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Seismic Design Decision Analysis

Report No. 20

ECONOMIC IMPACT IN SEISMIC DESIGN DECISION ANALYSIS: A PRELIMINARY INVESTIGATION

by

Tapan Munroe

Cynthia Blair

June 1975

Sponsored by National Science Foundation
Research Applied to National Needs (RANN)
Grants GK-27955 and GI-29936

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Abstract

This study is an attempt at incorporating considerations of economic impact into Seismic Design Decision Analysis. The economic impact losses considered here are those that result from the loss of income in a region resulting from damage to buildings and structures induced by earthquakes. This paper has focussed primarily upon illustrating the methodology of incorporating economic impact into Seismic Design Decision Analysis.

An analytical basis of obtaining economic impact probability matrices has been established. Economic impact loss estimates for several locations and different seismic risk considerations have been obtained. And, finally, the efficacy of anti-seismic design strategies for Boston, San Francisco, and the Puget Sound area have been evaluated by combining building damage and economic impact losses in the benefit-cost analysis. Some tentative conclusions regarding design strategies have been indicated for these locations.

Preface

This is the 20th in a series of reports covering work supported by the National Science Foundation under the program of Research Applied to National Needs (RANN). The work has been done under NSF Grant No. GI-27955X3, with Dr. Charles Thiel as program manager. A list of previous reports follows this preface.

This is the first SDDA report that attempts to deal with economic impacts of earthquakes. Chapter 2 reviews the basis of the earthquake risk data that have been used in our calculations. The methodology of derivation of economic impact probability matrices is discussed in Chapter 3. Chapter 4 contains an economic evaluation of earthquake resistant building practices in several United States locations. Estimation of earthquake induced losses is carried out for the San Francisco and the Boston Areas.

The authors would like to express their appreciation for the help and support of Professor Robert V. Whitman at all stages of this research effort. Thanks are also due to Dr. Betsy Schumacker and Professor D. Veneziano for many helpful suggestions during the course of this work.

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List of Previous Reports

1. Whitman,R.V., C.A. Cornell, E.H.Vanmarcke, and J.W.Reed,"Methodology and Initial Damage Statistics," Department of Civil Engineering Research Report R72-17, M.I.T., March 1972.

2. Leslie,S.K. and J.M.Biggs,"Earthquake Code Evolution and the Effect of Seismic Design on the Cost of Buildings," Department of Civil Engineering Research Report R72-20, M.I.T., May 1972.

3. Anagnostopoulos,S.A.,"Non-Linear Dynamic Response and Ductility Requirements of Building Structures Subjected to Earthquakes," Department of Civil Engineering Research Report R72-54, M.I.T., September 1972.

4. Biggs, J.M. and P.H.Grace, "Seismic Response of Buildings Designed by Code for Different Earthquake Intensities," Department of Civil Engineering Research Report R73-7, M.I.T., January 1973.

5. Czarnecki,R.M., "Earthquake Damage to Tall Buildings," Department of Civil Engineering Research Report R73-8, M.I.T., January 1973.

6. Trudeau, P.J.,"The Shear Wave Velocity of Boston Blue Clay," Department of Civil Engineering Research Report R73-12, M.I.T., February 1973.

7. Whitman,R.V., S.Hong, and J.W.Reed,"Damage Statistics for High-Rise Buildings in the Vicinity of the San Fernando Earthquake," Department of Civil Engineering Research Report R73-24, M.I.T., April 1973.

8. Whitman, R.V., "Damage Probability Matrices for Prototype Buildings," Department of Civil Engineering Research Report R73-57, November 1973.

9. Whitman, R.V., J.M.Biggs, J. Brennan III, C.A. Cornell, R.de Neufville, and E.H.Vanmarcke, "Summary of Methodology and Pilot Application," Department of Civil Engineering Research Report R73-58, M.I.T., October 1973.

10. Whitman, R.V., J.M.Biggs, J.Brennan III, C.A. Cornell, R. de Neufville, and E.H.Vanmarcke, "Methodology and Pilot Application," Department of Civil Engineering Research Report R74-15, July 1974.

11. Cornell, C.A. and H.A.Merz, "A Seismic Risk Analysis of Boston," Department of Civil Engineering Research Report P74-2, April 1974.

12. Isbell, J.E. and J.M.Biggs, "Inelastic Design of Building Frames to Resist Earthquakes," Department of Civil Engineering Research Report R74-36, May 1974.

13. Ackroyd, M.H. and J.M.Biggs, "The Formulation and Experimental Verification of Mathematical Models for Predicting Dynamic Response of Multistory Buildings," Department of Civil Engineering Research Report R74-37, May 1974.

14. Taleb-Agha, G., "Sensitivity Analyses and Graphical Method for Preliminary Solutions,"Dept. of Civil Engineering R74-41,June 1974.

15. Panoussis, G.,"Seismic Reliability of Lifeline Networks," Department of Civil Engineering Research Report R74-57, September 1974.

16. Yegian, M., R.V.Whitman,J.Christian and Tezian, "Ground Motion Amplification Studies, Bursa, Turkey."

17. de Neufville, R., (Being written)

18. Tong,W-H, "Seismic Risk Analysis for Two-Sites Case,"Dept. of Civil Engineering Research Report R75023, Order No. 504.

19. Wong, E., "Correlation Between Earthquake Damage and Strong Ground Motion," Dept. of Civil Engineering Research Report R75-24, Order No. 505.

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Chapter 1.
Introduction

The major objective of this study is to develop a methodology that would incorporate the income effect resulting from damage to structures and lifelines induced by earthquake ground shaking and secondary earthquake hazards such as landslides, sea waves, and fires, into Seismic Design Decision Analysis (SDDA).[1] In this evaluative technique, the effects of earthquakes, aside from structural damage, have been subsumed under a category entitled, "incident losses."[2] These losses include (i) the damage to the contents of a structure; (ii) the cost of clean-up and restoration of order in buildings; (iii) the cost of injury and losses due to injury. It is our intent in this paper to incorporate another element of "incident losses" - the economic impact losses resulting from loss of income resulting from earthquakes in a given community, into the analysis, and evaluate the desirability of adopting earthquake resistant building strategies in different locations in the United States subject to varying levels of seismic risk. The major thrust of this effort is directed towards the methodological modification of SDDA. This is only a preliminary effort and a great deal remains to be done before our objective can be fully realized.

In our assessment of economic impact, we are not concerned with the economic aspects of loss of life, the direct costs of casualties, the cost of replacement and repair of structures and lifelines, and the loss of contents of buildings. We are, however, interested in the loss of income due to injury resulting from structural damage. Economic impact, in our case, can be assessed by measuring the loss of jobs or output in a specified region resulting from ground shaking and other hazards of earthquakes that induce disruption to structures and lifelines. An alternate measure of the impact would be the decline in the various income streams, such as wages, salaries, rents, profits, and taxes. There can be several probable causes of this type of impact stemming from an earthquake:

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[1] R.V.Whitman, et al, "Summary of Methodology and Pilot Application," M.I.T., Dept. of Civil Engineering Report R74-15, July 1974.

[2] Ibid., pp. 63-72.

(i) disruption of physical plant - the various types of structures that we are concerned with are as follows: manufacturing plants, commercial establishments, government offices, private dwellings that are also used as location of economic production. (We do not consider the typical private dwelling as a plant, since whatever production that takes place within it is traditionally not counted in the social accounting framework);

(ii) disruption of lifelines - the various types of lifelines that we are particularly concerned with are: roads, bridges, overpasses, gas lines, power lines, sewage lines, airport, seaport, bus and truck terminals, hospitals, police stations and fire stations. It is important to realize that in some cases, even though damage to a plant may not disrupt production, damage to the access facilities of a plant may curtail production;

(iii) psychological effects of an earthquake - this may lower efficiency, and also may create increased absenteeism, and therefore affect output and income;

(iv) injuries from an event may also create absenteeism and lower efficiency, and thus lower output and income.

The methodology followed in this paper is illustrated by the flow diagram in Figure 1. The major elements involved in the analysis are as follows:

1. Seismic risk analysis: estimates of seismic risk have been obtained from various sources for various locations;

2. Economic impact probability matrix: these have been developed for assessing economic impact along the lines of the damage probability-matrices developed in the M.I.T. project on seismic design decision analysis;

3. Benefit-Cost evaluation of earthquake resistant design strategies for different locations incorporating building damage and economic impact losses;

4. Estimation of earthquake induced losses in the San Francisco and the Boston area.

Chapter 2

Seismic Risk Analysis

The risk analysis methodology described here has been utilized in the seismic design decision analysis project at M.I.T., and it deals with the evaluation of the likelihood of occurrence of seismic ground motions of various intensities at a given site.[3] In order to make probabilistic

[3] C.A.Cornell & H.A.Merz, "A Seismic Risk Analysis of Boston," M.I.T. Dept. of Civil Engineering Report P74-2, April 1974; R.V.Whitman et al, "Methodology and Pilot Application," op.cit.

predictions about seismic risk it is necessary to integrate data on potential times, locations, and sizes of significant earthquakes, along with data on the variation (attenuation) of intensity over space between the epicenter and a given site.

Specifically,in probabilistic seismic site risk analysis it is necessary to estimate the probability that ground motions of certain intensity will be equalled or exceeded in a certain time period in the future. Ground motions of a certain intensity at a site occur because (i) an earthquake of that intensity occurs adjacent to the site, or (ii) an earthquake of a higher intensity occurred at a distance away from the site. Both these possibilities have to be considered in order to assess risk at the site.

The estimation of the expected number of events at a site that will have intensities greater than or equal to x in one year (or any other period) involves the summing up of the expected number of earthquakes associated with point sources. The calculation is carried out for each point source and added to give the total annual expected number of earthquakes for a site. Figure 2 shows the most likely estimate of annual risk for Boston for firm ground sites. It also includes a seismic risk curve for locations in Boston with poor soil conditions.

The Cape Ann earthquake of 1755, which is often the cause of seismic concern in the Boston region, had its epicenter 50 miles northeast of the city. The epicentral intensity of this event was MMI VIII; in Boston the intensity was MMI V or VI for firm ground, and VII for poor soil conditions. We can see from Figure 2 that the annual risk for firm ground sites in Boston of experiencing an MMI of VI is about 10^{-3} (1 in 1000). The risk of such an event in a ten year period is approximately 10^{-2} (1 in 100); and in a 100 year period, approximately 10^{-1} (1 in 10).

A Baysian weighted risk estimate for Boston appears in Figure 3. It reflects uncertainty factors introduced by the nature of seismic phenomena and the imperfect state of human knowledge of the phenomena. Seismic risk data dealing with other locations have also been included in this paper. Figure 4 provides the data for the San Andreas fault on the west coast for various site distances from the fault. Figure 5 contains seismic risk data for sites in the Puget Sound area.

Chapter 3.
Economic Impact Probability Matrix

Economic impact probability matrices (EIPM) have been developed following a methodology analogous to the damage probability matrices (DPM) (Figure 6a) developed in the M.I.T. project.[4] It is important to keep in mind that we have attempted to construct the economic impact matrices for a region, whereas, in the case of DPM's, each matrix was for a certain type of a building. Furthermore, the DPM's are only concerned with damage to buildings resulting from ground-shaking; whereas, we are also concerned with economic impact induced by secondary earthquake hazards such as landslides, sea waves, fires, etc., on structures.

The form of the matrix is as shown in Figure 6b. The economic impact on a region is described by a set of impact states (EIS); the intensity of the earthquake is described by the Modified Mercalli Intensity (MMI) scale.

The economic impact expected from future earthquakes need to be expressed in probabilistic terms because of several reasons:

(i) individual and institutional responses in identical communities will be different when they are exposed to the earthquake of same intensity; hence the level of economic impact will also be different;

(ii) details of ground motion will be different for similar communities exposed to the earthquake of same intensity; hence, the level of economic impact will also be different.

The first step in the construction of the EIPM is the establishment of consistent economic impact states in descriptive and quantitative terms. Following Whitman's technique, we use two methods of defining each damage state. First, we describe the extent of economic impact on the region; and second, we use familiar economic variables such as percentage increase in employment or percent decline in income in the region due to the event. Every effort is made to maintain consistency between the descriptive measure of a state and its quantitative assessment.

In defining the economic impact states, it is essential that we take into cognizance the time horizon of the economic impact. Since we are concerned with income, we have to consider a certain time span for the effect to materialize. On the other hand, we have to impose a certain time span beyond which we do not consider the impact. The time horizon

[4] Whitman, R.V., "Damage Probability Matrices for Prototype Buildings," M.I.T. Dept. of Civil Engineering Report, Oct. 1973; and Whitman, R.V., J.W. Reed & S.T. Hong, "Earthquake Damage Probability Matrices," Proc. 5th World Conf. on Earthquake Engineering, Santiago, Chile, June 1973.

selected for our purposes will be one year from the onset of the earthquake event, since most effects would have worked themselves out by that time.

In order to simplify the problem we will consider the economic impact in terms of changes in income rather than changesin unemployment level, since the former may be relatively easier to assess than unemployment. Another reason for this choice is obvious since we are interested in dollar losses to the region resulting from the event.

In the framework of national income accounting, the income (or the output) of an economy may be measured in terms of the various income flows such as wages and salaries, rent, interest, profit and taxes. We will be concerned with this approach rather than the alternate one of measuring output by adding up the value of the various expenditures in the economy such as consumption expenditures, investment expenditures, government expenditures, and net exports.

Another point of clarification is in order here, and this deals with our particular concern with regional rather than national perspective in describing the economic impact states (EIS). Costs and losses measured from the national perspective are those that are reflected in the national income accounts. The costs and losses in the regional perspective are similar to the national income type measures, except that they have to include the flows that originate from the rest of the economy to the region.[5] For example, in the case of the earthquake hazard, we have to calculate a net loss of income due to the event after taking into account the federal and state transfer payments flowing into the disaster stricken region.

In order to be more specific about the regional perspective of economic impact of an earthquake, we are concerned with:

(i) the loss in income to the region (LI_r); and

(ii) the difference between the transfer payments flowing into the region from extra-regional sources because of the disaster and the transfer payments that would have flowed into the region under normal circumstances (TP_r). Thus, regional economic impact, $EI_r = LI_r - TP_r$ --(1). In our analysis, we have not considered the environmental and income distribution aspects of regional impact.

The basis of the economic impact probability matrices are the actual experiences of two major earthquakes that have occurred in the western part

[5]Charles W. Howe, Benefit-Cost Analysis for Water System Planning, American Geophysical Union, Water Resources Monograph #2, 1971, p.39; David C. Major, Multiobjective Water Resource Planning, American Geophysical Union, Water Resource Monograph #4, 1973.

of the United States. The ones that have been considered include the 1964 Alaska earthquake and the 1971 San Fernando earthquake. The data available in these cases appear to be far superior compared to the record of any of the other events, in terms of both quality and quantity.

Based upon the case studies (summarized in Appendix A), we have been able to establish the qualitative descriptions of the various economic impact states. These are described in Table I. The six impact states have been assigned somewhat similar designations (O, VL, L, M, H, C) as those in the description of the damage states utilized in the M.I.T. seismic design decision analysis (Table II). The latter table also includes a summary of "incident loss" data obtained from the San Fernando case. Data in columns 4 and 5 in this table, representing the extent of economic losses due to building damage, are clearly related to the economic impact measure. Based upon the records of the two case studies there appears to be little economic impact until one reaches damage state H. The economic impact increases significantly from there on to state C. For the sake of comparison, the description of damage states established in the SDDA project is provided in Figure 7. The shortened version of the SDDA damage states are illustrated in Figure 8. It is important to note that the relationship between the damage states and the economic impact state is not linear. The relationship between CIR and CDR is plotted in Figure 9.

The central impact ratios (CIR) in Table I were obtained from a thorough examination of the descriptions of the earthquakes in Appendices A and B. The completed matrix is shown in Table III. At the lower Modified Mercalli Intensities (MMI), in the V-VII range, the probabilities cluster around the first two economic impact states, O and VL; at the higher intensities the probabilities tend to spread down to states M and H.

In the estimation of these probabilities (P_{EIS}), intensity distribution maps (Figures 10 and 11) for the Alaska and the San Fernando earthquakes were utilized in conjunction with the descriptions of economic impact in each of the towns considered in Appendices A and B. The data in Table III will be utilized in our assessment of economic impact in the next section of this paper. The data in Table III has been assumed to be for design strategy corresponding to the uniform building code (UBC) zone 3 in view of the locations of the two earthquake events which form our data base. However, this is a fairly bold assumption in view of the fact that a significant number of structures in the two cases did not conform to UBC design codes.

This assumption is only defensible in view of the fact that our prime objective here is only to illustrate the methodology.

For the purposes of illustration of the technique of obtaining the economic impact probability matrix (EIPM), we have constructed tables IV and V on a judgemental basis of the data in Appendices A and B. The CIR values are approximate and somewhat subjective; the intensity data for the various locations in the two events were obtained from Figures 10 and 11. The completed matrix is shown in Table VI. In our judgement this matrix is not as complete and representative as that in Table III, since the latter case incorporated a more thorough evaluation and interpretation of the two case studies. For this reason we decided to proceed with our calculations on the basis of the matrix in Table III. Table VI was derived only for the purpose of illustrating the technique.

It is essential that the definition of the impact ratio be made more thorough and operational before we are in a position to obtain EIPM's on a more rigorous basis. This has been done in Appendix C.

Chapter 4
Evaluation of Efficiency of Earthquake Resistant Adjustments

The structural seismic design alternatives that are usually considered in seismic design engineering correspond to the requirements for zones 0, 1, 2 and 3 of the Uniform Building Code. A map (Figure 12) showing the various seismic hazard zones in the United States is included in this paper. The design strategies corresponding to the various zones are denoted by K, where K, in our case, may have values 0, 1, 2 and 3.

The expected annual economic impact ratio (EAEIR) for a given location where buildings are designed according to strategy K is given by:

$$EAEIR^{(K)} = \frac{EAEI^{(K)}}{IC^{(K)}} \qquad (2)$$

where $EAEI^{(K)}$ = expected annual economic impact under design strategy K,

and $IC^{(K)}$ = the initial cost of buildings with design strategy K in the region.

The expected annual economic impact ratio can also be expressed as[6]:

$$EAEIR^{(K)} = \sum_{I} \sum_{EIS} P^{(K)}_{EISI} \times CIR_{EIS} \times SR_{I} \qquad (3)$$

[6] R.V. Whitman, et al, "Methodology and Pilot Application," op.cit.,p.56.

where P_{EISI} = the probability that the region (location) containing buildings designed according to strategy K will experience economic impact state EIS when a ground motion of intensity I occurs in the location;

CIR_{EIS} = Central impact ratio associated with economic impact state EIS;

SR_I = the annual probability of occurrence of an earthquake producing ground motion of intensity I in the location.

The expected annual loss ratio can also be expressed in terms of annual economic impact probability $AEIP^{(K)}_{EIS}$[7]:

$$\text{thus,} \quad EAEIR^{(K)} = \sum_{EIS} AEIP^{(K)}_{EIS} \times CIR_{EIS} \qquad (4)$$

$$\text{where } AEIP^{(K)}_{EIS} = \sum_{I} P^{(K)}_{EISI} \times SR_I, \qquad (5)$$

and can be defined as the probability that the region with buildings designed with strategy K will be subjected to an economic impact state EIS in a given year.

Figure 13 depicts the steps involved in evaluating $EAEIR^{(K)}$.

In order to incorporate the concept of time value of money in our analysis we use the present value method of assessing dollar losses. For a region in which buildings use design strategy K, let $EIL_t{}^{(K)}$ represent the present value of expected impact losses resulting from earthquakes which occur in the period t. For the "long run" case, $EIL_t{}^{(K)} = \frac{1}{\sigma} EAEI^{(K)}$, where σ = the continuous discount rate, and EAEI has been defined earlier.

The term $\frac{EIL^{(K)}}{IC^{(o)}} \cdot 10^6$ is the present value of expected discounted losses per million dollars of initial building cost with no earthquake resistant provisions, where $IC^{(o)}$ = initial building cost with no earthquake resistance, i.e., K=0.

$$\text{Again,} \quad \frac{EIL^{(K)}}{IC^{(o)}} \cdot 10^6 = \frac{1}{\sigma} \frac{EAEI^{(K)}}{IC^{(o)}} \qquad (6)$$

$$\text{Now } IC^{(K)} = IC^{(o)} + ICP^{(K)} = IC^{(o)} \left(1 + \frac{ICP^{(K)}}{IC^{(o)}} = IC^{(o)}\right) \qquad (7)$$

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[7] R.V.Whitman et al, "Methodology and Pilot Application," op.cit.,p.57.

(by virtue of the assumption that $[1 + \frac{ICP^{(K)}}{IC^{(o)}}] = 1$,)

where $IC^{(o)}$ = the initial cost of buildings as a function of design strategy K; and $ICP^{(K)}$ = the initial cost premium.

$$\text{Thus } \frac{EIL^{(K)}}{IC^{(o)}} \times 10^6 = \frac{1}{\sigma} \cdot \frac{EAEI^{(K)}}{IC^{(o)}} = \frac{1}{\sigma} \cdot \frac{EAEI^{(K)}}{IC^{(K)}} = \frac{1}{\sigma} EAEIR^{(K)} \qquad (8)$$

(Equation 8 is obtained by substituting $IC^{(o)} = IC^{(K)}$, the relationship from Equation 7.)

Based upon the economic impact probability matrix (EIPM) for UBC zone 3, it was possible to calculate $EAEIR^{(3)}$ for the three locations considered in this paper: Boston, San Andreas Fault and sites in the Puget Sound area. In order to obtain the EAEIR's for UBC zones 0,1 and 2, it was necessary to obtain the mean economic impact ratio's (MEIR) for the various intensities for each of the design strategies. This was done on the basis of the interrelationship between the mean damage ratio's (MDR) obtained from prior work.[8] Table VII shows the percentage changes in MDR for the various intensities resulting from changes in the UBC design strategy, and the subsequent derivation of the MEIR's based upon this data.

The expected annual economic impact ratio ($EAEIR^K$) for UBC zone 3 was obtained, using Equation 14, from the $EIPM^{(3)}$ obtained earlier. The $EAEIR^K$ for UBC zones 0,1 and 2 were obtained by using the expression,[9]

$$EAEIR^{(K)} = \sum_I MEIR_I^{(K)} \times SR_I \qquad (9)$$

Table VIII contains the $EALR^{(K)}$ (column 4) and $EAEIR^{(K)}$ (column 6) data for the three locations with different risk considerations. The $EALR^{(K)}$ data for Boston were obtained from Whitman's work[10], and the results for San Andreas Fault and the Puget Sound area were obtained from our calculations. Columns 5 and 7 contain the expected discounted building damage losses (expression analogous to Equation 4) and expected discounted economic impact losses (also Equation 4).

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[8] R.V.Whitman, et al, "Methodology and Pilot Application," op.cit, Tables 6.1, 6.2, 6.3 and 6.4.

[9] Ibid.,p.57, eq. 6.5

[10] Ibid.,Table 6.6

Column 9 in Table VIII contains the total of expected discounted building damage losses and economic impact losses. The benefits of design strategies are given by the decline in total losses as we move from one design strategy to another in Column 10. For example, in the case of Boston (if the city were to be on firm ground), the benefit of adopting UBC zone 2 strategy over 0 or 1 is $45 per million dollars worth of initial building value; the benefit of adopting zone 3 strategy over 2 is $24 per million dollars worth of initial building value.

The initial cost premiums[11] for each of the UBC design strategies are contained in Column 11 of Table VIII. Column 12 contains the increments in cost premium as we move from one design strategy to another. The benefit-cost ratio's for the adoption of building strategies is shown in Column 13.

In the case of Boston, the benefit-cost ratios in each of the four risk conditions are considerably less than unity. Thus, on the basis of building damage and economic impact losses, UBC design strategies are not justifiable. Of course, if considerations of loss of human life are included, one may reach a different conclusion.[12] In the case of sites 10 Km from the San Andreas fault, the benefit-cost ratio appears to be very favorable, indicating the desirability of adopting UBC design strategies, the payoff for zone 3 strategy being significantly higher than zone 2 strategy. It is interesting to note that the adoption of UBC design strategies do not appear to be justifiable for sites at a distance of 100 Km from the San Andreas fault. In the Puget Sound area, for sites with poor soil conditions, design strategies are clearly justifiable; whereas, for sites with firm ground conditions, zone 2 design strategy is justifiable, but zone 3 strategy appears to be marginally acceptable with a benefit-cost ratio of 1.1.

It is important to note that although the benefit-cost ratios in Table VIII change with the inclusion of economic impact losses (Column 14, Table VIII) in our calculations, the basis of decision making regarding the adoption of UBC design strategies does not appreciably change except for the case of sites with firm ground in the Puget Sound area.

Before moving on to the next section, we should note that the cost premium data used in obtaining the

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[11] Whitman, "Methodology and Pilot Application," Table 6.5.

[12] Ibid., pp.71-72.

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A factor that should be brought out before we move on to the next section deals with the nature of anti-seismic building strategies with respect to damage and loss alleviation. The cost premium used in obtaining the

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[11] Whitman, "Methodology and Pilot Application," Table 6.5.

[12] Ibid., pp.71-72.

benefit-cost ratios in Table VIII were concerned with damage mitigation of medium height concrete buildings and did not include two things: first, the added costs of reinforcing other types of buildings, and, second, the expenditures for alleviating damages resulting from secondary hazards such as landslides and fires. Thus, the costs may have been somewhat understated, and, therefore, the benefit-cost ratio somewhat larger than what it would have been otherwise. In order to improve the analysis, realistic values of cost premiums need to be obtained from empirical data.

Chapter 5

Estimation of Earthquake Induced Losses in the San Francisco and the Boston Area

Estimates of earthquake induced losses have been carried out for the San Francisco and the Boston area on the basis of the analytical framework utilized in the preceeding section. Table IX summarizes the data for the San Francisco area.

Column 2 of table IX provides data on construction value at risk in the San Francisco area which forms the basis of our total loss estimates.[13] The expected discounted building damage losses have been calculated in columns 3, 4 and 5, and the expected discounted economic impact losses are tabulated in columns 6, 7 and 8. Columns 9, 10 and 11 contain the total expected discounted earthquake losses for the San Francisco area for 1970, 1980, 1990, and the year 2000. If we consider the building values for 1970, then under the condition that the entire stock of buildings have been subjected to zone 3 design strategy, the total losses amount to almost $6 billion, of which $10 billion are due to economic impact losses. For the year 2000, the losses under similar conditions may climb to $16.5 billion, of which $2.8 billion are expected to be economic impact losses.

Loss estimates similar to the San Francisco case were carried out for the Boston area. Since it was not possible to obtain construction value data for Boston at this time, the data was imputed on the basis of the per capita construction values in the San Francisco area. The estimated Boston construction value data for 1970, 1980, 1990 and 2000 are shown in Table X. In making comparisons between the San Francisco and the Boston cases, it must be remembered that in the latter case the area considered is the Standard Metropolitan Statistical Area (SMSA), whereas, in the former case, the area considered is much larger than the San Francisco SMSA.

[13] J.H.Wiggins et al, Budgeting Justification for Earthquake Engineering Research, NSF Report #74-1201-1, May 10, 1974, Washington,D.C.,p.68.

On the basis of 1970 construction values, without the adoption of seismic design strategies, and assuming that all of Boston is on firm ground, the expected total loss for the Boston area amounts to about $4 million, and about $79 million if Boston were to be on poor soil (Table XI). The economic impact losses corresponding to these data are $620,000 and $15 million respectively.

On the basis of year 2000 construction values, and with no anti-seismic design strategies, the total losses for the Boston area amount to $12 million for firm ground and $248 million for poor soil conditions, respectively. The economic impact losses corresponding to these total loss data are $2 million and $47 million respectively.

To obtain some perspective of our results, it may be worth comparing our data with the results obtained in the study by Wiggins[14] involving the San Francisco area. The basis of calculations is not the same for the two studies, since in the latter case the loss estimate was predicated upon the reoccurrence of the 1906 San Francisco catastrophe and contains only building damage data. In our case we are calculating expected losses on a probabilistic basis and we include economic impact losses. Table XII contains the comparative data for the two studies.

For the construction value base year of 1970, the loss data for UBC zone 2 design strategy is in very close agreement with both cases - $10.5 billion in our study, and $10.2 billion in the Wiggins' study. The discrepancy for similar comparison widens as we go on to 1980, 1990, and the year 2000. One reason for this divergence may be the fact that in Wiggins' study there is an assumption that with each decade, more structural measures will be adopted, and we have not made this assumption. Thus, Wiggins' estimates of losses are lower with each decade relative to ours.

A recent study carried out at the University of Colorado also attempts to estimate the losses due to the reoccurrence of the 1906 earthquake.[15] Their results show that the total losses for the reoccurrence of the major catastrophe in the Bay area would amount to about $13 billion, $6 billion of which would be economic impact losses and the remaineder in building damage losses. A comparison of this data with our results based upon 1970 construction values (Table IX, column 5) shows that as far as total magnitude of losses are concerned, our data is in the same value range. The economic impact losses in our case are somewhat smaller: $1.5 billion to $1 billion

[14] J.H.Wiggins, op.cit.

[15] H.C.Cochrane, et al, "Social Science Perspectives on the Coming San Francisco Earthquake-Economic Impact, Prediction & Reconstruction,"Natural Hazard Research,Working Paper #25,University of Colorado,Boulder,Colo.,1975.

depending upon the design strategy, compared to the $6 billion figure in the Cochrane study. But this is not very surprising, since in our assessment of economic impact we have approached the problem from a regional perspective, where inflows into the region resulting from the disaster are netted out in obtaining the final result. In the Cochrane study, this aspect is not taken into consideration.

Again we must say that although we need not obtain complete agreement between our results and those of the two studies cited above, the loss estimates obtained in our study appear to be reasonable in terms of order of magnitude.

Chapter 6
Concluding Remarks

In this paper, we have tried to incorporate economic impact losses into Seismic Design Decision Analysis (SDDA). Economic impact losses considered here are those that result from the loss of income in a regionresulting from damage to buildings and structures induced by earthquakes. We are not only concerned with damage caused by ground-shaking, but also secondary earthquake hazards such as landslides, sea-waves, and fires.

This paper has focussed primarily on illustrating the procedure of incorporating economic impact into SDDA. We have tried to establish the analytical basis of obtaining economic impact probability matrices, and, using subjective probability data, we have tried to estimate economic impact losses for several locations and different seismic risk considerations. We have also tried to evaluate the efficacy of anti-seismic design strategies for Boston, San Francisco, and the Puget Sound area by combining the building damage and economic impact losses in the benefit-cost analysis. Some tentative conclusions regarding design strategies have been indicated for these locations.

At least on the basis of benefit-cost analysis it is difficult to see a justification for anti-seismic design strategies in the Boston area after including economic impact considerations in the analysis. For the San Francisco and the Puget Sound area, seismic design strategies appear to be justifiable.

It must be noted that our estimates of economic impact losses are considerably lower relative to building damage, and, as such, do not significantly alter the basis of decision-making for anti-seismic building strategies, except for the Puget Sound area.

The estimate of losses for the San Francisco area in our study appear to be reasonable in comparison with the results obtained in two recent studies.

Much work remains to be done in providing a thorough empirical basis for developing economic impact probability matrices. This is at the heart of our methodology. The analytical framework established for developing these matrices illustrated in our paper can be utilized to accomplish this end. Furthermore, realistic values of incremental cost of design strategies need to be obtained in order to improve upon the benefit-cost evaluation of structural adjustments to the earthquake hazard.

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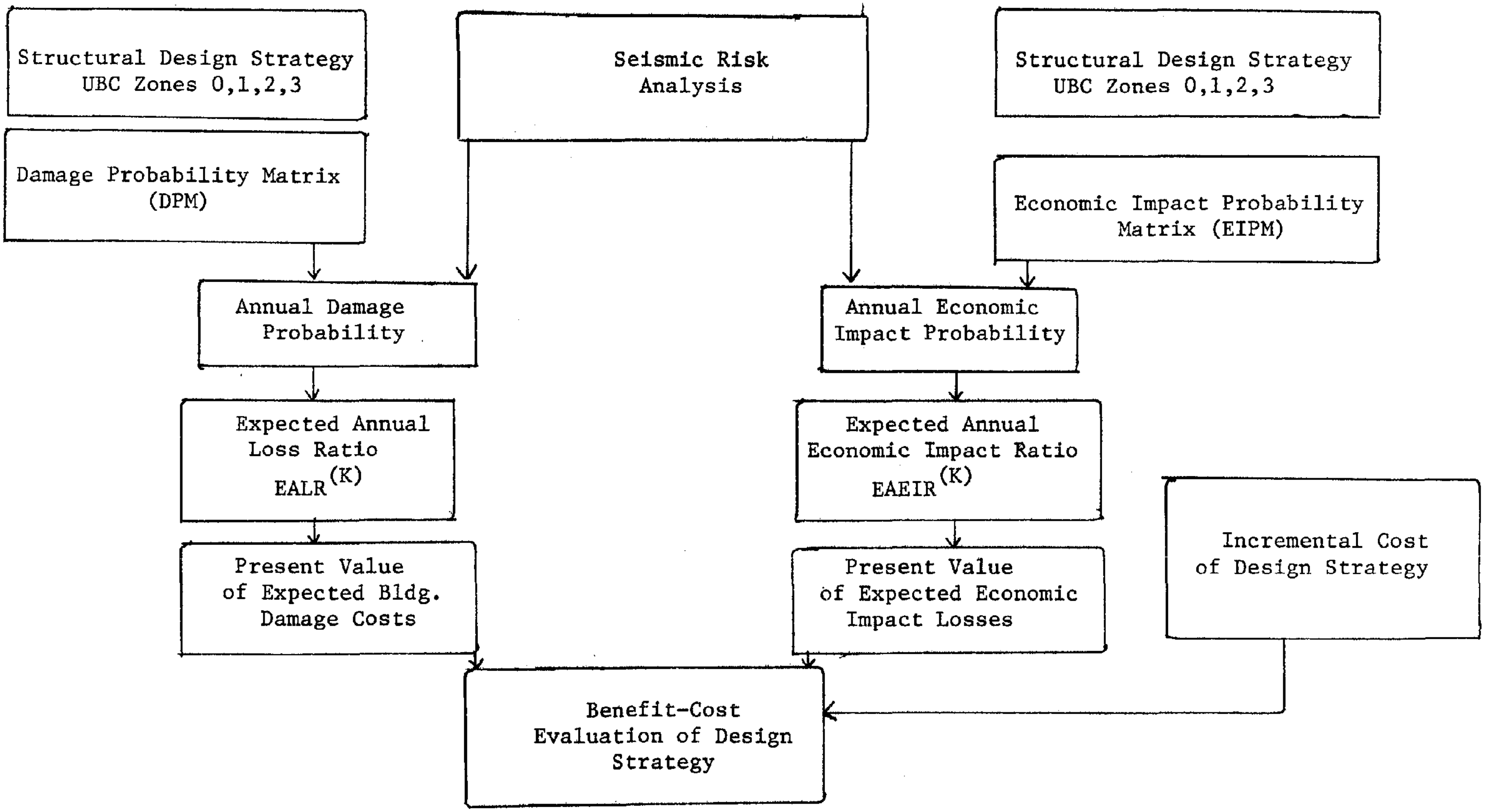


Figure 1.

Methodology Flow Diagram

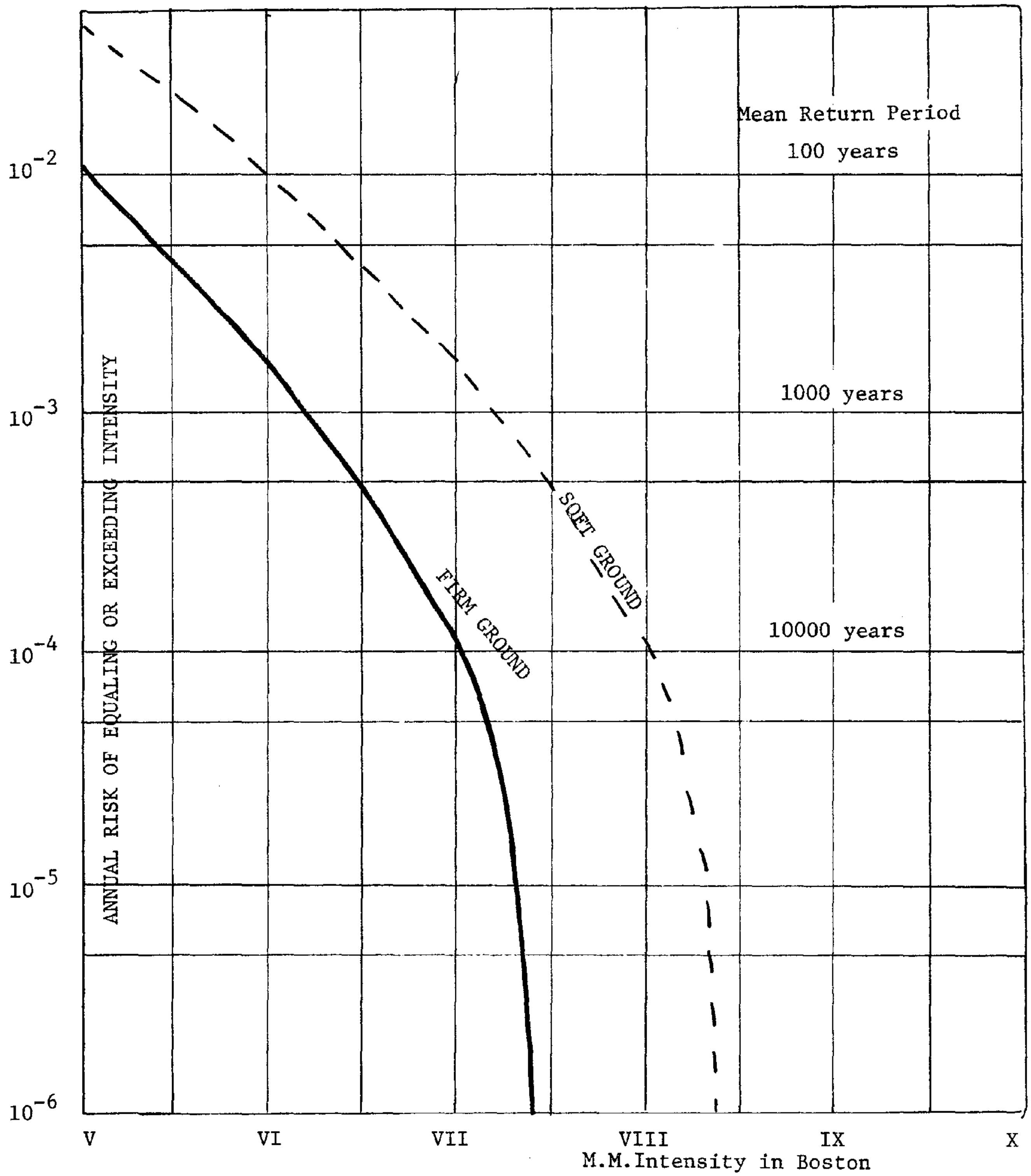


Figure 2. Most Likely Estimate

Source: R.V. Whitman et al, "Methodology and Pilot Application," M.I.T. Civil Engineering Report #R74-15, July 1974, Figure 4.4.

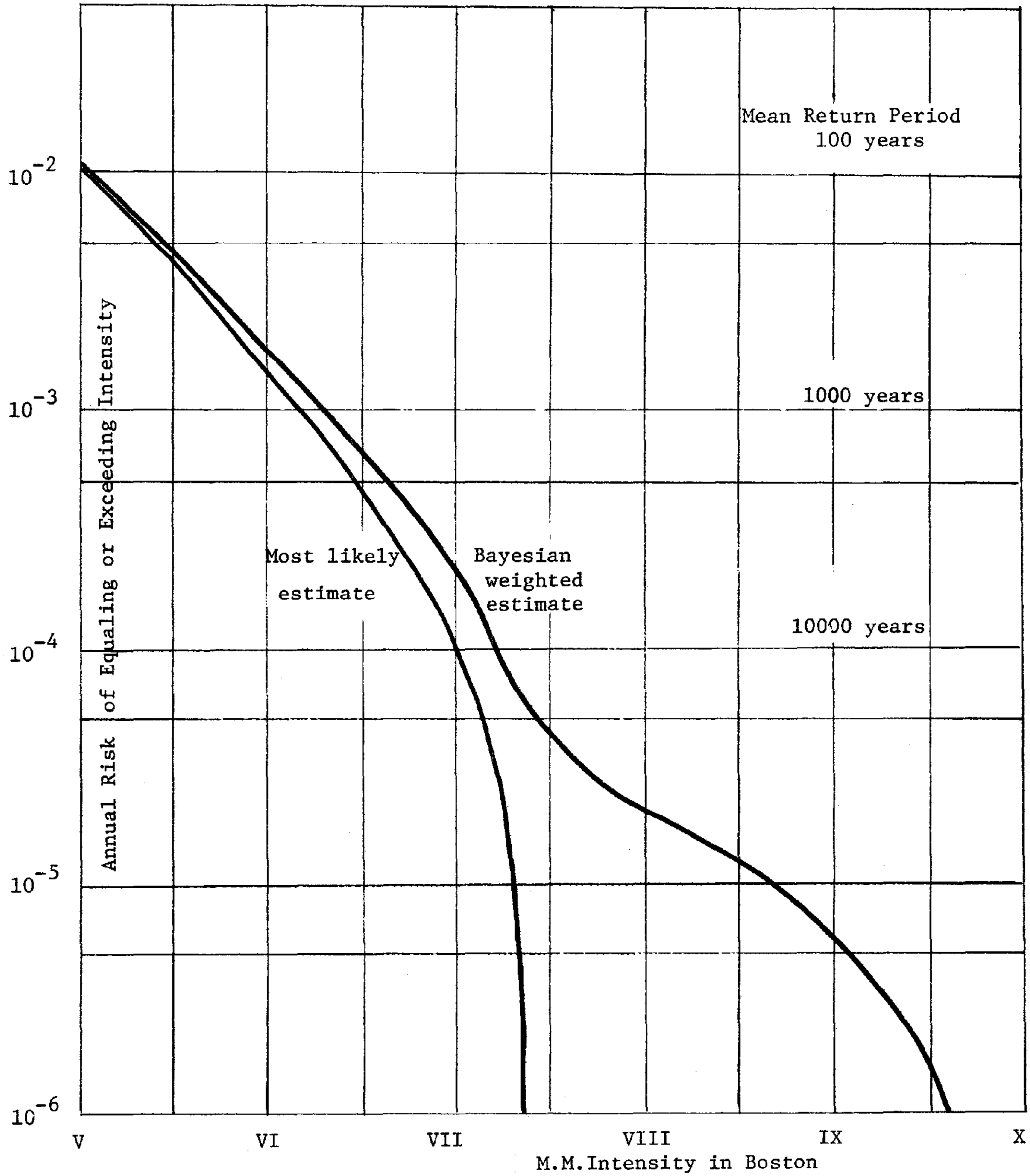


Figure 3. Bayesian Weighted Estimate

Source: R.V. Whitman et al, "Methodology and Pilot Application," M.I.T. Civil Engineering Report #R74-15, July, 1975, Figure 4.6.

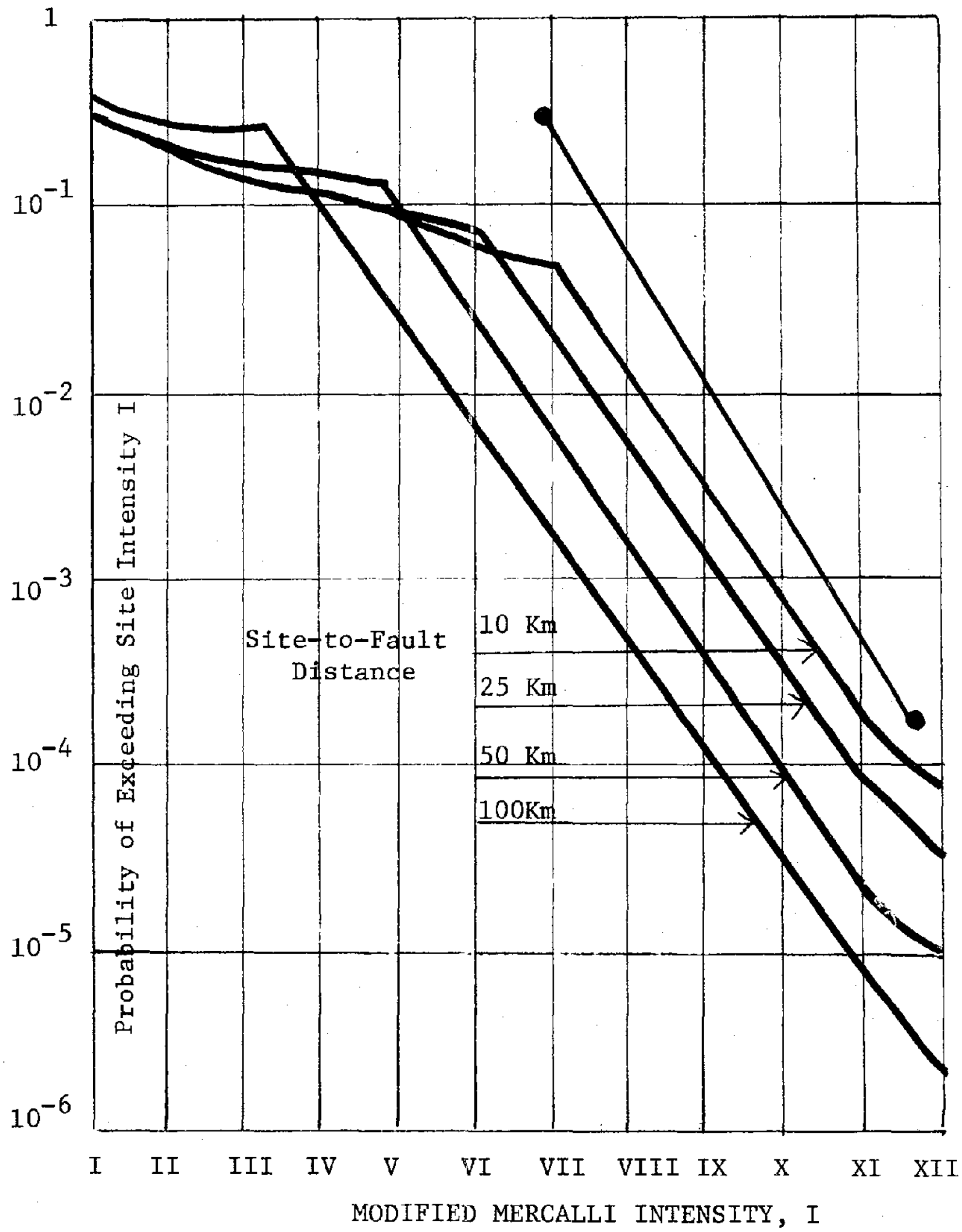
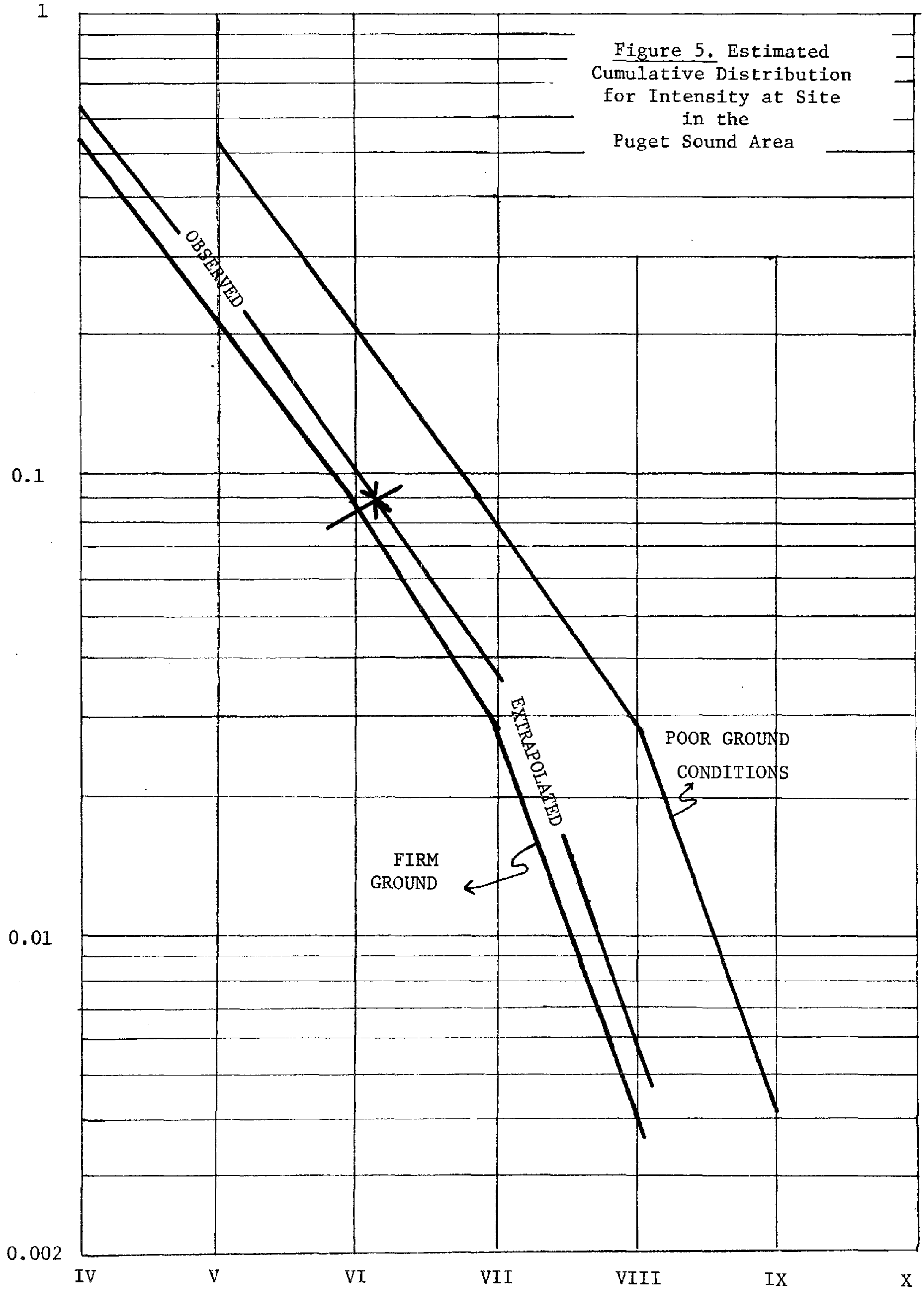


Figure 4. Probability of exceeding site intensity I when an earthquake occurs along the San Andreas Fault (from Liu and Dougherty, "Earthquake Risk Analysis - Application to Telephone Dial Offices in California," Bell Telephone Laboratories, 1975)



Source: Prof. R.V. Whitman, Personal Communication, M.I.T.,Department of Civil Engineering, May 15, 1975.

Damage State DS	Central Damage Ratio CDR %	MMI Intensity					
		V	VI	VII	VIII	IX	X
0 - None	0						
L - Light	0.3						
M - Moderate	5		$P_{DSI}^{(K)*}$				
H - Heavy	30						
T - Total	100						
C - Collapse	100						

Figure 6a.

Damage Probability Matrix

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* $P_{DSI}^{(K)}$ - The probability that the building system designed according to strategy K will experience damage state DS when a ground motion of intensity I occurs at the building site.

Economic Impact State EIS	Central Impact Ratio CIR %	MMI					
		V	VI	VII	VIII	IX	X
O							
VL							
L				$P^{(K)}_{EIS}$*			
M							
H							
C							

Figure 6b.

Economic Impact Probability Matrix

*$P^{(K)}_{EIS}$ - The probability that the region under study in which structures have been subjected to design strategy K will experience economic impact state EIS when a ground motion of intensity I occurs at the site.

	Description of Level of Damage	Damage Ratio*	
		Central Value	Range
0	No Damage.	0	0 - 0.05
1	Minor non-structural damage--a few walls and partitions cracked, incidental mechanical and electrical damage.	0.1	0.05-0.3
2	Localized non-structural damage--more extensive cracking (but still not widespread); possibly damage to elevators and/or other mechanical/ electrical components.	0.5	0.3-1.25
3	Widespread non-structural damage-- possibly a few beams and columns cracked, although not noticeable	2	1.25-3.5
4	Minor structural damage--obvious cracking or yielding in a few structural members; substantial non-structural damage with widespread cracking	5	3.5-7.5
5	Substantial structural damage requiring repair or replacement of some structural members; associated extensive non-structural damage	10	7.5-20
6	Major structural damage requiring repair or replacement of many structural members; associated non-structural damage requiring repairs to major portion of interior; building vacated during repairs	30	20-65
7	Building condemned.	100	20-65
8	Collapse.	100	65-100

*Ratio of cost of repair to replacement cost.

Figure 7.

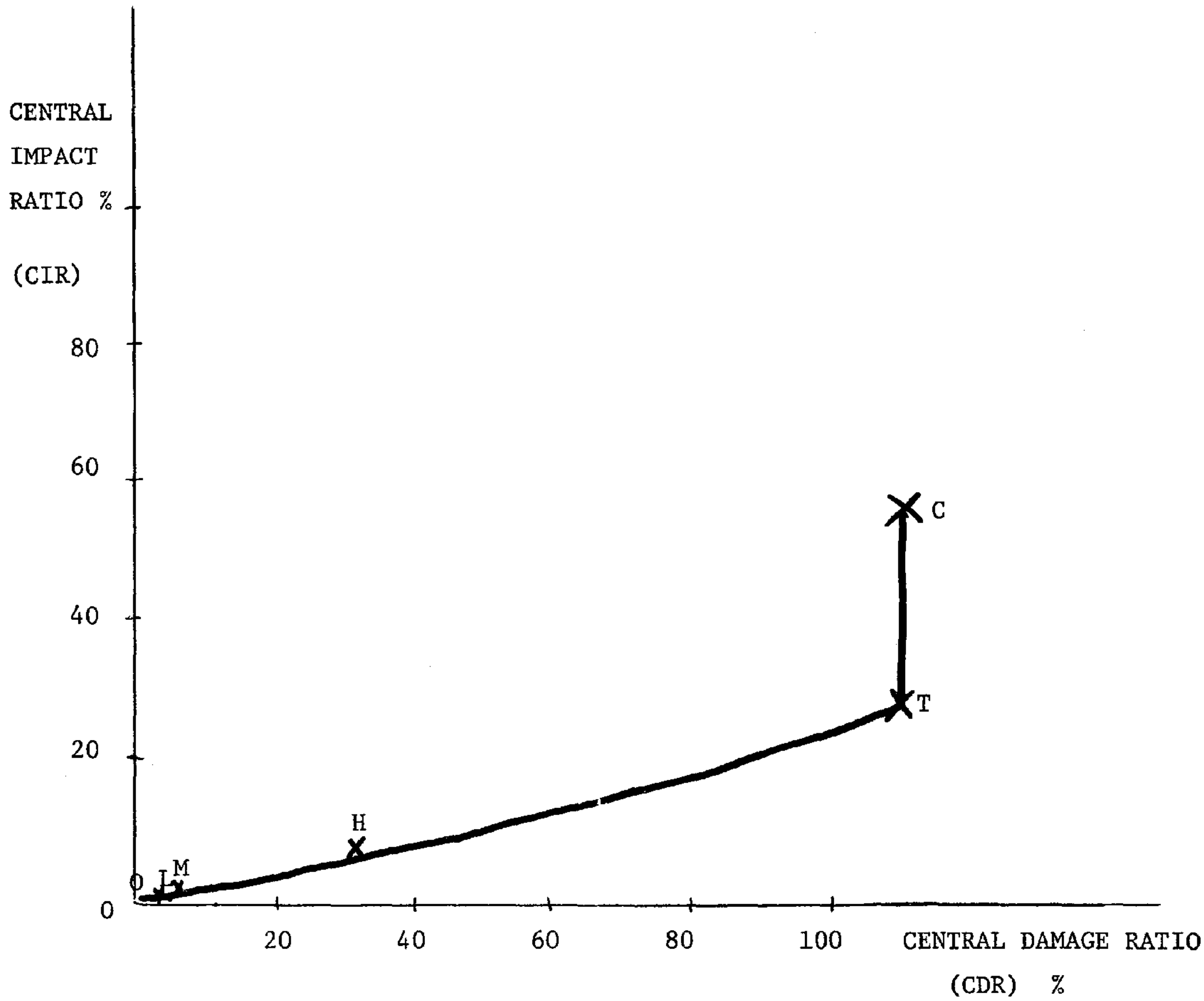
Earthquake Damage States

Source: R.V. Whitman et al, "Methodology and Pilot Application," M.I.T. Civil Engineering Report #R74-15, July 1974, Figure 2.2.

Extended (Original) Damage States	Shortened Damage States		
	Level of Damage	Symbol	Central Damage Ratio %
0	None	0	0
1 2	Light	L	0.3
3 4 5	Moderate	M	5
6	Heavy	H	30
7	Total	T	100
8	Collapse	C	100

Figure 8.

Relation Between Extended and Shortened Damage States



<u>Figure 9.</u>

<u>Relationship Between CDR and CIR</u>

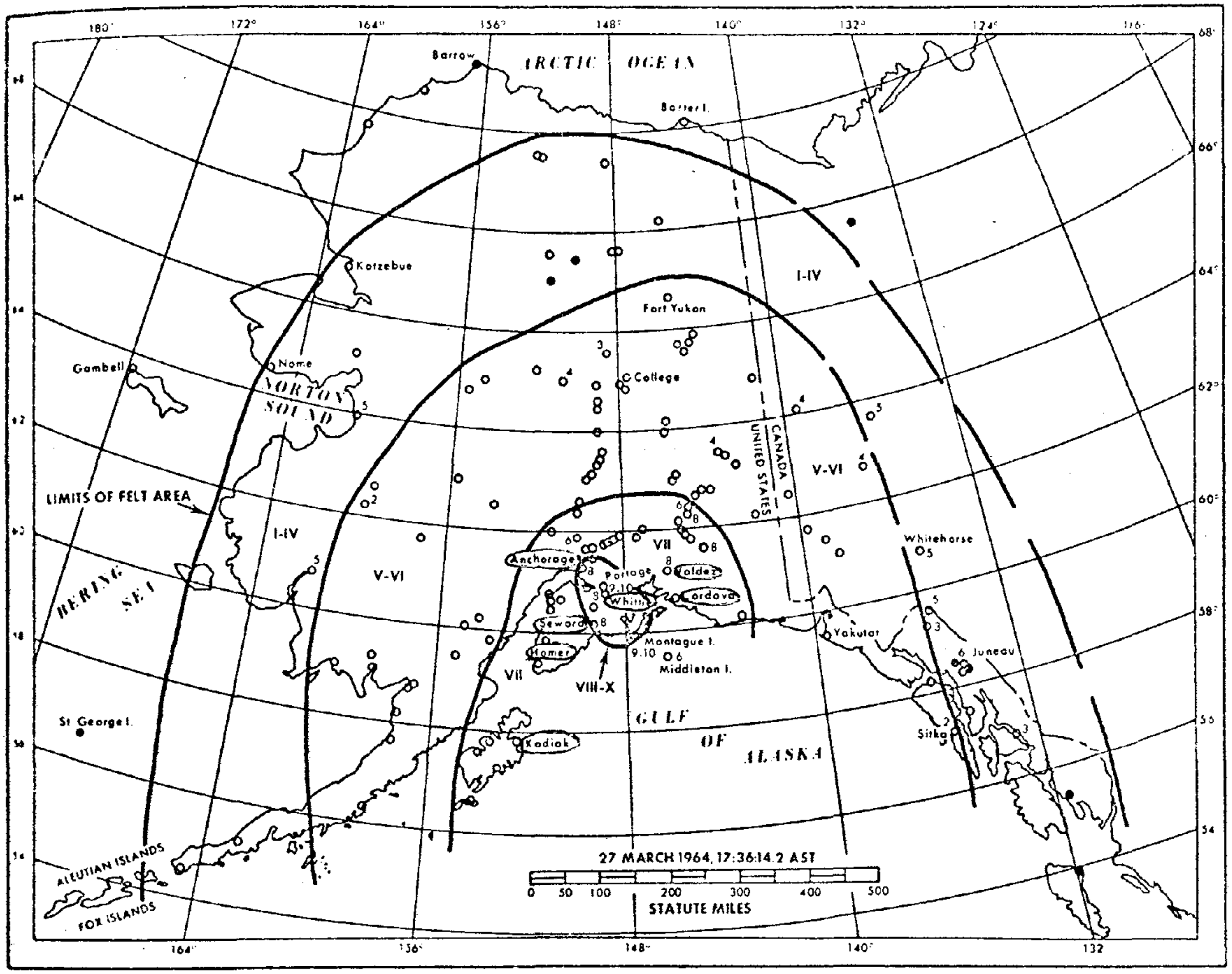


Figure 10

ISOSEISMAL INTENSITY MAP OF THE ALASKA EARTHQUAKE

(Von Hake and Cloud, 1966)

Source: Committee on the Alaska Earthquake of the Div. of Earth Sciences, National Research Council, <u>The Great Alaska Earthquake of 1964 - Engineering</u>, National Academy of Sciences, Washington, D.C., 1973. (p.29)

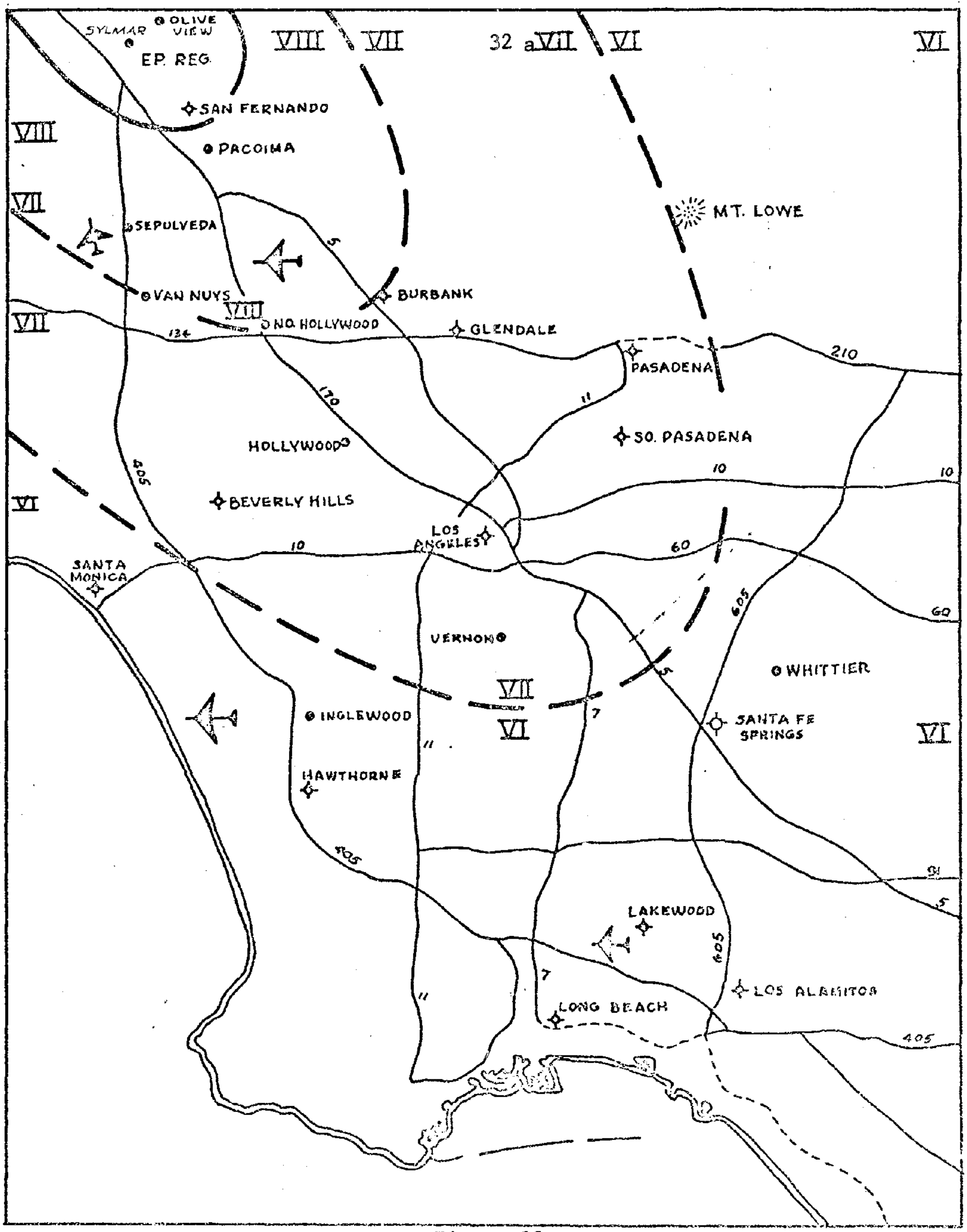
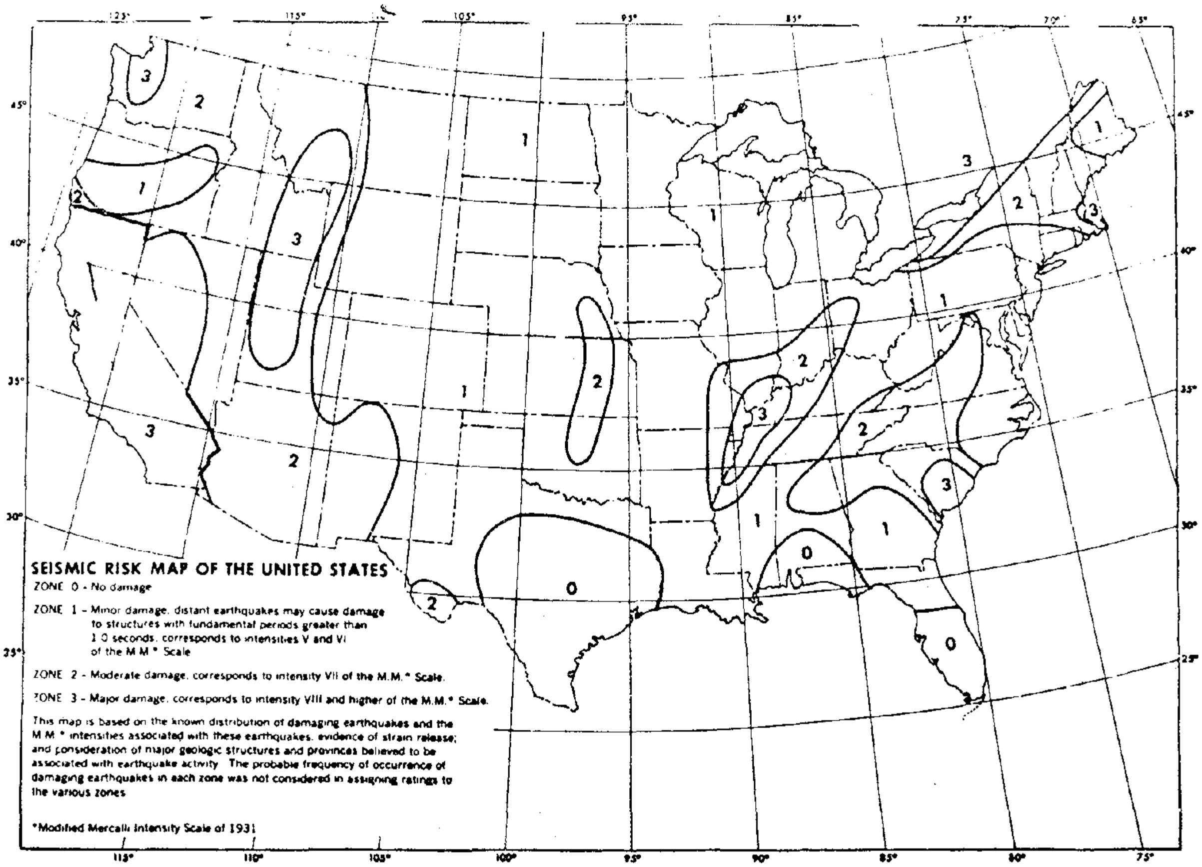


Figure 11.

Geographical Area of Study with Zones of Modified Mercalli Intensity

Source: R.V.Whitman, "Damage Probability Matrices for Prototype Buildings," M.I.T. Dept. of Civil Engineering, Report #R73-57, Figure 3.2.



<u>Figure 12.</u>

<u>Seismic Zone Map of the United States</u>

Source: <u>Uniform Building Code,</u> International Conference of Building Officials, 1973, p. 131.

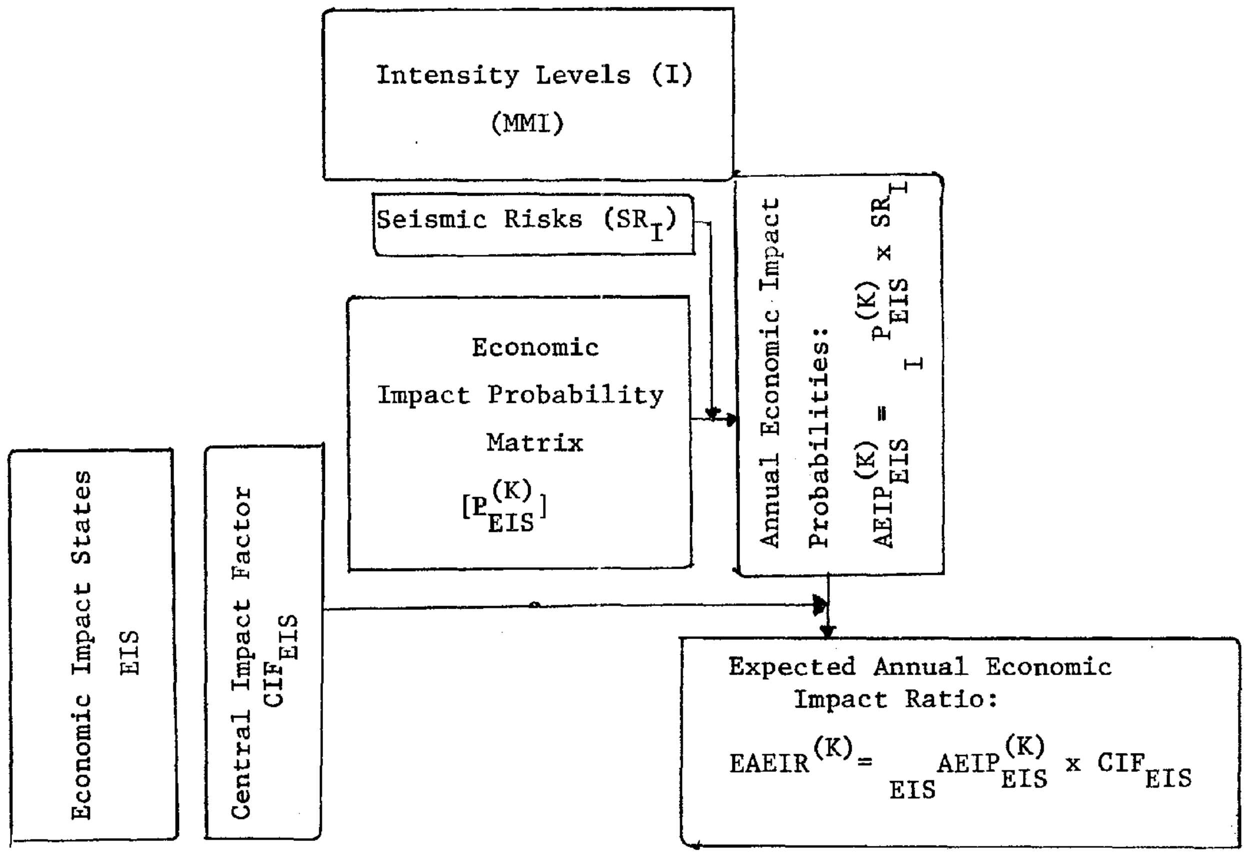


Figure 13.

Method of Computation of Expected Annual

Economic Impact Ratio

Source: Adapted from Figure 6.3, R.V.Whitman et al, "Methodology and Pilot Application," MIT Civil Engineering Report #R74-15, July 1974, Figure 6.3.

Table I.

Economic Impact States

1 Economic Impact States (EIS)	2 Central Impact Ratio (CIR) %	3 Description of Impact States
0 - none	0	No economic disruption.
VL - very light	0.1	Little or no economic impact-minor disruption to plant function - little or no reduction in output due to plant damage; there may be some decline in output as a result of absenteeism stemming from psychological effects of an earthquake or due to inconveniences resulting from minor damage to roads, elevators, or private residences.
L - light	0.5	Economic impact noticable - some of the plants and lifelines are damaged - some plants may be out of function for a short duration - 1 day or less, some production time is lost due to clean-up and restoration needs - not very significant.
M - moderate	8	Economic impact significant in plants, lifelines damaged, some damage induced by secondary hazards, considerable decline in the region's output; many plants closed for a considerable period of time; outside aid flows into the region.
H - heavy	30	Widespread economic impact - disruption of physical plant and lifeline networks - unemployment level comparable to the days of great depression; many plants closed for a long time, if not totally condemned; considerable damage from secondary hazards; considerable external aid flows into the region.
C - catastrophic	60	Economic Impact Massive - majority of physical plants in the region not operational due to earthquake damage, the region may survive because of massive external aid.

Table II.

Damage States and Indirect Losses

1	2	3	4 (T_{ro})	5 (T_{bf})	6 Fraction of People			
Damage State (DS)	Level of Damage	Central Damage Ratio* (CDR)%	Time to Restore Order in Bldgs. (Man/hrs / 100 sq ft)	Length of Time bldg is out of function	Injured with w/o Conventional Ceilings		Dead with w/o Suspended Light fixtures	
					with	w/o	with	w/o
0	None	0	0	0	0	(0)	0	(0)
L	Light	0.3	≤ 3.5	0	0	(0)	0	(0)
M	Moderate	5	4.5	<1 day	$\frac{1}{100}$	$\frac{1}{500}$	0	(0)
H	Heavy	30	4.5-6.5	up to 3 mos. in some cases	$\frac{1}{50}$	$\frac{1}{75}$	$\frac{1}{400}$	$\frac{1}{500}$
T	Total	100	>6.5	>3 mos.	$\frac{1}{10}$	$\frac{1}{20}$	$\frac{1}{100}$	$\frac{1}{500}$
C	Collapse	100	>several days	1-2 yrs	most		1/4	(1/4)

Note: Data for columns 3,4,5, and 6 were obtained from R.V. Whitman et al, "Methodology and Pilot Application," Report # MIT-CE-R74-15, July 1974, Department of Civil Engineering, M.I.T., Table 7.2 and Figure 2.2.

*Damage ratio is defined as the ratio of the cost of repair of the damage to the replacement cost of the building.

Table III

Economic Impact Probability Matrix for UBC Zone 3

I (MMI)		V	VI	VII	VIII	IX	X
EIS	CIR						
O	0	.99	.90	.70	.05	.02	0
VL	.001	.01	.08	.20	.60	.30	.10
L	.005	0	.02	.07	.20	.30	.25
M	.08	0	0	.03	.10	.20	.35
H	.30	0	0	0	.04	.10	.20
C	.60	0	0	0	.01	.08	.10

Table IV

Data for the 1964 Alaska Earthquake for the Derivation of Economic Impact Probabilities

Towns and Cities in the Study Region	Intensity Experienced (MMI)	Central Impact Ratio[1] (CIR) %
Anchorage	VIII	32
Portage	VIII	30
Whittier	IX	33
Seward	VII	9
Homer	VII	7
Valdez	VII	9
Cordova	VII	8
Kodiak	VII	7
Fort Yukon	V	0.5
College	VI	1.0
Yakutak	VI	1.0
Sitka	V	0.1

[1]Estimates of CIR were obtained on a subjective basis from Appendix B.

Table V

Data for the 1971 San Fernando Valley Earthquake for the Derivation of Economic Impact Probabilities

Towns and Cities in the Study Region	Intensity Experienced (MMI)	Central Impact Ratio[1] (CIR) %
San Fernando	X	32
Sepulvada	VIII	30
Van Nuys	VII	10
North Hollywood	VIII	10
Burbank	VII	9
Hollywood	VII	10
Glendale	VII	1
Beverly Hills	VII	0.5
Los Angeles	VII	1
Pasadena	VII	1
South Pasadena	VII	8
Santa Monica	VI	13
Inglewood	VI	.54
Whittier	VI	.6
Lakewood	VI	.1
Long Beach	VI	1

[1]Estimates of CIR were obtained on a subjective basis from Appendix A.

Table VI

Economic Impact Probability Matrix

Derived from the Alaska and the San Fernando Valley Cases

MMI		V	VI	VII	VIII	IX	X
EIS	IR(%)						
0	0	0	0	0	0	0	0
VL	.1	1(.5)*	1(.143)	0	0	0	0
L	.5-1	1(.5)	5(.714)	4(.36)	0	0	0
M	7-10	0	1(.143)	7(.64)	3(.75)	0	0
H	11-40	0	0	0	1(.25)	1(1.0)	3(1.0)
C	41-60	0	0	0	0	0	0
Total number of towns in intensity category		2	7	11	4	1	3

*The number in the parenthesis is P_{EIS}

Table VII

Derivation of MEIR's from MDR Data

UBC Design Strategy	Changes in the MDR with UBC Design Strategy for Various Intensities						
	MMI	V	VI	VII	VIII	IX	X
3	MDR	0	.0013	.0140	.10	.446	1.0
	% Δ in MDR	0	23	36	80	124	0
2	MDR	0	.0016	.019	.1798	1.0	1.0
	% Δ in MDR	0	25	57	191	0	0
0,1	MDR	0	.002	.0299	.523	1.0	1.0

MEIR changes with UBC Design Strategy changes for various intensities interpolated from the above data

3	MEIR	.00001	.0002	.003	.028	.096	.149
	% Δ in MDR	0	23	36	80	124	0
2	MEIR	.00001	.000246	.00408	.0504	.215	.149
	% Δ in MDR	0	25	57	191	0	0
0,1	MEIR	.00001	.00031	.0064	.1466	.215	.149

Table VIII

Evaluation of Design Strategies for Various Locations

1	2	3	4	5	6	7
Location	Basis of Risk	UBC Design Strategy	$EALR^{(K)}$ per m$ of initial bldg.cost	Expected Discounted Damage per m$ $10^6 \cdot \frac{EDC^{(K)}}{IC^{(o)}}$	$EAEIR^{(K)}$ per m$ of initial bldg.cost	Expected Discounted Impact Loss per m$ $10^6 \cdot \frac{EIL^{(K)}}{IC^{(o)}}$
BOSTON	Most Likely Estimate (Firm Ground)	0,1	6.1	122 >40	1.2	23·28
		2	4.1	82 >18	.9	18·28
		3	3.2	64	.6	12
	Poor Soil	0,1	119	2380 >1140	27.8	556.2
		2	62	1240 > 360	18.1	362.4
		3	44	880	9.1	182
	Bayesian Weighted Risk	0,1	25	500 >200	21.0	419.6
		2	15	300 >116	12.3	246.6
		3	9.2	184	6.1	122
	Risk Curve UB-12	0,1	610	12,200 >5000	194.4	3887
		2	360	7,200 >3200	105.1	2102
		3	200	4,000	58.2	1164
SAN ANDREAS FAULT	10 Km Distance	0,1	8321	166,420 >53000	1976.1	39522
		2	5661	113,220 >47360	1238.8	24775
		3	3293	65,860	675	13500
	100 Km Distance	0,1	360	7,200 >2900	86.1	1722
		2	215	4,300 >1700	48.6	971.2
		3	130	2,600	27.7	554
PUGET SOUND	Firm Ground Sites	0,1	3114	63,284 >34604	793.2	15863
		2	1384	27,680 >9610	336.9	6737
		3	903	18,070	209.5	4190
	Poor Soil Sites	0,1	19055	381,110 >164390	5557	111140
		2	10836	216,720 > 98100	3263	65260
		3	5931	118,620	1439.3	28787

Table VIII (cont'd)

8 $EALR^{(K)}$ + $EAEIR^{(K)}$ per m$ of initial bldg.cost (4+6)	9 Total Expected Discounted Damage + Loss(5+7) per m$	10 Change in Damage + Loss with Design Strategy (per m$)	11 Initial Cost Premium (per m$ of initial bldg.cost)	12 Change in Cost Premium with Design Strategy (per m$)	13 Benefit-Cost Ratio of Bldg. Design Strategy $\frac{\Delta(10)}{\Delta(12)}$	14 Benefit-Cost Ratio of Bldg. Design Strat Based on Bdg Damage Alone $\frac{\Delta(5)}{\Delta(10)}$
7.3	145.3	45	0.0	29,000	.0015	.001
5.0	100.3	24.3	29,000	11,000	.0022	.0016
3.8	76		40,000			
122	2936.2	1333.8	0	29,000	.046	.04
80	1602.4	540.4	29,000	11,000	.049	.03
53	1062		40,000			
46	919.6	373	0	29,000	.013	.007
27.3	546.6	240.6	29,000	11,000	.022	.01
15.3	306		40,000			
804.4	16,087	6,785	0	29,000	.234	.17
465	9,302	4,138	29,000	11,000	.376	.29
258.2	5,164		40,000			
10,297	205,942	67,947	0	29,000	2.34	1.8
6,899	137,995	58,635	29,000	11,000	5.33	4.3
3,914	79,360		40,000			
446	8,922	3,651	0	29,000	.126	.1
263.6	5,271	2,117	29,000	11,000	.192	.15
157.7	3,154		40,000			
3907	78,147	43,730	0	29,000	1.51	1.19
1721	34,417	12,157	29,000	11,000	1.1	0.87
1112.5	22,260		40,000			
24,612	492,250	210,270	0	29,000	7.25	5.67
14,099	281,980	134,573	29,000	11,000	12.23	8.92
7,370	147,407		40,000			

Table IX

Expected Earthquake Losses for the San Francisco Area in 1970, 1980, 1990, and 2000

1 Year	2 Construction Value in the San Francisco Area (m$ - 1970 prices)[1]	3	4 Expected Discounted Building Damage Losses Based on SDDA (m$ - 1970 prices)[2]	5
		UBC 1	UBC 2	UBC 3
1970	76,488	12,729 (166·42x76·488)	8,660 (113·22x76·488)	5,037 (65·86x76·488)
1980	113,348	18,863	12,833	7,465
1990	157,318	26,181	17,812	10,361
2000	208,398	34,682	23,594	13,725

[1] J.H.Wiggins et al, Budgeting Justification For Earthquake Engineering, NSF Report #74-1201-1, May 10, 1974, Washington, D.C., p.68.

Table IX (continued)

6	7	8	9	10	11
Expected Discounted Economic Impact Losses based on SDDA (m$ - 1970 Prices)[2]			Expected Total Discounted Losses for the San Francisco Area (m$ - 1970 Prices)		
UBC 0,1	UBC 2	UBC 3	UBC 0,1	UBC 2	UBC 3
3,023 (76·488x39·522)	1,895 (76·488x24·775)	1,033 (13.5x 76·488)	15,752	10,555	6,070
4,480	2,808	1,530	23,343	15,641	8,995
6,218	3,898	2,124	32,399	21,710	12,485
8,236	5,163	2,813	42,918	28,757	16,538

[2]Expected discounted building damage and economic impact loss data per m$ of construction value were obtained from Table VIII, columns 5 and 7, respectively.

Table X

Estimate of Construction Value in the Boston Area
in 1970, 1980, 1990, and 2000

Year	Construction Value at risk, San Francisco Area (m$ in 1970 prices)[1]	Population at risk in the San Francisco Area[2]	Per Capita Construction Value in the San Francisco Area ($-1970 prices)	Population at risk in the Boston area	Construction value at risk in the Boston area (m$ in 1970 prices)
1970	76,488	7,795,137	9,812	2,730,228[3]	26,789
1980	113,348	9,252,058	12,251	3,328,148[4]	40,773
1990	157,318	10,708,978	14,690	4,056,846[4]	59,595
2000	208,398	12,165,899	17,130	4,945,535[4]	84,717

[1] J.H.Wiggins et al, Budgeting Justification for Earthquake Engineering Research, NSF, Report #74-1201-1, May 10, 1974, NSF, Washington, D.C., p.68. (Data is for the greater San Francisco risk area and not just the SMSA.)

[2] Ibid.

[3] Data is from the 1970 Census for the Boston SMSA.

[4] Calculation is based upon an average annual population increase rate of 1.9% year for the New England states; J.H.Wiggins, Op.Cit.,p.56.

Table XI

Losses for the Boston SMSA
for 1970, 1980, 1990 and 2000

Year	Construction Value at Risk in the Boston Area (m$ in 1970 prices)	Expected Discounted Building Damage Losses Based on SDDA (m$ in 1970 prices)		
		UBC 0,1	UBC 2	UBC 3
1970	26,789	3.27[1] (.122x26.789) 63.76[2] (2.38x26.789)	2.20[1] (.082x26.789) 33.21[2] (1.24x26.789)	1.71[1] (.064x26.789) 23.57[2] (.88x26.789)
1980	40,773	4.97[1] 97.01[2]	3.34[1] 50.56[2]	2.61[1] 35.88[2]
1990	59,595	7.27[1] 141.84[2]	4.89[1] 73.90[2]	3.81[1] 52.44[2]
2000	84,717	10.34[1] 201.63[2]	6.95[1] 105.05[2]	5.42[1] 74.55[2]

[1] Calculations are based upon the most likely estimate of risk in Boston (See Figure 2).

[2] Calculations are based upon risk estimates for poor soil conditions in Boston (See Figure 2).

Table XI (continued)

	Expected Discounted Economic Impact Losses based on SDDA (m$ in 1970 prices)			Expected Total Discounted Losses for the Boston SMSA (m$ in 1970 prices)		
Yr.	UBC 0,1	UBC 2	UBC 3	UBC 0,1	UBC 2	UBC 3
1970	.62(26.789x .233) 14.9(26·789 x556)	.48(26.789 x.018) 9.7(26.789x .362)	.32[1](.012x 26.789) 4.88(.182x 26.789)	3.89 78.66	2.68 42.91	2.03 28.45
1980	0.93 22.7	0.73 14.76	0.49 7.42	5.9 119.7	4.07 65.32	3.1 43.3
1990	1.37 33.1	1.07 21.6	0.72 10.85	8.64 174.94	5.96 95.5	4.53 63.29
2000	1.95 47.1	1.52 30.7	1.02 15.42	12.3 248.6	8.17 135.7	6.44 89.97

Table XII

Calculations Based on Construction Value Existing in YEAR	Total Expected Discounted Losses for the San Francisco Area[1] (m$ in 1970 prices)			Building Damage Losses due to the Reoccurrence of the 1906 San Francisco Earthquake[2] (m$ in 1970 prices)
	UBC 0,1	UBC 2	UBC 3	
1970	15,752	10,555	6,070	10,243
1980	23,343	15,641	8,995	13,721
1990	32,399	21,710	12,485	17,553
2000	42,918	28,757	16,538	20,840

[1] Source of data: Table IX, columns 9, 10 and 11.

[2] Source of data: J.H.Wiggins et al, Budgeting Justification for Earthquake Engineering Research, NSF Report #74-1201-1, May 10, 1974, p. 68.

APPENDIX A

An Economic Profile of the San Fernando Earthquake

The San Fernando earthquake occurred on February 9, 1971, at 6:01 a.m. killing 67 and injuring about 2500 people. Figure 1 shows the epicenter of the earthquake in relation to the various centers of population in the affected area. The most heavily shaken area is indicated in Figure 2. This region had a population of 1,284,000 in an area of 289 square miles.

The epicenter of the earthquake was near the northern boundary of the San Fernando Valley. Aside from the immediate vicinity of the epicenter, major building damage was also incident along the northern edge of the valley. Several unincorporated L.A. areas north of the Valley, such as Newhall, Valencia, and Saugus experienced heavy ground shaking and considerable damage to older buildings.[1]

The cities of Pasadena, Alhambra, South Pasadena, and San Gabriel, east of the Valley, were exposed to different levels of ground shaking. The pre-1933 downtown buildings of these cities experienced heavy damage. Similar damage patterns were experienced in the cities of Glendale and Burbank.[2]

In the city of San Fernando, an enclave within the city of Los Angeles, the older buildings surrounding the business district experienced very large damage. Most of the buildings in the downtown area of San Fernando were of non-reinforced masonry, and may be identified as pre-1933 buildings, and these suffered considerable damage.[3]

The aggregate economic data of the San Fernando Earthquake are summarized in Table 1-A. Crude estimates of income type losses are also indicated in this table. These are the 20%-30% decline in tax revenue, and the $16 million decline in the regional income. Data on pre-disaster insurance and post-disaster type adjustments (relief expenses and loans and grants) are also included in this table.

The total building and structural damage losses in the San Fernando earthquake amounted to $497.8 million. Table 2-A provides a breakdown of this amount according to the sector of the economy (public and private), and

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[1] Steinbrugge, Karl V., and Eugene E. Schader, "Earthquake Damage & Related Statistics," San Fernando, California, Earthquake of February 9, 1971, NOAA, Washington, D.C., 1973, p. 692.

[2] Ibid., p. 692.

[3] Ibid., pp. 692, 722.

the location within the stricken region. The damage to the private sector ($259.3 million) was slightly larger than that incident upon the public sector ($238.5 million). In terms of spatial distribution of building damage, the City of Los Angeles ranked first ($273.6 million), the county of Los Angeles ranked second ($100 million), and the city of San Fernando ranked third ($35.7 million).

The details of the $170.3 million private sector building damage (Table 2-A) are given in Table 3-A. The data is disaggregated into three different damage levels and three different types of buildings: single family dwelling, apartment and commercial-industrial. The last category of buildings is of particular interest to us since damage associated with commercial or industrial buildings may very likely involve income type losses to a stricken area. This category of building losses ($61.6 million) amounts to about 44% of the total reported building damage in the city of Los Angeles. Personal property and business inventory losses for the city of Los Angeles were estimated to be $50,000,000 (Table 4-A).

Building damage losses outside the city of Los Angeles but within the disaster stricken area are indicated in Table 5-A. The damage for the City of San Fernando ($35.5 million) represents about 66% of the building damage losses for the entire area outside the city of Los Angeles. The data is broken down into different levels of damage: those buildings that became unsafe for human occupancy, and those that were demolished. Within the last category of damage three types of buildings were considered: residential, school and commercial. Damage to the last type of building is directly linked to earthquake-induced income losses.

Earthquake damage losses to industrial plants are also very closely linked to income losses. Table 6-A shows the damage data for two different industrial tracts, Arroyo and Bradley, situated only a few miles from the epicenter. The total damage to these industrial tracts amounted to $2 million, or 17.6% of the pre-earthquake value of the structures.

Table 1-A

General Data on the San Fernando Earthquake

1. General	
Date	February 9, 1971
Time of Occurrence	6:01 a.m.
Duration	1 minuate (12 seconds of strong shaking
Epicenter	9 miles northeast of San Fernando
Magnitude	6.6 Richter
Highest Intensity Estimated	X MMI
2. Damage and Losses	
Damage to Structures	$497,800,000
Private	259,300,000
Public	238,500,000
Loss of Tax Revenue	~ Decline by 20%-30% of expected revenue in the first year
Loss of Income	Approximately 16,000,000 ($2,000,000 a week for 8 weeks)
Injuries	2,543
Death Toll	67
3. Pre-disaster Adjustments	
Earthquake Insurance Compensation	$48,574,452
4. Post-disaster Adjustments	
Total Federal Aid for Reconstruction	450,000,000
Relief Expenses:	
Red Cross Emergency Expenses	1,066,440

Long Term Recovery Aid for Private Sector:	
Red Cross	400,000
SBA Homeowners Loans (as of May 1971)	42,870,271
SBA Business Loans (as of May 1971)	13,472,754

Source: Tapan Munroe and John Carew, "An Economic Analysis of Adjustment to Earthquakes - the San Fernando Valley & Alaska Earthquakes," Mimeograph, 49th Annual Conference of the Western Economic Association, June 1974, Las Vegas, Nevada, Table 15.

Table 2-A

Summary of Earthquake Building and Structure Damage Losses

Private Sector:	
Buildings (Excluding Land and Contents)	
Los Angeles City	170,300,000
San Fernando City	35,500,000
Elsewhere	18,000,000
Non-Building Structures (Excluding Land)	259,300,000
Public Sector:	
Los Angeles City	103,300,000
San Fernando City	200,000
Los Angeles County	100,000,000
Other local areas	5,000,000
Porter Ranch (aftershock damage)	8,000,000
Utilities	22,000,000
	497.800,000

Source: Karl V. Steinbrugge and Eugene Schader, "Earthquake Damage and Related Statistics," San Fernando, California, Earthquake of February 19, 1971, NOAA, Washington, D.C., 1973, p. 694.

Table 3-A

City of Los Angeles Building Damage Losses

(Private Sector)

Damage Level	Building Type	No. of Bldgs.	Estimated $ Losses	Aver.Loss $/bldg.
1. Unsafe for Human Occupancy	single family dwelling	415	10,400,000	25,060
	apartments	54	11,500,000	212,963
	commercial & industrial	382	38,200,000	100,000
			60,100,000	
2. Major-Moderate Damage	single family dwellings	2,469	24,700,000	10,004
	apartments	192	7,700,000	40,104
	commerical & industrial	883	17,700,000	20,045
			50,100,000	
3. Minor Damage	single family dwellings	13,711	6,900,000	503
	apartments	1,748	17,500,000	10,011
	commercial & industrial	5,698	5,700,000	1,000
			30,100,000	
Total		25,552	$140,300,000	
Unreported Damage			30,000,000	
Grand Total			170,300,000	

Source: Karl V. Steinbrugge and Eugene E. Schader, "Earthquake Damage and Related Statistics," San Fernando, California, Earthquake of February 9, 1971, NOAA, Washington, D.C., 1973, p. 695.

Table 4-A

Earthquake Losses - City of Los Angeles

(Private Sector)

Item	Estimated $ Loss
Personal Property & Inventory Losses	50,000,000

Source: Karl V. Steinbrugge & Eugene Schader, "Earthquake Damage and Related Statistics," San Fernando, California, Earthquake of February 9, 1971, NOAA, Washington, D.C., p. 695.

Table 5-A

Building Damage Losses Outside the

City of Los Angeles (Private Sector)

MMI*	City	# of Bldgs Damaged	Distance from Epicenter miles	km	# Unsafe for Human Occupancy	# of Bldgs Demolished Resid	Comm	Schools	Estimated Total $ Losses
VI	Alhambra	55	24	38	15	0	5	0	2,000,000
VI	Beverly Hills	135	22	35	0	2	2	0	800,000
VII	Burbank	445	12.6	20	25	3	3	1	4,000,000
	Compton	0			0	0	0	0	10,000
VII	Glendale	–	16	26	31	13	23	5	2,000,000
V	Long Beach	–	43	69	0	0	0	0	–
VI	Pasadena	10	20.5	33	4	0	0	1	2,500,000
	San Gabriel	0			0	0	0	0	9,000
VI	Santa Monica	20	24	38	1	0	0	0	50,000
VI	South Pasadena	20	21	34	1	0	0	0	275,000
	Vernon	30			5	0	0	0	100,000
VII	L.A.County including Newhall, Saugus, & Valencia	1720	11	18	97	15	9	0	6,800,000
VIII or more	San Fernando City	1520	7	11	437	95	123	3	35,500,000
	Total								54,044,000

*Intensity estimates are based upon circular isoseismals, Karl Steinbrugge, et al, p. 703.

Source: Karl V. Steinbrugge & Eugene Schader, Op. Cit., p. 695.

Table 6-A

Earthquake Building Damage Losses to Light Industrial Plants*

Industrial Tract	No. of Bldgs.	Pre-earthquake Value (Present Worth) $	Earthquake Damage Loss	Loss as % of Value	Average Loss ($/bldg)
Arroyo	33	4,527,000	788,000	17.4	23,879
Bradley	23	7,172,000	1,277,000	17.8	55,521
Total	56	11,699,000	2,005,000		

* A total of 56 buildings were examined in the Arroyo and Bradley industrial tracts in the San Fernando area, and most of them had one story.

In the San Fernando earthquake hospitals in the stricken region suffered a great deal of damage. A total of 33 licensed hospitals existed in the valley at the time of the earthquake. Out of these, the Olive View Hospital, Holy Cross Hospital, Pacoima Lutheran Hospital, and the Veterans Administration Hospital were severely damaged. Table 7-A lists the damaged hospitals along with the extent of damage to buildings and equipment, and loss of beds. The building and equipment damage losses to the four hospitals mentioned above were respectively $31.4 million, $5 million, $6 million, and $10 million.

The bed-losses in the case of the Olive View, Holy Cross, and the Veterans Administration hospitals, are related to income losses in the region. If we assume that the average per diem revenue generated by a hospital bed in around $100, then for the case of Olive View hospital the revenue loss would be $13,503,000. Similar revenue losses for the Holy Cross Hospital, the V.A. Hospital, and the Pacoima Lutheran would respectively be $627,000, $13,325,500, and $330,000. These estimates assume that these hospitals did not have any excess capacity. The revenue losses for the four hospitals amount to bout $14.6 million. No mention has been made of these losses in the literature. The entire amount of these losses is, however, not to be thought of as income type losses for the region. If these short falls in revenue are added on to other regional income losses, such as decline in wages or salaries, we will have a problem of double counting. The only thing we can add to the regional income loss in this case is the decline in the profits of the hospital (if it is a profit-making organization), and the decline in wages and taxes resulting from the revenue loss.

Apart from bed-losses, the closure of a hospital implies significant income losses to a region. The V.A. hospital at Sylmar was shut-down permanently as it was badly damaged (Damage Ratio of 0.67). The Olive View Hospital was closed for approximately 7 months (Damage Ratio of 0.96); the Holy Cross Hospital for about a month (Damage Ratio of 0.56); the Pacoima Lutheran for a month (Damage Ratio of 1.00). These hospital closures imply decline in regional production, and, therefore, decline in regional income.

Public school buildings in the region fared quite well in the San Fernando earthquake. Out of 9200 individual school buildings at 660 sites, no damage was incident upon 160 of the sites. Not a single public school building collapsed at any of the sites; these included both pre Field Act and post Field Act buildings.* The damage statistics are given in Table 8-A.

*On the whole, post Field Act buildings did better than pre Field Act buildings. John F. Meehan,"Public School Buildings," San Fernando Earthquake of Feb. 9, 1971, op.cit.,pp.669-670.

The data includes the cost of clean-up aside from repairs, damage to equipment and supplies. The total losses of $2.9 million represent a small percentage of the market value of the schools. For example, the Los Angeles Unified School District reported in 1970-71 that the assessed valuation of the buildings amounted to $9.27 billion. This implies that the actual market value of these buildings amounted to about $37 billion. Thus it is apparent that the school building losses were insignificant compared to the estimated valuation of the buildings. As far as income type losses associated with the public schools are concerned, it can be safely assumed that they were not very significant if we consider the fact that there was not much interruption in school activities.

Data on the impact of the earthquake on taxable properties is of interest to us because of our particular concern with income type losses. Table 9-A summarizes the data on decline in assessed valuations* of various types of taxable assets such as land, improvement in buildings, fixtures, personal property, and business inventory. The major losses to land values occurred along the fault lines because of 5-foot vertical offset which implied expensive regrading operations. The table lists the declines in assessed valuations by different sections of the stricken area.

A preliminary effort at construction economic impact probability matrices (EIPM) has been attempted using the data in Table 9-A. We have used the percentage decline in the various assessed valuations as the impact ratio Each region was assigned an intensity level based upon circular isoseismals with the following radii:**

MMI	Radii (Km)
VII or greater	14
VII	25
VI	79
V	161
IV	263

*Assessed valuations are 25% of fair market values.

**W.A.Rinehart & S.T.Algermissen, N.O.A.A., in Karl Steinbrugge and Eugene Schader, op.cit. p.703.

The impact ratio and intensity (MMI) data have been rearranged according to the various locations in Table 10-A. Economic impact probability matrices have been constructed for each of the categories of losses - land, improvement, personal property, and business inventory, and they appear in Table 11-A.

Table 7-A

Earthquake Damage to Hospitals in the San Fernando Valley Area[1]

Location	Ownership[2]	Year Founded	Pre-earthquake Bed Capacity	Estimated Replacement Value Bld & Equip (m$)	Loss $ Bld	Loss $ Equip	Bed Loss
Canoga Park	Prop	1968	72	2.2	2,000	1,000	0
Canoga Park	Prop	1962	80	2.75	50,000	(combined)	0
Glendale	NP	1926	310	10.9	20,000	0	0
Granada Hills	NP	1966	201	6.0	5,000	0	0
N.Hollywood	Prop	1952	84	2.5	5,000	5,000	0
Northridge	NP	1955	206	6.0	300,000	55,000	0
Olive View	LA	1920	888				
	a.Medical Bldg.			25.0	25,000,000		
	b.Psychiatry Bld.			6.0	6,000,000		
	c.Central Heating			1.5	375,000		
Pacoima (Lutheran)	NP	1957	110	4.75	6,000,000(comb)[3]		110
Panorama City	NP	1962	321	9.1	250,000(comb)		
San Fernando (Holy Cross)	NP	1961	259	9.0	4,000,000	1,000,000	209
"	Prop	1922	69	1.4	1,000	1,000	0
Sepulvada	FG	1955	906	30.0	900,000(comb)		0
Sun Valley	Prop.	1967	111	4.0	1,000	0	0
Sylmer(VA)	FG	1926	365	15.0	10,000,000(comb)		365
Van Nuys	NP	1958	281	18.0	70,000	5,000	0
Total					52,979,500	1,067,000	1,327

[1] In all,17 hospitals were damaged or destroyed out of 23 licensed hospitals in the valley with a total bed capacity of 6,751.

[2] NP=non-profit; Prop=Proprietary; LA=Los Angeles County; FG=Federal Government. Source: Karl Steinbrugger, p. 714.

[3] The reason for the losses being higher than the replacement value was not clear to the authors.

Table 8-A

Estimate of Losses of Schools in the San Fernando Earthquake

[Dollars]

School district	Cleanup 1	Repairs 2	Equipment 3	Supplies 4	Books 5	Other 6
Los Angeles Unified	$47,408	$2,014,571	$7,112	$52,714	$724	$55,510
Los Angeles Community College	300	21,500				
La Canada Unified		3,139	745	49		
Newhall Elementary	4,065	14,506	940	264		
Pasadena Community College	537	16,215				
Pasadena Unified	970	10,549				
Saugus Union Elementary		35,641	512			
Soledad-Agua Dulce Unified Elementary	100	18,931				
Temple City Unified	92	7,167	150	40		
Whittier Unified High School		4,519				
Burbank Unified	2,677	12,828	193	487		
Beverly Hills Unified		10,887				
El Segundo Unified		61,310				
Glendale Unified	10,414	308,424	1,953	3,167		
Glendale Community College	1,087	24,594				
Wm. S. Hart Unified High School	3,400	133,494	1,595	1,766		
Santa Monica Unified Jr. College						
Culver City Unified						
Inglewood Unified						
Lancaster Elementary						
Westside Union Elementary						
Palmdale Elementary						
Sulphur Springs Union Elementary	3,390	38,725	47	50		
Total	74,440	2,737,000	13,247	58,537	724	55,510
Sum (includes damage to pre-Field Act buildings and post-Field Act buildings)						$ 2,939,458

Source: Reprinted from John F. Meehan, "Public School Buildings," in San Fernando Earthquake of February 9, 1971, NOAA, Washington, D.C., 1973, p.682.

Table 9-A

Impact of Earthquake in Terms of Fall in Assessed Value,

Los Angeles County

Location	Category of Value	Land m$	Improvements[1] m$	Fixtures m$	Personal Property m$	Business Inventory m$
San Fernando City:	Preearthquake Value	14.224 (56·89)	14.971 (59·88)	0.132 (.53)	0.197 (.79)	0.572 (2·29)
	Assessed Loss	6.926 (27·84)	2.636 (10·54)	.002 (.008)	.003 (.02)	.002 (.008)
	% Loss	49.5 (%)	17.6 (%)	1.38 (%)	1.51 (%)	0.28 (%)
Burbank:	Preearthquake Value	115.634 (462·54)	124.945 (499·8)	14.236 (56·94)	26.960 (107.8)	14.039 (56·16)
	Assessed Loss	0	.380 (1·52)	0	.023 (.09)	0
	% Loss	0	0.3 (%)	0	.1 (%)	0
Glendale:	Preearthquake Value	144.203 (576.81)	170.770 (683.1)	1.903 (7·6)	4.872 (19·49)	3.116 (12·46)
	Assessed Loss	0	.715 (2·86)	0	.001 (.004)	.004 (.016)
	% Loss	0	.4 (%)	0	0	.1 (%)
Hardest Hit Area:	Preearthquake Value	46.580 (186·32)	54.380 (217.5)	.667 (2·67)	.612 (2.45)	1.333 (5·33)
	Assessed Loss	22.135 (88·54)	11.691 (46·76)	.004 (.016)	.021 (.084)	.011 (.044)
	% Loss	47.5 (%)	21.2 (%)	.53 (%)	3.35 (%)	0.85 (%)
San Fernando Valley:	Preearthquake Value	948.793 (3795·2)	1,382.755 (5531)	30.437 (121·7)	50.133 (200·5)	37.917 (151·67)
	Assessed Loss	52.160 (208·64)	20.045 (80.2)	1.825 (7·3)	.048 (o.19)	.021 (.08)
	% Loss	5.5 (%)	1.45 (%)	negligible	0.1 (%)	0.1 (%)

Note: All data appearing inside parentheses in the above table are the fair market value; calculation of faire market value was based upon the assumption that the assessed valuation was 25% of fair market value as determined by the Los Angeles County Assessor's Office.

[1] Improvements were primarily on residential structures.

Source: Karl Steinbrugge, Op. Cit., p.719

Table 10-A

Location	Intensity	Impact Ratio (%) Land	Improvement	Personal Property	Business Inventory
San Fernando City	IX	49.5	17.6	1.51	0.28
Sepulvada	IX				
Pacoima	VIII				
Burbank	VII	0	.3	.1	0
Glendale	VII	0	.4	0	.1
Hardest Hit Area (Sylmar) Olive View Area	X	47.5	21.2	3.35	.85
San Fernando Valley		5.5	5.5	0.1	0.1
(Pasadena,	VII				
Alhambra,	VII				
Newhall	VIII				

Source: Impact ratio data is from Table 9-A.

Table 11-A

Economic Impact Probability Matrix

(a) Land Value

Damage State	Impact Ratio	Intensity (MMI) V	VI	VII	VIII	IX	X
0 - none	0	-	-	0.5(2)[1]	-	-	-
VL - very light	<.5	-	-	-	-	-	-
L - light	0.6-1.5	-	-	-	-	-	-
M - moderate	1.6-10	-	-	0.5(2)	0.5(1)	-	-
H - heavy	11-30	-	-	-	-	-	-
VH - Catastrophic	31-60	-	-	-	0.5(1)	1.0(3)	1.0(1)

(b) Improvement

Damage State	Impact Ratio	V	VI	VII	VIII	IX	X
0	0	-	-	-	-	-	-
VL	<.5	-	-	0.5(2)[1]	-	-	-
L	0.6-1.5	-	-	-	-	-	-
M	1.6-10	-	-	0.5(2)	0.5(1)	-	-
H	11-30	-	-	-	0.5(1)	1.0(2)	1.0(2)
VH	31-60	-	-	-	-	-	-

[1] Data in parenthesis represents the number of locations that exhibit the specific damage state at that level of MMI resulting from the earthquake.

Table 11-A (continued)

(c) Personal Property

Damage State	Impact Ratio	Intensity (MMI) V	VI	VII	VIII	IX	X
0	0	-	-	.25(1)	-	-	-
VL	<.5	-	-	.75(3)	0.5(1)	-	-
L	0.6-1.5	-	-	-	0.5(1)	1.0(2)	-
M	1.6-10	-	-	-	-	-	1.0(2)
H	11-30	-	-	-	-	-	-
VH	31-60	-	-	-	-	-	-

(d) Business Inventory

Damage State	Impact Ratio	V	VI	VII	VIII	IX	X
0	0	-	-	.25(1)	-	-	-
VL	<.5	-	-	.75(3)	1.0(2)	1.0(2)	-
L	0.6-1.5	-	-	-	-	-	1.0(2)
M	11-30	-	-	-	-	-	-
H	31-60	-	-	-	-	-	-
VH							

APPENDIX B

An Economic Profile of the Alaska Earthquake

At the beginning of the 1960's, Alaska's previously-booming economic growth began to subside. Its importance as a military base had ceased in the mid-Fifties; employment in government projects was only 5% in 1963, down 6.5% from 1951. The new emphasis on its strategic location for travel and trade was just beginning. The fishing industry was thriving, bringing in annual returns of over $200 million. Eight and a half per cent of the population was engaged in the manufacture of commodities at the time of the earthquake.

The study of the effects of the 1964 earthquake on the Alaskan economy consists largely of a study of the physical damages of the disaster: damage to and destruction of plants, docks, transportation systems, fisheries, and communication systems. The immediate consequences of the disaster are indicators of the long term effects on levels of production, unemployment, and shifts in concentration of industry.

This report is a study of three effects of the 1964 Alaskan Earthquake which relate to economics. The first effect, Damage to Structures, has been viewed relative to interference with business rather than as a detailed study of structural inefficiency. The second, Damage to Lifelines, is again a discussion of obstacles to production and trade, as well as reparation costs. The third, most extensive discussion, Economic Repercussions attempts to summarize the effects of the earthquake on the economy, with emphasis on changes in types and numbers of businesses, costs of damage and sources of funding, and length of time for completion of repairs. Graphs showing unemployment levels for the years following the earthquake are also included in the study. Finally, a Damage Probability Matrix is constructed, based on the damage states described herein and the resulting economic input. Modified Mercalli intensities are compared with Impact States to determine the probability of an input state occurring, given a particular MMI.

Table 1-B

General Data on the Prince William Sound, Alaska, Earthquake

1. General	
Date	March 27, 1964
Time of Occurrence	5:36 p.m.
Duration	3-4 minutes
Epicenter	61.04^{o} N & 147.73^{o} W
Magnitude	8.3-8.75 Richter
Highest Intensity Estimated	IX-X-MMI
2. Damage and Losses	
Damage to Structures	$311,000,000
Private	77,000,000
Public	240,000,000
Loss of Tax Revenue	14,000,000
Loss of Income	Not Known
Injuries	40 seriously
Death Toll	115 (+11 in California, 4 in Oregon)
3. Pre-disaster Adjustments	
Earthquake Insurance Compensation	$1,500,000
4. Post-disaster Adjustments	
Total Federal Aid for Reconstruction	
Private Sector	$109 million
Public Sector	190 million
Relief Expenses: Federal	
Government Emergency Expenses	8 million
Red Cross Emergency Expenses	1 million
Salvation Army Emergency Relief Expenses	$500,000

Misc. Services Emergency Relief Expenses	$500,000
Long Term Recovery Aid for Private Sector:	
Red Cross Grants	800,000
SBA Loans	82,200,000
FNHA Forgiveness of Mortgages	6,000,000
IRS Tax Relief	15,000,000
REA Loans	2,700,000
FHA Loans	300,000

ANCHORAGE

Anchorage, with a population of 50,000 in 1964, is the trade, communications, and transportation center of Alaska. The city's main industry, however, is based on the two military installations, Elmendorf Airforce Base and the Army's Fort Richardson. The damage suffered by the city as a result of the earthquake was extensive.

Damage to Structures[1]

The ocean dock was almost destroyed. All other docks were somewhat damaged, including the city dock and several privately-owned docks. Two cement storage bins collapsed on two different docks; on one of these docks, a crane also tipped over.

Damage to fuel-storage facilities caused the loss of 1/6 of Standard Oil's gas (50,000 out of 300,000 gallons on hand), though the Union Oil Company suffered no storage losses (200,000 on hand) and Shell had only light losses (11 million gallons on hand).

The 112 mile railroad track connecting Anchorage with Whittier was lost. Damage to buildings was extensive; a detailed listing is contained in Table 2-B.

Damage to Lifelines[2]

Power

Although neither of the two Municipal Light turbines was damaged, the gas fuel lines were broken. One plant lost a boiler. Nevertheless, some power was restored within an hour and a half, with restoration continuing throughout that night and the next day. Within two days, most power had been restored. Damage to Municipal Light was estimated at $250,000.

Oil tanks containing alternate fuel ruptured from the earth's shaking, and the transmission lines between Cooper Lake and Anchorage were severely damaged. The hydroelectric plant at Eklutna also suffered damage.

Telephone Service

Physical damage to the telephone system was severe: battery racks collapsed, wires snapped, cables were damaged, and small fires occurred.

Civilian long-distance service was cut off, but within the 24 hours, long-distance service was available for emergencies. Within 3 days, 90% of service was restored.

Gas

There were hundreds of pipeline failures in the Anchorage area, and some outlets, such as in Turnagain Heights, which was totally destroyed, disappeared. Within one day, however, gas was restored to the Municipal Light and Power turbines, and within one week, service was restored to 4,000 of the company's 5,000 customers.

Water

Fifty to sixty per cent of the water distribution system was lost, but within 2 days three-quarters of the population received water service. After one more day, almost all service was restored.

Sewerage

Temporary lines were set up within two weeks, as the sewer system had suffered great damage. By September 30, 1964, all sewer repairs had been completed.

Economic Repercussions (2)

The mining industries (petroleum, natural gas) and the manufacturing industries (fish processing, cement products, food) were not much affected by the earthquake. The trade, finance, insurance, real estate and service industries suffered a decline due to both destruction of stores and restaurants and the decreased tourist trade. However, much business was restored by summer. New jobs were created in the process of reconstruction.

The earthquake did cause a shift in employment activities, at least temporarily. The Contract Construction industry increased its number of employees by 51.6% between March and April; however, by May, this industry dropped 45.6%, returning to its normal level. Between March and April, Transportation, Communication and Utilities decreased 9%; Trade, Services, and Miscellaneous decreased .6%; and Civilian Government increased 2.2%. Therefore, changes in employment were transient and limited to the construction industry.

Permanent repairs on the light and power systems were completed by August 1965; the water system, November 1964; and the sewer system, July 1965. Repairs to city-owned buildings (see Table B-2) and the Anchorage International Airport were finished in November 1964. Most schools were restored by August 1964. The majority of the repairs were funded by city funds rather than Federal funds, although the Office of Emergency Planning contributed $17,260,000. The Anchorage Independent School District gave $5,529,000.(3)

The damage suffered by Anchorage is classified as IX-X on the MMI scale. The Impact State of M(Moderate) has been assigned to Anchorage, on the basis of the overall economic impact of the disaster. Although physical damage may have been as serious as H(Heavy), there were no secondary hazards as a result of the earthquake.

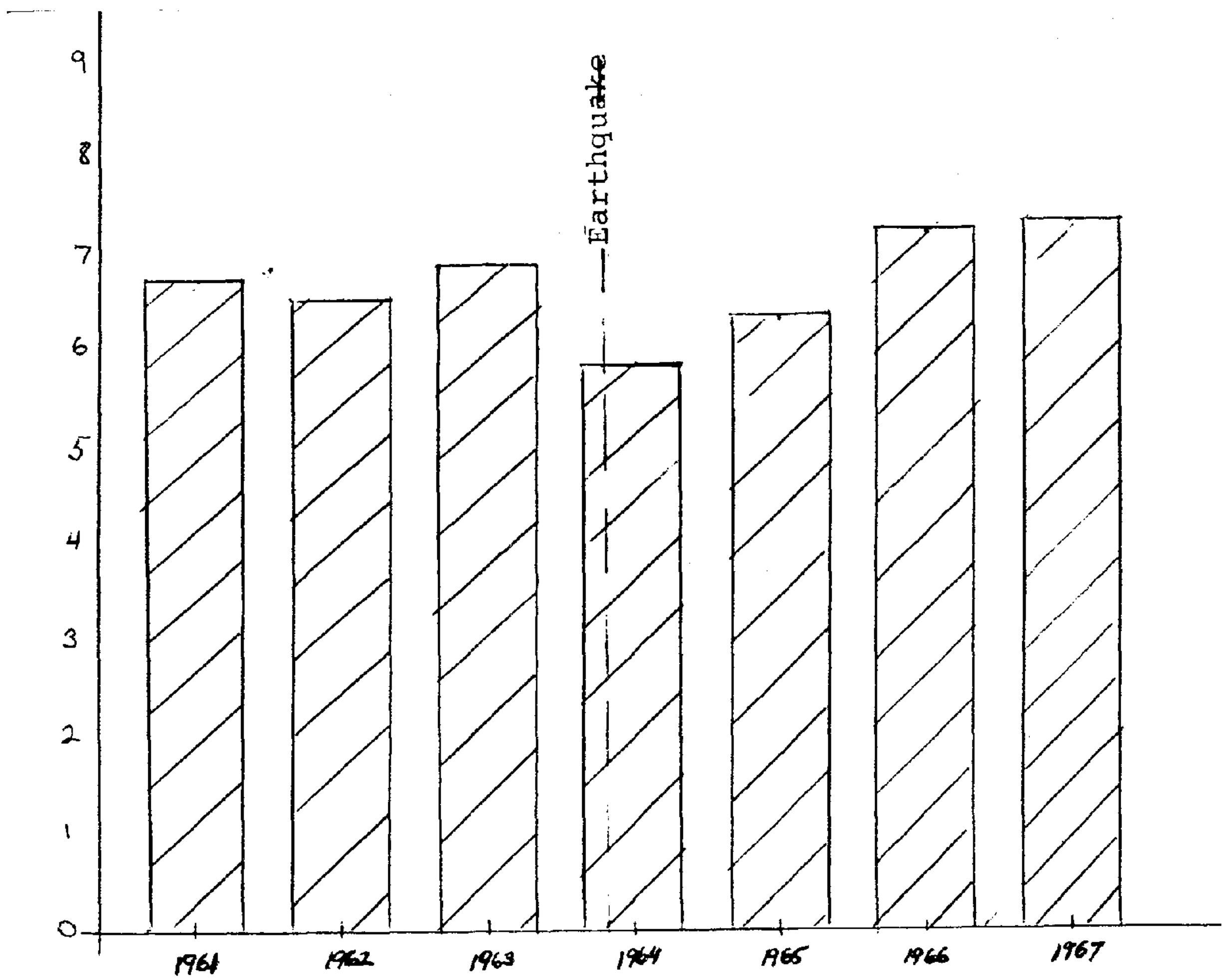

Figure 1-B

Percentage of Civilian Work Force Unemployed*

Anchorage

*Unemployment data from Ref(2),pp63-73.

Table 2-B

DAMAGE TO STRUCTURES IN ANCHORAGE

Building	Cost of Repair	
I. STATE-OWNED BUILDINGS		
1. Mines and Minerals Building	damaged beyond repair	
demolition cost	$ 8,000	
new replacement building	165,000	
2. State Highway Dept.		
a. Office Building	40,000	
b. Maintenance Building	72,000	
3. Alaska Psychiatric Institute	162,000	
II. CITY-OWNED BUILDINGS		
1. Water-Treatment Plant		
2. Public Safety Building	51,229	
3. City Warehouse	29,756	
4. Merrill Field Control Tower	3,315	
5. Fire Station No. 2	8,256	
6. Fire Station No. 3	12,093	
7. Fairfax Telephone Exchange	500	
8. Federal Telephone Exchange	1,000	
9. Broadway Telephone Building	28,900	
10. Public Health Center	16,300	
III. SCHOOLS		
1. West Anchorage High	195,633	
	800,000	3 phases of repair
	1,223,306	
2. Old Government Hill School	1,122,800	
3. Denali School	1,084,002	
4. Central Junior High	120,000	
5. East Anchorage High	198,400	
IV. PRIVATE STRUCTURES		
1. Four Seasons Apartment Building-collapsed completely		
2. Hillside Apartment Building (demolition of old building; construction of new)	1,100,000	
3. Mt. McKinley Building-damage not severe		
4. L Street Building	300,000	
5. J.C.Penney Building damaged beyond repair; removed and replaced		

Source: Reference (1).

KODIAK

Kodiak, a fishing and processing city with a population of 8,000, suffered earthquake damage in three stages: (a) the earthquake itself; (b) a series of tsunamis, bringing about extensive flooding; and (c) a severe wind storm several days afterward. A quarter of the population was killed, and 40% of the business district, as well as many private residences, were destroyed.

Damage to Structures[1]

Seventy-seven per cent of the city's fishing boats were destroyed, badly damaged, or missing. In numerical terms, 35 were sunk, 17 were missing, 25 were damaged, and 20 were slightly damaged. Repairs to these vessels, plus 30 salmon boats (out of 325) cost $2,444,250.

Three canneries were lost. King Crab, Inc., and the Kodiak Ice and Cold Storage Company were damaged but survived. The Cold Storage Company's first floor was flooded with 8 feet of water. A fishery and packing installation were lost. The salmon cannery survived, and the two other plants were damaged only slightly. On the waterfront, approaches, boats, piers, piles and buildings, as well as the City Dock, suffered damage.

Damage to Lifelines[2]

Communications

Until early in the morning of the day after the earthquake (Saturday), there was no telephone communication at all, as the lines had been shaken down and the central office and switching gear had been destroyed. By the following day (Sunday), however, the phone system had improved. By Sunday, residents would make long-distance calls. In the interim, communication within the city was carried out by taxicab. The Red Cross sent out over 3,000 telegrams, at a cost of $7,000. The local newspaper was not published for two weeks, as the printing equipment had been destroyed.

Electric Power

The electric power system was completely disrupted. The power plant was flooded, but generators began to be restored a few hours after the flooding ended. By April 1, restoration was almost complete outside the disaster area.

Water and Sewer Systems

Little damage was suffered by the water and sewer systems, except in the part of town that was completely destroyed. There was no water until midmorning of the day after the earthquake (Saturday), but within 2 days, water was supplied to most residents. When Urban Renewal was begun after one week, restoration of the water and sewer systems became a long-term project.

Roads and Streets

Although several roads were washed out, including sections of the main road running along the ocean front, damage was minimal. Street and road loss was estimated at $445,000.

Economic Repercussions(2)

Overall, the fishing industry was hit hard, with the king crab industry suffering the most (1963's production of 40 million pounds dropped to 24 million in 1964). Wholesale value of salmon products rose soon after the disaster; in fact, 1964 produced record packs of salmon. However, this phenomenon is believed to be completely unrelated to the earthquake. By mid-May, five salmon canneries were in operating condision, with several new canneries opening in the area.

Despite extensive damage, Kodiak was able to participate fully in the 1964 fisheries season. Improved financing terms made replacement of lost boats, equipment and waterfront structures possible. A 1964 decrease in employment in fish product-industries was only temporary; by 1965, the level of production of predisaster years was reattained.

Repairs of structures and the sewage lift station, as well as clean-up debris, were completed by September 1964. By October 1964, sidewalks and the sewer, water and storm drain systems were repaired. A new city dock was usable in December 1964 and finished in July 1965. A small-boat harbor was opened in January 1965; new inner floats were used in October 1964. A $10 million urban renewal program was also initiated immediately after the earthquake.

One hundred people were hired for various jobs immediately after the earthquake, for such work as distributing food at community centers. The Red Cross was responsible for paying these workers. A clean-up program was funded by the Office of Emergency Funding. Pilfering and other disruption was minimal; nevertheless, the bars were ordered closed for 10 days.

Since 1964, a state ferry system has been instituted, connecting Kodiak with Anchorage and the Kenai Peninsula, increasing the city's accessibility. Commercial airlines have now instituted flights between Kodiak and Seattle, greatly improving the tourist trade. The Office of Emergency Planning's contribution of \$3,194,000[3] greatly helped the city's recovery.

Kodiak's MMI classification is VII, but its impact state is H(Heavy), on the basis of the overall economic impact on the community. In particular, this is due to extensive damage from tsunamis (secondary hazards) and high levels of unemployment. Part of the city was completely destroyed, which also contributes to its high impact state rating.

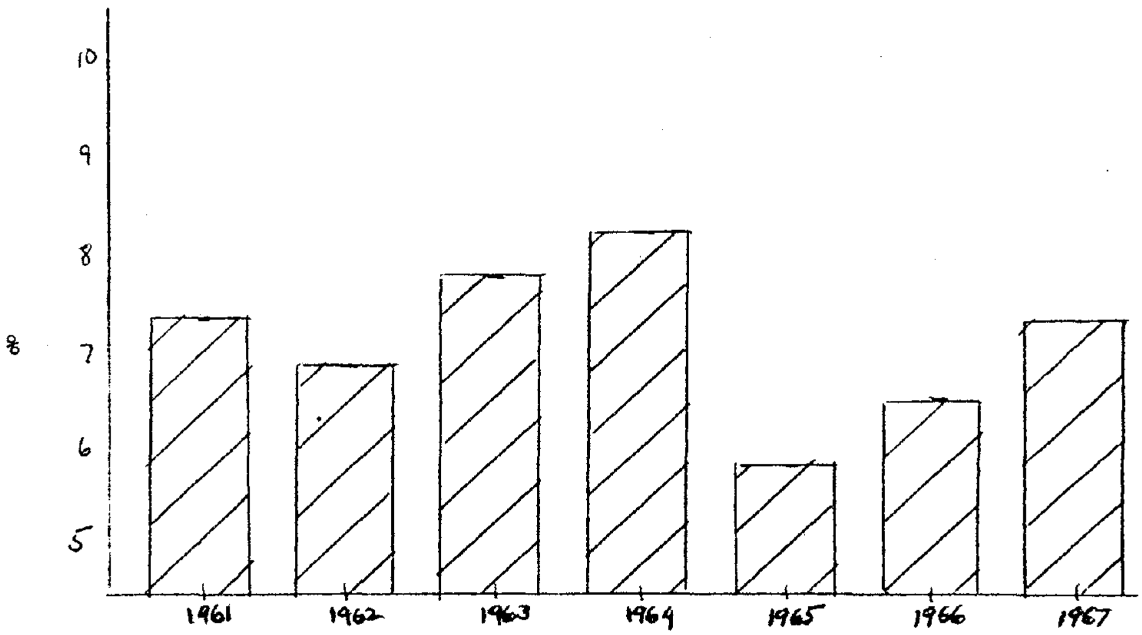

Figure 2-B

Percentage of Work Force Unemployed

Kodiak

SEWARD

Seward's 2,300 residents were engaged, for the most part, in the transportation industry at the time of the earthquake. Before 1961, Seward was the rail center for interior Alaska, and its ocean port handled a large volume of freight. The city's attempts to expand its industry to the seafood and tourist trades had failed. The earthquake incurred extensive damage, and Seward has never recovered, in terms of both its economy and its level of population.

Damage to Structures(1)

Destruction was caused by slides, fires, locally generated waves and tsunamis. Waterfront fuel-storage tanks at the Standard Oil site exploded, and the resulting fire on the water spread to the land, and houses, boats, floats, pilings and debris were carried away. The Texaco installation burned for several days. The ocean port was destroyed, and the ocean terminum of the Seward-Anchorage highway and the Alaska Railroad were severely damaged. The small-boat harbor disappeared. The electric generating station was lost, as were most of the petroleum bulk storage tanks.

The facilities that were completely lost include four docks; most of the Alaska Railroad dock, including one warehouse and part of a second; a halibut cannery; the small-boat harbor; a fleet of over 30 fishing boats; 40 pleasure craft valued at $2 million; 2 railroad-owned cranes; water trackage; 3 residences leveled from fire and 83 others declared unfit; the old Federal Building; several wells; and the generating plant and power lines.

Damage to Lifelines(2)

Most railroad trackage and the water, sewer and power lines were lost. The radio tower was down, as well as the telephone lines, and for several hours there was no communication with the rest of the state. The Alaska Telephone Company ran on an emergency battery which managed to provide 8 hours of service, and long distance was operational by 2 a.m. Saturday. Ninety per cent of the water system was damaged. The airport parking strip was destroyed, as were all planes, including the Civil Air Patrol.

By Monday, most had sewer service, and regular electric power was restored to the high school, where hundreds of people were staying. They remained there for 5 days, until electricity began to be restored in homes. Line breaks were also repaired by Monday, but some blackouts did ensue. There were no shortages of gasoline and fuel oil.

Economic Repercussions[2]

The economy was forced to a standstill as waterfront facilities were almost totally destroyed. Airport, hospital and public school repairs were completed by September 1964; the dock, water and sewer systems, electricity distributing system and power plant were restored within the next 2 months. The small-boat harbor was repaired in March 1965, and the floats and inner harbor facilities in May.

A poultry producer was forced to kill 5,000 fowl because he had no feed, water, power, or heat. All citizens were forced to eat at public central feeding places. Prescriptions were filled from a damaged pharmacy, and eventually free medicine was dispensed. Bars were closed, and banks allowed no withdrawals, only deposits. Everyone was given typhoid shots, and the only health problem was an outbreak of intestinal influenza among children and infants ten days after the earthquake.

The Red Cross and Salvation Army flew in from Anchorage on Monday, bringing clothing and interviewing people for grants. The Red Cross gave $85,976 assistance for shelter, food and clothing. The Salvation Army paid for laundry and donated $10,000 to the Seward Civil Air Patrol. This money was used for a new radio and an airplane. Seward had been designated as an "All-American City" and other cities sharing that title, especially San Diego and Allentown, Pennsylvania, made contributions.

Schools opened on April 13, and on April 2, a number of bars, a bowling alley, and a movie theater opened and the newspaper published a regular weekly edition. In mid-April, the Small Business Administration began to arrange loans. Highway service north to Anchorage was not available until May 25.

A temporary harbor opened mid-July; the permanent one was complete a year later. A $1,590,000 Urban Renewal program was initiated. A $6 million docks contract was awarded to the Corps of Engineers in September 1964. The new dock opened in August 1966.

One year after the earthquake, the economy was weak and failing even further. The fact that business prospered temporarily and that population had only decreased by 100 immediately after the earthquake was merely due to Federal funding and reconstruction. By fall of 1964, employment had already begun to fall; 11 out of 14 Standard Oil workers went to Anchorage.

Population decrease over the four years following the earthquake was significant indeed:

1964	-	2,300
1965	-	2,213
1966	-	1,800
1967	-	1,471

By 1967, Seward businesses were suffering; the city's only furniture store, its only bakery, a grocery and a variety store had disappeared. Credit business was practically non-existant. Seward's status as a trade center had been lost, with most traffic going to Anchorage instead, and the economy and population level have never recovered. Even the Office of Emergency Planning's aid of $10,268,000[3] failed to salvage the city.

Seward, with an MMI rating of IX-X, suffered an impact state of H(Heavy), mainly because of the long-term effects of the earthquake on the economy.

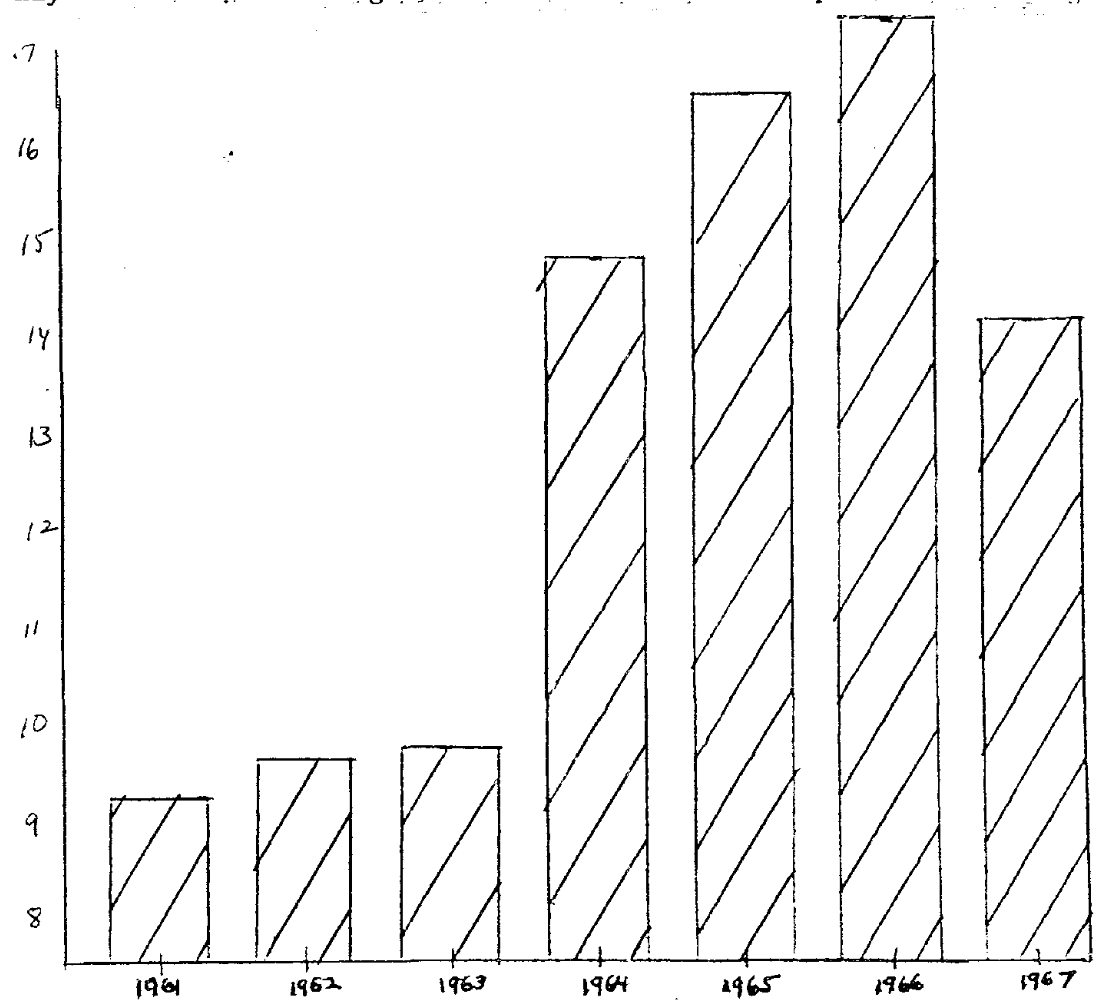

Figure 3-B Percentage of Work Force Unemployed Seward

CORDOVA

Damage to Cordova, a fishing and canning center with a population of 2,000, was extensive. The ensuing tsunami caused additional damage to waterfront facilities. Nevertheless, the community managed to recover quickly.

Damage to Structures(2)

The motion of the earthquake shook loose the city dock. The radio station tower fell, but the station was off for only a short time. Warehouses were knocked off their foundations, and some small buildings, including houses, fell into the bay. Two crafts were also destroyed. The tsunami caused great damage to the city dock, small-boat harbor, canneries, houses, and ferry slip. Water got into the canneries, causing extensive flooding.

Damage to Lifelines(2)

Little damage was suffered by telephone, water and sewer service, which continued to function during the earthquake. Whatever damage was suffered by the sewer system was repaired by the end of August; in the meantime, there were no sanitation hazards. There was no serious damage to the ocean dock.

The new Copper River Highway was the most heavily damaged area. It was estimated that it would cost $17 million to make the road usable, and $25-30 million to restore it to its original condition. All bridges in the area were destroyed or damaged.

Cordova harbor was dredged at a cost of $620,000 in Federal aid. This project was completed in the summer of 1966.

ECONOMIC REPERCUSSIONS(2)

Tectonic uplift caused the entire city to rise 7 feet, rendering the shoreline useless. The water was made too shallow, and shellfish beaches were exposed. Although the tsunami did not damage boats or floats, the damage it caused to the harbor made immediate repair mandatory.

Three or four businesses relocated through a special state grant of $106,000. A small canning company, the Crystal Falls Canning Company, was abandoned, as it became inaccessible from the sea. The New England Fish Company, one of the three large canneries, suffered extensive damage. Pilings and water and electric lines had to be replaced, and the dock was extended.

In June 1964, the Alaska Packers Association decided not to operate its Cordova Cannery that year. The industry would have suffered even more, had it not been for the Governor's success at persuading the Japanese to buy Alaskan fish. Only one cannery, the Parks Canning Company, was not affected.

Despite the extensive physical damage and other setbacks, Cordova was able to recover in time for the 1964 fisheries season. Boats, equipment and shore facilities were replaced under favorable financing terms. The community faced no shortages of food, clothes, shelter, or health facilities. The small-boat harbor was replaced by mid-September of that year, and the U.S. Bureau of Public Roads provided $20,900,000 for reconstruction of the Copper River Highway, as well as $5 million for bridge repairs. The Office of Emergency Planning gave $1,421,000 for reconstruction.(3) A new ferry terminal was constructed. In the fall of 1964, a $2 million Urban Renewal program was begun. In 1965, the year following the earthquake, the unemployment rate in Cordova improved 1.4%, due to the increased construction and repairs.

Although recovery in Cordova was quick, it was due mainly to the large inflow of funds. Damage was quite extensive and the overall economic impact of the earthquake, taking into consideration both damage and financial aid, was M(Moderate).

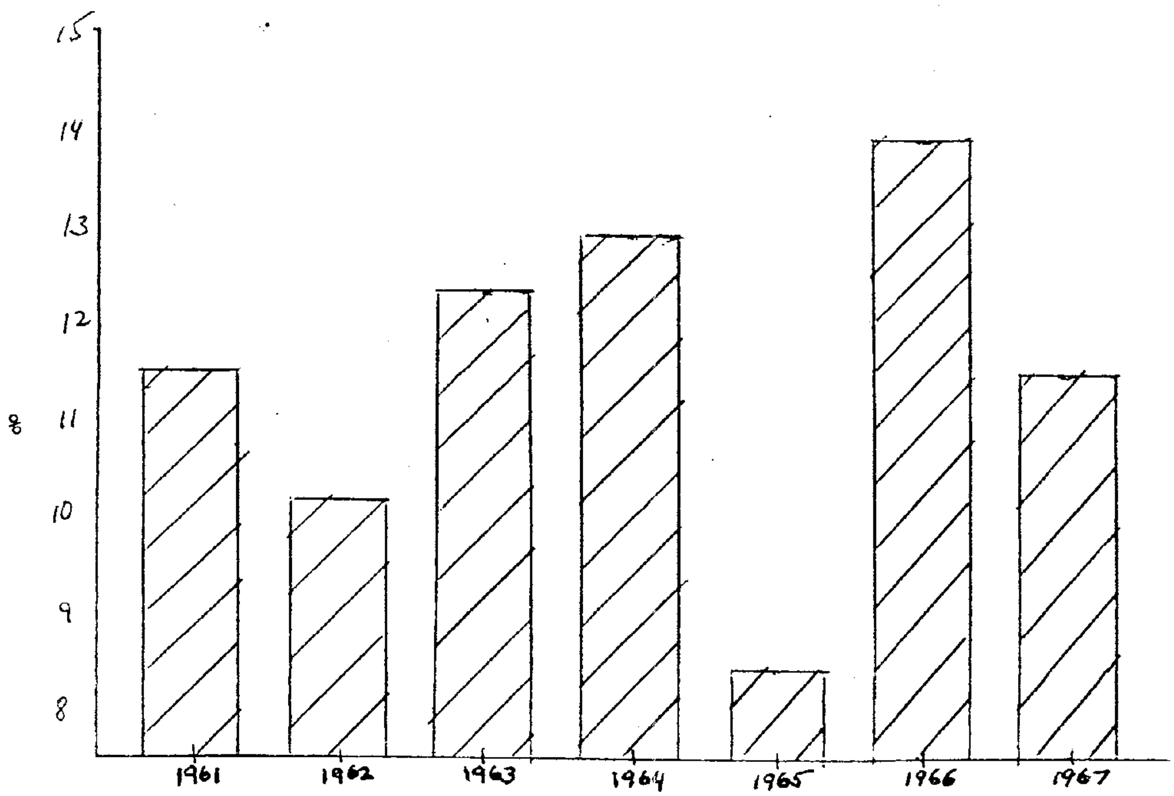

Figure 4-B Percentage of Work Force Unemployed

Cordova-McCarthy Area

VALDEZ

The transporation community of Valdez, with a population of 1,200, was located only 50 miles east of the earthquake's epicenter. It suffered extreme damage, so much so, in fact, that the entire city picked up and relocated. However, even the move did little to salvage the economy, and growth in Valdez has been limited.

Damage to Structures(2)

Damage was severe, especially as the earthquake and tsunamis caused a submarine land slide along the waterfront. The majority of the waterfront facilities slid into the bay: warehouses, a packing plant, a cannery, a bar, and even bystanders fell into the burning oil and debris in the water. Most of the rest of the village also suffered greatly.

Sixty-eight out of the 70 boats in the harbor were destroyed. A fire on Front Street claimed a small hotel and Standard Oil's pumping control station. Only one of the three power plant generators ceased to function. The city's seven churches were not damaged, but the elementary school was beyond repair. The high school was also severely damaged. The nursing home was destroyed, and the patients were brought to the Anchorage Psychiatric Institute.

Damage to Lifelines(2)

The water and sewage systems were completely destroyed. Local telephone lines were heavily damaged, though some long distance service did remain available. By Saturday, the telephone lines were rerouted, so that available phones did work. During the first few days, electric power had been reduced to less than 50% normal output, but within a month, all power was restored. Until the middle of April, only water that was delivered from other locations was potable.

Economic Repercussions(2)

At the time of the earthquake, Valdez's economy was changing from a highway center to a government town with a nursing home and highway-maintenance headquarters as its main industries. Many of the structures in the city were substandard, and the port and community facilities were old and insufficient. After the earthquake, most residents evacuated within 2 or 3 weeks, and many never returned. Because the city was so hopelessly damaged, Federal funds were provided to permit the city to move to the new Mineral Creek location. The residents of Valdez were reluctant to make the move, but construction was begun and the new city sprang up quickly.

Immediately after the earthquake, however, the inhabitants of Valdez were faced with a crisis. The city of Fairbanks, which was not badly hit, helped Valdez to a great extent, donating free legal assistance in drawing up Urban Renewal plans, tearing down unsafe buildings, and filling crevices on the highway connecting the two cities.

Food supply was never a problem, and the Army brought fresh water, water purifiers, emergency lighting, communications equipment, and a doctor. The Red Cross served food until May 20. Guards prevented people from entering unsafe buildings. There was no rush to withdraw money from banks; in fact, the activities of clean-up and reconstruction caused deposits to actually increase by about one-third for the year after the earthquake.

The old Valdez Airport and the Robe Lake Seaplane Base were repaired by May 1964. By August, repairs to the sewer and water systems, as well as the junior high, were completed.

At the new Mineral Creek site, a grade school was ready by September 1964; a dock was usable by November (completed in August 1965); and a small-boat basin and inner harbor facilities opened in May 1965.

On April 10, a mimeographed news sheet was put out, and in early August one of the town's two papers began printing a regular edition.

Meanwhile, construction at the Mineral Creek site progressed rapidly. The following facilities were opened within the next two years:

<u>May 1965</u> - municipal dock warehouse, small boat harbor, ferry slip

<u>October 1965</u> - barge landing

<u>August 1966</u> - water and sewer systems, state highway, public schools, city offices

<u>October 1966</u> - hospital

Three churches, street paving, curbs and gutters, cold-storage facilities, Valdez Dock company's dock, food stores, 45 private residences, and a state-city hospital were also constructed on the new site.

In August 1966, over two years after the earthquake, the economy had improved by 20% since the period immediately preceding the earthquake. Nevertheless, this progress was short-lived, primarily due to construction and repairs. The city experienced a decline soon afterward and, despite all funding and reconstruction, Valdez, even at its new site, is an economically failing community. Even the Office of Emergency Planning's contribution of \$5,977,000(3) failed to help.

Because of Valdez's total destruction and its subsequent relocation, an impact state classification of C (catastrophe) has been assigned to it, even though its MMI was only VII.

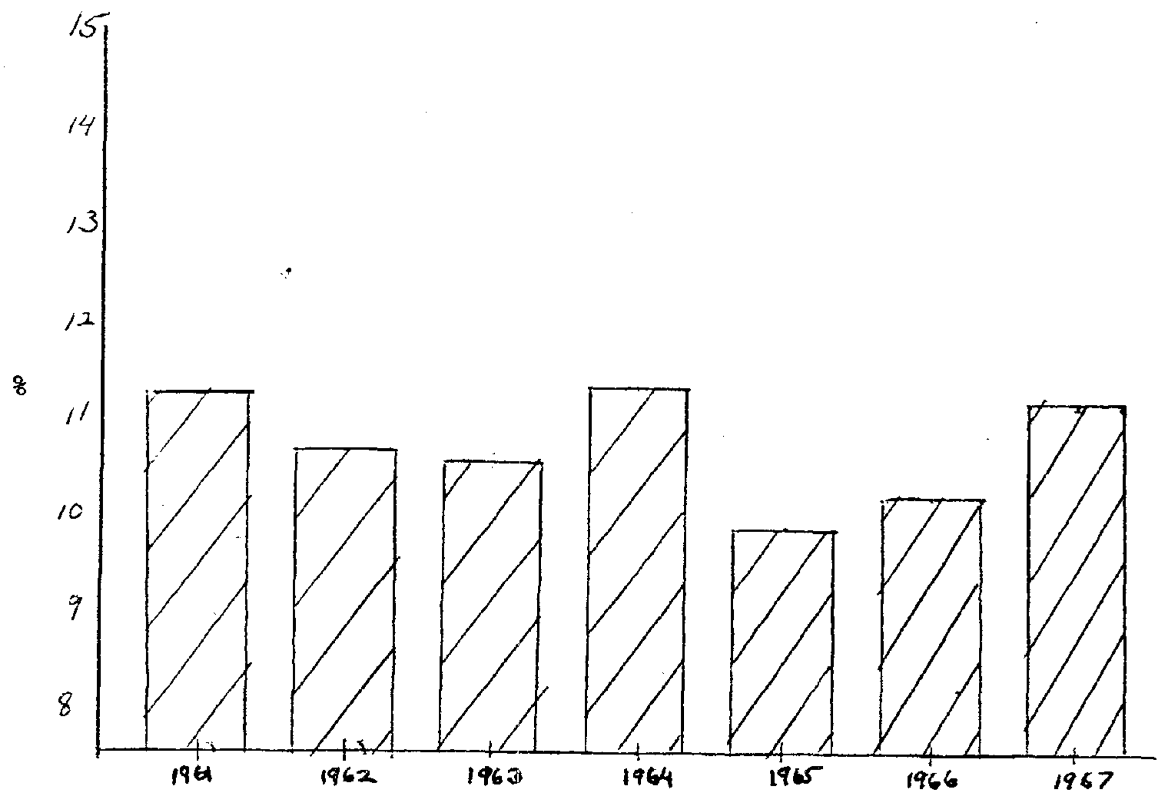

Figure 5-B Percentage of Work Force Unemployed
Whittier-Valdez

SELDOVIA

The fishing and seafood processing city of Seldovia is reachable only by sea or air, as no roads connect the area with the rest of Alaska. The city is small, with a population of 450. Businesses are clustered along a boardwalk. Earthquake damage was not severe; even the ensuing tsunami retreated quickly, damaging boats only slightly. In fact, Seldovia received no aid from the outside, even when flood tides threatened the area two weeks later, damaging some warehouse stores.

Damage to Structures[2]

The earthquake left no fissures and no casualties. The power plant and other facilities were able to function as usual, suffering only minimal damage. In the small Standard Oil tank farm, a tank was knocked over, but did not rupture. The townspeople themselves repaired the boardwalk.

Damage to Lifelines[2]

Telephone service was maintained throughout the earthquake, and the power plant and lines suffered no damage. There were no major roads in the area. In general, the effects of earthquake shaking on lifeline systems were minimal or insignificant.

Economic Repercussions[2]

At the time of the earthquake, the king crab plants were operating, but the salmon fishing and canning season had not yet begun. The crab plants then in operation were able to continue production as usual. However, several weeks after the disaster, the canneries threatened to leave Seldovia unless an Urban Renewal program was instituted. The buildings they occupied at that time were old and of little value, and the situation suddenly presented them with the opportunity to sell. The canneries refused to decide whether to relocate until such factors as land value, water supply, dock facilities and tax rates could be determined. An urban renewal program was instituted, which created a main thoroughfare with a shopping center and bowling alley. The program also raised the boardwalk, as the waterfront had dropped several feet and, as the town stood on pilings, there was danger of high winds and high tides.

Immediately following the earthquake, businesses and schools were closed for two days. Airport and boat repairs were completed by September 1964.

The economy of Seldovia, with its MMI of VII, suffered only lightly from the earthquake and the city has correspondingly been assigned an impact state rating of L(Light). No funds from the outside flowed in, and damages were light enough so that residents could complete repairs.

WHITTIER

The majority of Whittier's 70 citizens were engaged in government and transportation industries at the time of the earthquake, as the city housed an army port and a railroad installation. In 1964, the port's future seemed uncertain, as little shipping was going on in this isolated area.

The earthquake brought with it three sea waves: the first did little damage; the second was 40 feet high, boiling and carrying debris; and the third was 30 feet high. The earth's shaking caused avalanches in nearby mountains.

Damage to Structures[2]

Fire broke out on the waterfront and burning oil flowed into the fiord as a tank at the Union Oil farm exploded. The Columbia Lumber Company's building was leveled, and the Two Brothers Lumber Company was flooded. Great boulders, cast up by the huge waves, were left scattered over the waterfront. The air-strip was destroyed, and a chunk of the disengaged dock hit and destroyed the post office and depot.

Damage to Lifelines[2]

Following the earthquake, Whittier had no heat or light. The sewage system and telephone lines were completely destroyed. By Monday, however, the power plant was functioning,and heat and light had been supplied to the high school, in which the majority of citizens were staying. Within 5 days a field telephone system was set up. There was no food shortage, and the deep water wells were not damaged.

Economic Repercussions[2]

By Monday, repairs to the wharf, trackage, bridges, and tunnel had begun. The survivors worked to take care of each other, refusing aid from Civil Defense However, the Army did send a pysician, and the Red Cross sent some extra food. For ten days the residents were fed at the high school, where many of them also stayed while private residences were being inspected.

The Department of the Interior repaired all rail facilities. The sewage system was completed by the summer of 1964. Because Seward's shipping facilities had been destroyed and the Cook Inlet was frozen, Whittier's shipping increased as it carried the loads of the other two cities. This increased level of tonnage has remained constant throughout the years. The Office of Emergency Planning's aid of $14,000[3] helped in the completion of repairs.

Because of extensive damage, high unemployment, outside aid, and secondary hazards, Whittier, with MMI XI-X, has been assigned an impact state value of H(Heavy). This is because of the great impact the earthquake had upon the economy, particularly in terms of the factors listed above.

HOMER

The city of Homer contained canneries, motels, restaurants, and a small-boat basin and City Dock. Reconstruction of damage caused by the earthquake cost $1,565,000.

Damage to Structures(1)

Serious damage was suffered by the highway, city dock, small boat harbor, POL tankage, canneries and tourist facilities. The Land's End Hotel was flooded, and the Porpoise Room restaurant was completely destroyed. The Salty Dawg Saloon and the Standard Oil Tank farm were also extensively damaged.

Economic Repercussions(2)

The economy came to a halt as a result of the extensive structural damage. A temporary dock was built; the permanent dock was to be completed in November, 1964. In August, the 10-month construction of a small-boat harbor and related facilities was begun. Sections of it were usable by winter. Highway construction and improvement was delayed until spring. Minor repairs to the hospital and grade school were completed by August. In 1967, the Land's End Hotel was rebuilt near the new small-boat harbor.

Homer, with MMI VII, was assigned the impact state M(Moderate). Although outside aid was relatively low and no secondary hazards occurred, repairs were extensive and reconstruction was slow.

KENAI-COOK INLET[2]

The Kenai-Cook Inlet area consists of several small towns and villages which are engaged in either the fishing and fish processing industry or petroleum production and refining.

The area has experienced extensive out-migration since 1964, but this is probably due more to the dropping of military personnel caused by changes in the defense-communications systems than to the earthquake. Despite this out-migration, a continuing boom in offshore petroleum development in the Cook Inlet has compensated for any negative effects on the economy due to either the earthquake or the decline of the military industry in the area.

PALMER[2]

Palmer suffered relatively minor damage. It served as a temporary refuge for those emigrating from Anchorage.

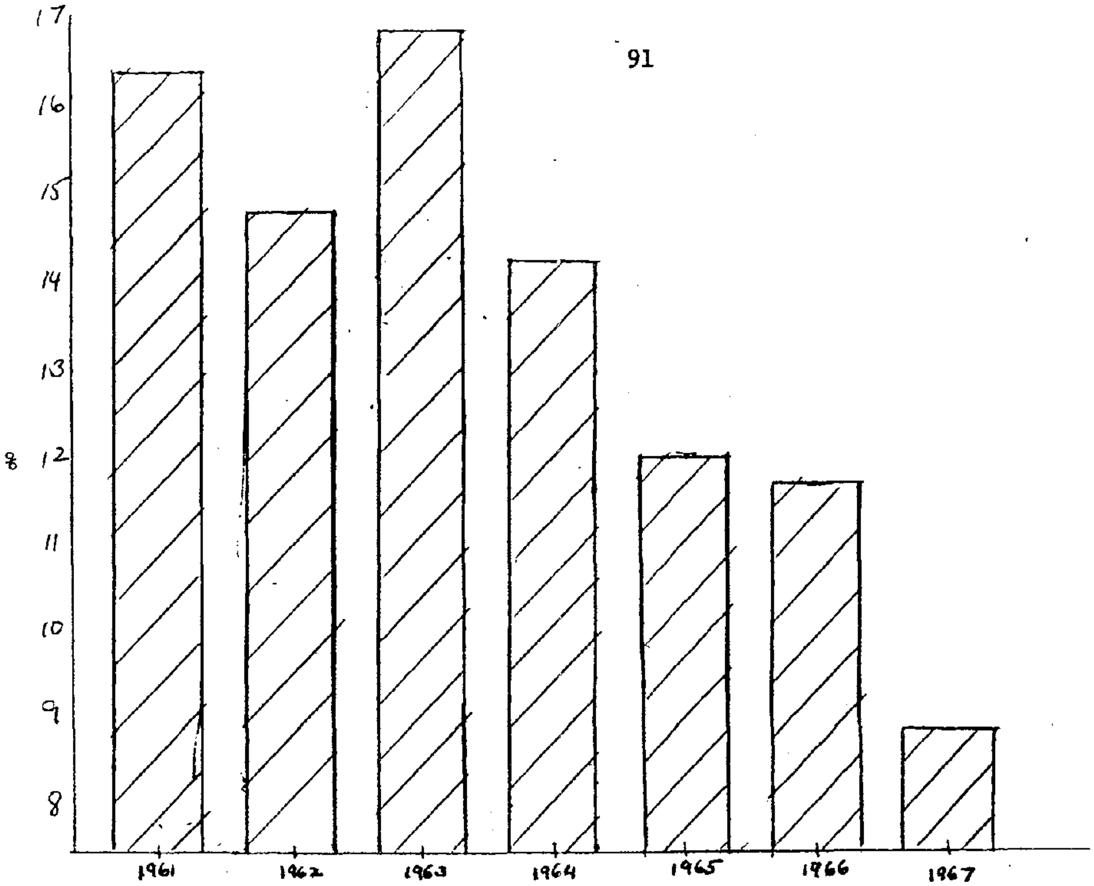

Figure 6-B. KENAI-COOK INLET

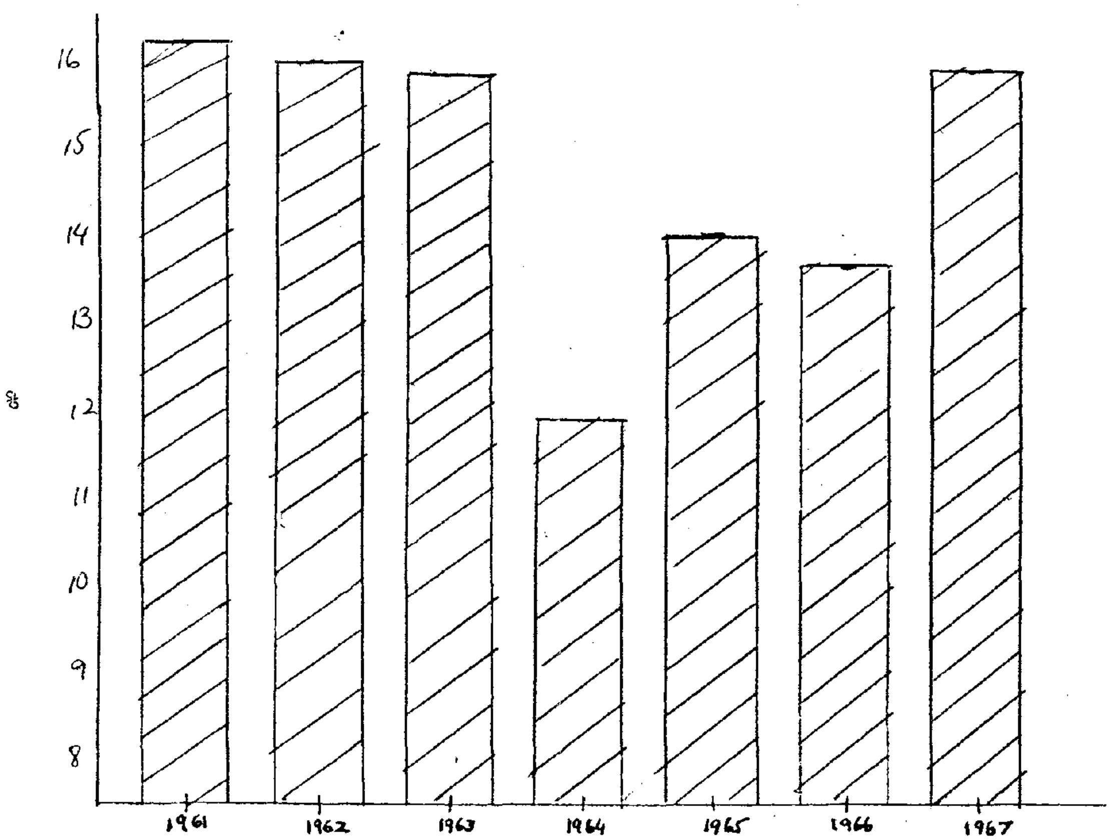

Figure 7-B. PALMER

Table 2-B

Damage Probability Matrix: Alaska

The Damage Probability Matrix for Alaska was obtained by 1) rating the individual cities according to damage incurred by the earthquake, on the basis of the six Damage States defined in the body of the report; 2) cross-tabulating the Damage State with the Modified Mercalli Intensity scale rating; and 3) determining the porbability of a particular Damage State occurring, given the MMI rating, based on the example of the Alaska cities.

DAMAGE PROBABILITY MATRIX

Damage State	Intensity - MMI					
	V	VI	VII	VIII	IX	X
O	-	-	-	-	-	-
VL	-	1(100%)	-	-	-	-
L	-	-	1(20%)	-	-	-
M	-	-	2(40%)	-	1(33%)	-
H	-	-	1(20%)	-	2(67%)	-
NH	-	-	1(20%)	-	-	-

MMI	City	Damage State
VI	Palmer	VL
VII	Kodiak	H
	Cordova	M
	Valdez	C
	Homer	M
	Seldovia	L
IX	Anchorage	M
	Whittier	H
	Seward	H

REFERENCES

(1) Committee on the Alaska Earthquake of the Div. of Earth Sciences, National Research Council, The Great Alaska Earthquake of 1964 - Engineering, National Academy of Sciences, Washington, D.C., 1973.

(2) The Great Alaska Earthquake of 1964 - Human Ecology, Ibid.

(3) Ibid., Appendix F.

APPENDIX C

Derivation of Impact Ratio

We know that,

I_r = wages + salaries + rent + interest + profit + tax revenue

where I_r is the regional income.

Let I_{r_i} = wages + salaries + rent + interest + profit

and T_{r_i} = total regional tax revenue;

Thus, $I_r = I_{r_i} + T_{r_t}$ (1)

but $T_{r_t} = T_{r_i} + T_{r_p} + T_{r_s}$,

where T_{r_i} = regional income tax revenue, T_{r_p} = regional property tax revenue,

T_{r_s} = regional sales tax revenue.

Thus, $I_r = I_{r_i} + T_{r_i} + T_{r_p} + T_{r_s}$ (2)

The simple tax function is given by

$T_{r_i} = f(I_{r_i})$

or $T_{r_i} = K_1 \ I_{r_i}$ (3)

where K_1 is the average propensity for income taxation.

Now $LT_{r_i} = K_2 LI_{r_i}$

or $LI_{r_i} = \frac{LT_{r_i}}{K_2}$ (4)

where the terms LT_{r_i} and LI_{r_i} respectively represent the loss in income tax revenue and loss in I_{r_i} resulting from the earthquake, and K_2 the marginal propensity for income taxation.

Let LT_{r_t}, LT_{r_p} and LT_{rs} respectively be the loss in total rax revenue, the loss in property tax revenue, and the loss in sales tax revenue.

Thus, $LT_{r_t} = LT_{r_i} + LT_{r_p} + LT_{r_s}$ (5)

From eq (1) in the text we know that the regional impact is given by

$$EI_r = LI_r - TP_r$$

Now $LI_r = LI_{r_i} + LT_{r_t}$ (6)

or $LI_r = \frac{LT_{r_i}}{K_2} + LT_{r_i} + LT_{r_p} + LT_{r_s}$ from eqs. (5) and (6),

or $LI_r = LT_{r_i}(\frac{1}{K_2} + 1) + LT_{r_p} + LT_{r_s}$ (7)

Thus $EI_r = LT_{r_i}(\frac{1}{K_2} + 1) + LT_{r_p} + LT_{r_s} - TP_r$ (8)

We will now define the Impact Ratio (IR) in percentage change terms as

$$IR = \frac{EI_r}{I_r} \cdot 100 \qquad (9)$$

Thus $$IR = \frac{(LT_{r_i}(1/K_2 + 1) + LT_{r_p} + LT_{r_s}) - TP_r}{I_{r_i} + T_{r_i} + T_{r_p} + T_{r_s}} \cdot 100$$

$$IR = \frac{LT_{r_i}(1/K_2 + 1) + LT_{r_p} + LT_{r_s} - TP_r}{\frac{T_{r_i}}{K_1} + T_{r_i} + T_{r_p} + T_{r_s}} \cdot 100$$

$$IR = \frac{LT_{r_i}(1/K_2 + 1) + LT_{r_p} + LT_{r_s} - TP_r}{T_{r_i}(1/K_1 + 1) + T_{r_p} + T_{r_s}} \cdot 100 \qquad (10)$$

The advantage of using expression (10) for IR is that we can calculate it by using tax data which may be relatively easier to obtain than the various income flows in the region. The central impact ratio (CIR) for each damage state may be calculated by obtaining the mean values of the impact ratios for a given damage state.