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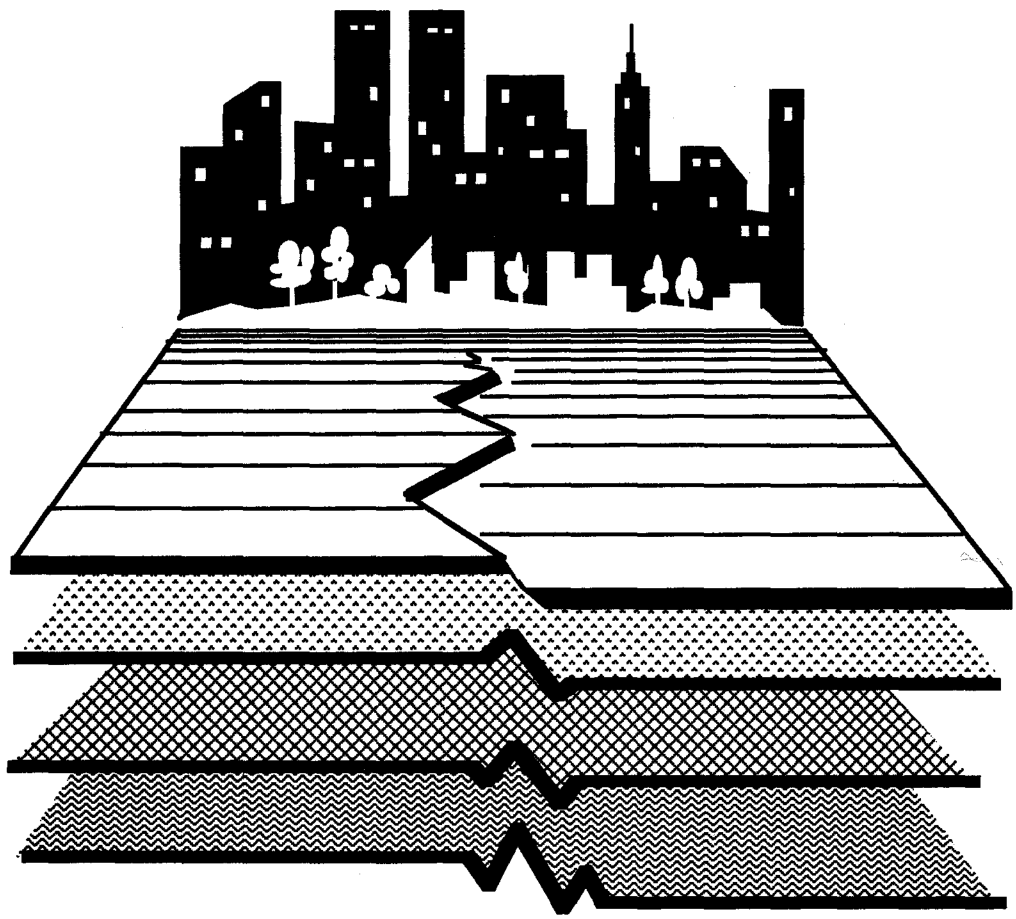
A Benefit-Cost Model for the Seismic Rehabilitation of Buildings

Volume 1: A User's Manual



EARTHQUAKE HAZARDS REDUCTION SERIES 62

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NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

A BENEFIT-COST MODEL FOR THE SEISMIC REHABILITATION OF HAZARDOUS BUILDINGS

VOLUME 1: A USER'S MANUAL

Prepared for the Federal Emergency Management Agency
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by

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FEMA Foreword

The Federal Emergency Management Agency (FEMA) is pleased to have sponsored the preparation of this publication on a cost/benefit methodology for the seismic rehabilitation of hazardous buildings. The publication is one of a series that FEMA is sponsoring to encourage local decisionmakers, the design professions, and other interested groups to undertake a program of mitigating the risks that would be posed by existing hazardous buildings in case of an earthquake. Publications in this series examine both engineering and architectural aspects as well as societal impacts of such an undertaking. They are prepared under the National Earthquake Hazards Reduction Program.

With respect to this particular publication, FEMA gratefully acknowledges the expertise and efforts of the management and staff of VSP Associates, Inc., its consultants, and the many individuals and organizations who provided valuable information and comments during the course of the effort.

The Federal Emergency Management Agency

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EXECUTIVE SUMMARY

Objective and Background

As part of its continuing program for reducing seismic hazards in existing buildings, FEMA contracted with VSP Associates, Inc. to develop a standard benefit/cost model that could be used throughout the United States by community officials, analysts or practitioners to help evaluate the economic benefits and costs of seismic rehabilitation of existing hazardous buildings. The benefit/cost models presented in this report are the result of an extensive, two-year research and development project. At the onset of this project, it was hoped that an existing benefit/cost model could be modified and applied to the seismic rehabilitation of existing buildings. However, after a thorough review of the literature, it was concluded that no such usable model existed. Therefore, completion of this project required a great deal of research and the development of original benefit/cost models applicable to the seismic rehabilitation of existing buildings.

Is it worth it? This is the primary question asked by decision makers who are considering building rehabilitation programs that seek to decrease expected casualties and property damage from future earthquakes. In most cases, the value of life is the principal motivation for implementing seismic rehabilitation programs, while in some instances property protection or continued function may be the driving economic forces.

It is clearly recognized that the greatest hazards to life loss, injury, and property damage from earthquakes are posed by existing buildings that were not designed and constructed to resist strong ground motions. Decisions about the seismic rehabilitation of existing buildings to reduce those potential losses require careful engineering and economic analysis and consideration of societal priorities. Retroactively requiring improvements in a community's existing building stock is among the most conflictual and difficult types of public policy decisions. Nevertheless, retrofitting existing buildings has significant benefits for the future, including lower repair costs, less loss of building function, and improved life safety for occupants.

Several important tasks were completed during this project, including thoroughly searching the literature and developing the concept of the models, defining the variables to be included and data needed to support the variables, conducting field data collection in nine cities, refining the data and the models, and lastly, completing example cost benefit analyses. The nine cities from which data on the costs and benefits of seismic rehabilitation were sought included Hayward, California; Seattle, Washington; Salt Lake City and Provo, Utah; Kansas City and St. Louis, Missouri; Memphis, Tennessee; Charleston, South Carolina; and Boston, Massachusetts. A multidisciplinary advisory panel of economists, engineers, and other experts played an important review and guidance role throughout this project.

The Benefit/Cost Models

There are two benefit/cost computer models included in this report. The single-class model analyzes groups of buildings of a single structural type, a single use, and a single set of economic assumptions. The multi-class model analyzes groups of buildings which may have several structural types and uses. Essentially, the multi-class model aggregates results from single-class models corresponding to the range of buildings and uses being considered.

The expected net present value of a seismic rehabilitation investment is calculated using the computer spreadsheet programs. The term "expected" indicates that future benefits are not known with certainty, but rather are estimated based on mean or average values of currently available information. "Net present value" indicates that benefits which are expected to accrue in the future are discounted to their present value. The expected net present value of a seismic rehabilitation investment is the sum of the present value of benefits expected to accrue each year over the planning period, plus the present value of the salvage value of the rehabilitation investment at the end of the planning period, minus the initial cost of the rehabilitation. Benefits and costs are assumed to accrue to building owners and occupants, and are the direct economic impacts -- no allowance is made for indirect impacts to other sectors of the local economy, such as suppliers to businesses who suffer temporary reduction of activity, nor vendors who provide goods and services for post-earthquake recovery activities.

Benefit/cost ratios are an alternative way of viewing net present value results which may make it easier to compare and prioritize prospective rehabilitation projects. Benefit/cost ratios are calculated simply by dividing the expected present value of future benefits by the rehabilitation costs. Benefit/cost ratios greater than one correspond to positive expected net present values, while ratios less than one correspond to negative expected net present values.

Prospective rehabilitation projects with benefit/cost ratios greater than one are economically justified, while projects with ratios less than one are not justified on the basis of the economic assumptions made in the model. The extent to which benefit/cost ratios are greater than or less than one provides important guidance as to the relative economic justification of prospective rehabilitation projects.

Once the necessary data have been entered, the programs run the benefit/cost analysis and provide results to the user. The program outputs are presented in tables and include concise summaries of the entered data, model results and the calculated benefit/cost ratios. The spreadsheet format allows users to conduct sensitivity analyses by changing one variable at a time while all the other variables remain constant. In this manner, the sensitivity of calculated benefit/cost ratios to specific input data sets can be determined and a wide range of "what ifs" can be explored.

There are two primary intended applications of these benefit/cost models. One application is to provide a quick and inexpensive preliminary estimate of whether a prospective seismic rehabilitation program is economically justifiable. For some cities in low seismicity areas, or for some building classes within high seismicity cities, the expected economic benefits of prospective rehabilitation programs may be so low that such programs should not be considered further.

The second application is to perform more detailed analyses, in situations where a preliminary analysis suggests that prospective rehabilitation programs should be considered further. In such cases, the analysis should be supported by as much accurate local data as possible on seismic risk, building parameters, and economic factors. Benefit/cost analyses can provide useful guidance about the scope and content of prospective rehabilitation programs. For example, depending on acceptable seismic risk, rehabilitation programs might include or exclude some classes of buildings, occupancies or uses from the program. Depending on seismic hazard, whole cities or only specific areas where damaging earthquake ground motions are expected to be amplified might be included.

The benefit/cost models are not intended to be applied to specific, individual buildings. Individual buildings differ enormously in critical details of construction, vulnerability to earthquake damage, effectiveness of prospective rehabilitation options, and in occupancy, use, and other factors. Since the models are based on typical, approximate values for building parameters and performance, their intended use is for classes of building types or for groups of buildings of various classes and uses. Application of the models to an individual building, without having the required engineering and economic data applicable to the specific building, may produce inaccurate and misleading results.

Example Results

Five examples illustrating the single-class benefit/cost model and two examples illustrating the multi-class model are included in this report. These examples were chosen to represent a broad range of geographic locations, building types, and building uses. All examples use a 4% discount rate and a 20-year planning horizon.

Single-Class Examples

The Charleston example considers retail stores in unreinforced masonry buildings. Given the expected probabilities of earthquakes, expected damages for buildings of this type, occupancies, retrofit costs of $24.00/square foot and the other variables entered in this example, benefit/cost ratios for this prospective strengthening program are low: 0.18 without including the value of life and 0.23 including the value of life. Therefore, these results suggest that this retrofit is not economically justified.

The St. Louis example considers offices in concrete frame buildings with unreinforced masonry infill walls. In this example, the benefit/cost ratios are even lower than those in the Charleston example, in part because the expected earthquake probabilities are less in St. Louis. The conclusion drawn is that this prospective retrofit is probably not economically justified.

The first Hayward example considers warehouses in concrete tilt-up buildings. Benefit/cost ratios are high, in large part due to the high earthquake probabilities in Hayward and to the relatively low retrofit costs required for tilt-ups. In this example, the benefit/cost ratio is about 10 without the value of life and about 12 with the value of life. The benefit/cost analysis suggests that retrofit is strongly justified economically, even without including the value of life.

The second Hayward example considers light industry in concrete tilt-up buildings. Benefit/cost results are extremely high for this example, primarily for the same reasons as in the previous Hayward example. However, the light industry use in this example results in much higher occupancy rates than in the previous warehouse example. Therefore, including the value of life has a larger impact on benefit cost ratios, which are about 10 without the value of life and about 23 with the value of life. This retrofit is thus strongly justified economically.

The Seattle example considers permanent residences (apartments) in unreinforced masonry buildings. In this example, the buildings are on poor soil, and expected earthquake damages are much higher than for buildings on firm soil sites. In this example, the benefit/cost ratio is 0.67 without the value of human life, which suggests that the retrofit is not economically justified on this basis. However, with the value of life included, the benefit/cost ratio becomes 3.69 which suggests that the retrofit is economically justified on this basis. This example illustrates the importance of the value of life in benefit/cost analysis.

Multi-Class Examples

In the first Seattle multi-class example, 26 of the buildings in the total inventory considered are located on firm soils. Without the value of life, the total benefit/cost ratio for this inventory is 0.58. The benefit/cost ratios for various combinations of facility class and social function class vary quite a bit. The results tables of the multi-class model break down the results by facility and social function class, and thus the user may explore these results to determine where benefits are highest and lowest. For example, parking garages have very low benefit/cost ratios and facilities with higher rents and incomes generally have higher benefit/cost ratios. With the value of life included, the benefit/cost ratio for the entire inventory is 1.21, which again demonstrates the importance of the value of life in such analyses.

In the second Seattle multi-class example, 41 of the buildings in the inventory considered are located on poor soils areas. As discussed in Chapter 3, this substantially increases the expected damages and thus also substantially increases the expected benefits of avoiding these damages by strengthening the buildings. Without the value of life, the total benefit/cost ratio is 2.03, which suggests that strengthening would be economically justified on this basis alone. With the value of life included, the benefit cost ratio becomes 5.05, which suggests that strengthening is strongly justified economically.

Contents of Volumes 1 and 2

Volume 1, a user's manual for public officials and practitioners, presents sufficient background information for users to understand how the benefit/cost models were developed, what the underlying assumptions are, and how to use the models. Volume 2 contains supporting technical information.

Within Volume 1, Chapter 1 provides an introduction to the use of benefit/cost analysis in decision making and an overview of the models. Chapter 2 reviews the economic assumptions of the benefit/cost models, with and without including the value of life. Chapter 3 guides the user through the model by presenting synopses of data entries required, example model results, and additional supporting information. Chapter 4, presents seven example applications of the benefit-cost models. Five examples demonstrate the single-class model, and two demonstrate the multi-class model.

Volume 2 complements Volume 1 by presenting four appendices that are designed to help the user understand about more about how the model was constructed and why certain assumptions and decisions were made. These appendices include: 1) a review of the relevant literature, 2) a section on estimating costs for seismic rehabilitation, 3) a compilation of tables for the Seattle building inventory, and 4) some insights into the building rehabilitation contexts of the nine cities visited during this project.

Volumes 1 and 2 and the software to run these benefit/cost models are available from the Federal Emergency Management Agency. The programs are on 5 1/4 inch diskettes and can be used on IBM and compatible personal computers. See section 1.3, A Synopsis of the Benefit/Cost Computer Models in Chapter 1 for additional computer specifications and information about using these models.

Conclusion

The first-generation benefit/cost models presented in this report are the result of a two-year research and development project. Nevertheless, this work should be considered somewhat experimental and subject to refinement by future work. Completion of this project suggests several areas where additional research and development would be very helpful. First, application of the models is limited by the paucity and uncertainty of necessary data. Results could be significantly improved by acquiring better data on retrofitting techniques and costs, on the seismic performance of retrofitted structures, and on damages and other losses expected in existing buildings. Second, the models could be improved by more rigorous determination of earthquake probabilities and more rigorous inclusion of site-specific soil characteristics which may greatly amplify earthquake damages. Third, the initial models were aimed at private-sector buildings. Extension of these models to public sector buildings would be an important and useful task. Fourth, the initial models were designed for "ordinary" buildings and not meant to be used for buildings with critical functions or special characteristics, including historical values. Extension of the existing models to include critical function structures and other special building characteristics would enhance the widespread applicability of the models. Fifth, the models assume life-safety rather than continued function as the primary goal of the proposed seismic rehabilitation program. Extension of these models to include preservation of building function would be an important task.

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CHAPTER 1

INTRODUCTION

1.1 FEMA's Program for Reducing Seismic Hazards in Existing Buildings

One of the objectives of the Earthquake Hazards Reduction Act of 1977 (P.L. 95-124) was "...the development of methods for...rehabilitation, and utilization of manmade works so as to effectively resist the hazards imposed by earthquakes..." The National Earthquake Hazards Reduction Program submitted to the Congress by the President on June 22, 1978, stressed that "...it is important that hazards be reduced from those (substandard) structures presenting the greatest risks in terms of occupancy and potential secondary impact."

In 1984, FEMA started a long-term program to encourage the reduction of seismic hazards posed by existing buildings throughout the country. The first project was the formulation of a comprehensive 5-year plan on what needed to be done and what the required resources would be. This plan was completed in 1985 and published under the title An Action Plan for Reducing Earthquake Hazards of Existing Buildings (FEMA 90). This plan identified a number of priority actions to be taken by the public and private sectors. FEMA has used this plan as the basis for developing a multi-volume, continuing series on the seismic rehabilitation of existing buildings.

By the end of fiscal year 1991, the following publications in this series have been published:

- A handbook (and supporting documentation) on how to conduct a rapid, visual screening of potentially hazardous buildings - Rapid Visual Screening of Buildings for Potential Seismic Hazards (FEMA 154 and 155).

- The first collection (and supporting documentation) of typical costs for the seismic rehabilitation of buildings - Typical Costs for Seismic Rehabilitation of Existing Buildings (FEMA 156 and 157).

- An engineering report which identifies the generally accepted techniques for the seismic rehabilitation of hazardous buildings - Techniques for Seismically Rehabilitating Existing Buildings (FEMA 172).

- A handbook (and supplemental readings) on establishing priorities for the seismic rehabilitation of buildings - Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings (FEMA 173 and 174).

- A handbook (and supporting documentation) on a methodology for evaluating the seismic safety of existing buildings - Handbook for Seismic Evaluation of Structures (FEMA 175 and 178).

- An evaluation of existing and potential financial incentives in the private and public sectors that would encourage a locality to undertake a seismic rehabilitation program - Financial Incentives for Seismic Rehabilitation of Hazardous Buildings - An Agenda for Action (FEMA 198 and 199).

In addition to these publications, preparation has begun on nationally applicable, consensus-approved guidelines for the seismic rehabilitation of existing buildings, based on acceptable performance and on the information handbooks and engineering reports published previously. These guidelines will also incorporate the latest research results and technical lessons learned from recent earthquakes. Materials will be developed to stimulate the use of these guidelines and to foster their introduction into the relevant national model codes and standards. Future efforts which are planned include the development of a homeowner's handbook on the seismic evaluation and rehabilitation of single-family dwellings.

1.2 The Role of Benefit/Cost Analysis in Reducing Seismic Hazards in Existing Buildings

As part of its continuing program for reducing seismic hazards in existing buildings, FEMA contracted with VSP Associates, Inc. to develop a standard benefit/cost model that could be used throughout the United States by community officials, analysts or practitioners to help evaluate the economic benefits and costs of seismic rehabilitation of existing hazardous buildings. The benefit/cost models presented in this report are the result of an extensive, two-year research and development project. At the onset of this project, it was hoped that an existing benefit/cost model could be modified and applied to the seismic rehabilitation of existing buildings. However, after a thorough review of the literature, it was concluded that no such usable model existed. Therefore, completion of this project required a great deal of research and the development of original benefit/cost models applicable to the seismic rehabilitation of existing buildings.

Several important tasks were completed during this project, including thoroughly searching the literature and developing the concept of the models, defining the variables to be included and data needed to support the variables, conducting field data collection in nine cities, refining the data and the models, and lastly, completing example cost benefit analyses. The nine cities from which data on the costs and benefits of seismic rehabilitation were sought included Hayward, California; Seattle, Washington; Salt Lake City and Provo, Utah; Kansas City and St. Louis, Missouri; Memphis, Tennessee; Charleston, South Carolina; and Boston, Massachusetts. A multidisciplinary advisory panel of economists, engineers, and other experts played an important review and guidance role throughout this project.

It is clearly recognized that the greatest hazards to life loss, injury, and property damage from earthquakes are posed by existing buildings that were not designed and constructed to resist strong ground motions. Decisions about the seismic rehabilitation of existing buildings to reduce those potential losses require careful engineering and economic analysis and consideration of societal priorities. Retroactively requiring improvements in a community's existing building stock is among the most conflictual and difficult types of public policy decisions. Nevertheless, retrofitting existing buildings has significant benefits for the future, including lower repair costs, less loss of building function, and improved life safety for occupants (California Seismic Safety Commission, 1991). **Is it worth it?** This is the primary question asked by decision makers who are considering building rehabilitation programs that seek to decrease expected casualties and property damage from future earthquakes. In most cases, the value of life is the principal motivation for implementing seismic rehabilitation programs, while in some instances property protection or continued function may be the driving economic forces.

The central economic question about rehabilitating earthquake-hazardous buildings is whether the benefits which accrue from rehabilitation are sufficiently valuable to warrant the expense. Benefit/cost analysis is a widely-used economic tool for helping to make economic decisions, especially in the public sector. Benefit/cost analysis is defined as "an estimation and evaluation of net benefits associated with alternatives for achieving defined public goals" (Sassone and Schaffer, 1978).

Benefits arising from a seismic rehabilitation program include the value of future losses avoided which could result from expected earthquake damages to unrehabilitated buildings. The economic value of human life can be included or excluded in the benefits analysis. Costs include the engineering, construction, and other costs required to rehabilitate buildings. Rehabilitating existing buildings may be economically justified when the expected benefits exceed costs (i.e., benefit/ cost ratio greater than one). Rehabilitating existing buildings may not be economically justified when the expected benefits are less than the rehabilitation costs (i.e., benefit/cost ratio less than one).

Benefit/cost ratios do not provide an absolute answer to the question as to whether rehabilitating existing buildings is justifiable. First, there are uncertainties in the data required to calculate benefit/cost ratios. Benefit/cost analyses using input data derived specifically for local conditions will produce more accurate and useful results than will analyses performed using average or nationwide data. Therefore, while very high or very low benefit/cost ratios strongly indicate whether a prospective rehabilitation program is economically justified, projects with benefit/cost ratios near one require more detailed analysis and consideration before conclusions are drawn. Second, benefit/cost analysis provides only part of the information necessary to support a thorough and careful decision making process.

Many variables are important in the decision-making process about whether or not to rehabilitate existing earthquake-hazardous buildings. There are seismologic and geologic considerations such as the expected frequency and intensity of future earthquakes and whether the buildings are located on solid rock, firm soil, or poor soil sites. There are engineering factors such as the variations in local building design and construction quality, the expected seismic performance of the buildings, the possible methods to rehabilitate the buildings, and the potential effectiveness of those methods to reduce casualties and damages from future earthquakes. There are social value judgements, such as what level of earthquake risk is deemed acceptable and what relative priorities should be placed on minimizing deaths and injuries, on reducing future economic damages, or on preserving critical functions, such as hospital, fire and police services. For example, a jurisdiction may conclude that death and injury to school children is socially unacceptable, and thus it could undertake to seismically rehabilitate school buildings even if the purely economic calculation results in a benefit/cost ratio less than one. Finally, there are economic variables such as the appropriate discount rate and the dollar value of human life which combine to determine whether or not rehabilitating a class of existing buildings is economically justified.

1.3 A Synopsis of the Benefit/Cost Computer Models

There are two benefit/cost computer models included in this report. The single-class model analyzes groups of buildings of a single structural type, a single use, and a single set of economic assumptions. The multi-class model analyzes groups of buildings which may have several structural types and uses. Essentially, the multi-class model aggregates results from single-class models corresponding to the range of buildings and uses being considered. Both models are spreadsheet programs written for Quattro Pro; versions 2.0 or 3.0 will run the programs. These programs require IBM-compatible computers with hard drives. The single-class model will run on any IBM-compatible computer with at least 640K of memory. The multi-class model is designed for a 80386 computer with at least 3 megabytes of memory. Either DOS 5.0 <u>or</u> DOS 3.0 and a memory manager device such as

QEMM-386 (Quarterdeck Office Systems) is required. A 80286 computer could be used for the multi-class model, if the computer has an expanded memory card such as the Intel AboveBoard or the AST Rampage card.

These programs are designed to enable users to perform benefit/cost analyses about rehabilitating existing earthquake-hazardous buildings. Illustrative applications and results are given in the next section. Fuller descriptions of the methodology, economic assumptions and parameters, and more detailed examples of uses of the programs are given in Chapters 2-4.

To perform a benefit/cost analysis, a user enters the necessary geologic, engineering, and economic data which are applicable to the buildings under consideration. Chapter 3 contains a thorough discussion of the input data variables required to perform a benefit/cost analysis. Original sources of data are fully referenced and many key data are compiled as reference tables in Chapter 3. To assist the user, the programs contain built-in help screens which define variables, give data input guidance, and direct the user through the benefit/cost programs. Furthermore, for many of the required input data, there are "default" values contained in the programs. These default values, which the user may select if desired, are based on national averages and other consensus values.

The default or consensus values contained in the programs are helpful for obtaining quick, "first-cut" benefit/cost results. However, the collection, input, and use of more accurate, local data for the buildings under consideration is strongly encouraged. Using locally derived data in place of typical or consensus data will greatly improve the validity and usefulness of the results, and confidence in the resulting benefit/cost values.

Once the necessary data have been entered, the programs run the benefit/cost analysis and provide results to the user. The program outputs are presented in tables and include concise summaries of the entered data, model results and the calculated benefit/cost ratios. The spreadsheet format allows users to conduct sensitivity analyses by changing one variable at a time while all the other variables remain constant. In this manner, the sensitivity of calculated benefit/cost ratios to specific input data sets can be determined and a wide range of "what ifs" can be explored.

1.4 Illustrative Examples and Results

Several illustrative examples of using the single-class benefit/cost model are given in Chapter 4. These results are briefly summarized here to give the user a preview of how this model may be applied.

Example 1 considers low-rise, unreinforced masonry retail stores in Charleston, South Carolina. Given the expected probabilities of earthquakes, expected damages for buildings of this type, occupancies, estimated retrofit costs and the other variables (as discussed in Chapter 3), benefit/cost ratios for this prospective rehabilitation program are low: 0.21 without including the value of life and 0.25 including the value of life. Therefore, these results suggest that this retrofit is not economically justified.

Example 2 considers concrete frame office buildings with unreinforced masonry infill walls in St. Louis, Missouri. In this case, benefit/cost ratios are even lower than in the Charleston example and the conclusion is that the retrofit is probably not justified economically.

Examples 3 and 4 consider concrete tilt-up buildings in Hayward, California used for light industry and warehouses, respectively. In these cases, the higher earthquake probabilities combined with low retrofit costs produce very high benefit/cost ratios. For the light industry use (Example 3), benefit/cost ratios are about 10 without the value of life and 23 including the value of life. Thus, this retrofit is strongly justified economically with or without including the value of life. For the warehouse use (Example 4), benefit/cost ratios are about 10 without the value of life and about 12 including the value of life. Retrofit is strongly justified in this example, as in Example 3, but the much lower occupancy rate results in the value of life having a much smaller impact on the benefit/cost ratio.

Example 5 considers mid-rise unreinforced masonry buildings used for permanent residences in Seattle, Washington. In this case, the buildings are on poor soil (see Chapter 3) and expected damages are higher than on firm soil sites. In this example, the benefit/cost ratio is 0.67 without the value of human life which suggests that the retrofit is not economically justified on this basis. However, with the value of life included, the benefit/cost ratio is 3.69 which suggests that the retrofit is economically justified on this basis. This example illustrates the importance of considering the value of life in benefit/cost analysis.

Chapter 4 also includes two examples of the multi-class model. These examples include groups of buildings with mixed facility classes and social function classifications in Seattle, Washington. These examples illustrate the importance of occupancy and the value of human life as well as the importance of whether the buildings are located on firm soil or on poor soil.

1.5 Targeted Users and Intended Applications

The benefit/cost models presented here are intended primarily for public sector users, including community officials, planners, and building department personnel. It is also intended for private sector analysts and practitioners involved with or supporting public sector decision making. Private sector property owners, developers, and others with interests in seismic rehabilitation programs may also find these benefit/cost models helpful for their own analyses.

There are two primary intended applications of these benefit/cost models. One application is to provide a quick and inexpensive preliminary estimate of whether a prospective seismic rehabilitation program is economically justifiable. For some cities in low seismicity areas, or for some building classes within high seismicity cities, the expected economic benefits of prospective rehabilitation programs may be so low that such programs should not be considered further.

The second application is to perform more detailed analyses, in situations where a preliminary analysis suggests that prospective rehabilitation programs should be considered further. In such cases, the analysis should be supported by as much accurate local data as possible on seismic risk, building parameters, and economic factors. Benefit/cost analyses can provide useful guidance about the scope and content of prospective rehabilitation programs. For example, depending on acceptable seismic risk, rehabilitation programs might include or exclude some classes of buildings, occupancies or uses from the program. Depending on seismic hazard, whole cities or only specific areas where damaging earthquake ground motions are expected to be amplified might be included.

The benefit/cost models are not intended to be applied to specific, individual buildings. Individual buildings differ enormously in critical details of construction, vulnerability to earthquake damage, effectiveness of prospective rehabilitation options, and in occupancy, use, and other factors. Since the models are based on typical, approximate values for building parameters and performance, their intended use is for classes of building types or for groups of buildings of various classes and uses. Application of the models to an individual building, without having the required engineering and economic data applicable to the specific building, may produce inaccurate and misleading results.

Benefit/cost analysis can provide useful guidance about prospective seismic rehabilitation. However, conclusions drawn from benefit/cost analysis must be interpreted carefully. Attention must be paid to the assumptions and limitations of the models, to uncertainties in the input data, and to the sensitivity of the results to variations in individual parameters. Nevertheless, benefit/cost analysis is a powerful tool that can provide essential information to decision makers concerned about seismic rehabilitation of existing earthquake-hazardous buildings to reduce future casualties and damage to property.

1.6 Organization of Chapters 2-4 and Volume 2

Chapter 2 contains a rigorous description of the benefit/cost models, including the economic assumptions and equations. Chapter 3 describes all of the variables considered in the models and provides a detailed user-guide to each of the data entries required to perform benefit/cost analyses with the models. Tables of typical or consensus values are included, along with references to sources of more information. The tables of results produced by the models are briefly described. Chapter 4 provides five examples of single-class model applications to buildings in Charleston, St. Louis, Hayward (2), and Seattle. In addition, this chapter includes two examples illustrating the use of the multi-class model. The references cited in Volume 1 are listed in a separate section, following Chapter 4.

This volume of the report contains all of the information which users need to perform benefit/cost analyses using these programs. Volume 2 of this report contains appendices with detailed supporting information. Within Volume 2, Appendix 1 contains a review of the economic literature and a discussion of some of the technical assumptions made in developing the models. Appendix 2 is a detailed review of available data on costs of seismic rehabilitation of existing buildings. Appendix 3 is a detailed compilation of building inventory information in Seattle which was used in the development of the models. Appendix 4 briefly reviews local factors which may influence the use of the benefit/cost models.

1.7 Future Work

The first-generation benefit/cost models presented in this report are the result of a two-year research and development project. Nevertheless, this work should be considered somewhat experimental and subject to refinement by future work. Completion of this project suggests several areas where additional research and development would be very helpful. First, application of the models is limited by the paucity and uncertainty of necessary data. Results could be significantly improved by acquiring better data on retrofitting techniques and costs, on the seismic performance of retrofitted structures, and on damages and other losses expected in existing buildings. Second, the models could be improved by more rigorous determination of earthquake probabilities and more rigorous inclusion of site-specific soil characteristics which may greatly amplify earthquake damages. Third, the initial models were aimed at private-sector buildings. Extension of these models to public sector buildings would be an important and useful task. Fourth, the initial models were designed for "ordinary" buildings and not meant to be used for buildings with critical functions or special characteristics, including historical values. Extension of the existing models to include critical function structures and other special building characteristics would enhance the widespread applicability of the models. Fifth, the models assume life-safety rather than continued function as the primary goal of the proposed seismic rehabilitation program. Extension of these models to include preservation of building function would be an important task.

CHAPTER 2

THE BENEFIT/COST MODEL

2.1 Introduction

This chapter describes the economic assumptions and equations which rigorously define the benefit/cost models. The expected net present value of a seismic rehabilitation investment is calculated using the computer spreadsheet programs. The term "expected" indicates that future benefits are not known with certainty, but rather are estimated based on mean or average values of currently available information. "Net present value" indicates that benefits which are expected to accrue in the future are discounted to their present value. Benefits and costs are assumed to accrue to building owners and occupants, and are the direct economic impacts -- no allowance is made for indirect impacts to other sectors of the local economy, such as suppliers to businesses who suffer temporary reduction of activity, nor vendors who provide goods and services for post-earthquake recovery activities.

The economic rationality of a prospective seismic rehabilitation of a group of existing structures can be determined by calculating the net present value of the investment. When expected benefits exceed costs, the net present value is positive (benefit/cost ratio greater than one) and the rehabilitation investment is economically justified. When expected benefits are less than costs, the net present value is negative (benefit/cost ratio less than one) and the rehabilitation investment is not economically justified. Expected net present values or benefit/cost ratios for various classes of buildings and uses can be compared and ranked.

The benefit/cost methodology developed for this project uses much of the nomenclature developed in ATC-13 (Earthquake Damage Evaluation Data for California, 1985, Applied Technology Council). As discussed in Chapter 3, much of the consensus data developed in ATC-13 is also used. Whenever possible, however, users are strongly encouraged to use more accurate local data rather than the consensus, typical, or average data compiled in ATC-13. The variables included in the models are briefly defined below. Each variable is discussed in more detail in Chapter 3 and many sources of data are compiled into reference tables in that chapter.

2.2 Expected Net Present Value Model Without the Value of Life

The expected net present value of a seismic rehabilitation investment is the sum of the present value of benefits expected to accrue each year over the planning period, plus the present value of the salvage value of the rehabilitation investment at the end of the planning period, minus the initial cost of the rehabilitation. The expected net present value model is thus defined as:

$$NPV = -INV + \frac{B_1}{1+i} + \frac{B_2}{(1+i)^2} + \dots + \frac{B_T}{(1+i)^T} + \frac{V_T}{(1+i)^T}$$

where:

INV is the cost of the rehabilitation;

B_t is the expected annual benefit attributed to the rehabilitation in year t;

V_T is any change that the rehabilitation will have on the salvage value of the buildings in the terminal year T;

T is the length of the planning horizon which should reflect the effective life of the rehabilitation of the buildings; and

i is the discount rate.

In this model, each year's expected benefit is discounted to its present value and then added together to yield the total expected net present value. The cost of the rehabilitation (INV) includes direct engineering/construction costs and, if desired, other indirect costs. The salvage value of the rehabilitation investment is the change that the retrofit will have on the value of the buildings at the end of the planning horizon. The planning horizon (T) is the time period, typically 20 or 30 years, over which future benefits are estimated. The discount rate (i) is the annual percentage rate by which future benefits are discounted to net present value.

If expected benefits are constant each year during the planning horizon time period, the expected net present value equation is simplified by substituting one term which includes the benefits accrued during the entire planning period in place of the annual benefit terms in the previous equation. In this case, the expected net present value equation can be reduced to:

$$NPV = -INV + B_t\left[\frac{1-(1+i)^{-T}}{i}\right] + \frac{V_T}{(1+i)^T}$$

Assuming that expected benefits are constant each year is equivalent to assuming that the annual probabilities of future earthquakes of various intensities are constant and that the effectiveness of the rehabilitation in reducing casualties, damages and losses is also constant.

The expected annual benefit which accrues from the rehabilitation is the sum of expected avoided losses accounting for the expected annual probability of damaging earthquakes. The expected annual benefit is assumed to be the sum of avoided building damages, rental losses, relocation expenses, personal and proprietor's income losses, business inventory losses, and personal property losses. The expected annual benefit of rehabilitating a group of buildings to meet life-safety earthquake standards is thus defined as:

$$B_t = \sum_{m=VI}^{XII} EAE^m \left[\sum_{s=1}^{S} \sum_{f=1}^{F} BD_{sf}^m + RT_{sf}^m + REL_{sf}^m + Y_{sf}^m + INV_{sf}^m + PP_{sf}^m \right]$$

where:

EAE^m is expected number of earthquakes annually by Modified Mercalli Intensity (MMI) ranging from VI-XII;

BD_{sf}^m is building damages avoided by social function and facility classes, and MMI;

RT_{sf}^m is rental losses avoided by social function and facility classes, and MMI;

REL_{sf}^m is relocation expenses avoided by social function and facility classes, and MMI;

Y_{sf}^m is personal and proprietors' income losses avoided by social function and facility classes, and MMI;

INV_{sf}^m is business inventory losses avoided by social function and facility classes, and MMI; and

PP_{sf}^m is personal property losses avoided by social function and facility classes, and MMI.

In this equation, the first summation symbol indicates that expected annual benefits must be summed over expected earthquakes with MMIs ranging from VI to XII. The second and third summation symbols indicate that expected damages and losses avoided must be calculated separately for each combination of social function classification (S) and facility classification (F) and then summed. The social function classification (ATC-13) categorizes building uses as residential, commercial, industrial and so on. The building facility classification (ATC-13) categorizes building structural types such as unreinforced masonry, concrete frame, steel frame and so on. Avoided damages and losses means the reduction in expected damages and losses in rehabilitated buildings versus those expected in unrehabilitated buildings of the same facility and social function classification.

Building damages avoided are assumed to be the product of the floor area of the buildings, times the building replacement value per square foot (which gives the replacement value of the building), times the expected mean damage function for building damages as a function of MMI of earthquakes, times the expected rehabilitation effectiveness in reducing building damage. Building damages avoided are thus defined as:

$$BD_{sf}^{m} = FA_{sf}RV_{sf}MDF_{f}^{m}ERE_{f}^{m}$$

where:

FA_{sf} is floor area in square footage by social function and facility classes;

RV_{sf} is building replacement value per square foot;

MDF_{f}^{m} is mean damage function by facility classification and MMI; and

ERE_{f}^{m} is expected rehabilitation effectiveness by facility class and MMI.

The mean damage function (ATC-13) is a measure of the expected percentage of building damage as a function of the MMI of earthquakes. The expected rehabilitation effectiveness is the percentage reduction in mean damage function expected from the strengthening rehabilitation.

Rental losses avoided are assumed to be the product of the square footage of the buildings, times the rental rate per square foot per day, times the expected loss of function in days, times the expected effectiveness of the rehabilitation in reducing loss of function. Rental losses avoided are thus defined as:

$$RT_{sf}^{m} = FA_{sf}RR_{sf}LOF_{s}^{m}ERE_{f}^{m}$$

where:

RR_{sf} is rental rate per square foot per day by social function and facility classes; and

LOF_{s}^{m} is loss of function in days by social function class and MMI.

Building damages may reduce the functionality of buildings, either completely or partially. The expected loss of function in damaged facilities is the total number of days of function expected to be lost. Loss of function depends on expected building damages (mean damage function) as a function of MMI and on social function classification. Estimates of loss of function from ATC-13 are used in the models.

Relocation expenses avoided are assumed to be the product of floor area in square feet, times the relocation costs per square foot per day, times the expected loss of function in days due to earthquake damage, times the expected effectiveness of the rehabilitation in reducing loss of function. Relocation expenses avoided are thus defined as:

$$REL_{sf}^{m} = FA_{sf}RC_{s}LOF_{s}^{m}ERE_{f}^{m}$$

where:

RC_s is relocation costs per square foot per day by social function class.

Income losses avoided are assumed to be the product of floor area of the buildings, times the income generated per square foot per day, times the expected loss of function in days due to earthquake damage, times the expected effectiveness of the rehabilitation in reducing loss of function. Income losses avoided are thus defined as:

$$Y_{sf}^{m} = FA_{sf}INC_{s}LOF_{s}^{m}ERE_{f}^{m}$$

where:

INC_s is personal and proprietors's income generated per square foot per day.

Business inventory losses are assumed to be the product of floor area of the buildings in square feet, times the annual gross sales or production, times the percent of gross sales or production which constitutes inventory, times the mean damage function, times the effectiveness of the rehabilitation in reducing building damage. Business inventory losses are thus defined as:

$$INV_{sf}^{m} = FA_{sf}SALES_{s}BI_{s}MDF_{f}^{m}ERE_{f}^{m}$$

where:

$SALES_s$ is annual gross sales or production; and

BI_s is inventory as a percent of gross sales or production.

Personal property losses are assumed to be the product of the floor area of the buildings in square feet, times the replacement value of the buildings per square foot, times the value of personal property (building contents) as a percentage of building value, times the mean damage function, times the effectiveness of the rehabilitation in reducing building damages. Personal property losses are thus defined as:

$$PP_{ss}^{m} = FA_{sf}RV_{sf}PPROP_{s}MDF_{f}^{m}ERE_{f}^{m}$$

where:

$PPROP_s$ is personal property (building contents) as a percentage of building replacement value.

2.3 Expected Net Present Value Model With The Value of Life

The expected net present value model discussed above does not include the value of life. However, reducing the expected number of deaths and injuries is often the principal motivation for strengthening programs. The model can be modified to include the value of expected deaths avoided by retrofitting to life-safety standards.

The expected net present value including the value of life is the expected net present value without the value of life, plus the present value of expected deaths avoided by seismic rehabilitation. The expected net present value including the value of life is thus defined as:

$$NPV^{vol} = NPV + VDA_t\left[\frac{1-(1+i)^{-T}}{i}\right]$$

where:

NPV is the expected net present value excluding the value of life; and

VDA_t is the annual value of expected deaths avoided by rehabilitating buildings to life-safety standards.

The annual value of avoided earthquake death loss is assumed to be the product of the area of the building in square feet, times the average occupancy per square foot, times the difference in expected death rates between unrehabilitated and rehabilitated buildings, times the dollar value of one human life. The annual value of reducing the earthquake death loss due to rehabilitation is thus defined as:

$$VDA_t = \sum_{m=VI}^{XII} EAE^m\left[\sum_{s=1}^{S}\sum_{f=1}^{F} RA_{sf}OCP_s(DR_f^m - DRR_f^m)\right]VOL$$

where:

OCP_s is the average occupancy rate per square foot;

DR_f^m is the expected death rate by central damage factor;

DRR_f^m is the expected death rate for rehabilitated buildings by central damage factor; and

VOL is the dollar value of one human life.

The summation symbols indicate that the expected deaths avoided must be summed over the range of MMI earthquakes for each combination of facility classification and social function classification.

2.4 Benefit/Cost Ratios

Expected net present values of seismic rehabilitation investments, as defined in the previous sections of this chapter, are specific dollar amounts which may be either positive or negative. If there were no future benefits, then the expected net present value of the investment is negative (i.e.,the cost of the rehabilitation). When the present value of future benefits (including the salvage value) is less than costs, then the expected net present value is also negative. When the present value of future benefits exceeds the initial cost, then the expected net present value becomes positive.

Benefit/cost ratios are an alternative way of viewing net present value results which may make it easier to compare and prioritize prospective rehabilitation projects. Benefit/cost ratios are calculated simply by dividing the expected present value of future benefits by the rehabilitation costs. Benefit/cost ratios greater than one correspond to positive expected net present values, while ratios less than one correspond to negative expected net present values.

Prospective rehabilitation projects with benefit/cost ratios greater than one are economically justified, while projects with ratios less than one are not justified on the basis of the economic assumptions made in the model. The extent to which benefit/cost ratios are greater than or less than one provides important guidance as to the relative economic justification of prospective rehabilitation projects.

CHAPTER 3

BENEFIT/COST VARIABLES AND RESULTS

3.1 Introduction

The variables included in the benefit/cost models and the various types of information which the user must enter for the analysis are discussed in this chapter. The Guide to Data Entry section below describes each of the required data entries and provides references to sources of information. The five main data entry screens which appear in the single-class benefit/cost model are shown in Table 3-1. (Tables for this chapter are in a separate section which follows page 3-22 of the text.) Most of the 30 data entry items are entered directly on these five main screens. Five of the data entries access secondary data entry screens: Earthquake Probabilities (Data Entry #3), Damage Probability Matrix (Data Entry #8), Expected Death Rates (Data Entry #17), Loss of Function (Data Entry #23), and Personal Property Value (Data Entry #25). For many of the data entry items, summary tables of information are provided. Whenever possible, the user should enter local data rather than the typical or consensus values which are compiled in the summary or reference tables.

Some of the data variables markedly affect benefit/cost ratios, while others typically have relatively minor effects. For example, the expected earthquake probabilities (Data Entry #3) vary greatly between cities and have a tremendous impact on benefit/ cost results. Whether facilities are on firm soil or poor soil (Data Entry #4) strongly affects expected damages and benefits. The damage probability matrices (Data Entry #8) are important because they govern expected physical and economic damages and casualties. Occupancy rates (Data Entry #16) and the value of human life (Data Entry #30) may dominate the analysis when the value of human life is included. The seismic rehabilitation cost items (Data Entries #10-13 are always important because they specify the cost portion of the benefit/cost ratio. Finally, the economic variables, discount rate (Data Entry #26), and planning horizon (Data Entry #27), strongly affect the present value of future benefits and thus have a major effect on benefit/cost ratios.

The numbered data entry items below correspond exactly to the numbered data entries in the single-class benefit/cost model, as shown in Table 3-1. The same data is also required in the multi-class model, although the data entry format is slightly different. After data entry is completed, the models provide the user with results, including benefit/cost ratios, in convenient tabular forms. The model results are described in Section 3.3 following the Guide to Data Entry.

3.2 Guide to Data Entry

3.2A Geographic and Geologic Information

1. Facility ID

This is a user-specified label which identifies the group of buildings under consideration. This label appears as the title in some of the results tables.

2. City

This label identifies the city in which the buildings are located.

3. Earthquake Probabilities

For the nine cities in Table 3-2, specifying the city name in the data entry part of the benefit/cost programs assigns the earthquake probabilities in Table 3-2, which are based on the seismic data given by Algermissen and others (1982) of the United States Geological Survey. These seismicity estimates indicate the expected frequency of earthquakes as a function of peak MMI within the source zone. As noted in Table 3-2, the probabilities for the source zones containing several of these cities were adjusted to account for strong seismicity in nearby source zones. The probabilities given in Table 3-2 are conservative and may overestimate actual seismicity, especially for earthquakes with smaller peak MMIs, because the shaking intensities (MMI) were assumed to be uniform throughout the source region, except for soils modification (Data Entry #4). This overestimation of seismicity is partially offset by the fact that larger earthquakes outside a source zone will be experienced as smaller MMI events within the source zone. A detailed description of earthquake probabilities and the methodology used to derive the probabilities in Table 3-2 is given in Section 3.4A of this chapter.

For the nine cities in Table 3-2, the user may use the earthquake probabilities in the table or enter different probabilities based on an analysis of expected seismicity of the area under consideration. For other cities, the user must enter the expected probabilities of future earthquakes as a function of MMI. The user may estimate the probabilities roughly, in a manner similar to that used to derive the information in Table 3-2. Alternatively, the user may obtain the required earthquake probability estimates from state geological surveys, from experienced geotechnical engineering firms, or from experienced earthquake consulting firms. If shaking intensity probabilities vary significantly within the area of consideration, the building inventory should be broken up and appropriate probabilities assigned to each subgroup of the inventory.

4. **Building Site Characteristics: Firm Soil or Poor Soil?**

Historically, earthquake damage has been much greater in areas of poor soils than in areas underlain by firm soil or bedrock. Poor soils include wet, soft soils near rivers, streams, tidal channels, bays and lakes and also some types of unengineered fills. Buildings on poor soil sites are subject to greater damage because the soils may amplify earthquake ground motions or suffer various types of ground failures, including liquefaction.

To account roughly for the greater damage expected at poor soil sites, the model adjusts the mean damage factor upward by one MMI level if "1" is entered in Data Entry #4. For example, for poor soil sites the expected damage for an MMI 7 event will correspond to that expected for an MMI 8 event at a firm soil site. The expected building damage and the other economic impacts of earthquakes will be modified accordingly.

The greater damage expected at poor soil sites may be modeled more accurately using the methodology outlined in ATC-13 (Applied Technology Council, 1985, pp 223-230). This procedure is considerably more complex than the simple adjustment described in the previous paragraph. However, if desired, users may adjust the damage probability matrix factors (Data Entry #8) according to the information given in ATC-13 Table 8.4 (page 230). To do this, the user must identify which of the five poor ground soil types in Table 8.4 most closely approximates the soil types at the site under consideration. Then the damage probability matrix entries for the type of building under consideration must be increased, using the information in Table 8.4 and equation 8.2a in ATC-13 (page 229). To account for poor soils in this manner, the user would enter "0" in Data Entry #4, and instead adjust the damage probability matrix (Data Entry #8) to account for poor soils.

3.2B Structural and Engineering Information

5. **Facility Class**

Facility class is the nomenclature adopted in ATC-13 to denote the primary structural systems of buildings and other facilities. The full Earthquake Engineering Facility Classification is given in ATC-13. In this model, we consider only buildings; these facility classifications are shown in Table 3-3.

The building facility classes most vulnerable to earthquake damage are marked in Table 3-3 by asterisks after the facility class number. These vulnerable classes are most often included in retrofit programs and, therefore are likely to be the classes of primary interest to most users. The major building facility classes are frequently subdivided into low-rise (1-3 stories), mid-rise (4-7 stories) and high-rise (8+ stories) because building height affects earthquake performance and seismic strengthening costs.

6. Building Size

Building size is the gross area in square feet of the buildings under consideration.

7. Gross Leasable Area

Gross leasable area is the usable area in square feet of the buildings under consideration.

8. Damage Probability Matrices

For each facility class under consideration, it is necessary to estimate the building performance in earthquakes of MMI ranging from VI (below which damage is minimal) to the maximum MMI earthquake expected in the particular city. Damage probability matrices, DPMs, (ATC-13) give consensus values of the expected amounts of damage as a function of MMI. The general form of damage probability matrices is shown in Table 3-4. Seven building damage states are defined, ranging from none (no damage) to destroyed (total destruction). For each damage state, a range of damage factors is given in percentages of building replacement value and a central damage factor is defined as the midpoint of the range.

Each building facility class will have a separate damage probability matrix. The sample DPM shown in Table 3-4 indicates that, for example, in a MMI VIII event, 30% of the buildings are expected to have no damage, 40% slight damage, 16% light damage and so on with 1% of the buildings destroyed. Table 3-5 illustrates DPMs from ATC-13 for the most vulnerable building facility classes. In this table, we have also compiled mean damage factors which are the weighted average of the probabilities of the various central damage factors.

The ATC-13 DPMs, including those compiled in Table 3-5 and those included in the computer programs, are based on California data. DPMs for non-California cities may vary because building codes, standards, and practices vary widely from city to city as well as with date of construction. For non-California cities, local DPMs could be developed based on consensus opinion of well-informed engineers, or the California-based DPMs could adjusted upwards to account for the absence of seismic provisions in codes and differences in building practices. Earthquake loss studies for St. Louis City and County (FEMA 192) and the metropolitan Boston area (URS Consultants, 1989) are examples of locally derived damage probability matrices.

9. Average Effectiveness of Retrofit

Effectiveness of retrofit is defined as the percentage reduction in expected damages in the strengthened facility compared to the expected damages in the unstrengthened facility. Like DPMs, the effectiveness of retrofit must be evaluated for each building facility class; suggested values are given in Table 3-6a. These estimates were based on engineering experience and judgement, assuming that life safety was the principal objective of the retrofit. Effectiveness of retrofit will vary depending on the rehabilitation techniques used, on the standard, code, or safety level to which seismic rehabilitation is carried out, and on the design, construction, and condition of the building before rehabilitation. If sufficient engineering data is available, users may wish to modify the effectiveness estimates in Table 3-6a to correspond more accurately to their assessment of the effectiveness of the strengthening standard being considered.

The effectiveness of retrofit with respect to building damage and the effectiveness with respect to loss of life and injuries are expected to be distinctly different and thus are treated separately in the benefit/cost models. Most seismic retrofit programs emphasize life safety criteria and, given this focus, are expected to be highly effective in reducing loss of life. Life safety effectiveness is considered in the models under Death and Injury rates (Data Entry #17) and discussed in that section of this chapter.

The effectiveness of retrofit with respect to building damage is primarily a collateral benefit associated with life-safety mitigations designed to reduce building collapses or partial collapses. The strengthening improvements needed to attain a life safety goal for a given facility class of building will vary depending on the structural systems that need attention to prevent collapse or partial collapse. The extent and type of these improvements will also determine the level of damage avoidance that is possible. Accordingly, each facility class in Table 3-6a was evaluated individually and the estimates developed for reduction in physical damage used in the model are derived from the minimum level of retrofit needed to address the life safety issues typically found in each class. The effectiveness of retrofit is expected to be higher during low MMI events and to gradually decrease with increasing MMI as the stronger shaking exceeds the strength of the retrofit (Table 3-6b).

Estimating the effectiveness of retrofit would be difficult even if clear and well-defined seismic strengthening standards were available. At present, some of the facility classes considered do not have well defined standards, and very few buildings that have received seismic improvements have ever been tested by earthquakes strong enough to demonstrate their effectiveness. Furthermore, effectiveness may vary regionally because strengthening programs in cities with low perceived seismic risk may be less rigorous than programs in cities with high perceived risk. Where risk perception is low, the minimum life-safety strengthening criteria will typically be less stringent and thus provide less protection from property damage.

The effectiveness estimates (Table 3-6) assume that strengthening programs are based primarily on life safety. In some cases, particularly for critical facilities, private or public sector owners may wish to preserve the function of a facility as well as to increase life safety. In such cases, the effectiveness of retrofit will be much higher because the standards and performance criteria for the strengthening would be much more stringent to meet the goal of assuring functionality. For this reason, evaluations of essential service building retrofits and similar projects where the goals exceed life safety should not use the effectiveness estimates given in Table 3-6. For such projects, the user would have to estimate effectiveness based on the specific engineering designs of the retrofits.

10 - 13. Retrofit Costs

In the benefit/cost models, three types of retrofit costs are considered. First, the estimated direct engineering and construction costs (per square foot of building space) are entered (Data Entry #10). This "hard" costs value will vary depending on the building type, location, and level of retrofit undertaken. Second, if desired, the user may include indirect costs such as planning and permitting as a percentage of direct costs (Data Entry #11). Third, additional costs which may be incurred if the buildings are occupied during retrofit may be included as a percentage of direct costs (Data Entry #12). Data Entry items 11 and 12, which are based on percentages of direct retrofit costs, should be entered as decimals (i.e., 0.10) but are displayed as percentages (i.e., 10%). The total retrofit costs (Data Item #13) are automatically calculated from Data Entries 10, 11, and 12.

A range of typical hard costs for structural strengthening on a per square foot basis is given in Table 3.7 for various facility classifications. These costs represent an estimate given currently available data. These estimated costs were derived from both a review of the existing literature and the information on strengthened buildings from the field data collection phase of this project. The study team visited nearly all buildings in the United States outside of California that have been modified to meet some higher level of earthquake resistance. There is very little actual cost data for some structural types because so few buildings have been strengthened. The user should adjust the figures in Table 3.7 for regional differences and compare these to local construction experience whenever possible.

A longer description of retrofit costs is included in Section 3.4B of this chapter. A full description is given in Appendix 2 of Volume 2.

14. Salvage Value

Strengthening to reduce seismic vulnerability adds to the value of a building. Salvage value is the change that the retrofit will have on the value of the buildings at the end of the planning horizon time period. This residual value of the retrofit, discounted to net present value, is a benefit which reduces the net cost of the retrofit. The salvage value should be entered as a decimal (i.e., 0.10) but is displayed as a percentage (i.e., 10% of retrofit cost). For the examples given in Chapter 4, we assumed a salvage value of 10% of the original cost.

3.2C Building Use Information

15. Social Function Classification

The social function classification given in ATC-13 is adopted for use in the benefit/cost models. The social function classification defines the use of the building as residential, commercial, industrial, with various subcategories. The classifications considered in the present model are summarized in Table 3-8. Social function classification affects other parameters in the models, including rent, business inventory, income, and personal property value.

16. Occupancy

Buildings occupancy depends strongly on social function and time of day. Typical occupancy rates per 1000 square feet for a range of social function classifications (from ATC-13) are shown in Table 3-8. Alternatively, users may enter local occupancy data for the buildings under consideration.

17. Death and Injury Rates

Death and injury rates increase with increasing damage to buildings and will vary depending on the design, construction and condition of individual buildings. Consensus values of death and injury rates for the seven damage states considered in ATC-13 are summarized in Table 3-9. These death and injury rates from ATC-13 depend only on the damage state and occupancy and not on the facility classification. These estimates also exclude casualties outside of damaged buildings or in adjacent buildings. These death and injury rates probably represent reasonable estimates for the more vulnerable facility classifications (Table 3-5), but may overestimate casualties for less vulnerable facility classifications such as ductile steel or ductile concrete frame buildings. Users may also enter their own estimates of death and injuries as a function of building damage state. When the value of life is included in benefit/cost calculations, sensitivity analysis to investigate the impacts of occupancy and casualty rates on benefit/cost ratios is recommended.

The second portion of Table 3-9 shows our estimates of the death and injury rates in rehabilitated buildings, as a function of damage states expected in unrehabilitated buildings. These estimates, which are based on engineering experience and judgement, assume that the strengthening rehabilitation lowers the death and injury rates to those that would be expected if the building damage states were three states lower. For example, if an unstrengthened building would be expected to incur damage state 6 (major), then we assume that deaths and injuries in the strengthened building will correspond to damage state 3 (light). For most damage states, this assumption is equivalent to reducing deaths and injuries by a factor of 1000. Seismic strengthening programs are often primarily motivated by life safety; reduction of deaths and injuries is the principal objective. Strengthening programs are thus expected to be much more effective in life loss reduction than for damage reduction.

The benefit/cost models do not include as a benefit the economic value of injuries avoided by retrofitting. Table 3-9 does include expected rates of injuries (minor and major) as a function of damage state for unstrengthened buildings and for rehabilitated buildings. Expected injuries are generally 4 to 30 times higher than expected deaths, for major and minor injuries, respectively. If we assume, very roughly, that major injuries average $10,000 in costs and minor injuries $1000, then the economic cost of injuries is well below 10% of the economic value of lives lost (using the consensus value of $1,740,000 per death). If desired, a user could make estimates of the economic costs of minor and major injuries and add these expected costs to the value of life entry (which would then include injuries as well as deaths).

3.2D Building Economic Information

18. Replacement Value

Expected damages for events of each MMI are calculated as the product of the mean damage function (from the damage probability matrices) and the replacement value of the building. If desired, the user may substitute other measures of building value, such as reproduction cost, for replacement value. Building repairs which maintain the same structure dimensions, materials and architecture are called "reproduction."

"Replacement" is the term used for replacing the function that a demolished building served. For example, an unreinforced masonry (URM) building used as a warehouse would not likely be replaced by another URM because codes would probably require reinforced masonry and because cheaper and better types of structures are now available for warehouses. In this report, "repair" and "reproduction" are used interchangeably, whereas "replacement" refers to duplicating a building's function with another construction type. A shortcoming in the replacement concept is that buildings of modern construction are not the same as old buildings.

The estimated replacement values of buildings for various social function classifications are shown in Table 3-10. These values from ATC-13 are based on 1985 costs and are intended for general guidance only. Whenever possible, more accurate local values for typical building replacement costs should be used.

19. Total Building Replacement Value

This information is calculated automatically from the replacement value per square foot (Data Entry #18) and building area (Data Entry #6).

20. Rental Income

Average rental rates for the buildings under consideration are entered on a per square foot per month basis. Rental rates vary widely with social function classification, but are intrinsically local because they depend on local economic conditions including vacancy rate, the desirability of the neighborhood, and the desirability of the buildings. Therefore, we have not attempted to compile rental rate information in this report. Typical local rents, appropriate for the social function classifications and locations of the buildings under consideration, can be obtained from local commercial realtors.

Rental incomes to building owners may be lost until functionality is restored after earthquake damage. Estimated loss of function times as a function of expected central damage factors and social function classification are discussed below under item #23.

21. Relocation Costs

Relocation costs may be incurred when building damage requires repairs and the pre-earthquake function of the facility is partially or fully lost. A typical relocation cost of $1.50/square foot/month is suggested in FEMA Handbook No. 174 (page 88). The user may adopt this typical value or enter more appropriate local values depending on the facility and social function classifications. In the models, total relocation costs depend on gross leasable area, relocation costs per square foot per month, and estimated loss of function times.

22. Income

In the models, income is defined as personal and proprietor's income. Disruption of income depends on occupancy and social function of the building. Income loss occurs when building damage disrupts commercial activity. The two critical parameters to be estimated are (1) the level of income generated by the enterprise, and (2) the length of time of disruption. Income estimates for specific industries can be derived from regional data published by the Bureau of Economic Analysis (BEA) in the U.S. Department of Commerce. Regional employment and income estimates are available through BEA's Regional Economic Information System. A building's income can be roughly estimated by multiplying the number of employees in a building by BEA's estimate of income per employee reported for the area and industry.

For retail stores, annual gross sales per square foot of floor space can be obtained from a national survey titled Dollars and Cents of Shopping Centers which is published every three years by the Urban Land Institute. Averages are reported for over 120 tenant classifications in neighborhood, community, regional and super regional shopping centers. Incomes can then be derived for the specific sector using earnings to gross product ratios published in BEA's "Estimates of Gross State Product By Industry," BEA staff paper 42, 1985.

Like rental income and relocation costs, income losses are expected to be proportional to the duration of complete or partial loss of function. Loss of function, which depends on expected central damage factors and social function classification, is discussed below.

23. Loss of Function

Earthquake damage may render buildings unfit for their normal functions until repairs are made or until destroyed buildings are replaced. Rents and other incomes may be lost during this loss of function interval and relocation costs may also be incurred.

Consensus opinions about expected loss of function and restoration times were developed in ATC-13. Loss of function depends on damage state and social function classification. Estimated loss of function times, from ATC-13, are compiled in Table 3-11. These consensus estimates have considerable uncertainty and loss of function and restoration time for specific facilities may differ markedly from these estimates. If local data, appropriate for the facility and social function classes under consideration, are available, they should be used in place of the values in Table 3-11.

24. Business Inventory

Business inventory varies markedly depending on social function and on the specific businesses being considered. Because business inventory varies so drastically depending on whether a business deals in million-dollar paintings or used bricks, it is not possible to give typical or consensus values. Rather, business inventory must be estimated in accordance with the types of businesses involved. A simple approach is to base the value of business inventory on annual sales, adjusted for the type of business.

25. Personal Property

Personal property includes all building contents except business inventory and non-structural building elements. The Estimated Composition and Contents of Various Facilities (ATC-13) summarizes typical values of building contents for various social function classifications. These estimates, which are expressed as percentages of building value, are summarized in Table 3-12 for the social function classifications considered in the models.

Alternatively, users may make local estimates based on tax assessor records of "unsecured property" which is movable assets or personal property in the nomenclature adopted here. For residences, the value of personal property may be estimated from homeowners insurance coverage ratios; personal property coverages are usually expressed as percentages of building values.

3.2E General Economic Factors

26. Discount Rate

The discount rate is used to calculate the present value of benefits which occur in the future. Increasing the discount rate lowers the present value of future benefits and lowers benefit/cost ratios. Conversely, assuming a lower discount rate raises the present value of future benefits and increases benefit/cost ratios.

The choice of an appropriate discount rate is one of the most difficult aspects of benefit/cost analysis. This issue is discussed more fully in Section 3.4C of this chapter and in Appendix 1 of Volume 2. These discussions of discount rates include the "Cost of Capital" model and two "market failure" models--the Social Time Preference and the Social Opportunity Cost approaches. The discount rate selected should be a real rate, excluding inflation. If inflation were included in the discount rate, then it would also be included in calculating future benefits and would effectively cancel out in the net present value calculation (see Chapter 2).

As discussed in Section 3.4C of this chapter and in Appendix 1 of Volume 2, the various approaches to determining appropriate discount rates yield values in the range of 3% to 6%. Using values as high as the 10% discount rate mandated by the Office of Management and Budget (Executive Order 12291, 1981) will produce unreasonable results. The benefit/cost examples shown in Chapter 4 were run using a 4% discount rate. For public sector considerations, a discount rate of 3 or 4% is reasonable. For private sector considerations, slightly higher rates of 4 to 6% is reasonable. The discount rate should be entered as a decimal (i.e., 0.04) but is displayed as a percentage (i.e., 4%).

27. Planning Horizon

The planning horizon is the time period over which the economic benefits of strengthening programs are considered. Typical planning horizons are 20 or 30 years. Longer planning horizons capture more future benefits and thus increase benefit/cost ratios. Short planning horizons capture future benefits for fewer years and thus result in lower benefit/cost ratios. Users may select whatever planning horizons are most appropriate for their particular evaluation.

Building codes and engineering analyses are often based on the maximum expected intensity of ground motions over long time periods of 50 to 250 years. However, planning horizons for economic analyses are typically shorter because benefits or costs in the far distant future contribute relatively little to the net present value of a proposed investment.

28. Selected Net Present Value Coefficient

The selected net present value coefficient is computed automatically from the discount rate and planning horizon selected by the user. As discussed in Chapter 2, the benefit/cost models assume that earthquakes in a given city have a constant probability of occurring each year. Consequently, the expected benefits of strengthening programs (avoided losses) are also computed as though they were received at a uniform rate proportionate to the annual earthquake probabilities.

The net present value coefficient is the present value of $1 per year in benefits, received over the planning horizon time period. Thus, the net present value coefficient decreases with increasing discount rate (future benefits are discounted more) and increases with increasing planning horizon (future benefits are captured over a longer time period). Net present value coefficients for ranges of discount rates and planning horizons are shown in Table 3-13. For example, with a 4% discount rate and a 30 year planning horizon, $1 per year in benefits has a net present value of $17.29. Higher coefficients indicate higher net present values for the benefits and thus will yield higher benefit/cost ratios.

29. Present Value of the Initial Rehabilitation Investment

This item accounts for the net present value of the expected salvage value (Data Entry #14) of the rehabilitation investment. In the benefit/cost models, this value is subtracted from the actual rehabilitation costs because it is the net present value of a future benefit (the salvage value at the end of the planning horizon).

The net present value of the salvage value of the rehabilitation investment depends on three factors: the salvage value as a percentage of the initial rehabilitation costs, the discount rate and the planning horizon. The effect of various ranges of discount rate and planning horizons on $1 of residual salvage value of a rehabilitation investment is shown in Table 3-14. For example, with a 4% discount rate and a 30 year planning horizon, $1 in salvage value at the end of the planning period has a net present value of $0.308. Typically, the net present value of the salvage value of the rehabilitation investment is only a few percent of rehabilitation costs and, thus, has only a minor impact on benefit/cost ratios.

30. Value of Life

The economic value of human life is an important and difficult issue. The benefit/cost models can be run including or excluding the value of human life. When the value of life is included, the value of avoided deaths is frequently one of the principal factors in producing high benefit/cost ratios for prospective strengthening programs, particularly for high occupancy facilities.

Executive Order 12291 (1981) required Federal agencies to justify proposed regulations with a benefit/cost analysis. Agencies responsible for public safety thus had to estimate the value of human lives. Scanlan (1990) observed that values have ranged from $1.1 million per life (Dept. of Agriculture) to $8 million per life (Environmental Protection Agency). Keech (1989) reviewed 25 updated studies for the Federal Aviation Administration. The consensus value obtained was $1,740,000 per life. A fuller discussion of the economic valuation of human life is given in Appendix 1 of Volume 2.

Users may choose to ignore the value of human life and perform benefit/cost analyses solely on other economic grounds or choose to include the value of life. The Federal agency studies suggest that the value ranges from $1 to $8 million per life. Keech's consensus value of $1,740,000 was used in the example benefit/cost analyses given in Chapter 4.

3.3 Model Results

Results from the single-class model are presented in convenient tabular form. Five tables summarize the major results of the benefit/cost calculation, based on the 30 data entries discussed above and the model assumptions discussed in Chapter 2. Examples of these five tables of results are given as Tables 3-15a through 3-15e.

1. Scenario Damages and Economic Losses

The damages and losses expected per earthquake for earthquakes of MMI from VI to XII are shown in Table 3-15a. This table includes expected building damages, rental income losses, other income losses, relocation costs, business inventory losses, personal property losses and total scenario losses. This information allows the user to see which damage or loss categories contribute most of the economic losses and also the total expected economic effects of earthquakes of various MMIs. For cities at risk for only moderate-size earthquakes, the larger MMI events shown in Table 3-15a are unlikely to occur but scenario damage and loss estimates are included for these events for completeness.

2. Expected Annual Damages and Economic Losses

The expected average annual damages and losses arising from all expected earthquake events, taking into account the probabilities of earthquakes of various MMIs in the city, are shown in Table 3-15b. This compilation of expected damages and losses represents the best estimate of future economic impacts which earthquakes would cause in the unrehabilitated buildings under consideration.

3. Expected Annual Damages and Economic Losses Avoided

The expected average annual damages and losses avoided by the prospective strengthening program are shown in Table 3-15c. Damages and losses avoided depend on the expected damages and losses without a strengthening program and on the estimated effectiveness of the strengthening program. The total losses avoided in this table represent the expected annual economic benefits of the strengthening program.

4. Total Expected Benefits and Costs

The total expected net present value of the economic benefits arising from the prospective strengthening program over the planning horizon are shown in Table 3-15d. Total benefits and costs are given as well as benefits minus costs (the expected net present value) and benefit/cost ratios, both with and without the value of life. Comparing the benefit/cost ratios with and without the value of life indicates the relative importance of including the value of life in the economic analysis for the particular buildings and occupancies under consideration. Because life safety is often the principal motivation for seismic rehabilitation programs, the expected number of annual deaths avoided and the value of the expected annual deaths avoided are also shown in this table.

5. Death Losses

The expected number of fatalities in scenario earthquakes of various MMIs, for the buildings under consideration are shown in Table 3-15e. Also shown are the expected average annual fatalities if the buildings remain in their unrehabilitated state and the expected average annual deaths avoided by the prospective seismic rehabilitation program.

3.4 Additional Information

3.4A Estimated Intensities and Frequencies of Future Earthquakes

To evaluate the economic benefits of retrofitting existing buildings, there are two critical seismic data inputs required for each study city: 1) an estimate of the maximum possible earthquake and 2) the expected frequency of occurrence of damaging earthquakes as a function of Modified Mercalli Intensity (MMI). Modified Mercalli Intensities are used, rather than earthquake magnitudes, because MMIs are related to building damages while magnitudes are not. The ATC-13 damage probability matrices for buildings are tabulated based on MMI. It is generally not yet possible to predict the location, time and intensity of <u>specific</u> future earthquakes. However, considerable progress has been made over the past few decades in understanding the <u>average</u>, long-term seismicity of most seismically active zones in the United States. For the present economic analysis, it is the average, long-term seismicity which is relevant.

The maximum possible earthquake expected in a given city is estimated partly from the historical record. For example, if a city has experienced an earthquake with MMI X, then it is reasonable to expect that earthquakes of this intensity will occur again in the future. However, the historical record of earthquakes in the United States does not exceed 500 years anywhere and is little more than 150 years in portions of the western United States. For many cities, these historical timescales are shorter than the expected recurrence times of major earthquakes. Therefore, earthquakes larger or much larger than those experienced in the historical record are expected for many cities in the United States.

It is possible to estimate the maximum possible earthquake in a given region from geologic information. In some regions, the historical record has been greatly extended through paleoseismic trenching studies which have revealed large, pre-historical earthquakes recorded in sedimentary layers. In addition, increasing understanding of the tectonic processes producing earthquakes has resulted in better estimates of the maximum earthquake likely in a given area. For example, large earthquakes require movement along long fault breaks. Thus, if a given earthquake source zone has only short fault segments, then large earthquakes are unlikely to occur.

For the study cities, we have generally used the estimates of maximum expected earthquakes compiled by Algermissen and others (1982). For Seattle, recent paleoseismic research has indicated that earthquakes up to MMI XII have occurred in the geologically recent past (Heaton and Hartzell, 1987). Thus, we have included these larger expected earthquakes in our analysis.

Many other researchers have produced detailed mathematical models of the probability distributions expected for future earthquakes (see, for example, the recent review by Anagnos and Kiremidjian, 1988). Such models attempt to predict the details of seismic patterns in particular seismic zones, although the necessary seismic data are often only partially available. For the present study, we adopt the work of Algermissen and others (1982) as the principal source for estimating the expected frequencies of future earthquakes as a function of MMI for the nine study cities.

The analysis of Algermissen and others (1982) is based on a mathematical relationship between the observed number of small earthquakes and the expected number of larger earthquakes:

$$\log_{10} EAE^{m} = a - b^{m}$$

where EAE^{m} is the expected number of earthquakes per year of a given MMI intensity, a and b are constants which are given or calculated from tables of seismic parameters for each earthquake source zone in the United States. The relationship used by Algermissen and others is a variation of the Gutenberg-Richter relation. The general applicability of the Gutenberg-Richter relationship has been verified from worldwide observations of seismicity (e.g., Evernden, 1975). Simply put, the Gutenberg-Richter relation quantifies the observation that, in any seismic zone, small earthquakes are much more frequent than large earthquakes. Given this relationship, it becomes possible to estimate the frequency of occurrence of large earthquakes from the observed frequency of occurrence of the much more numerous smaller earthquakes.

The expected frequencies of future earthquakes as a function of MMI for each of the nine cities (Table 3-2) have been calculated from the parameters given by Algermissen and others (1982) for the earthquake source zones in which the study cities are located and the earthquake source zones near the study cities. The calculated earthquake frequencies for a particular seismic zone in which a study city is located may overestimate the expected earthquake frequencies for the city, because some of the earthquakes in the source region will occur at some distance from the city, and thus the earthquake intensity experienced by the city will be lower than that experienced from an earthquake occurring in the source zone closer to the city. On the other hand, the calculated earthquake frequencies for the particular source zone in which a city is located may underestimate the expected earthquake frequencies for some study cities because earthquakes in nearby source zones may also affect some cities. For cities located in relatively small source zones and where the seismicity of nearby zones is comparable to that in the source zone where the city is located, these two competing effects approximately cancel each other out. In such cases, the expected earthquake frequencies in Table 3-2 were obtained simply by using the source zone in which the cities are located. In other cases, adjustments were made to account for the impacts of earthquakes in particularly active source zones closer to the study cities.

The expected earthquake frequencies as a function of MMI for the nine study cities, given in Table 3-2, are <u>estimates</u> based on the data of Algermissen and others (1982) and should only be used as estimates which illustrate the approximate extent of seismic risk faced by each of the study cities.

The uncertainties in the expected earthquake frequencies given in Table 3-2 are difficult to estimate. In general, uncertainties are lowest for the most active seismic areas and progressively increase with decreasing seismic activity. This pattern of uncertainty occurs not only because of the more frequent historical earthquakes in the active regions, but also because more research activity has been focused towards understanding the tectonics and seismicity of the more active areas. The estimates in Table 3-2 are conservative, and may overestimate seismic risk, especially for smaller MMI events.

Determining the expected frequencies of occurrence of earthquakes of various MMI for a given city is not an exact science. Ideally, for each city, all possible significant faults should be located and studied in detail; then, each fault should be considered with respect to the impact of events on the fault for the city. In particular, the distance of each fault from the city and the attenuation relationships appropriate for the local geology should be considered. At present, such detailed local geologic information is often not completely available. A less complete method, but more rigorous than the simple estimates made above, would be to use the seismic source zones given Algermissen and others (1982), but model quantitatively the distribution and attenuation of earthquakes in the source zone as a function of distance from the study city.

3.4B Seismic Rehabilitation Costs

The cost of seismic rehabilitation of buildings is difficult to estimate because: 1) individual building conditions vary dramatically, 2) there are very few examples of completed retrofits except for unreinforced masonry buildings, and 3) structural costs are seldom isolated from other improvements. During renovation, when access is gained to certain areas of a building, improvements can also be made in the electrical system, plumbing, insulation, or other components. There are economies, therefore, in completing numerous kinds of renovation simultaneously, so cost records of renovated buildings rarely indicate what would have been the cost of seismic rehabilitation alone. A methodological decision must be made, therefore, whether to use the estimated cost of seismic rehabilitation as if it were the only building improvement, or a share of costs that occur in conjunction with other improvements. Either approach presents a challenge to the engineers who must examine actual renovation cost records to (1) allocate a portion of total costs to seismic retrofit, and (2) estimate how much seismic retrofit alone would have cost.

A study by Comerio titled "Seismic Costs and Policy Implications" (1989) identifies seismic rehabilitation costs for unreinforced masonry buildings of primarily residential use, but the types of added costs it reveals would be representative of nearly any type of structure and any type of use. Comerio identifies the limitations of using building permit valuation to determine actual cost of seismic retrofit, and addresses the problem of separating it from the costs of architectural refinishing, engineering fees, permit fees, legal fees, financing costs, and the costs of other code-required modifications or improvements the owner chooses to include in the project. Although the methods used are perhaps too detailed for generic use by a local government seeking to determine seismic retrofit costs, the methodology could be generalized enough to easily calculate the cost ranges of retrofit.

Comerio describes the factors directly influencing the cost of retrofit for unreinforced masonry buildings in three categories:

1. original construction characteristics, particularly footprint size, height, and configuration;

2. variables related to the design and construction process (e.g., quality of design, minimum standards, the level of refinement of existing architectural finishes and the sensitivity of the designer and contractor in limiting replacement of such finishes, the contractor's experience, and whether the work is done with the occupants in place or when the building is vacant; and

3. specialized local requirements such as fire safety improvements or prevailing wage regulations tied to public financing for seismic improvements.

Comerio separates the direct cost factors which can be quantified as hard costs and soft costs from indirect factors such as delays in the construction, approval, or financing process, and loss of rental income or other opportunity costs. As such, hard costs can be generalized from case examples with a consistent format for attributing portions of the architectural, refinishing, painting, electrical, plumbing, and other general costs to the seismic structural work. Still, the costs are highly variable on a building-by-building basis, so an averaging technique must be used to facilitate application to all buildings in a particular category. Basic unit costs for structural rehabilitation can be obtained from various sources such as Englekirk and Hart, Typical Cost for Seismic Rehabilitation of Existing Buildings (FEMA 156); Comerio, Seismic Costs and Policy Implications (1989); Comerio, Earthquake Hazards and Housing (1987), Rutherford and Chekene, Seismic Retrofit Alternatives for San Francisco's UMB's (1990), and EQE Engineering, Identifying Potentially Hazardous Buildings in Hayward (1989). Sources of non-structural rehabilitation costs are the EQE report, FEMA 174, and Estimating and Analysis for Commercial Renovation by Means.

It is likely that the minimum standard specified for seismic rehabilitation will be the most critical determinant of cost. The minimum standard is the level of seismic rehabilitation design and other structural requirements set forth in a local or state standard. Since most of the case-study cities have not yet adopted formal standards, cost information will not be comparable or, in some cases, obtainable.

To summarize, the approach that should be used is to define a minimum level of seismic strengthening and adjust the California structural costs--which are based on a known specific level--to the minimum level. In many cases, the minimum level will be less stringent than that used in California. Once this has been done, the non-structural cost components can be added as appropriate to determine the total cost of seismic rehabilitation for each structure category.

3.4C Discount Rate

The choice of an appropriate discount rate is perhaps the most difficult and controversial issue in benefit-cost analysis. Given the numerous and divergent views on the topic, there is no one discount rate to use (Mikesell, 1977). This summary will discuss some of the issues involved in choosing a discount rate and suggest a procedure for selecting a rate. The three general approaches to establishing a discount rate to evaluate public investments are the cost of capital and two "market failure" alternatives (Young and Howe, 1988).

1. Cost of Capital Approach

Government agencies generally accept the cost of capital or the government long term borrowing rate as the discount rate. This procedure implicitly assumes that the capital markets function efficiently. For example, Congressional legislation adopted in 1967 sets the discount rate for water projects based on the government long term borrowing rate. The procedure has been criticized because it does not account for inflation. The current rate is 8 7/8% which reflects the inflationary period of the 1970's.

The Office of Management and Budget declared in 1981 that the discount rate to be used in Federal CBA would be 10%:

> "Analysis of benefits and costs including estimates of present value expressed in constant dollars using an annual discount rate of 10 percent; specific type of benefits, when received and by whom; and the type of costs, when incurred and by whom." (Executive Order 12291, dated February 17, 1981)

The rate is clearly above the cost of capital and it is not adjusted for inflation. If all benefits and costs are in current dollars, future costs and benefits can not be properly evaluated in a BCA using a discount rate that is not adjusted for inflation.

2. Market Failure Approaches

Two "market failure" alternative procedures are suggested by Young and Howe (1988), the Social Time Preference, and Social Opportunity Cost approaches.

The Social Time Preference Approach--maintains that the discount rate should be lower than the market rate. Howe (1979) summarized the arguments for using a Social Time Preference approach.

1. Future generations are not present to protect their interest. The bequest motivations of the current generation may imply concern for the next generation or two, but that is not a long enough time horizon. These factors call for heavier public weights on future events.

2. Market rates of interest do not measure even private time preferences, for the typical consumer is myopic and pays little attention to interest rates as long as monthly payments can be met. Consumers have little experience

with transactions in which interest is really a major factor, such as home or auto purchases. Their own feeling for intertemporal tradeoffs is, as a result, nonexistent or formed in ignorance.

3. There are so many different rates of return and interest with large differences between borrowing and lending rates even for the same individual that it is difficult to know which rates to average in calculating an appropriate opportunity cost rate.

4. Market rates of interest and return on private investment contain, on the average, a risk premium to cover the market uncertainties surrounding private investment. For a number of reasons, such risks are likely to be less important for the public sector and the risk premium should not be incorporated in the public discount rate.

To estimate the Social Time Preference discount rate, Young and Howe (1988) recommend using the tax free "20 Year Municipal Bond Buyer" index to average the rates from the past three years and the future 17 years. Adjustments for annual inflation can be made by subtracting from each year the observed or forecasted annual rate of inflation using the GNP Implicit Price Deflator. The deflator can be found in the Wharton Econometrics Long Term Alternative Scenarios and 25-Year Extensions.

The Social Time Preference discount rate can be calculated by:

$$i = \frac{\sum_{t=1}^{20} r_t}{20} - \frac{\sum_{t=1}^{20} dp_t}{20}$$

where:

i is calculated real interest rate;

r is observed or forecasted nominal interest rate for year t;

dp is observed or forecasted percent change in GNP implicit price deflator.

The calculated Social Preference discount rate using 1986 data was 3%.

Young and Howe (1988) suggest that if the investment is done at a state or local level of government and the federal tax represent a loss to the region, returns to private investments should be measured on an after tax basis. They also suggest that the if the funding source is private, the discount rate could be estimated using return on Moody's BAA Seasoned long-term corporate bonds. The estimated discount rate using the return on corporate bonds instead of municipal bonds and adjusted for inflation (1986 data) was 6.5%.

The Social Opportunity Cost Approach to estimating a discount rate considers the market rate of interest is too low to reflect the public interest for two reasons (Young and Howe, 1988). First, government taxation on private investments distorts market returns, and second, the discount rate should not be adjusted to achieve alternative social goals. Randall (1981) suggests the following procedure for estimating the Social Opportunity Cost discount rate.

1. The social discount rate should reflect the marginal efficiency of investment. The banks' prime lending rate is a reasonable indicator of marginal efficiency of investment, if it is adjusted for the rate of inflation, and for the corporate income tax.

2. Although the public sector is large and diversified, public investments are not risk-free. They are, perhaps, about as risky as the loans made by large banks to favored corporations. Thus the risk premium inherent in the banks' prime lending rate is appropriate for public investment.

3. The real rate of interest should be observed over a sufficient period of time to eliminate the effect of business cycles. In the U.S. this would be about 2.5 to 3%.

4. When the corporate income taxes approach fifty percent, a private corporation undertaking a low-risk investment needs to earn approximately twice the prime interest rate. This suggests that the marginal efficiency of investment in the U.S. private sector is about 6% in real terms (1981 dollars).

A sensitivity analysis using the discount rate as a variable allows testing the outcome of the benefit-cost ratio using different discount rates and will indicates the importance of the discount rate in affecting the outcome. It is suggested that a range of values be tested from the 10% interest rate mandated by Executive Order 12291 to the social preference discount rate of 3%.

TABLES FOR CHAPTER 3

TABLE 3-1
DATA ENTRY PROGRAM SCREENS

DATA ENTRY

Geographic & Geologic Information (Main Menu: ALT M)

1. Facility ID: Charleston Three Story URM Retail Stores

2. City: Charleston

3. Earthquake Probabilities: See ALT G

4. If the building inventory is located on poor soils, enter 1 in the following box, and damages will be adjusted according: 0

Structural & Engineering Information (Main Menu: ALT M)

5. Facility Class: URM Low Rise, #75

6. Size of Building (sq.ft.): 200,000

7. Gross Leasable Area(GLA) (sq.ft.): 190,000

8. Damage Probability Matrix: See ALT D

9. Average Retrofit Effectiveness as a Percent of Damages Avoided. Effectiveness of the retrofit is dependant on the Facility Classification.

MMI	Damages Avoided
VI	50%
VII	50%
VIII	45%
IX	40%
X	35%
XI	30%
XII	30%

10. Direct Retrofit Costs per sq. ft. of building area: $20.00

11. Additional Indirect Costs (as a % of direct costs): 20%

12. Cost Premium if the Structure is Occupied During Retrofit (as a % of Retrofit Costs):

13. Total Retrofit Costs (per sq.ft.): $24.00

14. Retrofit Salvage Value as a % of Retrofit Cost: 10%

TABLE 3-1 CONTINUED
DATA ENTRY PROGRAM SCREENS

Building Use (Main Menu: ALT M)

15. Social Function Classification: [Retail #4]
See Report or Table 3.2, Page 55, ATC-13.

16. Number of Occupants per 1000 Sq. Ft. by Social Function.
Daytime [10]
Nighttime [0]

17. Expected Death Rates See ALT J.

Building Economic Information (Main Menu: ALT M)

18. Replacement Building Value/sq.ft.: [$38.50]

19. Total Building Replacement Value: [$7,700,000]

20. Rental Rates per sq. ft. of building size per month: [$0.40]

21. Relocation Expenses per month per sq. ft. of GLA: [$1.50]

22. Income per sq. ft. of GLA per year: [$80]

23. Loss of Function Table see ALT L

24. Business Inventory ($/sq.ft.): [$20]

25. Personal Property Value (% of Building Replacement Value):
See Personal Property, ALT P. [9%]

General Economic Information (Main Menu: ALT M)

26. Enter the discount rate in decimal form (ie .04): [4%]
See ALT N.

27. Select the planning horizon in years: [20]

28. The selected net present value coefficient to be used for this analysis is: [13.59]

29. The coefficient to determine the present value of the initial rehabilitation investment is: [0.456386946]

30. Value of a Statistical Life: [$1,740,000]
See Help, ALT Z.

TABLE 3-2
EXPECTED NUMBER OF EARTHQUAKES PER YEAR

	Boston	Charleston	Memphis	St. Louis	Kansas City	Salt Lake City and Provo	Seattle	Hayward
Source Zone**	107	101	87	88*	84	40*	P001*	C38*
MMI 5	.19100	.18720	.29865	.13294	.04117	.68311	.34880	1.42158
6	.06040	.05920	.10355	.04609	.01428	.17968	.13886	.45944
7	.01910	.01872	.03591	.01599	.00495	.04726	.05528	.15088
8	.00604	.00592	.01245	.00554	.00172	.01237	.02201	.05034
9	.00191	.00187	.00432	.00052	0	.00318	.00876	.01706
10	.00060	.00059	.00150	.00018	0	.00077	.00349	.00587
11	0	0	.00052	0	0	0	.00139	.00411
12	0	0	.00018	0	0	0	.00034	.00136

* Source zone modified to account for strong seismicity in nearby zone(s).
** From Algermissen and others, 1982.

TABLE 3-3
EARTHQUAKE ENGINEERING FACILITY CLASSIFICATION
(From ATC-13, Table 3.1, pp 51-4)

	FACILITY CLASSIFICATION NUMBER
Wood Frame (Low Rise)	1
Unreinforced Masonry (Bearing Wall) a. Low Rise (1-3 Stories)	75*
b. Medium Rise (4-7 Stories)	76*
Unreinforced Masonry (with Load Bearing Frame) a. Low Rise	78*
b. Medium Rise	79*
c. High Rise (8+ Stories)	80*
Reinforced Concrete Shear Wall (with Moment-Resisting Frame) a. Low Rise	3
b. Medium Rise	4
c. High Rise	5
Reinforced Concrete Shear Wall (without Moment-Resisting Frame) a. Low Rise	6
b. Medium Rise	7
c. High Rise	8
Reinforced Masonry Shear Wall (without Moment-Resisting Frame) a. Low Rise	9
b. Medium Rise	10
c. High Rise	11
Reinforced Masonry Shear Wall (with Moment-Resisting Frame) a. Low Rise	84
b. Medium Rise	85
c. High Rise	86

* Facility classifications most vulnerable to earthquake damage.

TABLE 3-3 CONTINUED
EARTHQUAKE ENGINEERING FACILITY CLASSIFICATION
(From ATC-13, Table 3.1, pp 51-4)

	FACILITY CLASSIFICATION NUMBER
Braced Steel Frame a. Low Rise	12
b. Medium Rise	13
c. High Rise	14
Moment-Resisting Steel Frame (Perimeter Frame) a. Low Rise	15
b. Medium Rise	16
c. High Rise	17
Moment-Resisting Steel Frame (Distributed Frame) a. Low Rise	72
b. Medium Rise	73
c. High Rise	74
Moment-Resisting Ductile Concrete Frame (Distributed Frame) a. Low Rise	18
b. Medium Rise	19
c. High Rise	20
Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) a. Low Rise	87*
b. Medium Rise	88*
c. High Rise	89*
Precast Concrete (other than Tilt-up) a. Low Rise	81*
b. Medium Rise	82*
c. High Rise	83*
Tilt-up (Low Rise)	21*

* Facility classifications most vulnerable to earthquake damage.

TABLE 3-4
GENERAL FORM OF DAMAGE PROBABILITY MATRICES
(From ATC-13, Table 2.1, p.45)

Damage State	Damage Factor Range (%)	Central Damage Factor (%)	Probability of Damage in Percent By MMI and Damage State						
			VI	VII	VIII	IX	X	XI	XII
1 - None	0	0	95	49	30	14	3	1	0.4
2 - Slight	0-1	0.5	3	38	40	30	10	3	0.6
3 - Light	1-10	5	1.5	8	16	24	30	10	1
4 - Moderate	10-30	20	0.4	2	8	16	26	30	3
5 - Heavy	30-60	45	0.1	1.5	3	10	18	30	18
6 - Major	60-100	80	-	1	2	4	10	18	39
7 - Destroyed	100	100	-	0.5	1	2	3	8	38

The following definitions can be used as a guideline:

1 - None: No damage.
2 - Slight: Limited localized minor damage not requiring repair.
3 - Light: Significant localized damage of some components generally not requiring repair.
4 - Moderate: Significant localized damage of many components warranting repair.
5 - Heavy: Extensive damage requiring major repairs.
6 - Major: Major widespread damage that may result in the facility being razed, demolished, or repaired.
7 - Destroyed: Total destruction of the majority of the facility.

TABLE 3-5
DAMAGE PROBABILITY MATRICES
FOR THE MOST VULNERABLE FACILITY CLASSIFICATIONS
(From ATC-13, Table 7.10, pp 198-217)

75. Unreinforced Masonry (Bearing Wall, Low Rise)							
MODIFIED MERCALLI INTENSITY							
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00							
0.05	9.1	0.6					
5.00	90.5	55.5	10.9	0.5			
20.00	0.4	43.4	66.0	22.4	2.0	0.1	0.1
45.00		0.5	22.9	65.9	35.0	10.1	3.4
80.00			0.2	11.2	62.5	83.1	50.4
100.00					0.5	6.7	46.1
MDF[2]	4.7	11.7	24.2	43.1	66.7	77.7	88.0

76. Unreinforced Masonry (Bearing Wall, Medium Rise)							
MODIFIED MERCALLI INTENSITY							
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00							
0.05	4.7	1.5					
5.00	89.9	49.5	3.7				
20.00	5.4	46.4	53.3	7.6	0.9		
45.00		2.6	42.0	63.4	21.4	5.3	3.1
80.00			1.0	29.0	74.7	80.0	43.0
100.00					3.0	14.7	53.9
MDF[2]	5.6	12.9	30.5	53.3	72.6	81.1	89.7

[1] CDF, Central Damage Factor, corresponds to damage states, see discussion of data entry item #8, Chapter 3.

[2] MDF, Mean Damage Factor, is the average of the central damage factors, weighted according to the probabilities of each central damage factor.

TABLE 3-5 CONTINUED
DAMAGE PROBABILITY MATRICES
FOR THE MOST VULNERABLE FACILITY CLASSIFICATIONS
(From ATC-13, Table 7.10, pp 198-217)

78. Unreinforced Masonry (with Load Bearing Frame, Low Rise)							
	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	5.2						
0.05	38.8	3.2	0.7				
5.00	55.9	84.1	37.9	5.5	0.8	0.2	0.1
20.00	0.1	12.7	55.4	52.6	20.6	6.9	2.5
45.00			6.0	40.4	60.8	40.2	17.7
80.00				1.5	17.8	51.7	62.8
100.00						1.0	16.9
MDF[2]	3.0	6.8	15.7	30.2	45.8	61.8	75.6

79. Unreinforced Masonry (with Load Bearing Frame, Medium Rise)							
	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	0.5						
0.05	15.3	2.9					
5.00	81.2	66.6	13.5	1.9	0.3		
20.00	3.0	30.1	69.3	40.6	14.1	2.0	0.2
45.00		0.4	17.2	54.4	63.4	28.4	8.5
80.00				3.1	22.2	67.3	78.8
100.00						2.1	12.5
MDF[2]	4.7	9.5	22.3	35.2	49.1	69.1	79.4

[1] CDF, Central Damage Factor, corresponds to damage states, see discussion of data entry item #8, Chapter 3.

[2] MDF, Mean Damage Factor, is the average of the central damage factors, weighted according to the probabilities of each central damage factor.

TABLE 3-5 CONTINUED
DAMAGE PROBABILITY MATRICES
FOR THE MOST VULNERABLE FACILITY CLASSIFICATIONS
(From ATC-13, Table 7.10, pp 198-217)

80. Unreinforced Masonry (with Load Bearing Frame, High Rise)

	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00							
0.05	5.8	1.7					
5.00	87.0	51.2	10.2	0.3			
20.00	7.2	44.9	63.3	18.4	6.0	2.1	
45.00		2.2	26.2	66.5	51.5	26.9	9.6
80.00			0.3	14.8	42.5	68.2	87.6
100.00						2.8	2.8
MDF[2]	5.8	12.5	25.2	45.5	58.4	69.9	77.2

87. Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame, Low Rise)

	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	2.9						
0.05	45.7	1.1					
5.00	51.4	97.9	37.5	2.5	0.4		
20.00		1.0	62.3	88.0	44.6	6.6	0.5
45.00			0.2	9.5	54.6	78.8	41.6
80.00					0.4	14.6	57.9
100.00							
MDF[2]	2.8	5.1	14.4	22.0	33.8	48.5	65.1

[1] CDF, Central Damage Factor, corresponds to damage states, see discussion of data entry item #8, Chapter 3.

[2] MDF, Mean Damage Factor, is the average of the central damage factors, weighted according to the probabilities of each central damage factor.

TABLE 3-5 CONTINUED
DAMAGE PROBABILITY MATRICES
FOR THE MOST VULNERABLE FACILITY CLASSIFICATIONS
(From ATC-13, Table 7.10, pp 198-217)

88. Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame, Medium Rise)

	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	0.3						
0.05	30.9	0.3					
5.00	68.8	96.9	33.6	1.9	0.2		
20.00		2.8	65.7	65.1	30.8	3.6	0.5
45.00			0.7	33.0	67.7	70.0	27.9
80.00					1.3	26.4	71.2
100.00							0.4
MDF[2]	3.6	5.4	15.1	28.0	37.7	53.3	70.0

89. Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame, High Rise)

	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	0.1						
0.05	27.0	2.2					
5.00	72.9	89.3	32.2	3.0			
20.00		8.5	66.9	68.1	19.9	3.9	0.1
45.00			0.9	28.9	74.2	57.8	12.4
80.00					5.9	38.3	84.3
100.00							3.2
MDF[2]	3.8	6.2	15.4	26.8	42.1	57.4	76.2

[1] CDF, Central Damage Factor, corresponds to damage states, see discussion of data entry item #8, Chapter 3.

[2] MDF, Mean Damage Factor, is the average of the central damage factors, weighted according to the probabilities of each central damage factor.

TABLE 3-5 CONTINUED
DAMAGE PROBABILITY MATRICES
FOR THE MOST VULNERABLE FACILITY CLASSIFICATIONS
(From ATC-13, Table 7.10, pp 198-217)

81. Precast Concrete (other than Tilt-up) (Low Rise)							
MODIFIED MERCALLI INTENSITY							
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	9.8						
0.05	49.6	12.8	0.3				
5.00	40.6	86.8	72.4	1.8	0.2		
20.00		0.4	27.3	80.7	27	8.2	3.3
45.00				17.5	69.6	71.1	44.9
80.00					3.2	20.7	51.6
100.00							0.2
MDF[2]	2.3	4.5	9.1	24.1	39.3	50.2	62.3

82. Precast Concrete (other than Tilt-Up) (Medium Rise)							
MODIFIED MERCALLI INTENSITY							
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	15.3						
0.05	47.4	7.1	0.3				
5.00	37.3	92.1	68.8				
20.00		0.8	30.9	70.5	13.6	6.0	2.6
45.00			0.7	29.5	78.2	59.0	27.3
80.00					8.1	35.0	66.7
100.00							3.4
MDF[2]	2.1	4.8	9.9	27.4	44.4	55.8	69.6

[1] CDF, Central Damage Factor, corresponds to damage states, see discussion of data entry item #8, Chapter 3.

[2] MDF, Mean Damage Factor, is the average of the central damage factors, weighted according to the probabilities of each central damage factor.

TABLE 3-5 CONTINUED
DAMAGE PROBABILITY MATRICES
FOR THE MOST VULNERABLE FACILITY CLASSIFICATIONS
(From ATC-13, Table 7.10, pp 198-217)

83. Precast Concrete (other than Tilt-up) (High Rise)							
	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	14.3						
0.05	47.7	6.2	0.5				
5.00	38.0	90.7	55.7				
20.00		3.1	43.3	54.1	11.9	6.1	5.8
45.00			0.5	45.9	78.1	56.7	25.1
80.00					10.0	37.2	58.1
100.00							11.0
MDF[2]	2.1	5.2	11.7	31.5	45.5	56.5	69.9

21. Tilt-up (Low Rise)							
	MODIFIED MERCALLI INTENSITY						
CDF[1]	VI	VII	VIII	IX	X	XI	XII
0.00	0.3						
0.05	35.2	1.2					
5.00	64.5	97.7	49.7	8.7	1.2		
20.00		1.1	50.3	85.7	56.6	13.0	0.7
45.00				5.6	42.0	73.6	40.1
80.00					0.2	13.4	59.2
100.00							
MDF[2]	3.4	5.1	12.5	20.1	30.4	46.4	65.5

[1] CDF, Central Damage Factor, corresponds to damage states, see discussion of data entry item #8, Chapter 3.

[2] MDF, Mean Damage Factor, is the average of the central damage factors, weighted according to the probabilities of each central damage factor.

TABLE 3-6a
EXPECTED EFFECTIVENESS OF RETROFIT

FACILITY CLASSIFICATION NUMBER		EXPECTED REDUCTION IN DAMAGE[1]
1	Wood Frame (Low Rise)	50-20%
75	Unreinforced Masonry (Bearing Wall) a. Low Rise (1-3 Stories)	50-30%
76	b. Medium Rise (4-7 Stories)	50-30%
78	Unreinforced Masonry (with Load Bearing Frame) a. Low Rise	40-25%
79	b. Medium Rise	40-25%
80	c. High Rise (8+ Stories)	40-25%
3	Reinforced Concrete Shear Wall (with Moment-Resisting Frame) a. Low Rise	15-10%
4	b. Medium Rise	20-15%
5	c. High Rise	20-15%
6	Reinforced Concrete Shear Wall (without Moment-Resisting Frame) a. Low Rise	50-30%
7	b. Medium Rise	35-20%
8	c. High Rise	30-15%
9	Reinforced Masonry Shear Wall (without Moment-Resisting Frame) a. Low Rise	30-15%
10	b. Medium Rise	30-15%
11	c. High Rise	30-15%

TABLE 3-6a CONTINUED
EXPECTED EFFECTIVENESS OF RETROFIT

FACILITY CLASSIFICATION NUMBER		EXPECTED REDUCTION IN DAMAGE[1]
84	Reinforced Masonry Shear Wall (with Moment-Resisting Frame) a. Low Rise	35-20%
85	b. Medium Rise	35-20%
86	c. High Rise	35-20%
12	Braced Steel Frame a. Low Rise	35-20%
13	b. Medium Rise	35-20%
14	c. High Rise	35-20%
15	Moment-Resisting Steel Frame (Perimeter Frame) a. Low Rise	35-20%
16	b. Medium Rise	35-20%
17	c. High Rise	35-20%
72	Moment-Resisting Steel Frame (Distributed Frame) a. Low Rise	35-20%
73	b. Medium Rise	35-20%
74	c. High Rise	35-20%
18	Moment-Resisting Ductile Concrete Frame (Distributed Frame) a. Low Rise	35-20%
19	b. Medium Rise	35-20%
20	c. High Rise	35-20%

TABLE 3-6a
EXPECTED EFFECTIVENESS OF RETROFIT

FACILITY CLASSIFICATION NUMBER		EXPECTED REDUCTION IN DAMAGE[1]
87	Moment-Resisting Non-Ductile Concrete Frame (Distributed Frame) a. Low Rise	35-20%
88	b. Medium Rise	35-20%
89	c. High Rise	35-20%
81	Precast Concrete (other than Tilt-up) a. Low Rise	40-25%
82	b. Medium Rise	40-25%
83	c. High Rise	40-25%
21	Tilt-up (Low Rise)	50-30%

[1] High end of range for MMI VI, low end of range for MMI XII.

TABLE 3-6b
EXPECTED EFFECTIVENESS OF RETROFIT
MOST VULNERABLE FACILITY CLASSIFICATIONS

	FACILITY CLASSIFICATION NUMBER (EXPECTED PERCENTAGES OF REDUCTION IN DAMAGES)												
MMI	1	75	76	78	79	80	87	88	89	81	82	83	21
VI	50	50	50	40	40	40	35	35	35	40	40	40	50
VII	50	50	50	40	40	40	35	35	35	40	40	40	50
VIII	43	45	45	36	36	36	31	31	31	36	36	36	45
IX	35	40	40	33	33	33	28	28	28	33	33	33	40
X	28	35	35	29	29	29	24	24	24	29	29	29	35
XI	20	30	30	25	25	25	20	20	20	25	25	25	30
XII	20	30	30	25	25	25	20	20	20	25	25	25	30

TABLE 3-7
TYPICAL HARD SEISMIC REHABILITATION COSTS

STRUCTURAL TYPE[1]	FACILITY CLASSIFICATION[2]		TYPICAL COSTS PER S.F. ($)[3]
URM	75, 76	Unreinforced Masonry Bearing Wall	10-25
RM	9-11, 84-86	Reinforced Masonry	8-17
W	1	Wood	7-17
S1	15-17, 72-74	Steel Moment Frame	8-20
S2	12-14	Steel Braced Frame	8-20
S4	84-86	Steel Frames & Shear Walls	5-12
S5	78-80	Steel Frames & URM Infill	5-12
C1	18-20, 87-89	Cast in Place Reinforced Concrete Frame	10-12
C2	3-5, 6-8	Cast in Place Reinforced Concrete Shear Walls	8-30
C3	78-80	Cast in Place Reinforced Concrete Frame with URM Infill	20-25
PC1	21	Precast Concrete Tilt-Up	3-12
PC2	81-83	Precast Concrete Frame	8-30

[1] Classification based on ATC-14 and ATC-22.

[2] This classification from ATC-13 is used in the benefit/cost models.

[3] These costs are based on a small data base of primarily California buildings. These differ from the FEMA 156 report because they include examples reviewed after the completion of that report.

TABLE 3-8
SOCIAL FUNCTION CLASSIFICATION AND OCCUPANCY
(From ATC-13, Table 3.2 pp 55-6 and Table 4.12 pp 126-7)

SOCIAL FUNCTION CLASSIFICATION	SOCIAL FUNCTION CLASS	TYPICAL OCCUPANTS PER 1000 SQ. FT.	
		DAY TIME (3:00pm)	NIGHT TIME (3:00am)
RESIDENTIAL			
* Permanent Dwelling	1	1.2	3.1
* Temporary Lodging	2	0.6	2.5
* Group Institutional Housing	3	2.0	3.0
COMMERCIAL			
* Retail Trade	4	10.0	-
* Wholesale Trade	5	1.0	-
* Personal and Repair Services	6	4.0	0.1
* Professional, Technical and Business Services	7	4.0	-
* Health Care Services	8	5.0	2.0
* Entertainment and Recreation	9	6.0	-
* Parking	10	0.2	-
INDUSTRIAL			
* Heavy Fabrication and Assembly	11	3.0	0.3
* Light Fabrication and Assembly	12	5.0	0.3
* Food and Drugs Processing	13	2.5	0.3
* Chemicals Processing	14	2.5	0.3
* Metal and Minerals Processing	15	1.2	0.1
* High Technology	16	3.0	0.3
* Construction	17	4.0	0.1
* Petroleum	18	2.5	0.3
RELIGION AND NON-PROFIT	21	65	-
GOVERNMENT			
* General Services	22	4.0	-
* Emergency Response Services	23	3.0	0.4
EDUCATION	24	20	-
COMMUNICATION	34	4.0	1.0

TABLE 3-9
EXPECTED INJURY AND DEATH RATES

EXPECTED INJURY AND DEATH RATES FOR EXISTING BUILDINGS				
DAMAGE STATE	CDF(S) (%)	Fraction Injured		Fraction Dead
		Minor	Serious	
1	0	0	0	0
2	.5	0.000030	0.000004	0.0000010
3	5	0.000300	0.000040	0.0000100
4	20	0.003000	0.000400	0.0001000
5	45	0.030000	0.004000	0.0010000
6	80	0.300000	0.040000	0.0100000
7	100	0.400000	0.400000	0.2000000

From ATC-13, Table 9.3 p 266

EXPECTED INJURY AND DEATH RATES FOR REHABILITATED BUILDINGS				
DAMAGE STATE	CDF(S) (%)	Fraction Injured		Fraction Dead
		Minor	Serious	
1	0	0	0	0
2	.5	0.000000	0.000000	0.0000000
3	5	0.000000	0.000000	0.0000000
4	20	0.000000	0.000000	0.0000000
5	45	0.000030	0.000004	0.0000010
6	80	0.000300	0.000040	0.0000100
7	100	0.003000	0.000400	0.0001000

TABLE 3-10
TYPICAL REPLACEMENT VALUE OF BUILDINGS
(PER SQUARE FOOT OF FLOOR SPACE)
(From ATC-13, Table 4.6, pp 91-2)

SOCIAL FUNCTION CLASSIFICATION	TYPE OF BUILDING	BUILDING HEIGHT		
		LOW RISE	MEDIUM RISE	HIGH RISE
RESIDENTIAL				
* Permanent Dwelling	House and Condominiums	$50	$65	$60
	Apartment	60	65	60
	Mobile Home	30	-	-
* Temporary Lodging	Hotels; Motels	60	70	65
* Group Institutional Housing	Dormitories	70	65	60
	Convalescent Hospitals	75	70	65
COMMERCIAL				
* Retail Trade	Stores	55	65	85
* Wholesale Trade	Warehouses	40	55	-
* Personal and Repair Services	Service Stations; Shops	70	80	90
* Professional, Technical and Business Services	Offices	55	65	85
	Banks	80	80	90
* Health Care Services	Hospitals	95	95	95
	Medical Offices; Clinics	75	80	90
* Entertainment and Recreation	Restaurants; Bars	75	80	90
	Theaters	70	80	90
* Parking	Garages	25	50	50
INDUSTRIAL				
* Heavy Fabrication and Assembly Light Fabrication and Assembly Food and Drugs Processing Chemicals Processing Metal and Minerals Processing High Technology	Factories	45	60	-
* Construction	Offices	55	65	85
RELIGION AND NON-PROFIT	Churches	75	-	-
GOVERNMENT				
* General Services	Offices	70	80	90
* Emergency Response Services	Police; Fire Stations	70	-	-
EDUCATION	Schools	60	70	-
	Colleges; Universities	65	75	85

TABLE 3-11
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Classes 1, 2, 3 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	0.2	0.2	0.8
5	0.3	1.5	3.3
20	1.9	5.4	10.5
45	15.2	30.5	71.9
80	57.2	93.8	146.6
100	105.5	152.1	211.9

Social Function Classes 4, 5, 6, 7, 9 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.2	2.4	5.8
5	3.4	10.2	20.0
20	9.8	44.6	71.0
45	37.0	111.6	202.7
80	114.7	213.7	343.1
100	214.8	355.9	439.3

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Class 8 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	2.3	7.5	20.5
5	17.3	27.5	56.0
20	53.5	93.3	156.8
45	171.2	276.7	338.4
80	295.3	466.2	613.2
100	864.7	749.3	723.4

Social Function Class 10 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	0.0	0.2	0.4
5	0.4	1.9	6.5
20	5.7	14.3	24.4
45	29.2	46.4	76.1
80	75.3	124.4	172.2
100	248.7	260.9	258.3

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Classes 11, 12 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.7	3.4	5.6
5	5.8	13.8	22.6
20	27.8	54.2	99.3
45	73.8	130.2	248.0
80	170.8	267.9	405.5
100	420.2	466.8	538.1

Social Function Class 13 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.0	2.2	4.4
5	3.0	6.4	16.1
20	17.5	37.3	72.7
45	122.8	180.9	235.6
80	150.5	257.6	380.7
100	362.5	503.8	534.1

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Class 14 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.7	3.4	5.6
5	5.8	13.8	22.6
20	27.8	54.2	99.3
45	73.8	130.2	248.0
80	170.8	267.9	405.5
100	420.2	466.8	538.1

Social Function Class 20 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.7	3.4	5.6
5	5.8	13.8	22.6
20	27.8	54.2	99.3
45	73.8	130.2	248.0
80	170.8	267.9	405.5
100	420.2	466.8	538.1

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Class 16 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	0.0	0.0	1.1
5	4.7	5.5	16.5
20	36.8	55.9	111.8
45	136.4	198.2	258.2
80	198.2	281.1	429.1
100	365.0	548.0	612.0

Social Function Class 17 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	2.4	3.6	6.7
5	5.9	12.9	27.9
20	26.0	41.1	68.1
45	56.7	79.0	121.0
80	107.6	162.1	257.3
100	157.8	219.6	330.1

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Class 21 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.4	2.2	3.0
5	4.0	8.9	17.0
20	9.5	42.6	71.7
45	34.1	106.5	214.6
80	137.2	268.5	382.6
100	363.2	410.9	534.9

Social Function Class 22 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.4	3.2	5.1
5	6.0	11.4	28.4
20	34.3	53.3	91.2
45	86.8	136.0	196.3
80	157.8	245.1	396.3
100	271.4	393.3	652.0

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Class 23 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	2.2	4.1	5.1
5	5.8	9.5	18.2
20	22.8	32.5	60.4
45	47.1	79.4	134.9
80	93.7	175.1	256.1
100	136.6	210.0	346.8

Social Function Class 24 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	2.8	4.2	5.7
5	6.4	11.4	15.5
20	21.5	43.8	72.1
45	80.8	125.2	183.0
80	177.7	267.2	362.1
100	312.3	386.5	562.6

TABLE 3-11 CONTINUED
WEIGHTED STATISTICS FOR LOSS OF FUNCTION AND RESTORATION TIME OF SOCIAL FUNCTION CLASSIFICATION (IN DAYS)
(From ATC-13, Table 9.11, pp 290-304)

Social Function Class 34a Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	0.0	1.5	3.9
5	1.5	3.1	9.8
20	6.7	32.1	85.0
45	47.9	92.5	251.7
80	155.4	295.4	523.5
100	251.9	344.2	629.3

TABLE 3-12
ESTIMATED COMPOSITION AND CONTENTS OF VARIOUS FACILITIES
IN TERMS OF EARTHQUAKE ENGINEERING FACILITY CLASSIFICATIONS
(AS A PERCENTAGE OF THE FACILITY BASE VALUE)
(From ATC-13, Table 4.11 pp 119-124)

SOCIAL FUNCTION CLASSIFICATION (SFC)	SFC NO.	FACILITY INCLUDED IN BASE VALUE	CATEGORY 2 EQUIPMENT/CONTENTS					
			RESIDENTIAL	OFFICE	ELECTRICAL	MECHANICAL	HIGHTECH	VEHICLES
RESIDENTIAL								
• PERMANENT DWELLING	1	HOUSES AND CONDOMINIUMS	30	-	2	2	-	15
		APARTMENTS	25	-	2	2	-	10
		MOBILE HOMES	25	-	2	2	-	-
• TEMPORARY LODGING	2	HOTELS AND MOTELS	15	2	2	2	-	-
• GROUP INSTITUTIONAL LODGING	3	DORMITORIES, ETC.	15	2	2	2	-	-
COMMERCIAL								
• RETAIL TRADE[1]	4	STORES	-	5	2	2	-	-
• WHOLESALE TRADE[1]	5	WAREHOUSES & SALES OFFICES	-	10	1	1	-	-
• PERSONAL AND REPAIR SERVICES	6	REPAIR SHOPS, SERVICE STATIONS, ETC.	-	5	5	5	-	10
• PROFESSIONAL, TECHNICAL AND BUSINESS SERVICES	7	OFFICES, BANKS, ETC.	-	25	2	2	5	-
• HEALTH CARE SERVICES	8	HOSPITALS	-	15	15	70	80	5
		MEDICAL OFFICES & CLINICS	-	15	10	10	10	-
• ENTERTAINMENT & RECREATION	9	RESTAURANTS, BARS, THEATERS, ETC.	-	5	5	5	5	-
• PARKING	10	GARAGES	-	-	-	-	-	40
RELIGION AND NONPROFIT	21	CHURCHES	-	15	2	2	-	-
		OTHER OFFICES	-	25	2	2	5	-
GOVERNMENT								
• GENERAL SERVICES	22	OFFICES	-	25	2	2	5	-
• EMERGENCY RESPONSE SERVICES	23	POLICE AND FIRE STATIONS	5	20	5	5	20	25
EDUCATION	24	SCHOOLS, COLLEGES & UNIVERSITIES	-	20	5	5	5	10
COMMUNICATION	34	BROADCAST STUDIOS	-	20	50	10	15	-

TABLE 3-12 CONTINUED
ESTIMATED COMPOSITION AND CONTENTS OF VARIOUS FACILITIES IN TERMS OF EARTHQUAKE ENGINEERING FACILITY CLASSIFICATIONS (AS A PERCENTAGE OF THE FACILITY BASE VALUE)

(From ATC-13, Table 4.11 pp 119-124)

SOCIAL FUNCTION CLASSIFICATION (SFC)	SFC NO.	FACILITY INCLUDED IN BASE VALUE	PIPE LINES	STORAGE TANKS		CHIMNEYS			CRANES	CONVEYERS	CATEGORY 2 EQUIPMENT/CONTENTS				
				O.G. LIQUID	O.G. SOLID	MASONRY	CONCRETE	STEEL			OFFICE	ELECTRICAL	MECHANICAL	HIGHTECH	VEHICLES
INDUSTRIAL															
• HEAVY FABRICATION AND ASSEMBLY[2]	11	FACTORIES	5	5	5	-	-	5	10	10	5	15	25	5	-
• LIGHT FABRICATION AND ASSEMBLY[2]	12	FACTORIES	5	5	5	-	-	-	-	10	5	15	25	5	-
• FOOD AND DRUG PROCESSING[2]	13	FACTORIES	10	20	20	-	-	5	-	10	5	15	25	5	-
• CHEMICALS PROCESSING[2]	14	FACTORIES	10	20	20	2	2	2	-	10	5	15	25	5	-
• METAL AND MINERALS PROCESSING[2]	15	FACTORIES	5	5	5	5	5	5	15	10	5	15	35	5	-
• HIGH TECHNOLOGY[2]	16	FACTORIES	10	15	10	-	-	2	-	5	5	25	20	35	-
• CONSTRUCTION[3]	17	FACILITIES & EQUIPMENT	-	-	-	-	-	-	-	-	15	2	3	-	15

FOOTNOTES

[1] Does not include merchandise inventories.
[2] Does not include inventories of raw material and/or manufactured goods.
[3] Does not include inventories of buildings under construction; obtain from building permit records.

TABLE 3-13
THE NET PRESENT VALUE CRITERION

Discount Rate	Planning Horizon (Years)			
	10	20	30	50
3%	8.530	14.877	19.600	25.730
4%	8.111	13.590	17.292	21.482
5%	7.722	12.462	15.372	18.256
6%	7.360	11.470	13.765	15.762

TABLE 3-14
THE SALVAGE VALUE OF THE REHABILITATION INVESTMENT

Discount Rate	Planning Horizon (Years)			
	10	20	30	50
3%	0.744	0.554	0.412	0.228
4%	0.676	0.456	0.308	0.141
5%	0.614	0.377	0.231	0.087
6%	0.558	0.312	0.174	0.054

TABLE 3-15a
MODEL RESULTS

Scenario Damages and Economic Losses =
(Possible Damages * Mean Damage Function by MMI (ALT D))
+ (Possible Economic Losses * Loss of Function by MMI (ALT L))

Main Menu: ALT M

City: Charleston
Facility: URM Low Rise, #75
Social Function: Retail #4
Soil: NORMAL

MMI	Building Damages (Replacement Value * Mean Damage Funct-ion)	Rental Income (Rental Rates * Time Not Rented)	Relocation Expenses (Relocation Expenses * Time of Relocation)	Income Losses (Income Rates * Time Out of Bus -iness)
VI	$358,089	$8,613	$34,000	$141,589
VII	$899,591	$30,603	$120,800	$503,058
VIII	$1,864,170	$113,291	$447,200	$1,862,312
IX	$3,320,240	$318,339	$1,256,600	$5,232,964
X	$5,132,050	$597,259	$2,357,600	$9,817,951
XI	$5,986,365	$878,889	$3,469,300	$14,447,496
XII	$6,773,690	$878,889	$3,469,300	$14,447,496

MMI	Business Inventory (Inventory Value * Mean Damage Funct-ion)	Personal Property (Property Value * Mean Damage Funct-ion)	Total Scenario Losses
VI	$176,719	$32,228	$751,238
VII	$443,954	$80,963	$2,078,968
VIII	$919,980	$167,775	$5,374,728
IX	$1,638,560	$298,822	$12,065,525
X	$2,532,700	$461,885	$20,899,444
XI	$2,954,310	$538,773	$28,275,133
XII	$3,342,860	$609,632	$29,521,867

TABLE 3-15b
MODEL RESULTS

Expected Damages and Economic Losses =
Scenario Damages & Economic Losses (ALT S)
* Expected Number of Earthquakes by MMI (ALT G)

Main Menu: ALT M

City: Charleston
Facility: URM Low Rise, #75
Social Function: Retail #4
Soil: NORMAL

MMI	Building Damages	Rental Income	Relocation Expenses	Income Losses
VI	$21,199	$510	$2,013	$8,382
VII	$16,840	$573	$2,261	$9,417
VIII	$11,036	$671	$2,647	$11,025
IX	$6,209	$595	$2,350	$9,786
X	$3,028	$352	$1,391	$5,793
XI	$0	$0	$0	$0
XII	$0	$0	$0	$0
Total	$58,312	$2,701	$10,662	$44,402

MMI	Business Inventory	Personal Property	Total Expected Losses
VI	$10,462	$1,908	$44,473
VII	$8,311	$1,516	$38,918
VIII	$5,446	$993	$31,818
IX	$3,064	$559	$22,563
X	$1,494	$273	$12,331
XI	$0	$0	$0
XII	$0	$0	$0
Total	$28,777	$5,248	$150,103

TABLE 3-15c
MODEL RESULTS

Expected Damages and Economic Losses Avoided = Expected Damages & Economic Losses (ALT E) * Effectiveness of the Rehabilitation (ALT A)				
Main Menu: ALT M				
City: Charleston				
Facility: URM Low Rise, #75				
Social Function: Retail #4				
Soil: NORMAL				

MMI	Building Damages	Rental Income	Relocation Expenses	Income Losses
VI	$10,599	$255	$1,006	$4,191
VII	$8,420	$286	$1,131	$4,709
VIII	$4,966	$302	$1,191	$4,961
IX	$2,484	$238	$940	$3,914
X	$1,060	$123	$487	$2,027
XI	$0	$0	$0	$0
XII	$0	$0	$0	$0
Total	$27,529	$1,205	$4,755	$19,803

MMI	Business Inventory	Personal Property	Total Losses Avoided
VI	$5,231	$954	$22,237
VII	$4,155	$758	$19,459
VIII	$2,451	$447	$14,318
IX	$1,226	$224	$9,025
X	$523	$95	$4,316
XI	$0	$0	$0
XII	$0	$0	$0
Total	$13,586	$2,478	$69,355

TABLE 3-15d
MODEL RESULTS

RESULTS (Main Menu: ALT M)	
City: Charleston	
Social Function: Retail #4	
Facility: URM Low Rise, #75	
Soil: NORMAL	
Present Value of Damages and Losses Avoided = Expected Damages & Economic Losses Avoided (ALT V) * Present Value Coefficient (ALT N)	
Building Damages	$374,129
Rental Income Losses	$16,372
Relocation Expenses	$64,625
Income Losses	$269,123
Business Inventory Losses	$184,635
Personal Property Losses	$33,672
Total	$942,554
Rehabilitation Costs & Salvage Value:	
Total Costs	$4,800,000
Present Value of Investment in Terminal Year	$219,066
Total	$4,580,934
Benefits Cost Calculations Without the Value of Deaths Avoided:	
Benefits-Costs Without the Value of Deaths Avoided	($3,638,380)
Benefits/Costs Without the Value of Deaths Avoided	0.21
Benefit Cost Calculation With the Value of Deaths Avoided:	
Expected Number of Annual Deaths Avoided	0.00860
Value of Expected Number of Annual Deaths Avoided	$14,965
Present Value of Expected Number of Deaths Avoided	$203,381
Benefits-Costs With the Value of Deaths Avoided	($3,434,999)
Benefits/Costs With the Value of Deaths Avoided	0.25

TABLE 3-15e
MODEL RESULTS

EXPECTED DEATH LOSSES (Main Menu: ALT M)			
City:	Charleston		
Facility:	URM Low Rise, #75		
Social Function:	Retail #4		
Soil:	NORMAL		
MMI	Scenario	Expected	Avoided
VI	0.001000	0.0000592	0.0000592
VII	0.010000	0.0001872	0.0001872
VIII	0.100000	0.0005920	0.0005920
IX	1.000000	0.0018700	0.0018681
X	10.000000	0.0059000	0.0058941
XI	200.000000	0.0000000	0.0000000
XII	200.000000	0.0000000	0.0000000
Expected Annual Death Losses:		0.0086084	0.0086006

CHAPTER 4

EXAMPLE APPLICATIONS OF THE BENEFIT/COST MODELS

4.1 Introduction

Five examples illustrating the single-class benefit/cost model and two examples illustrating the multi-class model are included in this chapter. These examples were chosen to represent a broad range of geographic locations, building types, and building uses. All examples use a 4% discount rate and a 20-year planning horizon.

The single-class examples include:

1) Charleston, South Carolina - retail stores in unreinforced masonry buildings,
2) St. Louis, Missouri - offices in concrete frame buildings,
3) Hayward, California - light industry in concrete tilt-up buildings,
4) Hayward, California - warehouses in concrete tilt-up buildings, and
5) Seattle, Washington - apartments in unreinforced masonry buildings.

The Charleston example is given in full detail with all of the data entry and results screens from the program reproduced as tables in this chapter. The other four examples are given in summary form. (Tables for this chapter are in a separate section which follows page 4-5 of the text.)

This chapter also contains two examples of the multi-class model. These examples include groups of buildings with mixed facility classes and mixed social function classifications in Seattle, Washington. In the first and second examples, the buildings considered are on firm soil and on poor soil, respectively.

4.2 Single-Class Model Examples

The main program menu is shown in Table 4-1. From this main menu, the user selects the five main data entry screens:

- Geographic and Geologic Information,
- Structural and Engineering Information,
- Building Use Information,

- Building Economic Information, and
- General Economic Information.

On each of these screens, the user enters the requested information in the data entry boxes. Each of the numbered data entry items is discussed in Chapter 3. Examples of these five main data entry screens are shown in Table 4-2a.

The five main data entry screens (Table 4-2a) also reference secondary data entry screens. From the main data entry screens, the user selects these secondary data entry screens:

- Expected Number of Earthquakes by MMI,
- Damage Probability Matrix,
- Expected Death and Injury Rates,
- Personal Property, and
- Loss of Function.

On each of these screens, the user reviews or enters the requested data. Each of these required data entry items is also discussed in Chapter 3. Examples of these five secondary data entry screens are shown in Table 4-2b.

Once the necessary data have been entered, the program performs the benefit/cost computation. Results are presented in five tables:

- Scenario Damages and Economic Losses,
- Expected Damages and Economic Losses,
- Expected Damages and Economic Losses Avoided,
- Total Benefits and Costs, and
- Expected Death Losses.

A summary discussion of these tables of results was given in Chapter 3. Examples of these five tables of results are shown in Table 4-2c.

Example 1: Charleston, South Carolina - Retail Stores

The Charleston example (Table 4-2) considers retail stores in unreinforced masonry buildings. Given the expected probabilities of earthquakes, expected damages for buildings of this type, occupancies, retrofit costs of $24.00/square foot and the other variables entered in this example (Tables 4-2a, 4-2b), benefit/cost ratios for this prospective strengthening program are low: 0.21 without including the value of life and 0.25 including the value of life. Therefore, these results suggest that this retrofit is not economically justified.

These results for this particular Charleston example, however, do not mean that every prospective retrofit in Charleston will have a low benefit/cost ratio. Depending on factors such as whether the buildings are on poor soil or firm soil, the buildings' type, use, and occupancy and on the value chosen for human life, very different results could be obtained. The user is strongly encouraged to explore a range of "what ifs" by varying the input parameters to investigate a range of possible combinations of factors and assumptions.

Example 2: St. Louis, Missouri - Office Buildings

The St. Louis example (Table 4-3) considers offices in concrete frame buildings with unreinforced masonry infill walls. The five main data entry screens for this model are shown in Table 4-3a. Secondary data entry screens are shown in Table 4-3b.

Summary results of this example are shown in Table 4-3c. In this example, the benefit/cost ratios are 0.26 without the value of life and 0.28 with the value of life included. The conclusion drawn is that this prospective retrofit is probably not economically justified.

Example 3: Hayward, California - Warehouses

This Hayward example considers warehouses in concrete tilt-up buildings. The five main data entry screens for this model are shown in Table 4-4a. Secondary data entry screens are shown in Table 4-4b.

Summary results of this example are shown in Table 4-4c. Benefit/cost ratios are high, in large part due to the high earthquake probabilities in Hayward and to the relatively low retrofit costs required for tilt-ups (see Tables 3-2 and 3-7). In this example, the benefit/cost ratio is about 8 without the value of life and about 10.5 with the value of life. The benefit/cost analysis suggests that retrofit is strongly justified economically, even without including the value of life.

Example 4: Hayward, California - Light Industry

This Hayward example considers light industry in concrete tilt-up buildings. The five main data entry screens for this model are shown in Table 4-5a. Secondary data entry screens are shown in Table 4-5b.

Summary results of this example are shown in Table 4-5c. Benefit/cost results are extremely high for this example, primarily for the same reasons as in the previous Hayward example. However, the light industry use in this example results in much higher occupancy rates than in the previous warehouse example. Therefore, including the value of life has a larger impact on benefit cost ratios, which are about 12 without the value of life and about 25 with the value of life. This retrofit is thus strongly justified economically.

Example 5: Seattle, Washington - Apartments

This Seattle example considers permanent residences (apartments) in unreinforced masonry buildings. In this example, the buildings are on poor soil, and expected earthquake damages are much higher than for buildings on firm soil sites. The five main data entry screens for this model are shown in Table 4-6a. Secondary data entry screens are shown in Table 4-6b.

Summary results of this example are shown in Table 4-6c. In this example, the benefit/cost ratio is 1.6 without the value of human life, which suggests that the retrofit may be economically justified on this basis. However, with the value of life included, the benefit/cost ratio becomes 4.5 which suggests that the retrofit is clearly economically justified on this basis. This example illustrates the importance of the value of life in benefit/cost analysis.

4.3 Multi-Class Model Examples

The multi-class model is based on the same economic assumptions and equations and requires the same data entries as the single-class model. However, the multi-class model is designed to consider groups of buildings which vary in facility classification (structural types) and social function classifications (uses). Effectively, the multi-class model performs single-class analyses for each combination of facility and social function classification and then aggregates the results. The multi-class model is a series of linked spreadsheets which are loaded and accessed automatically by the program. The user accesses each spreadsheet from a main menu, as in the single-class model.

The building inventory used to demonstrate the multi-class model pertains to census tracts 81 and 92 located in Seattle. This inventory includes a wide mixture of facility classes and uses. Some of the codes used in the Seattle inventory are different from ATC-13 and needed to be redesignated. Those are the structure system class (SSC) which is similar to the ATC-13 facility class, and the use class (UC) which is the same as the ATC-13 social function class. Use class 99 represents vacant buildings and for the purposes of this analysis, they were assigned to appropriate social function classes. In addition, many of the buildings are located on soils which are expected to liquify during earthquakes. As explained earlier, buildings which are located on poor soils require the mean damage factor and the loss of function coefficients to be adjusted upward. Therefore, building inventories on poor soils must be analyzed separately from those on firm soils.

The detailed building inventories for these multi-class examples and detailed results are given in Appendix 3 of Volume 2. The principal results are summarized below.

Example 6: Seattle, Washington - Mixed Buildings on Firm Soils

In the total inventory considered, 26 of the buildings are located on firm soils. Without the value of life, the total benefit/cost ratio for this inventory is 0.62. The benefit/cost ratios for various combinations of facility class and social function class vary quite a bit. The results tables of the multi-class model break down the results by facility and social function class and thus the user may explore these results to determine where benefits are highest and lowest. For example, parking garages have very low benefit/cost ratios and facilities with higher rents and incomes generally have higher benefit/cost ratios. With the value of life included, the benefit/cost ratio for the entire inventory is 1.66, which again demonstrates the importance of the value of life in such analyses.

Example 7: Seattle, Washington - Mixed Buildings on Poor Soils

In the total inventory considered, 41 of the buildings are located on poor soils areas. As discussed in Chapter 3, this substantially increases the expected damages and thus also substantially increases the expected benefits of avoiding these damages by strengthening the buildings. Without the value of life, the total benefit/cost ratio is 2.03, which suggests that strengthening would be economically justified on this basis alone. With the value of life included, the benefit cost ratio becomes 5.20, which suggests that strengthening is strongly justified economically.

TABLES FOR CHAPTER 4

TABLE 4-1 SINGLE-CLASS BENEFIT/COST MODEL MAIN MENU SCREEN

EARTHQUAKE REHABILITATION BENEFIT COST ANALYSIS MAIN MENU	
This Menu	ALT M
Help	ALT Z
GEOGRAPHIC & GEOLOGIC INFORMATION	ALT A
Expected Number of Earthquakes by MMI	ALT G
STRUCTURAL & ENGINEERING INFORMATION	ALT C
Damage Probability Matrix	ALT D
BUILDING USE INFORMATION	ALT F
Expected Death & Injury Rates	ALT J
BUILDING ECONOMIC INFORMATION	ALT W
Personal Property	ALT P
Loss of Function	ALT L
GENERAL ECONOMIC INFORMATION	ALT O
RESULTS:	
Scenario Damages & Economic Losses	ALT S
Expected Damages & Economic Losses	ALT E
Expected Damages & Economic Losses Avoided	ALT V
Total Benefits and Costs	ALT R
Death Losses	ALT H
PRINT TO PRINTER:	ALT B
EXIT QUATTRO PRO AND RETURN TO DOS	CTL X

TABLE 4-2a MAIN DATA ENTRY SCREENS
CHARLESTON RETAIL STORES EXAMPLE

DATA ENTRY

Geographic & Geologic Information (Main Menu: ALT M)

1. Facility ID: Charleston Three Story URM Retail Stores

2. City: Charleston

3. Earthquake Probabilities: See ALT G

4. If the building inventory is located on poor soils, enter 1 in the following box, and damages will be adjusted according: 0

Structural & Engineering Information (Main Menu: ALT M)

5. Facility Class: URM Low Rise, #75

6. Size of Building (sq.ft.): 200,000

7. Gross Leasable Area(GLA) (sq.ft.): 190,000

8. Damage Probability Matrix: See ALT D

9. Average Retrofit Effectiveness as a Percent of Damages Avoided. Effectiveness of the retrofit is dependant on the Facility Classification.

MMI	Damages Avoided
VI	50%
VII	50%
VIII	45%
IX	40%
X	35%
XI	30%
XII	30%

10. Direct Retrofit Costs per sq. ft. of building area: $20.00

11. Additional Indirect Costs (as a % of direct costs): 20%

12. Cost Premium if the Structure is Occupied During Retrofit (as a % of Retrofit Costs):

13. Total Retrofit Costs (per sq.ft.): $24.00

14. Retrofit Salvage Value as a % of Retrofit Cost: 10%

TABLE 4-2a CONTINUED
MAIN DATA ENTRY SCREENS
CHARLESTON RETAIL STORES EXAMPLE

Building Use (Main Menu: ALT M)

15. Social Function Classification: See Report or Table 3.2, Page 55, ATC-13. — Retail #4

16. Number of Occupants per 1000 Sq. Ft. by Social Function.
    - Daytime: 10
    - Nighttime: 0

17. Expected Death Rates See ALT J.

Building Economic Information (Main Menu: ALT M)

18. Replacement Building Value/sq.ft.: $38.50

19. Total Building Replacement Value: $7,700,000

20. Rental Rates per sq. ft. of building size per month: $0.40

21. Relocation Expenses per month per sq. ft. of GLA: $1.50

22. Income per sq. ft. of GLA per year: $80

23. Loss of Function Table see ALT L

24. Business Inventory ($/sq.ft.): $20

25. Personal Property Value (% of Building Replacement Value): See Personal Property, ALT P. — 9%

General Economic Information (Main Menu: ALT M)

26. Enter the discount rate in decimal form (ie .04): See ALT N. — 4%

27. Select the planning horizon in years: 20

28. The selected net present value coefficient to be used for this analysis is: 13.59

29. The coefficient to determine the present value of the initial rehabilitation investment is: 0.456

30. Value of a Statistical Life: See Help, ALT Z. — $1,740,000

TABLE 4-2b SECONDARY DATA ENTRY SCREENS
CHARLESTON RETAIL STORES EXAMPLE

Expected Number of Annual Earthquakes by Location & MMI:
Main Menu ALT M

If your city is not listed, the expected number of earthquakes for has not been calculated. If they are calculated, enter them in the row marked other, and change the city name in this table and in the assumptions section.

City	MMI							
	V	VI	VII	VIII	IX	X	XI	XII
Boston	0.19100	0.06040	0.01910	0.00604	0.00191	0.00060	0.00000	0.00000
Charleston	0.18720	0.05920	0.01872	0.00592	0.00187	0.00059	0.00000	0.00000
Memphis	0.29865	0.10355	0.03591	0.01245	0.00432	0.00150	0.00052	0.00018
St. Louis	0.13294	0.04609	0.01599	0.00554	0.00052	0.00018	0.00000	0.00000
Kansas City	0.04117	0.01428	0.00495	0.00172	0.00000	0.00000	0.00000	0.00000
Salt Lake	0.68311	0.17968	0.04726	0.01237	0.00318	0.00077	0.00000	0.00000
Provo	0.68311	0.17968	0.04726	0.01237	0.00318	0.00077	0.00000	0.00000
Seattle	0.34880	0.13886	0.05528	0.02201	0.00876	0.00349	0.00139	0.00034
Hayward	1.42158	0.45944	0.15088	0.05034	0.01706	0.00587	0.00411	0.00136
Other								

Damage Probability Matrix (Table 7.10, Page 198, ATC-13)
Main Menu: ALT M
Facility: URM Low Rise, #75
(Table 7.10, Page 198, ATC-13) See ALT K

Central Damage Function	Modified Mercalli Intensity						
	VI	VII	VIII	IX	X	XI	XII
0.00							
0.50	9.1	0.6					
5.00	90.5	55.5	10.9	0.5			
20.00	0.4	43.4	66	22.4	2	0.1	0.1
45.00		0.5	22.9	65.9	35	10.1	3.4
80.00			0.2	11.2	62.5	83.1	50.4
100.00					0.5	6.7	46.1
Mean Damage Function	4.6505	11.683	24.21	43.12	66.65	77.745	87.97

TABLE 4-2b CONTINUED
SECONDARY DATA ENTRY SCREENS
CHARLESTON RETAIL STORES EXAMPLE

Expected Injury and Death Rates.* (Main Menu ALT M)				
Damage State	CDF(S) (%)	Fraction Injured		Fraction Dead
		Minor	Serious	
1	0	0	0	0
2	.5	0.000030	0.000004	0.0000010
3	5	0.000300	0.000040	0.0000100
4	20	0.003000	0.000400	0.0001000
5	45	0.030000	0.004000	0.0010000
6	80	0.300000	0.040000	0.0100000
7	100	0.400000	0.400000	0.2000000
(Table 9.3, Page 260, ATC-13)				

Expected Injury and Death Rates for Rehabilitated Buildings.				
Damage State	CDF(S) (%)	Fraction Injured		Fraction Dead
		Minor	Serious	
1	0	0	0	0
2	.5	0.000000	0.000000	0.0000000
3	5	0.000000	0.000000	0.0000000
4	20	0.000000	0.000000	0.0000000
5	45	0.000030	0.000004	0.0000010
6	80	0.000300	0.000040	0.0000100
7	100	0.003000	0.000400	0.0001000

TABLE 4-2b CONTINUED
SECONDARY DATA ENTRY SCREENS
CHARLESTON RETAIL STORES EXAMPLE

Estimated Composition & Contents of Various Facilities in Terms of Earthquake Engineering Facility Classifications (as a percentage of the Facility Base Value)	
Main Menu: ALT M	
The data in this table must be updated for each Social Function. The data are presented in Table 4.11, ATC-13, page 119.	
Social Function Classification: Retail #4	
Buildings	100%
Pipelines (at grade)	0%
Storage Tanks:	
O.G. Liquid	0%
O.G. Solid	0%
Chimneys:	
Masonry	0%
Concrete	0%
Steel	0%
Cranes	0%
Conveyors	0%
Residential	0%
Office	5%
Electrical	2%
Mechanical	2%
High Technology	0%
Vehicles	0%
Percent of Replacement Value	9%

Weighted Statistics for Loss of Function and Restoration Time of Social Function Classifications (days). ATC-13, page 290 give Loss of Function for California. If no other data exists, ATC-13 can be used until more can be developed. These tables can be copied from: ALT Q.

Main Menu ALT M

Social Function Class: Retail #4

Damage State	Central Damage Factor	Mean Time to Restore to % of function: 30%	60%	100%	Total Loss of Function
2	0.50	1.2	2.4	5.8	3.4
3	5.00	3.4	10.2	20.0	12.08
4	20.00	9.8	44.6	71.0	44.72
5	45.00	37.0	111.6	202.7	125.66
6	80.00	114.7	213.7	343.1	235.76
7	100.00	214.8	355.9	439.3	346.93

Source: Table 9.11, Page 290, ATC-13.

TABLE 4-2c RESULTS TABLES
CHARLESTON RETAIL STORES EXAMPLE

Scenario Damages and Economic Losses =
(Possible Damages * Mean Damage Function by MMI (ALT D))
+ (Possible Economic Losses * Loss of Function by MMI (ALT L))

Main Menu: ALT M

City: Charleston
Facility: URM Low Rise, #75
Social Function: Retail #4
Soil: NORMAL

MMI	Building Damages (Replacement Value * Mean Damage Funct-ion)	Rental Income (Rental Rates * Time Not Rented)	Relocation Expenses (Relocation Expenses * Time of Relocation)	Income Losses (Income Rates * Time Out of Bus -iness)
VI	$358,089	$8,613	$34,000	$141,589
VII	$899,591	$30,603	$120,800	$503,058
VIII	$1,864,170	$113,291	$447,200	$1,862,312
IX	$3,320,240	$318,339	$1,256,600	$5,232,964
X	$5,132,050	$597,259	$2,357,600	$9,817,951
XI	$5,986,365	$878,889	$3,469,300	$14,447,496
XII	$6,773,690	$878,889	$3,469,300	$14,447,496

MMI	Business Inventory (Inventory Value * Mean Damage Funct-ion)	Personal Property (Property Value * Mean Damage Funct-ion)	Total Scenario Losses
VI	$176,719	$32,228	$751,238
VII	$443,954	$80,963	$2,078,968
VIII	$919,980	$167,775	$5,374,728
IX	$1,638,560	$298,822	$12,065,525
X	$2,532,700	$461,885	$20,899,444
XI	$2,954,310	$538,773	$28,275,133
XII	$3,342,860	$609,632	$29,521,867

TABLE 4-2c CONTINUED
RESULTS TABLES
CHARLESTON RETAIL STORES EXAMPLE

Expected Damages and Economic Losses =
Scenario Damages & Economic Losses (ALT S)
* Expected Number of Earthquakes by MMI (ALT G)

Main Menu: ALT M

City: Charleston
Facility: URM Low Rise, #75
Social Function: Retail #4
Soil: NORMAL

MMI	Building Damages	Rental Income	Relocation Expenses	Income Losses
VI	$21,199	$510	$2,013	$8,382
VII	$16,840	$573	$2,261	$9,417
VIII	$11,036	$671	$2,647	$11,025
IX	$6,209	$595	$2,350	$9,786
X	$3,028	$352	$1,391	$5,793
XI	$0	$0	$0	$0
XII	$0	$0	$0	$0
Total	$58,312	$2,701	$10,662	$44,402

MMI	Business Inventory	Personal Property	Total Expected Losses
VI	$10,462	$1,908	$44,473
VII	$8,311	$1,516	$38,918
VIII	$5,446	$993	$31,818
IX	$3,064	$559	$22,563
X	$1,494	$273	$12,331
XI	$0	$0	$0
XII	$0	$0	$0
Total	$28,777	$5,248	$150,103

TABLE 4-2c CONTINUED
RESULTS TABLES
CHARLESTON RETAIL STORES EXAMPLE

Expected Damages and Economic Losses Avoided =
Expected Damages & Economic Losses (ALT E)
* Effectiveness of the Rehabilitation (ALT A)

Main Menu: ALT M

City: Charleston
Facility: URM Low Rise, #75
Social Function: Retail #4
Soil: NORMAL

MMI	Building Damages	Rental Income	Relocation Expenses	Income Losses
VI	$10,599	$255	$1,006	$4,191
VII	$8,420	$286	$1,131	$4,709
VIII	$4,966	$302	$1,191	$4,961
IX	$2,484	$238	$940	$3,914
X	$1,060	$123	$487	$2,027
XI	$0	$0	$0	$0
XII	$0	$0	$0	$0
Total	$27,529	$1,205	$4,755	$19,803

MMI	Business Inventory	Personal Property	Total Losses Avoided
VI	$5,231	$954	$22,237
VII	$4,155	$758	$19,459
VIII	$2,451	$447	$14,318
IX	$1,226	$224	$9,025
X	$523	$95	$4,316
XI	$0	$0	$0
XII	$0	$0	$0
Total	$13,586	$2,478	$69,355

TABLE 4-2c CONTINUED
RESULTS TABLES
CHARLESTON RETAIL STORES EXAMPLE

RESULTS (Main Menu: ALT M)	
City:	Charleston
Social Function:	Retail #4
Facility:	URM Low Rise, #75
Soil:	NORMAL
Present Value of Damages and Losses Avoided = Expected Damages & Economic Losses Avoided (ALT V) * Present Value Coefficient (ALT N)	
Building Damages	$374,129
Rental Income Losses	$16,372
Relocation Expenses	$64,625
Income Losses	$269,123
Business Inventory Losses	$184,635
Personal Property Losses	$33,672
Total	$942,554
Rehabilitation Costs & Salvage Value:	
Total Costs	$4,800,000
Present Value of Investment in Terminal Year	$219,066
Total	$4,580,934
Benefits Cost Calculations Without the Value of Deaths Avoided:	
Benefits-Costs Without the Value of Deaths Avoided	($3,638,380)
Benefits/Costs Without the Value of Deaths Avoided	0.21
Benefit Cost Calculation With the Value of Deaths Avoided:	
Expected Number of Annual Deaths Avoided	0.00860
Value of Expected Number of Annual Deaths Avoided	$14,965
Present Value of Expected Number of Deaths Avoided	$203,381
Benefits-Costs With the Value of Deaths Avoided	($3,434,999)
Benefits/Costs With the Value of Deaths Avoided	0.25

TABLE 4-2c CONTINUED
RESULTS TABLES
CHARLESTON RETAIL STORES EXAMPLE

EXPECTED DEATH LOSSES (Main Menu: ALT M)			
City:	Charleston		
Facility:	URM Low Rise, #75		
Social Function:	Retail #4		
Soil:	NORMAL		
MMI	Scenario	Expected	Avoided
VI	0.001000	0.0000592	0.0000592
VII	0.010000	0.0001872	0.0001872
VIII	0.100000	0.0005920	0.0005920
IX	1.000000	0.0018700	0.0018681
X	10.000000	0.0059000	0.0058941
XI	200.000000	0.0000000	0.0000000
XII	200.000000	0.0000000	0.0000000
Expected Annual Death Losses:		0.0086084	0.0086006

TABLE 4-3a MAIN DATA ENTRY SCREENS
ST. LOUIS OFFICE BUILDINGS EXAMPLE

DATA ENTRY

Geographic & Geologic Information (Main Menu: ALT M)

1. Facility ID: St. Louis Office Buildings

2. City: St. Louis

3. Earthquake Probabilities: See ALT G

4. If the building inventory is located on poor soils, enter 1 in the following box, and damages will be adjusted according: 0

Structural & Engineering Information (Main Menu: ALT M)

5. Facility Class: Concrete Frame, Unreinf. Masonry Infill # 79

6. Size of Building (sq.ft.): 2,022,000

7. Gross Leasable Area(GLA) (sq.ft.): 2,022,000

8. Damage Probability Matrix: See ALT D

9. Average Retrofit Effectiveness as a Percent of Damages Avoided. Effectiveness of the retrofit is dependant on the Facility Classification.

MMI	Damages Avoided
VI	35%
VII	35%
VIII	31%
IX	28%
X	24%
XI	20%
XII	20%

10. Direct Retrofit Costs per sq. ft. of building area: $7.90

11. Additional Indirect Costs (as a % of direct costs):

12. Cost Premium if the Structure is Occupied During Retrofit (as a % of Retrofit Costs): 10%

13. Total Retrofit Costs (per sq.ft.): $8.69

14. Retrofit Salvage Value as a % of Retrofit Cost: 10%

TABLE 4-3a CONTINUED
MAIN DATA ENTRY SCREENS
ST. LOUIS OFFICE BUILDINGS EXAMPLE

Building Use (Main Menu: ALT M)

15. Social Function Classification: [Prof./Bus. Services, #7]
See Report or Table 3.2, Page 55, ATC-13.

16. Number of Occupants per 1000 Sq. Ft. by Social Function.
Daytime [4]
Nighttime [0]

17. Expected Death Rates See ALT J.

Building Economic Information (Main Menu: ALT M)

18. Replacement Building Value/sq.ft.: [$43.06]

19. Total Building Replacement Value: [$87,067,320]

20. Rental Rates per sq. ft. of building size per month: [$0.36]

21. Relocation Expenses per month per sq. ft. of GLA: [$1.50]

22. Income per sq. ft. of GLA per year: [$100]

23. Loss of Function Table see ALT L

24. Business Inventory ($/sq.ft.): [$0]

25. Personal Property Value (% of Building Replacement Value):
See Personal Property, ALT P. [34%]

General Economic Information (Main Menu: ALT M)

26. Enter the discount rate in decimal form (ie .04):
See ALT N. [4%]

27. Select the planning horizon in years: [20]

28. The selected net present value coefficient to
be used for this analysis is: [13.59]

29. The coefficient to determine the present value of the initial
rehabilitation investment is: [0.456]

30. Value of a Statistical Life: [$1,740,000]
See Help, ALT Z.

TABLE 4-3b SECONDARY DATA ENTRY SCREENS
ST. LOUIS OFFICE BUILDINGS EXAMPLE

Damage Probability Matrix (Table 7.10, Page 198, ATC-13)
Main Menu: ALT M
Facility: Concrete Frame, Unreinf. Masonry Infill # 79

Central Damage Function	Modified Mercalli Intensity						
	VI	VII	VIII	IX	X	XI	XII
0.00	0.5						
0.50	15.3	2.9					
5.00	81.2	66.6	13.5	1.9	0.3		
20.00	3	30.1	69.3	40.6	14.1	2	0.02
45.00		0.4	17.2	54.4	63.4	28.4	8.5
80.00				3.1	22.2	67.3	78.8
100.00						2.1	12.5
Mean Damage Function	4.7365	9.5445	22.275	35.175	49.125	69.12	79.369

Estimated Composition & Contents of Various Facilities in Terms of Earthquake Engineering Facility Classifications (as a percentage of the Facility Base Value)	
Main Menu: ALT M	
The data in this table must be updated for each Social Function. The data are presented in Table 4.11, ATC-13, page 119.	
Social Function Classification: Prof./Bus. Services, #7	
Buildings	100%
Pipelines (at grade)	0%
Storage Tanks:	
O.G. Liquid	0%
O.G. Solid	0%
Chimneys:	
Masonry	0%
Concrete	0%
Steel	0%
Cranes	0%
Conveyors	0%
Residential	0%
Office	25%
Electrical	2%
Mechanical	2%
High Technology	5%
Vehicles	0%
Percent of Replacement Value	34%

TABLE 4-3b CONTINUED
SECONDARY DATA ENTRY SCREENS
ST. LOUIS OFFICE BUILDINGS EXAMPLE

Weighted Statistics for Loss of Function and Restoration Time of Social Function Classifications (days). ATC-13, page 290 give Loss of Function for California. If no other data exists, ATC-13 can be used until more can be developed. These tables can be copied from: ALT Q.

Main Menu ALT M

Social Function Class: Prof./Bus. Services, #7

Damage State	Central Damage Factor	Mean Time to Restore to % of function: 30%	60%	100%	Total Loss of Function
2	0.50	1.2	2.4	5.8	3.4
3	5.00	3.4	10.2	20.0	12.08
4	20.00	9.8	44.6	71.0	44.72
5	45.00	37.0	111.6	202.7	125.66
6	80.00	114.7	213.7	343.1	235.76
7	100.00	214.8	355.9	439.3	346.93

Source: Table 9.11, Page 290, ATC-13.

TABLE 4-3c RESULTS TABLES
ST. LOUIS OFFICE BUILDINGS EXAMPLE

RESULTS (Main Menu: ALT M)	
City:	St. Louis
Social Function:	Prof./Bus. Services, #7
Facility:	Concrete Frame, Unreinf. Masonry Infill #80
Soil:	NORMAL
Present Value of Damages and Losses Avoided = Expected Damages & Economic Losses Avoided (ALT V) * Present Value Coefficient (ALT N)	
Building Damages	$2,074,531
Rental Income Losses	$75,097
Relocation Expenses	$312,905
Income Losses	$1,714,548
Business Inventory Losses	$0
Personal Property Losses	$705,341
Total	$4,882,422
Rehabilitation Costs & Salvage Value:	
Total Costs	$19,328,298
Present Value of Investment in Terminal Year	$882,118
Total	$18,446,180
Benefits Cost Calculations Without the Value of Deaths Avoided:	
Benefits-Costs Without the Value of Deaths Avoided	($13,563,758)
Benefits/Costs Without the Value of Deaths Avoided	0.26
Benefit Cost Calculation With the Value of Deaths Avoided:	
Expected Number of Annual Deaths Avoided	0.01245
Value of Expected Number of Annual Deaths Avoided	$21,656
Present Value of Expected Number of Deaths Avoided	$294,315
Benefits-Costs With the Value of Deaths Avoided	($13,269,443)
Benefits/Costs With the Value of Deaths Avoided	0.28

EXPECTED DEATH LOSSES (Main Menu: ALT M)			
City:	St. Louis		
Facility:	Concrete Frame, Unreinf. Masonry Infill #80		
Social Function:	Prof./Bus. Services, #7		
Soil:	NORMAL		
MMI	Scenario	Expected	Avoided
VI	0.004044	0.0001864	0.0001864
VII	0.040440	0.0006466	0.0006466
VIII	0.404400	0.0022404	0.0022404
IX	4.044000	0.0021029	0.0021008
X	40.440000	0.0072792	0.0072719
XI	808.800000	0.0000000	0.0000000
XII	808.800000	0.0000000	0.0000000
Expected Annual Death Losses:		0.0124555	0.0124461

TABLE 4-4a MAIN DATA ENTRY SCREENS
HAYWARD WAREHOUSES EXAMPLE

DATA ENTRY

Geographic & Geologic Information (Main Menu: ALT M)

1. Facility ID: Hayward Warehouse Concrete Tilt-ups
2. City: Hayward
3. Earthquake Probabilities: See ALT G
4. If the building inventory is located on poor soils, enter 1 in the following box, and damages will be adjusted according: 0

Structural & Engineering Information (Main Menu: ALT M)

5. Facility Class: Concrete Tilt-up #21
6. Size of Building (sq.ft.): 3,089,875
7. Gross Leasable Area(GLA) (sq.ft.): 3,089,875
8. Damage Probability Matrix: See ALT D
9. Average Retrofit Effectiveness as a Percent of Damages Avoided. Effectiveness of the retrofit is dependant on the Facility Classification.

MMI	Damages Avoided
VI	50%
VII	50%
VIII	45%
IX	40%
X	35%
XI	30%
XII	30%

10. Direct Retrofit Costs per sq. ft. of building area: $5.50
11. Additional Indirect Costs (as a % of direct costs): 10%
12. Cost Premium if the Structure is Occupied During Retrofit (as a % of Retrofit Costs): 0%
13. Total Retrofit Costs (per sq.ft.): $6.05
14. Retrofit Salvage Value as a % of Retrofit Cost: 10%

TABLE 4-4a CONTINUED
MAIN DATA ENTRY SCREENS
HAYWARD WAREHOUSES EXAMPLE

Building Use (Main Menu: ALT M)

15. Social Function Classification: | Wholesale Trade, #5 |
See Report or Table 3.2, Page 55, ATC-13.

16. Number of Occupants per 1000 Sq. Ft. by Social Function.
Daytime | 1 |
Nighttime | 0 |

17. Expected Death Rates See ALT J.

Building Economic Information (Main Menu: ALT M)

18. Replacement Building Value/sq.ft.: | $40.00 |

19. Total Building Replacement Value: | $123,595,000 |

20. Rental Rates per sq. ft. of building size per month: | $0.90 |

21. Relocation Expenses per month per sq. ft. of GLA: | $1.50 |

22. Income per sq. ft. of GLA per year: | $45 |

23. Loss of Function Table see ALT L

24. Business Inventory ($/sq.ft.): | $100 |

25. Personal Property Value (% of Building Replacement Value): See Personal Property, ALT P. | 12% |

General Economic Information (Main Menu: ALT M)

26. Enter the discount rate in decimal form (ie .04): See ALT N. | 4% |

27. Select the planning horizon in years: | 20 |

28. The selected net present value coefficient to be used for this analysis is: | 13.59 |

29. The coefficient to determine the present value of the initial rehabilitation investment is: | 0.456 |

30. Value of a Statistical Life: | $1,740,000 |
See Help, ALT Z.

TABLE 4-4b SECONDARY DATA ENTRY SCREENS
HAYWARD WAREHOUSES EXAMPLE

Damage Probability Matrix (Table 7.10, Page 198, ATC-13)
Main Menu: ALT M
Facility: Concrete Tilt-up #21
(Table 7.10, Page 198, ATC-13) See ALT K

Central Damage Function	Modified Mercalli Intensity						
	VI	VII	VIII	IX	X	XI	XII
0.00	0.3						
0.50	35.2	1.2					
5.00	64.5	97.7	49.7	8.7	1.2		
20.00		1.1	50.3	85.7	56.6	13	0.7
45.00				5.6	42	73.6	40.1
80.00					0.2	13.4	59.2
100.00							
Mean Damage Function	3.401	5.111	12.545	20.095	30.44	46.44	65.545

Estimated Composition & Contents of Various Facilities
in Terms of Earthquake Engineering Facility Classifications
(as a percentage of the Facility Base Value)

Main Menu: ALT M

The data in this table must be updated for each Social Function. The data are presented in Table 4.11, ATC-13, page 119.

Social Function Classification: Wholesale Trade, #5	
Buildings	100%
Pipelines (at grade)	0%
Storage Tanks:	
O.G. Liquid	0%
O.G. Solid	0%
Chimneys:	
Masonry	0%
Concrete	0%
Steel	0%
Cranes	0%
Conveyors	0%
Residential	0%
Office	10%
Electrical	1%
Mechanical	1%
High Technology	0%
Vehicles	0%
Percent of Replacement Value	12%

TABLE 4-4b CONTINUED
SECONDARY DATA ENTRY SCREENS
HAYWARD WAREHOUSES EXAMPLE

Weighted Statistics for Loss of Function and Restoration Time of Social Function Classifications (days). ATC-13, page 290 give Loss of Function for California. If no other data exists, ATC-13 can be used until more can be developed. These tables can be copied from: ALT Q.

Main Menu ALT M

Social Function Class: Wholesale Trade, #5

Damage State	Central Damage Factor	Mean Time to Restore to % of function: 30%	60%	100%	Total Loss of Function
2	0.50	1.2	2.4	5.8	3.4
3	5.00	3.4	10.2	20.0	12.08
4	20.00	9.8	44.6	71.0	44.72
5	45.00	37.0	111.6	202.7	125.66
6	80.00	114.7	213.7	343.1	235.76
7	100.00	214.8	355.9	439.3	346.93

Source: Table 9.11, Page 290, ATC-13.

TABLE 4-4c RESULTS TABLES
HAYWARD WAREHOUSES EXAMPLE

RESULTS (Main Menu: ALT M)	
City:	Hayward
Social Function:	Wholesale Trade, #5
Facility:	Concrete Tilt-up #21
Soil:	NORMAL
Present Value of Damages and Losses Avoided = Expected Damages & Economic Losses Avoided (ALT V) * Present Value Coefficient (ALT N)	
Building Damages	$29,137,753
Rental Income Losses	$5,815,852
Relocation Expenses	$9,693,087
Income Losses	$23,900,764
Business Inventory Losses	$72,844,384
Personal Property Losses	$3,496,530
Total	$144,888,371
Rehabilitation Costs & Salvage Value:	
Total Costs	$18,693,744
Present Value of Investment in Terminal Year	$853,158
Total	$17,840,586
Benefits Cost Calculations Without the Value of Deaths Avoided:	
Benefits-Costs Without the Value of Deaths Avoided	$127,047,785
Benefits/Costs Without the Value of Deaths Avoided	8.12
Benefit Cost Calculation With the Value of Deaths Avoided:	
Expected Number of Annual Deaths Avoided	1.81706
Value of Expected Number of Annual Deaths Avoided	$3,161,688
Present Value of Expected Number of Deaths Avoided	$42,968,370
Benefits-Costs With the Value of Deaths Avoided	$170,016,155
Benefits/Costs With the Value of Deaths Avoided	10.53

EXPECTED DEATH LOSSES (Main Menu: ALT M)			
City:	Hayward		
Facility:	Concrete Tilt-up #21		
Social Function:	Wholesale Trade, #5		
Soil:	NORMAL		
MMI	Scenario	Expected	Avoided
VI	0.001545	0.0007098	0.0007098
VII	0.015449	0.0023310	0.0023310
VIII	0.154494	0.0077772	0.0077772
IX	1.544938	0.0263566	0.0263303
X	15.449375	0.0906878	0.0905971
XI	308.987500	1.2699386	1.2693037
XII	308.987500	0.4202230	0.4200129
Expected Annual Death Losses:		1.8180241	1.8170620

TABLE 4-5a MAIN DATA ENTRY SCREENS
HAYWARD LIGHT INDUSTRY EXAMPLE

DATA ENTRY

Geographic & Geologic Information (Main Menu: ALT M)

1. Facility ID: Hayward Light-Industry Concrete Tilt-ups

2. City: Hayward

3. Earthquake Probabilities: See ALT G

4. If the building inventory is located on poor soils, enter 1 in the following box, and damages will be adjusted according: 0

Structural & Engineering Information (Main Menu: ALT M)

5. Facility Class: Concrete Tilt-up #21

6. Size of Building (sq.ft.): 3,089,875

7. Gross Leasable Area(GLA) (sq.ft.): 3,089,875

8. Damage Probability Matrix: See ALT D

9. Average Retrofit Effectiveness as a Percent of Damages Avoided. Effectiveness of the retrofit is dependant on the Facility Classification.

MMI	Damages Avoided
VI	50%
VII	50%
VIII	45%
IX	40%
X	35%
XI	30%
XII	30%

10. Direct Retrofit Costs per sq. ft. of building area: $5.50

11. Additional Indirect Costs (as a % of direct costs): 10%

12. Cost Premium if the Structure is Occupied During Retrofit (as a % of Retrofit Costs): 0%

13. Total Retrofit Costs (per sq.ft.): $6.05

14. Retrofit Salvage Value as a % of Retrofit Cost: 10%

TABLE 4-5a CONTINUED
MAIN DATA ENTRY SCREENS
HAYWARD LIGHT INDUSTRY EXAMPLE

Building Use (Main Menu: ALT M)

15. Social Function Classification: [Light Industry #12]
See Report or Table 3.2, Page 55, ATC-13.

16. Number of Occupants per 1000 Sq. Ft. by Social Function.
Daytime [5]
Nighttime [0.3]

17. Expected Death Rates See ALT J.

Building Economic Information (Main Menu: ALT M)

18. Replacement Building Value/sq.ft.: [$100.00]

19. Total Building Replacement Value: [$308,987,500]

20. Rental Rates per sq. ft. of building size per month: [$1.03]

21. Relocation Expenses per month per sq. ft. of GLA: [$1.50]

22. Income per sq. ft. of GLA per year: [$75]

23. Loss of Function Table see ALT L

24. Business Inventory ($/sq.ft.): [$25]

25. Personal Property Value (% of Building Replacement Value):
See Personal Property, ALT P. [70%]

General Economic Information (Main Menu: ALT M)

26. Enter the discount rate in decimal form (ie .04): [4%]
See ALT N.

27. Select the planning horizon in years: [20]

28. The selected net present value coefficient to be used for this analysis is: [13.59]

29. The coefficient to determine the present value of the initial rehabilitation investment is: [0.456]

30. Value of a Statistical Life: [$1,740,000]
See Help, ALT Z.

TABLE 4-5b SECONDARY DATA ENTRY SCREENS
HAYWARD LIGHT INDUSTRY EXAMPLE

Damage Probability Matrix (Table 7.10, Page 198, ATC-13)
Main Menu: ALT M
Facility: Concrete Tilt-up #21
(Table 7.10, Page 198, ATC-13) See ALT K

Central Damage Function	Modified Mercalli Intensity						
	VI	VII	VIII	IX	X	XI	XII
0.00	0.3						
0.50	35.2	1.2					
5.00	64.5	97.7	49.7	8.7	1.2		
20.00		1.1	50.3	85.7	56.6	13	0.7
45.00				5.6	42	73.6	40.1
80.00					0.2	13.4	59.2
100.00							
Mean Damage Function	3.401	5.111	12.545	20.095	30.44	46.44	65.545

Estimated Composition & Contents of Various Facilities
in Terms of Earthquake Engineering Facility Classifications
(as a percentage of the Facility Base Value)

Main Menu: ALT M

The data in this table must be updated for each Social Function. The data are presented in Table 4.11, ATC-13, page 119.

Social Function Classification: Light Industry #12

Buildings	100%
Pipelines (at grade)	0%
Storage Tanks:	
O.G. Liquid	5%
O.G. Solid	5%
Chimneys:	
Masonry	0%
Concrete	0%
Steel	0%
Cranes	0%
Conveyors	10%
Residential	0%
Office	5%
Electrical	15%
Mechanical	25%
High Technology	5%
Vehicles	0%
Percent of Replacement Value	70%

TABLE 4-5b CONTINUED
SECONDARY DATA ENTRY SCREENS
HAYWARD LIGHT INDUSTRY EXAMPLE

Weighted Statistics for Loss of Function and
Restoration Time of Social Function Classifications (days).
ATC-13, page 290 give Loss of Function for California. If
no other data exists, ATC-13 can be used until more
can be developed. These tables can be copied from: ALT Q.

Main Menu ALT M

Social Function Class: Light Industry #12

Damage State	Central Damage Factor	Mean Time to Restore to % of function: 30%	60%	100%	Total Loss of Function
2	0.50	1.7	3.4	5.6	3.77
3	5.00	5.8	13.8	22.6	14.92
4	20.00	27.8	54.2	99.3	64.32
5	45.00	73.8	130.2	248.0	160.4
6	80.00	170.8	267.9	405.5	293.81
7	100.00	420.2	466.8	538.1	481.34

Source: Table 9.11, Page 290, ATC-13.

TABLE 4-5c RESULTS TABLES
HAYWARD LIGHT INDUSTRY EXAMPLE

RESULTS (Main Menu: ALT M)	
City:	Hayward
Social Function:	Light Industry #12
Facility:	Concrete Tilt-up #21
Soil:	NORMAL
Present Value of Damages and Losses Avoided = Expected Damages & Economic Losses Avoided (ALT V) * Present Value Coefficient (ALT N)	
Building Damages	$72,844,384
Rental Income Losses	$8,559,219
Relocation Expenses	$12,464,883
Income Losses	$51,225,545
Business Inventory Losses	$18,211,096
Personal Property Losses	$50,991,068
Total	$214,296,195
Rehabilitation Costs & Salvage Value:	
Total Costs	$18,693,744
Present Value of Investment in Terminal Year	$853,158
Total	$17,840,586
Benefits Cost Calculations Without the Value of Deaths Avoided:	
Benefits-Costs Without the Value of Deaths Avoided	$196,455,610
Benefits/Costs Without the Value of Deaths Avoided	12.01
Benefit Cost Calculation With the Value of Deaths Avoided:	
Expected Number of Annual Deaths Avoided	9.63043
Value of Expected Number of Annual Deaths Avoided	$16,756,946
Present Value of Expected Number of Deaths Avoided	$227,732,360
Benefits-Costs With the Value of Deaths Avoided	$424,187,970
Benefits/Costs With the Value of Deaths Avoided	24.78

EXPECTED DEATH LOSSES (Main Menu: ALT M)			
City:	Hayward		
Facility:	Concrete Tilt-up #21		
Social Function:	Light Industry #12		
Soil:	NORMAL		
MMI	Scenario	Expected	Avoided
VI	0.008188	0.0037620	0.0037620
VII	0.081882	0.0123543	0.0123543
VIII	0.818817	0.0412192	0.0412192
IX	8.188169	0.1396902	0.1395505
X	81.881688	0.4806455	0.4801649
XI	1637.633750	6.7306747	6.7273094
XII	1637.633750	2.2271819	2.2260683
Expected Annual Death Losses:		9.6355278	9.6304285

TABLE 4-6a MAIN DATA ENTRY SCREENS
SEATTLE APARTMENTS EXAMPLE

DATA ENTRY

Geographic & Geologic Information (Main Menu: ALT M)

1. Facility ID: Seattle Permanent Resident Five Story URMs

2. City: Seattle

3. Earthquake Probabilities: See ALT G

4. If the building inventory is located on poor soils, enter 1 in the following box, and damages will be adjusted according: 1

Structural & Engineering Information (Main Menu: ALT M)

5. Facility Class: URM Med Rise #76

6. Size of Building (sq.ft.): 148,500

7. Gross Leasable Area(GLA) (sq.ft.): 141,075

8. Damage Probability Matrix: See ALT D

9. Average Retrofit Effectiveness as a Percent of Damages Avoided. Effectiveness of the retrofit is dependant on the Facility Classification.

MMI	Damages Avoided
VI	50%
VII	50%
VIII	45%
IX	40%
X	35%
XI	30%
XII	30%

10. Direct Retrofit Costs per sq. ft. of building area: $17.50

11. Additional Indirect Costs (as a % of direct costs): 20%

12. Cost Premium if the Structure is Occupied During Retrofit (as a % of Retrofit Costs): 0%

13. Total Retrofit Costs (per sq.ft.): $21.00

14. Retrofit Salvage Value as a % of Retrofit Cost: 10%

TABLE 4-6a CONTINUED
MAIN DATA ENTRY SCREENS
SEATTLE APARTMENTS EXAMPLE

Building Use (Main Menu: ALT M)

15. Social Function Classification: Permanent Residence #1
See Report or Table 3.2, Page 55, ATC-13.

16. Number of Occupants per 1000 Sq. Ft. by Social Function.

Daytime	1.2
Nighttime	3.1

17. Expected Death Rates See ALT J.

Building Economic Information (Main Menu: ALT M)

18. Replacement Building Value/sq.ft.:	$59.84
19. Total Building Replacement Value:	$8,886,240
20. Rental Rates per sq. ft. of building size per month:	$0.50
21. Relocation Expenses per month per sq. ft. of GLA:	$1.50
22. Income per sq. ft. of GLA per year:	$0
23. Loss of Function Table see ALT L	
24. Business Inventory ($/sq.ft.):	$0
25. Personal Property Value (% of Building Replacement Value): See Personal Property, ALT P.	39%

General Economic Information (Main Menu: ALT M)

26. Enter the discount rate in decimal form (ie .04): See ALT N.	4%
27. Select the planning horizon in years:	20
28. The selected net present value coefficient to be used for this analysis is:	13.59
29. The coefficient to determine the present value of the initial rehabilitation investment is:	0.456
30. Value of a Statistical Life: See Help, ALT Z.	$1,740,000

TABLE 4-6b SECONDARY DATA ENTRY SCREENS
SEATTLE APARTMENTS EXAMPLE

Damage Probability Matrix (Table 7.10, Page 198, ATC-13)
Main Menu: ALT M
Facility: URM Med Rise #76
(Table 7.10, Page 198, ATC-13) See ALT K

Central Damage Function	Modified Mercalli Intensity						
	VI	VII	VIII	IX	X	XI	XII
0.00							
0.50	4.7	1.5					
5.00	89.9	49.5	3.7				
20.00	5.4	46.4	53.3	7.6	0.9		
45.00		2.6	42	63.4	21.4	5.3	3.1
80.00			1	29	74.7	80	43
100.00					3	14.7	53.9
Mean Damage Function	5.5985	12.9325	30.545	53.25	72.57	81.085	89.695

Estimated Composition & Contents of Various Facilities in Terms of Earthquake Engineering Facility Classifications (as a percentage of the Facility Base Value)

Main Menu: ALT M

The data in this table must be updated for each Social Function. The data are presented in Table 4.11, ATC-13, page 119.

Social Function Classification: Permanent Residence #1	
Buildings	100%
Pipelines (at grade)	0%
Storage Tanks:	
O.G. Liquid	0%
O.G. Solid	0%
Chimneys:	
Masonry	0%
Concrete	0%
Steel	0%
Cranes	0%
Conveyors	0%
Residential	25%
Office	0%
Electrical	2%
Mechanical	2%
High Technology	0%
Vehicles	10%
Percent of Replacement Value	39%

TABLE 4-6b CONTINUED
SECONDARY DATA ENTRY SCREENS
SEATTLE APARTMENTS EXAMPLE

Weighted Statistics for Loss of Function and
Restoration Time of Social Function Classifications (days).
ATC-13, page 290 give Loss of Function for California. If
no other data exists, ATC-13 can be used until more
can be developed. These tables can be copied from: ALT Q.

Main Menu ALT M

Social Function Class: Permanent Residence #1

Damage State	Central Damage Factor	Mean Time to Restore to % of function:			Total Loss of Function
		30%	60%	100%	
2	0.50	0.2	0.2	0.8	0.8
3	5.00	0.3	1.5	3.3	3.3
4	20.00	1.9	5.4	10.5	10.5
5	45.00	15.2	30.5	71.9	71.9
6	80.00	57.2	93.8	146.6	146.6
7	100.00	105.5	152.1	211.9	211.9

Source: Table 9.11, Page 290, ATC-13.

TABLE 4-6c RESULTS TABLES
SEATTLE APARTMENTS EXAMPLE

RESULTS (Main Menu: ALT M)	
City:	Seattle
Social Function:	Permanent Residence #1
Facility:	URM Med Rise #76
Soil:	POOR
Present Value of Damages and Losses Avoided = Expected Damages & Economic Losses Avoided (ALT V) * Present Value Coefficient (ALT N)	
Building Damages	$3,223,829
Rental Income Losses	$66,723
Relocation Expenses	$210,706
Income Losses	$0
Business Inventory Losses	$0
Personal Property Losses	$1,257,293
Total	$4,758,552
Rehabilitation Costs & Salvage Value:	
Total Costs	$3,118,500
Present Value of Investment in Terminal Year	$142,324
Total	$2,976,176
Benefits Cost Calculations Without the Value of Deaths Avoided:	
Benefits-Costs Without the Value of Deaths Avoided	$1,782,376
Benefits/Costs Without the Value of Deaths Avoided	1.60
Benefit Cost Calculation With the Value of Deaths Avoided:	
Expected Number of Annual Deaths Avoided	0.37033
Value of Expected Number of Annual Deaths Avoided	$644,366
Present Value of Expected Number of Deaths Avoided	$8,757,149
Benefits-Costs With the Value of Deaths Avoided	$10,539,525
Benefits/Costs With the Value of Deaths Avoided	4.54

EXPECTED DEATH LOSSES (Main Menu: ALT M)			
City:	Seattle		
Facility:	URM Med Rise #76		
Social Function:	Permanent Residence #1		
Soil:	POOR		
MMI	Scenario	Expected	Avoided
VI	0.003193	0.0004433	0.0004433
VII	0.031928	0.0017650	0.0017650
VIII	0.319275	0.0070272	0.0070202
IX	3.192750	0.0279685	0.0279405
X	63.855000	0.2228540	0.2227425
XI	63.855000	0.0887585	0.0887141
XII	63.855000	0.0217107	0.0216998
Expected Annual Death Losses:		0.3705271	0.3703255

REFERENCES

Algermissen, S.T. and others. Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States, USGS Open-File Report 82-1033. 1982.

An Action Plan for Reducing Earthquake Hazards of Existing Buildings (FEMA 90). 1985.

Anagnos, T. and Kiremidjian, A.S. A review of earthquake occurrence models for seismic hazard analysis, Probabilistic Engineering Mechanics, Volume 3 pp. 3-11. 1988.

Applied Technology Council. ATC-13, Earthquake Damage Evaluation Data for California, Redwood City, CA. 1985.

Bureau of Economic Analysis. Estimates of Gross State Product By Industry, Staff Paper 42. 1985.

Comerio, Mary. Seismic Costs and Policy Implications, City of Los Angeles, Community Development Department, Rent Stabilization Division. 1989.

Comerio, Mary. Earthquake Hazards and Housing, City of San Francisco, Planning Department. 1987.

Englekirk and Hart. Typical Cost for Seismic Rehabilitation of Existing Buildings (FEMA 156). 1988.

EQE Engineering. Identifying Potentially Hazardous Buildings in Hayward. 1989.

Estimated Future Earthquake Losses for St. Louis City and County, Missouri. (FEMA 192). 1990.

Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings (FEMA 173 and 174). 1989.

Evernden, J.F. "Seismic Intensities, "Size" of Earthquakes and Related Parameters," in Seismological Society of America Bulletin, 65, pp. 1287-1313. 1975.

Financial Incentives for Seismic Rehabilitation of Hazardous Buildings - An Agenda for Action (Fema 198 and 199). 1990.

Handbook for Seismic Evaluation of Structures (FEMA 175 and 178). 1989.

Heaton, Thomas H., and Stephen H. Hartzell. "Earthquake Hazards on the Cascadia Subduction Zone." Science 236, 162-168. 1987.

Howe, Charles W. Natural Resource Economics, Issues, Analysis, and Policy. New York: John Wiley & Sons. 1979.

Keech, Ward, Stefan Hoffer, Calvin Timmerman, and Frank Beradino. "Economic Values of Federal Aviation Administration Investment and Regulatory Programs." Office of Aviation Policy and Plans, Federal Aviation Administration, Dept. of Transportation, Washington, D.C., 175pp. Oct. 1989.

Mikesell, Raymond F. "The Rate of Discount for Evaluating Public Projects." American Institute for Public Policy Research. Washington, D.C. 1977.

Randall, Alan. Resource Economics, An Economic approach to Natural Resource and Environmental Policy. Columbus: Grid Publishing, Inc. 1981.

Rapid Visual Screening of Buildings for Potential Seismic Hazards (FEMA 154 and 155). 1988.

Rutherford and Chekene. Seismic Retrofit Alternatives for San Francisco's UMB's. 1990.

Sassone, Peter G., and William A. Schaffer. Cost-Benefit Analysis: A Handbook. 1978.

Scanlan, Christopher. "What's it Worth to Save a Life." The Sacramento Bee, page 1. July 14, 1990.

Techniques for Seismically Rehabilitating Existing Buildings (FEMA 172). 1989.

Typical Costs for Seismic Rehabilitation of Existing Buildings (FEMA 156 and 157). 1988.

Urban Land Institute, Dollars and Cents of Shopping Centers. 1987.

URS Consultants. Metropolitan Boston Area Earthquake Loss Study (prepared for the Massachusetts Civil Defense Agency). 1989.

Wetherill, Edward B. Estimating and Analysis for Commercial Renovation. Kingston, Mass: R.S. Means Co. 1985.

Wharton Econometrics Long Term Alternative Scenarios and 25-Year Extensions, cited in Young, Robert A and Charles W. Howe. "Handbook for the Economic Evaluation of Application for Appropriation of Surface and Groundwater in the State of Idaho." Idaho Water Resources Research Institute, University of Idaho. 1988.

Young, Robert A and Charles W. Howe. "Handbook for the Economic Evaluation of Application for Appropriation of Surface and Groundwater in the State of Idaho." Idaho Water Resources Research Institute, University of Idaho. 1988.

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