left(-\frac{dR}{dC}\right) + \underbrace{\left[\frac{(1-\pi^\circ-R)U'}{P_E(1-\pi^\circ-R)U' + (1-P_E)(1-\pi^\circ)\bar{U}'}\right]}_{(b)}\left(-\frac{dL}{dC}\right)\right\}$$

The term in square brackets (a) is simply the marginal value of safety (defined in the previous section as $U/(1-\pi^\circ)U'$), but now adjusted for two states of the world, one in which no event occurs and expected utility is $(1-\pi^\circ)\cdot\bar{U}$ where $\bar{U} \equiv U(W)$ and the other in which an event does occur and expected utility is $(1-\pi^\circ-R)U$ where $U \equiv U(W-L)$. Thus, where we denote the marginal value of safety as MVS and define the reduction in risk to life from codes as ΔR, replacing $-dR/dC$, we can approximate the benefits of safety from codes to the individual as $P_E \cdot \text{MVS} \cdot \Delta R$ based on Eq. (4).

The term (b) in square brackets in Eq. (4) can be shown to be approximately equal to unity if R and L are small [Brookshire, et al., p. 111]. Thus, where we define ΔL as the reduction in property losses attributable to building codes if an earthquake occurs, replacing $-dL/dC$, benefits from this source are approximately $P_E \cdot \Delta L$ from Eq. (4).

Thus, the value to an individual of an earthquake building code program can be approximated as

$$(5)\qquad P_E(\text{MVS} \cdot \Delta R + \Delta L)$$

where

P_E = annual probability of an earthquake;

MVS = marginal value of safety;

ΔR = reduction in risk of death to the individual;

and ΔL = reduction in property losses.

In summary, the benefits associated with adopting and enforcing earthquake resistive building codes result from the fact that earthquake resistive buildings will sustain less damages in the event of an earthquake compared to conventional-not-earthquake-resistive buildings, and as a result, fewer lives will be lost as well.

The Probability and Expected Damages of a San Andreas Earthquake

The odds and the detailed effects on private property (buildings) of a large earthquake in the Los Angeles area are described in this section.

Probability of Earthquake Events Affecting Los Angeles County

Two types of events might be of particular concern for the study area of Los Angeles County. First, locally damaging events such as the Long Beach or San Fernando earthquakes appear to have an annual probability of at least 1/100, perhaps as high as 1/50 based on the classic article of event probabilities by Allen et al. [1965]. Second, a large event on the San Andreas (slightly above magnitude 8) would have an average ground shaking intensity of Modified Mercalli VII over the entire county (see NOAA, [1973]) and may have a probability of about 1/145 per year. Sieh [1978] has estimated that large events occur on the San Andreas fault in Southern California with an average recurrence interval of about 145 years based on excavations of late Holocene marsh deposits at Pallet Creek. The rest of this section focuses on better estimating the latter probability of a large event on the San Andreas in Southern California, using Sieh's information on the recent history of the fault.

Figure 1 shows approximate dates of probable large events on the San Andreas taken from Sieh [1978] but updated to include a newly discovered event occurring about 1600 A.D. Figure 2 shows the distribution of the 9 intervals between the 10 events that Sieh has identified.[4] This distribution strongly suggests that statistical failure theory as typically applied to aircraft wings, automotive tires, and manufactured parts might be appropriate. This statistical approach to mechanical or structural failures from stress, strain and wearing out uses the Weibull distribution which is a cumulative distribution of the form

$$F(t) = 1 - e^{-\alpha t^{\beta}} \qquad (6)$$

where F is the cumulative fraction in a given sample which has failed up to time t, from time zero. The rate at which failure occurs, f(t), is given by the probability density function which is just the time derivative of Eq. (6).

$$f(t) = \frac{dF}{dt} = \alpha\beta t^{\beta-1} e^{-\alpha t^{\beta}} \qquad (7)$$

Note that if $\beta > 1$ then the cumulative distribution given in Eq. (6) is "S" shaped and asymptotically approaches one and the probability density function is bell shaped and asymptotically approaches zero. If we consider large earthquakes on the San Andreas fault in Southern California to be failures, we can take the interval between large earthquakes to be the length of time, t, until failure occurs. Thus, we can plot the cumulative data from Sieh in 25 year intervals as shown in Figure 3. For the nine recorded intervals between failures (earthquakes), zero out of nine (0/9) occurred up to 50 years after the last event, one out of nine (1/9) occurred prior to 100 years and so on. Twenty-five year intervals were chosen to reflect some of the uncertainty over the precise date of historic earthquake events. Figure 3 could be constructed on one year intervals which would, of course, exaggerate the precision of Sieh's dating techniques. Similarly, 50 year intervals might be too wide, reducing the number of observations for analysis below the number of intervals.

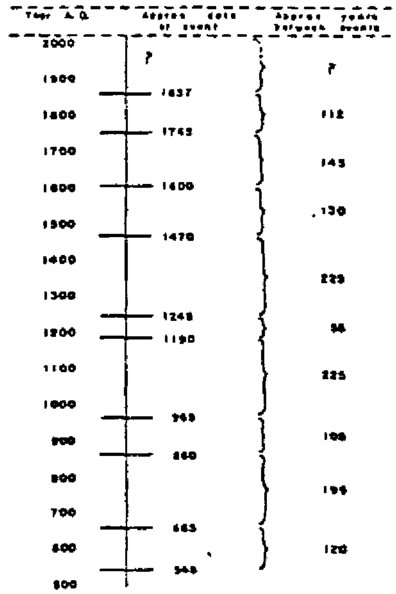

Figure 1

Approximate Dates of Past, Possibly Large, Earthquakes on the San Andreas Fault in Southern California

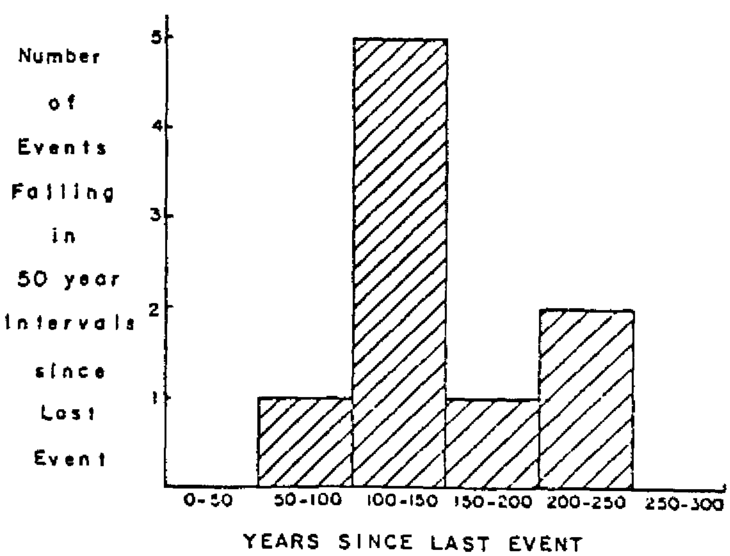

Figure 2

The Nine Intervals Between Events are Distributed as Follows

The geological record indicates that 10 events have occurred since 500 A.D.; on average, once each 145 years.

Only one event (of nine) has likely occurred within 100 years after the previous event and only three events (of nine) have occurred between 150-250 years after the previous events. Five (of nine) events have likely occurred between 100 and 150 years after the previous events.

The last large event on the San Andreas Fault in Southern California was the Fort Tejon Earthquake of 1857, 123 years ago.

A Weibull cumulative distribution can be fitted to the nine observations shown in Figure 3 as follows: the function, $F(t) = 1 - e^{-\alpha t^{\beta}}$, can be linearized for application of linear regression by rearranging terms and taking natural logs of both sides so

$$\ln \frac{1}{1-F(t)} = \alpha t^{\beta} \qquad (8)$$

Taking natural logs again gives

$$\ln\ln \frac{1}{1-F(t)} = \ln \alpha + \beta \ln t \qquad (9)$$

which is linear on the right-hand side. Linear regression yields the following equation fitted to the data of Figure 3:

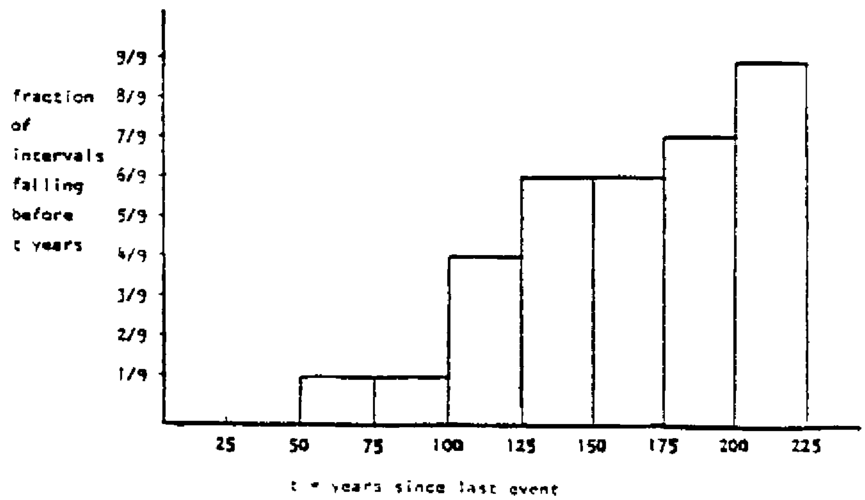

Figure 3

Cumulative Data in 25 Year Intervals

$$\ln\ln \frac{1}{1-F(t)} = \underset{(-8.19)}{-27.57} + \underset{(7.60)}{5.45} \ln t \qquad (10)$$

$R^2 = .89 \qquad F = 57.69 \qquad DF = 7$

Thus, estimates for α and β are:

$$\alpha = e^{-27.57} \text{ and } \beta = 5.45.$$

The equation is highly significant statistically. Each coefficient is significant at the 99 percent level as shown by the t-statistics in parenthesis below the estimated coefficients in Eq. (10). The high R^2 indicates that a large percentage of the variation in the dependent variable is explained by the postulated distribution, and the F-statistic indicates that the entire relationship is significant at the 99 percent level as well.

Given these estimates of α and β, the resulting estimated probability density function can be plotted against one based on the actual data, and this is shown for comparison in Figure 4. Starting in the year 1857, just <u>after</u> the Fort Tejon earthquake, the probability of an event is about .9 for the year 1980, 123 years in the future. However, given that no event has occurred up to 1980, standing in 1980 (=T*), Bayes' Theorem implies that the probability of an event is

$$(11) \qquad p(T^*) = \frac{f(T^*)}{\int_{T^*}^{\infty} f(t)dt}$$

For the Weibull distribution, p(T*) takes the form:

$$(12) \qquad p(T^*) = \alpha\beta(T^*)^{\beta-1},$$

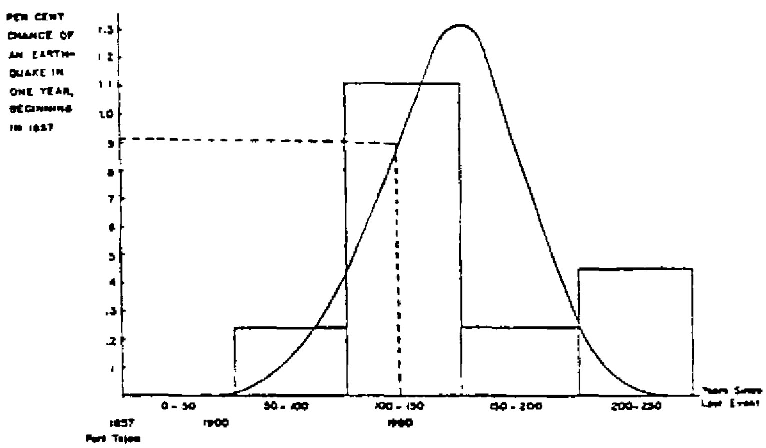

Figure 4

Probability Estimation Based on the Historical Record of Major Events

so the probability of an event occurring in the year T*, given no prior event since year zero, rises at the β-1 or 4.45 power over time. This relationship is shown in Figure 5 and implies that in 1980 the annual odds of a large earthquake on the San Andreas in Southern California are about 1.2 percent; by the year 2000, if no event has occurred, the odds will have risen to 2.3 percent. Using the same approach, the odds of an event <u>over</u> the next thirty years are about 45%.

In summary, given (1) that economic analysis utilizes an expected value approach; (2) that this analysis indicates current odds of a large event on the San Andreas to be about 1.2 percent; and (3) that a large event implies average ground shaking over all of Los Angeles County of MM VII (see NOAA, [1973]), we focus on analysis of a possible large event on the San Andreas throughout the remainder of the study. However, in expected value terms (expected loss in property and life) other events similar to the Long Beach or San Fernando events will, of course, contribute significantly (but to a smaller degree) to expected damages.

Finally, it should be noted that, based on a Weibull analysis similar to the one conducted here and on subjective estimates of the increased risk of an event given geophysical anomalies in the area of the San Andreas fault in Southern California, a recent report by the Federal Emergency Management Agency [1980] has estimated the odds of a large event as being from 2 percent to 5 percent this year (See Table 1. "Major California Earthquakes," p. 15). We thus use as a high estimate of risk the 5 percent figure in our analysis.

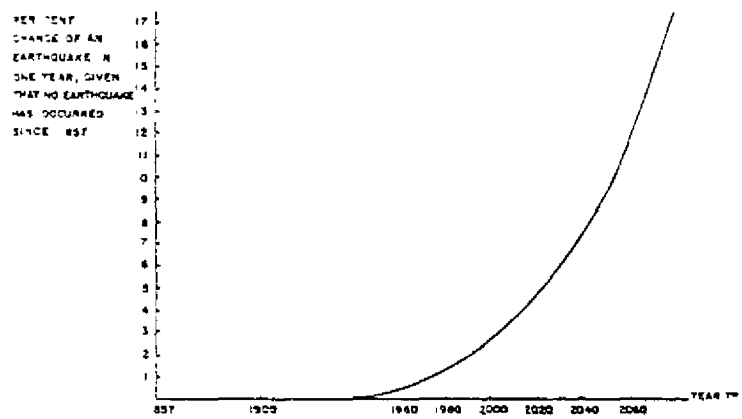

Figure 5

Probability of an Event in T*, Given no Event Occurs Before T*

Property Damage from Ground Shaking

Given an understanding of the odds of a large event, expected value of losses can be calculated if property losses are known. This section develops information on property losses.

The expected damage to single family dwellings in a major earthquake includes damages to home foundation, interior and exterior finishes, and masonry chimneys. The extent of these damages, if they occur, will depend upon the type of structure and finish of the home as well as its age, and upon the intensity of ground shaking.

Figure 6 shows estimates of expected damage to single family dwellings; that is, for each Modified Mercalli intensity level we can estimate the percentage of home value that would be damaged. These percentages have been calculated for new and old homes with chimneys and without chimneys, the lowest occurring in new and old homes without chimneys, and the highest occurring in old homes with chimneys (Figure 6 was derived from computer codes developed by Rinehart, Algermissen and Gibbons [1976]).

For commercial buildings (all structures except single family homes) damages are shown in Figure 7 (this figure is adopted from Algermissen, Steinbrugge and Lagorio [1978]). Note that potential damage is much higher than for single family dwellings, especially for unreinforced masonry, brick, or stone structures. Although such structures may no longer be built under current codes, a significant number of older buildings of this type survive in Los Angeles County, most built prior to the 1930-1940 period.

These relationships are used in the next section to develop property losses.

Benefits from Reduced Property Losses

Increasingly stringent earthquake resistive building codes have been adopted and enforced in California, following the 1933 Long Beach earthquake which killed over 100 people and resulted in 40-50 million dollars in property damage [NOAA, 1973, pp. 56-58]. Therefore, the year 1933 has been adopted as the dividing time for "old" versus "new" buildings. The "old" building designation refers to those structures built before 1933, assumed here to be built before the implementation of earthquake resistive codes and therefore, to be less earthquake resistant than "new" buildings built after 1933 under earthquake resistant codes (although in some cases, pre- and post-1940 data are used as an approximation in order to utilize census data).

Besides age, buildings are also differentiated by type, since earthquakes result in ground shaking and the magnitude of damages sustained by buildings varies with respect to type of structure. (For example, taller and unreinforced structures suffer heavier damages in an earthquake, other things being equal [see Figures 6 and 7].) To incorporate this factor into the analysis, a distinction has been made between single family dwellings (SFD), which are one or two stories and primarily wood frame structures, and commercial-industrial (C) buildings which are three or more stories and generally constructed of building materials other than wood. Multiple family dwellings are also included in the C category. Furthermore, since single family dwelling units with fireplaces and chimneys are damaged more extensively in earthquakes, other things being equal (Figure 6), the percentage of single family dwelling units (old and new) with chimneys has been estimated and incorporated into the analysis. Summarizing the foregoing discussion, the estimation of benefits associated with property loss reduction can be formulated as:

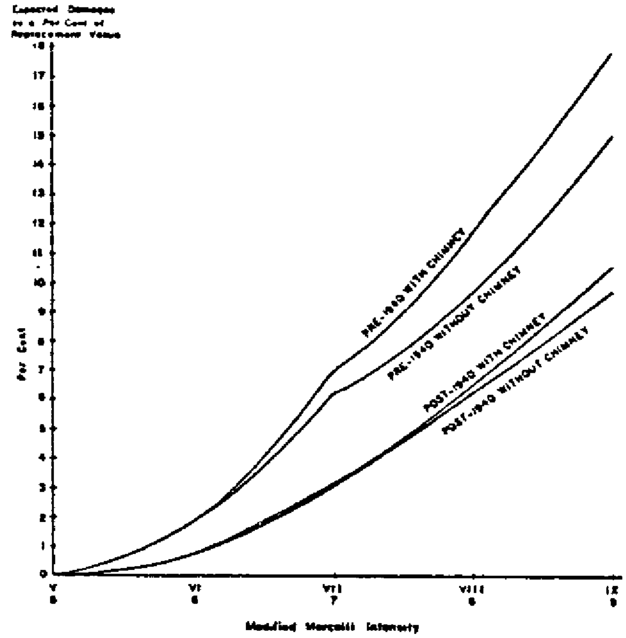

Figure 6

Damage to Single Family Dwellings

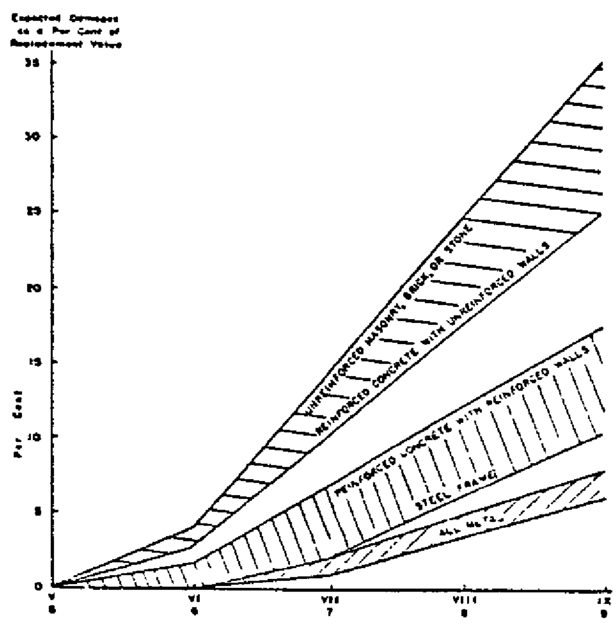

Figure 7

Damage to Buildings by Type, Excluding
Single Family Dwellings

$$\Delta L = \Delta L_{SFD} + \Delta L_C$$

where:

$$\Delta L_{SFD} = (\text{value of SFD}) \cdot W_{SFD} \cdot \Delta D_{SFD}$$

$$\Delta L_C = (\text{value of C}) \cdot W_C \cdot \Delta D_C$$

where:

ΔD_{SFD} = change in fraction of damages sustained by single family dwelling units attributed to the incorporation of earthquake resistive building codes, taking into account the percentage of units (old and new) with chimneys

ΔD_C = change in fraction of damages sustained by commercial-industrial buildings (including multi-family dwellings) attributed to the incorporation of the earthquake resistive building codes

W_C = value of new commercial-industrial buildings plus multi-family dwelling units as a proportion of the value of total (old and new) commercial-industrial buildings (including multi-family dwellings)

W_{SFD} = value of new single family dwelling units as a proportion of the value of total (old and new) single family dwelling units.

Based on the information in Figures 6 and 7, for an area-wide average ground shaking intensity of VII, ΔD_{SFD} is estimated at 3.5 percent of building replacement cost, and ΔD_C is about 5 percent. These estimates of ΔD_{SFD} and ΔD_C are probably conservative because the relationship between fraction damaged and ground shaking intensities becomes nonlinear for high ground shaking levels. The fractions of replacement value damaged are applied to the valuations of private and commercial properties made by the Los Angeles County Assessor's Office of $45.9 billion and $80.46 billion respectively. These valuations are weighted by W_{SFD} and W_C, .74 and .83 respectively, which reflect the proportion of the capital stock that is "new" (post-1933). This proportion is estimated by using a "new"/"old" (pre-1933) building inventory of dwelling units conducted by the Federal Emergency Management Agency in Los Angeles.

Utilizing the available data, the reduction in financial losses (or savings) to the community due to reduced property damages in buildings built under earthquake resistive codes would amount to some $4.51 billion in 1980, in the event of a major earthquake on the San Andreas fault. If one takes the probability of such an event this year to be 1.2 percent from the Weibull analysis of Section 4, the expected value of this savings is $54 million per year. If one uses the higher FEMA estimate of 5 percent, the benefit is $226 million per year.

Benefits from Increased Safety

Because structures are made safer when they are built according to earthquake resistive building codes (i.e., property damage is reduced), fewer lives will be lost and less injury will occur in the event of a major earthquake. The benefit to the community in terms of the reduced risk to life can be approximated using the following formulation:

$$MVS \cdot (\Delta R_{SFD} + \Delta R_C)$$

where:

MVS = the marginal value of safety reflecting lives saved

$$\Delta R_{SFD} = (r^{\circ}_{SFD} \cdot \frac{\Delta D_{SFD}}{D^{\circ}_{SFD}} \cdot W_{SFD}) \cdot \text{Population}$$

$$\Delta R_C = (r^{\circ}_C \cdot \frac{\Delta D_C}{D^{\circ}_C} \cdot W_C) \cdot \text{Population}$$

where:

r°_{SFD} = risk of death per 100,000 population in single family

r°_C = risk of death per 100,000 population in commercial structures (including multi-family dwellings) without earthquake resistive building codes)

D^j_{SFD} = damage to single family dwellings, as a percent of replacement cost, in a major earthquake; $j = 0$, without earthquake resistive codes; $j = 1$, with earthquake resistive codes

D^j_C = damage to commercial structures (including multi-family dwellings), as a percent of replacement cost, in a major earthquake; $j = 0$, without earthquake resistive codes; $j = 1$ with earthquake resistive codes

ΔD_{SFD} = $D^{\circ}_{SFD} - D^1_{SFD}$

ΔD_C = $D^{\circ}_C - D^1_C$

W_{SFD}, W_C = weights to reflect new buildings as proportion of the totals (as previously defined).

The risk of death in an earthquake varies with the time of occurrence during the day, depending on where large segments of the population are at those times. Expected numbers of deaths have been estimated for a major event on the San Andreas fault occurring at either 2:30 a.m., 2:00 p.m., and 4:30 p.m. [NOAA, 1973, pp. 151-169]. Many of the deaths at the 4:30 p.m. hour would be caused by freeway collapse during the rush hour, a factor not accounted for by building codes. The estimate of likely deaths at the early morning hour (32.14/100,000) reflects the fact that the majority of the population in Los Angeles County would be in single family dwellings which are mostly safe wood frame structures (although about one-third of the population is in higher risk multi-family dwellings). However, the expected death rate is much higher in the afternoon (143.65/100,000), when it is assumed that only 40 percent of the population would be subject to the lower risk in dwellings and 60 percent of the population would be found in more hazardous commercial areas.

These risk of death factors are apportioned between single family dwellings and commercial structures (including multi-family dwellings) for the 2:30 a.m. and 2:00 p.m. hours. Then, a weighted average risk for any hour can be estimated; in this analysis, the 2:30 a.m. risk is assumed to be relevant for 16 hours and the 2:00 p.m. risk is assumed relevant for the remaining 8-hour work day to arrive at a conservative weighted average for risk of death if a major event occurs.

In order to estimate the reduced risk (or improvement in safety) due to earthquake resistive building codes, the average risk to life is apportioned between risk in old buildings built before codes were in effect and risk in new buildings. This is accomplished by utilizing information about the proportion of new single family dwellings and new commercial buildings to old dwellings and buildings. Assuming this approximates the proportion of the population in new/old structures, risk of death in new and old structures is derived.[5] The property damage estimates in Figures 6 and 7 indicate a 53 percent improvement with earthquake resistive building codes in new versus old single family dwellings, and a 45.5 percent improvement for commercial structures. Assuming that deaths associated with structure damage decrease proportionately with reductions in damage, then R_{SFD} can be estimated to be 10.98 lives saved/100,000 population in the new single family dwellings due to the implementation of earthquake resistive building codes in about three-fourths (W_{SFD} = .74) of total single family dwellings. Likewise, R_C is estimated to be 31.74 lives saved/100,000 in new commercial structures due to codes in 83 percent of the total current stock of commercial buildings (W_C = .83).

Applying these risk factors to a 1980 population estimate of 7.1631 million people in Los Angeles County, the expected savings in life due to earthquake resistive building codes used in structures is about 3,060 deaths avoided. Using a marginal value of safety factor of $340,000-1 million per life saved [Thaler and Rosen, 1975, and Smith and Deyak, 1975], the safety benefit in terms of lives saved due to codes is some $1.041 billion at the lower bound, and some $3.06 billion at the upper bound. Multiplying by an assumed probability of an event this year of 1.2 percent, the expected value of safety due to codes in 1980 ranges from $12.5 million to $37 million. If one uses the higher 5 percent probability of an event, safety benefits range from $52 million to $154 million.

The Costs of Earthquake Resistive Building Codes

In general, earthquake resistive building codes require such precautionary measures as extra bracing between the structure frame (either cross-bracing or sheathing of the inner walls), extra bolting and carrying through of the studs of the structure to its foundation, and extra care and reinforcement in chimney and fireplace construction. In split-level dwellings, extra costs are associated with the requirement of extra wide walls on the garage in the lower level to reduce the possibility of collapse. These types of code designations are required not only for earthquake resistance but also for wind resistant design of dwellings and commercial structures.

Efforts directed toward obtaining the impact of the earthquake resistive building codes on building cost did not succeed in locating any published or quotable estimations of associated costs. Thus, a range of cost estimates obtained from discussions with experts in earthquake resistive building design are used in this analysis. An approximation of 2-3 percent of construction costs is associated with adherence to earthquake resistive building codes in single family dwellings, and 3-5 percent in commercial structures. It should be noted, however, that these costs are not only for earthquake resistance, but also for wind resistance in structures.

Annual extra costs of construction can be derived by applying a real rate of interest of 2-1/2 percent to total costs.[6] Use of this real rate is identical to 9 percent over the life of a home or commercial loan. Therefore, the cost, to Los Angeles County for construction of earthquake and wind resistant buildings as an annualized cost is formulated as:

$$\text{Annualized Cost} = \text{CRF} \cdot [(\text{Total Construction Costs of SFD}) \cdot \Delta C_{SFD} \cdot W_{SFD} + (\text{Total Construction Costs of C}) \cdot \Delta C_C \cdot W_C]$$

$\text{CRF} = i/\{1-[1/(1+i)^T]\}$ = Capital Recovery Factor

i = the real rate of interest paid (above the inflation rate) on mortgage loans

T = length of loan (taken to be 30 years)

ΔC_{SFD} = the percentage increase in the construction cost of single family dwellings due to the incorporation of earthquake resistive building codes

ΔC_C = the percentage increase in the construction cost of commercial-industrial structures (including multi-family dwellings) due to the incorporation of earthquake resistive building codes

W_{SFD}, W_C = weights to reflect new buildings as a proportion of the totals (as previously defined).

Total construction costs of single family dwellings and of commercial-industrial structures (and multi-family dwellings) are approximated by the total values of single family dwellings and of commercial structures (and multi-family dwellings), specified as \$45.09 billion and \$80.46 billion respectively. Weighting these values to reflect the proportion of "new" structures which are assumed to be built according to code specifications (74 percent of all single family dwellings and 83 percent of commercial structures), the range of total costs paid out per year by the community is estimated to be \$127.6 million to \$207.4 million due to the incorporation of <u>both</u> earthquake resistive and wind resistive building codes.

Obviously, most costs could be attributed to wind resistance and incremental costs of earthquake resistance would be a minor fraction of the $127.6-$207.4 million range for annual joint costs. The proper way to treat this problem from an economic-theoretical perspective is not to apportion costs, but rather to calculate the sum of the benefits from earthquake and wind resistant structures. We will, rather, on a completely arbitrary basis, allocate half of the costs calculated above to earthquake annual cost of earthquake building codes. Thus, as an order of magnitude approximation, we estimate the annual cost of earthquake building codes to fall in a range of $63.8 million - $103.7 million for Los Angeles County.

Conclusions and Caveats

The results from analyzing the post-1933 implementation of earthquake resistive building codes in Los Angeles County are summarized below in the estimates of expected property and safety benefits compared to increased construction costs:

Expected Value of Benefits in 1980
=$67 million to $91 million for a 1.2 percent probability, and $278 million to $380 million for a 5 percent probability of an event

Annualized Costs in 1980
=$64 million to $104 million

It is important to note that benefits are biased downward for several reasons. Some important components of benefits that have not been included due to the difficulty of estimation are the expected value of savings due to codes from the possibility of a San Fernando or Long-Beach type event, expected benefits from the lessening in emergency operations requirements due to safer structures built under codes, and expected savings from the decreased economic disruption that would occur from faster restoration of damaged buildings. Furthermore, though costs due to earthquake resistive building codes are estimated as a fraction of the costs of both earthquake and wind resistant structure design, the benefits estimation covers benefits in an earthquake only and does not account for benefits due to wind resistance for comparative purposes. Finally, a comparison of benefits and costs should not be undertaken for one year on an annualized basis; rather, discounted present values over all future probabilistic states of the world should be used as the conceptual basis.

In summary, the comparison presented between the approximations of expected value of total benefits due to earthquake resistive codes in 1980 and the annual costs associated with adhering to codes in building construction reveals that benefits tend to overlap but mostly exceed costs in Los Angeles County at the present time. For the reasons stated above, this comparison of annual benefits and costs may be viewed only as a qualified justification for the incorporation of earthquake resistive building codes into structure design. (For a complete report on this research see Brookshire et al.[1980].)

FOOTNOTES

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2. As a first approximation, we ignore risk aversion in this example.

3. We ignore bequeathment in this simple model which, however, does give characteristics to the marginal value of safety which are consistent with existing empirical studies.

4. Note that the distribution shown in Figure 2 for recurrence intervals shows no evidence of bimodality as claimed by Sieh in his 1978 article. This is the result of including the newly discovered event at about 1600 A.D. which effectively adds two intervals to the 100-150 year column and takes one interval away from the 200-250 year column, thus giving the distribution shown, rather than the bimodal distribution implicit in Sieh's earlier speculative argument of bimodality.

5. See Brookshire, et al., Appendix B, for details on the methodology used to estimate risk of death if no earthquake resistive building codes existed.

6. The historical real annual rate of interest paid on mortgage loans has been about 2.5 percent.

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