THE USE OF EARTHQUAKE RESEARCH
FOR DEVELOPING A STATE GOVERNMENT'S SEISMIC SAFETY POLICY

Delbert B. Ward[I] and Craig E. Taylor[II]

SUMMARY

    Public policies for earthquake hazards reduction should be derived
from scientific information about risk levels that leads to accurate
assessments of policy benefits which, in turn, may be compared with
policy costs. Earthquake safety has a social cost, whether it is in
risk to property and life or in dollars to mitigate the risk. This paper
contains a method for deriving public policy from such information and
assessments. In specific situations, one of which is treated in this
paper, such an analytical procedure for policy development illuminates
the ramifications of a particular policy action. In the development of
the methodology, some research data could be used directly. However,
most data required adaptation to the specific applied problems.

LINKAGE BETWEEN STATE SEISMIC SAFETY POLICY AND RESEARCH

    State government actions in the United States greatly influence
the extent to which earthquake safety concerns are included in land
development and building construction. States have shaped seismic
hazards programs through adoption of seismic safety policies, provision
of statutory authorities to state agencies and local governments,
and ascription of responsibilities to the private sector.

    State seismic safety policies evolve largely from research infor-
mation that scientists produce. In that sense, seismic safety policy is
affected by the subject-matter, quality, thoroughness, and bias in such
information. In this paper, we discuss how earthquake research has been
used to develop seismic safety policy. In particular, we describe the
use of available data to prepare a state policy for replacement or repair
of existing buildings that may be vulnerable to earthquake damage. We
discuss the method of policy analysis, the research data used, problems
encountered in adapting the data, and the adequacy of available data for
policy decisions.

    In the process of adapting seismic research for use in public
policy development, it becomes apparent that there is much that is un-
known that is needed to draw more definitive conclusions about seismic
risk, that new techniques are needed to put scientific data into a
workable form, and that some conclusions must be drawn from incomplete
or uncertain data. Uncertainty of some data causes special problems for
policy decisions on seismic hazards when risk, although definitely
present, is not high. Seismic safety policies are made whatever research

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[I]Executive Director, Utah Seismic Safety Advisory Council

[II]Research Analyst, Utah Seismic Safety Advisory Council

deficiencies may remain. To illustrate the process of policy development, we shall outline procedures for analyzing possibly unsafe existing buildings and also the basis for an associated feasible program for replacing or retrofitting hazardous buildings in Utah's seismic environment. Other seismic safety programs, besides those for existing buildings, have evolved through the application of the procedures we describe.

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DEVELOPMENT OF A SEISMIC SAFETY POLICY
FOR SELECTED CLASSES OF EXISTING BUILDINGS

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A Guideline For Decisions

Benefit-cost methodology was used as a guideline for policy decisions relating to seismically unsafe existing buildings. Estimates of losses to life and property in various seismic environments in Utah were compared with costs for retrofitting or replacing classes of potentially hazardous buildings. Such comparisons depend upon the quality of estimates of the probable seismic environment, of likely damage resulting from earthquakes of a different strength, and of hazards to life resulting from the likely damage. Information also must be compiled about existing buildings, such as their number, locations, construction types, and occupancy rates. Some of this information may be obtained to any desirable degree of accuracy from files or the field. Other information can only be estimated from research data.

The methodology used has implications statistically valid only for aggregate conditions among classes of buildings in given seismic zones and not for particular facilities. We also have eschewed postulating an epicentral location for a maximum credible earthquake and determining its consequences. Such a postulate, useful for emergency preparedness programs, does not allow consideration of the damage expected from a variety of earthquakes of different strengths and that are expected over many years. A single postulated earthquake, for instance, may entail damage to facilities that we desire to distinguish, since considerations given to facilities damaged only in a rare severe earthquake are different from considerations given to facilities that may be damaged even in moderate earthquakes. We have modelled earthquake damage on a statistical basis. Accordingly, we use a statistical basis for damage effects and policy recommendations for hazards reduction.

The Methodology Condensed

Simplified mathematically, the benefit-cost method implies that seismic hazards reduction through replacing or retrofitting potentially unsafe buildings is justified if B > C x i, wherein B equals the mean annual benefits (building losses prevented, secondary damage avoided, lives saved), C equals the cost of replacement or retrofitting, and i equals the appropriate money discount rate. Use of this equation requires knowledge of earthquake effects on buildings, expected damage levels, and life safety hazards. The equation, although suspect as the sole determinant of policy, guides one to search for material relevant to policy.

Estimates of seismicity are indispensible in making estimates of losses and possible lives saved. The goal is to estimate all losses to

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selected classes of buildings and for the entire range of expected earthquakes and then to compare such estimates with those losses expected if replacement or seismic safety modifications are made. The functional expression is

$$\text{Eq. 1} \qquad A_{s,z} = \sum_{i=I}^{XII} L_{s,i} \times F_{z,i}$$

wherein $A_{s,z}$ is the expected loss to a structure of type s in seismic zone s, $L_{s,i}$ is the expected loss to a structure of type s at intensity i, and $F_{z,i}$ is the annual mean frequency of intensity i at a site randomly chosen in zone z. An analogous formula was developed for estimating injuries and life losses. Although numerous criticisms exist of placing a monetary value on life, we have found that structural losses alone cannot justify seismic hazards reduction by replacement or retrofitting in Utah's seismic environment. Hence, information about expected life loss is needed to compare various seismic safety programs both with one another and also with other safety programs. Equation 1 implies that loss estimates are for classes of structures and have validity for individual structures only as a statistical mean.

S.T. Algermissen, K.V. Steinbrugge, and H.L. Lagorio have provided a taxonomy useful for estimating expected losses to classes of construction at given earthquake intensities [1], [2]. In the absence of similar data for Utah, we assume that the California experience is applicable. Table 1 indicates roughly the specific values for $L_{s,i}$ which we borrowed from the aforementioned authors. Estimates of expected deaths and injuries at given earthquake intensities were derived from the methodology used for a U.S. Geological Survey report on earthquake losses in Salt Lake City [3].

In order to use the data referenced above, estimates of annual earthquake frequencies within seismic zones are needed. Not desiring to employ a methodology designed to make site-specific estimates, we did not use directly a methodology developed by S.T. Algermissen and D.M. Perkins [4] to estimate maximum expected ground accelerations, but instead began with the Utah subdivisions of macrozones of significant seismicity as prepared by those authors. In Utah, three zones, numbered zones 32, 33, and 34, are of special interest (See Figure 1). Annual earthquake frequencies can be determined for epicentral intensities from

$$\text{Eq. 2} \qquad \log_{10} N = a + bI.$$

The following specific equations are obtained.

For zone 32, $\log_{10} N = 2.03 - 0.56I.$
For zone 33, $\log_{10} N = 2.90 - 0.56I.$
For zone 34, $\log_{10} N = 2.65 - 0.56I.$

Recognizing both that the historical earthquake record in Utah is not extensive and that recent geological evidence indicates that the historical record may underestimate the seismicity near the Wasatch fault in zone 33, which recently has been identified as "seismic gap," we

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subdivided zone 33 into two new zones, zone 33A and zone 33B, and adjusted estimates of epicentral frequencies to account for geological evidence. With zone 33A defined as all locations within 20 kilometers of the Wasatch fault, combined with the fact that about 1/2 of all earthquakes of Intensity V or above in zone 33 have occurred in zone 33A, the following equations were obtained for the two subzones.

For zone 33A, $\log_{10} N = 2.40 - 0.52I$.
For zone 33B, $\log_{10} N = 2.70 - 0.58I$.

Given the zone-specific frequency estimates for epicentral intensities, frequencies of intensities at sites randomly chosen within a given zone are obtained by estimating the areas affected at such intensities within the zone (adjoining zones may have some significant effects) and dividing by the total area of the zone. Various modellings of attenuation patterns may be used to estimate the affected areas. The basic model used in the work reported here was derived from the equation

$$\text{Eq. 3} \qquad I_o - I = n \log_{10} \left[\frac{(\Delta^2 + h^2)^{\frac{1}{2}}}{h} \right],$$

wherein Δ = The epicentral distance from I_o to I,
$\quad$ h = depth of focus,
$\quad I_o$ = maximum intensity at the epicenter,
$\quad I$ = intensity at Δ from the epicenter, and
$\quad$ n = an exponent determined empirically.

Seismic records of Utah earthquakes were used to establish a reasonable focal depth, which is an extremely sensitive parameter in the equation. For example, the choice of a focal depth of 10 km. as opposed to 5 km. would multiply loss estimates by four.

A further refinement in the attenuation model accounts for possible influences due to soil variations. Here, the procedure employed was borrowed from Algermissen, Steinbrugge, and Lagorio ([1], p. 77), with minor adjustments for Utah soil conditions.

Table 2 contains 100-year site-specific earthquake estimates that were computed in accordance with the techniques and assumptions outlined above. From these data, and using Equation 1, we derived the 100-year estimated losses for selected classes of buildings, as shown in Table 3. The estimate of a 15 percent 100-year loss to class 5E structures in zone 33A may be compared to the 144 percent 100-year structural loss expected for similar class 5E structures in the San Francisco Bay area (Cf. [1], p. 118).

Using data in Table 2 in conjunction with other data, we determined the following 100-year baseline mortality rates due to seismicity. These rates must be further adjusted to account for type of occupant and type of structure. Injury rates, not included here, are derived in a similar manner.

For zone 32, the mortality rate = 0.0004%
For zone 33A, the mortality rate = 0.1703%

For zone 33B, the mortality rate = 0.0098%
For zone 34, the mortality rate = 0.0077%

Overall Conclusions and Policy Determinations

When the methodology just described is applied to specific classes
of buildings and the specific situation in Utah, overall results show
that expected property losses due to earthquakes fall extremely short
of costs to replace or retrofit existing buildings. For existing school
facilities, estimated annual mean seismic losses to property are $706,000
(1978 $); yet, the estimated replacement cost of class 5E structures
alone (a class very costly to retrofit) totals $640,000,000. Estimates
of deaths (0.58 annually) and injuries (9.43 annually) show that seismic
replacement or retrofitting programs fare very poorly in contrast to
other life safety programs, including those to ensure seismic code
compliance.

For the purposes of this paper, the important information to be
gained from the above discussion is not contained in the specific results
and policy conclusions briefly described above. Rather, the important
point is that we have a process for obtaining appropriate information
so that state seismic safety policy can be made rationally and with some
knowledge of the likely costs and benefits.

As is evident in the discussion of our methodology, we have relied
heavily upon research work by a number of authors. Yet, that research
work required adaptation in nearly all cases. Moreover, the risk assess-
ment methodology itself was constructed from a number of individual
research studies, often in ways that the original researchers probably
had not anticipated.

Application of research to policy decision making processes also
exposes a fundamental problem that requires attention--namely, that the
literature is thin, indeed, on procedures for practical utilization of
the research. Perhaps if researchers had been more aware of the particu-
lar applied uses of data, we could have avoided making gross assumptions
in a few situations in order to obtain results appropriate for policy
assessment.

This paper, then, has summarized the development of a methodology
for public policy assessment pertaining to earthquake safety. In
developing the methodology, numerous problems arose, some of which were
solved by appeal to scientific findings, but most of which were dealt
with by adaptation of whatever scientific information existed to the
specific problems at hand.

REFERENCES

1   Algermissen, S.T., K.V. Steinbrugge, and H.L. Lagorio (1978) _Estimation of Earthquake Losses to Buildings (Except Single Family Dwellings)_. U.S. Geological Survey, Open-File Report 78-441.

2   Algermissen, S.T. and K.V. Steinbrugge (1978) "Earthquake Losses to Buildings in the San Francisco Bay Area," _Proceedings of the Second International Conference on Microzonation for Safer Construction_, pp. 291-302, vol. I, San Francisco.

3   U.S. Geological Survey (1975) _A Study of Earthquake Losses in the Salt Lake City, Utah Area_. U.S. Government Printing Office.

4   Algermissen, S.T. and D.M. Perkins (1976) _A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States_. U.S. Geological Survey, Open-File Report 76-416.

Table 1

SELECTED MEAN BUILDING LOSSES AT GIVEN MODIFIED MERCALLI INTENSITIES
(As Percents of Replacement Costs)

Type of Building		Modified Mercalli Intensity				
Class	Brief Description	X	XI	VIII	VII	VI
5E	Unreinforced, mixed construction	50%	35%	25%	14.5%	4%
5C	Mixed construction, ordinary seismic damage control features	23%	17.5%	12.5%	7%	2%
5B	Mixed construction, superior seismic damage control features	18%	13%	7.5%	2%	0%

Table 2

ESTIMATED 100-YEAR EARTHQUAKE FREQUENCIES
IN UTAH BY SEISMIC ZONE AND BY INTENSITY

Zone	Intensity				
	X	IX	VIII	VII	VI
Zone 32	0	0	0.0006	0.0028	0.0124
Zone 33A	0.0085	0.0274	0.0636	0.2195	0.8098
Zone 33B	0.0002	0.0009	0.0111	0.0647	0.3764
Zone 34	0.0001	0.0014	0.0083	0.0393	0.1726

Table 3

ESTIMATED 100-YEAR BUILDING LOSSES DUE TO EARTHQUAKES
FOR SELECTED CLASSES OF BUILDINGS BY SEISMIC ZONE
(As Functions of Replacement Costs)

Zone	Class of Building		
	5E	5C	5B
Zone 32	0.0011	0.0005	0.0001
Zone 33A	0.1545	0.0761	0.0227
Zone 33B	0.0278	0.0136	0.0022
Zone 34	0.0153	0.0075	0.0022

NO ZONE   ZONE 26   ZONE 26

ZONE 30

Number denotes seismic source
zone as indicated in the refer-
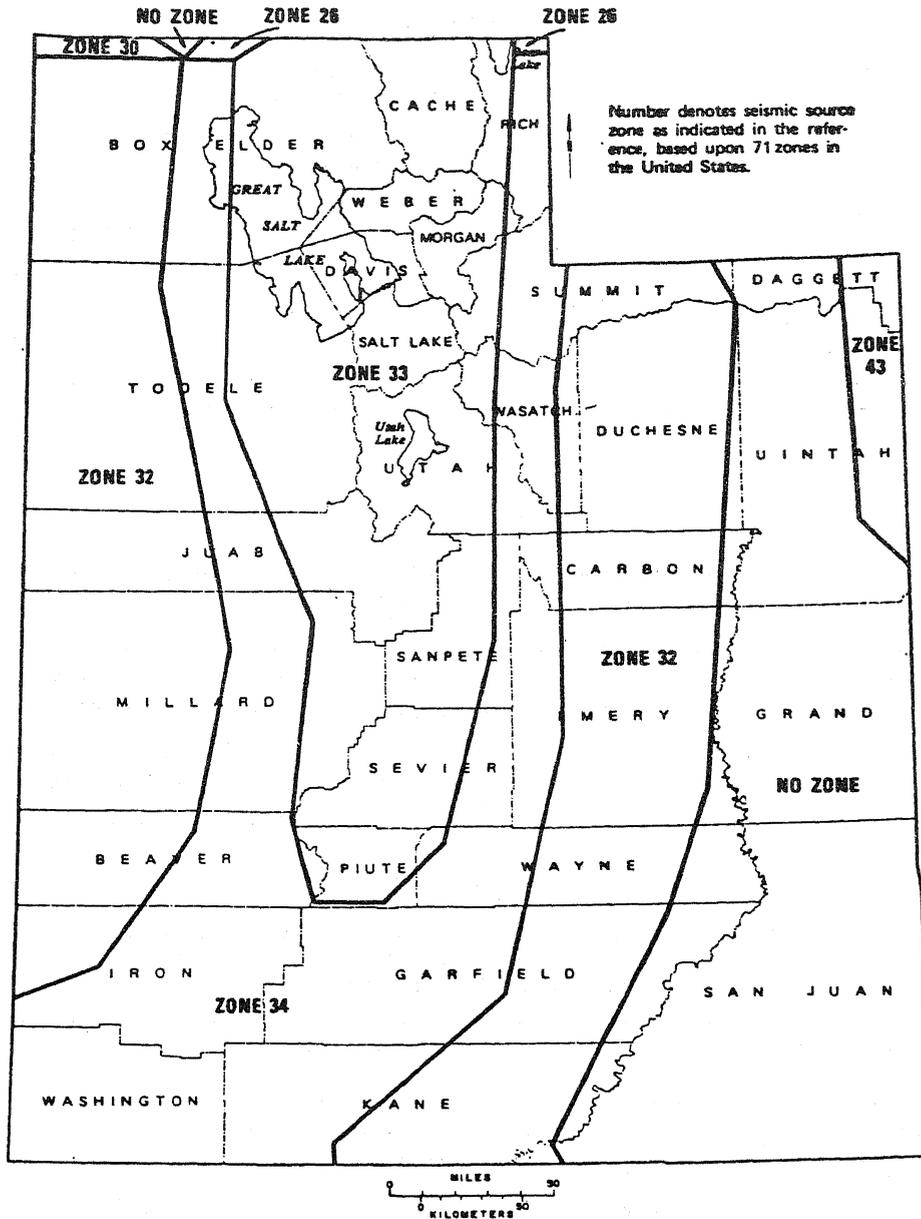ence, based upon 71 zones in
the United States.

Figure 1
SEISMIC SOURCE AREAS IN UTAH
(Reference: S.T. Algermissen, and D.M. Perkins, USGS Open File Report 76-416)