A BENEFIT-COST MODEL

FOR THE

SEISMIC REHABILITATION

OF

SAN FRANCISCO CITY HALL

USER'S GUIDE

DRAFT

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CHAPTER 1 ECONOMIC ASSUMPTIONS AND EQUATIONS

The economic assumptions and equations which rigorously define the benefit-cost analysis of seismic rehabilitation projects are summarized in this chapter.

1.1 Benefit-Cost Model Without the Value of Life

The net present value of benefits accounts for the time value of money, because benefits are expected to accrue in the future and dollars received in the future have a present value which is less than dollars received immediately. The expected net present value of a seismic rehabilitation project is the sum of the present value of net benefits expected to accrue each year over the life of the project, minus the initial cost of the rehabilitation project. The expected net present value, NPV, is defined as:

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

where:

- B_t is the expected annual net benefit of the rehabilitation project for year t;
- T is the length of the planning horizon (useful life of the rehabilitation project;
- V_T is any change that the rehabilitation will have on the salvage value of the building in the terminal year T;
- INV is the initial investment (the cost of the project); and
- i is the annual discount rate.

Each year's expected net benefit is discounted to its present value and then added together to yield the total expected net present value. The benefits of a hazard rehabilitation project are the avoided future damages (i.e., the extent to which the rehabilitation project is effective in reducing expected future damages). The planning horizon, or useful lifetime of the rehabilitation project, varies depending on the type of project. The discount rate corrects benefits expected in the future to their net present value. In theory, the salvage value of the rehabilitation investment, V_T, at the end of the planning horizon should be added to the expected net present value (as shown in the above equation). However, the salvage value is generally small and is not considered in the benefit-cost model presented in this volume.

Most of the cost of the rehabilitation project is generally incurred in the initial construction or implementation but substantial costs may be required annually to maintain the effectiveness of the rehabilitation project. Therefore the expected net annual benefit is the sum of expected benefits and expected costs.

$$B_t = AB_t - AC_t$$

where:

AB_t are the expected annual benefits; and

AC_t are the expected annual costs of maintaining the rehabilitation project.

For the model described in this volume, the expected annual costs of maintaining the rehabilitation are assumed to be negligible and are not considered. If, in a particular case, annual costs were important, they could be included in the benefit-cost analysis by adjusting the expected annual benefits (reducing expected annual benefits by expected annual costs).

If expected net benefits are constant each year over the life of the project, the expected net present value equation is simplified to the constant annual benefits and one discount term representing the present value for the entire planning horizon. With this simplification and the assumption that the salvage value is negligible, the expected net present value equation is reduced to:

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

This is the underlying equation which is used for the benefit-cost model in this report.

1.2 Benefit-Cost Model With the Value of Life

The benefit-cost module discussed above does not include the value of life. However, reducing the expected number of deaths and injuries is often the principal motivation for seismic hazard rehabilitation projects. The model can be modified to include the value of expected deaths avoided by retrofitting.

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 and injuries avoided by seismic rehabilitation. The expected net present value including the value of life is thus defined as:

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

where:

NPV^{vol}	is the expected net present value <u>including</u> the value of life;
NPV	is the expected net present value excluding the value of life;
VDA	is the annual value of expected deaths avoided;
VIA	is the annual value of expected injuries avoided;
i	is the annual discount rate; and
T	is the planning horizon.

Benefit-cost results are always presented both with and without including the value of life so that the benefits of avoiding physical damages and the benefits of avoiding deaths can be analyzed separately.

1.3 Economic Assumptions for Modeling Benefits

1.3.1 Underlying Assumptions

The benefits of a seismic hazard rehabilitation project are the reduction in damages that would otherwise be expected. Expected annual benefits are defined as the sum of expected <u>avoided damages and losses</u>. There are three different types of damages which are considered: scenario damages, expected annual damages, and expected annual avoided damages. Definitions of these terms are as follows:

<u>Scenario Damages</u>:

the expected damages per earthquake event of a given MMI (or range of effective peak ground acceleration, PGA, at the building .

<u>Expected Annual Damages</u>:

the product of scenario damages and the expected annual probability of an earthquake of a given MMI or PGA

Expected Annual Avoided Damages:

the product of expected annual damages and the effectiveness of the rehabilitation measure in reducing expected damages.

An example illustrating these damage terms is given below:

Table 1

Earthquake (MMI)	Scenario Damages	Annual Earthquake Probability	Expected Annual Damages	Effectiveness of Rehabilitation Measure	Expected Avoided Damages
VI	$20,000	10%	$2,000.	100%	$2,000.
VII	$25,000	5%	$1,250.	80%	$1,000.
VIII	$35,000	2%	$700.	50%	$350.
IX	$50,000	1%	$500.	25%	$125.
		Total: $4,450.		Total: $3,475.	

In this example, the scenario damages indicate the expected damages each time an earthquake of the given Modified Mercalli Intensity (MMI) occurs at the residence. Scenario damages do not depend on how frequently such earthquakes are expected to occur. The annual earthquake probabilities indicate the degree of seismic risk at the specific site under consideration. The expected annual damages are the product of scenario damages and annual earthquake probability. Expected annual damages ($4,450 in this example) are the best estimate of the average damages per year expected at this site; such estimates do not indicate that these damages will occur every year. Expected annual damages are those without undertaking the rehabilitation measure. The effectiveness of the rehabilitation measure is an estimate of how much expected damages will be reduced by the rehabilitation measure under consideration. The expected avoided damages (i.e., the benefits) are the product of expected annual damages and the effectiveness of the rehabilitation measure. The expected avoided damages ($3,475 in this example) are thus the expected benefits of undertaking the rehabilitation measure.

1.3.2 Detailed Economic Assumptions and Equations: Without the Value of Life

The expected Annual Benefits (AB) of a seismic hazard rehabilitation project are the sum of expected avoided damages (AVD) summed over the range of earthquake MMIs considered (usually MMI VI to MMI XII.

$$AB = \sum_{m=VI}^{M} AVD^{m}$$

where:

m	is the MMI;
M	is the maximum MMI considered; and
AVD^m	are the expected annual avoided damages from earthquakes of MMI m.

Expected avoided damages (AVD^m) are the product of scenario damages (SCD^m), the expected annual probability of an earthquake of MMI m (EAE^m), and the effectiveness of the rehabilitation measure (EFF^m):

$$AVD^{m} = SCD^{m}\ EAE^{m}\ EFF^{m}$$

where:

SCD^m	are scenario damages for an earthquake of MMI m;
EAE^m	is the expected annual probability of an earthquake of MMI m; and
EFF^m	is the effectiveness of the rehabilitation measure in reducing expected damages for earthquakes of MMI m.

Scenario damages SCD^{epa} are the sum of building damages (BD), contents damages (CD), relocation costs (REL), rental income losses (RENT), and the value of lost services (VLS) for earthquakes of each EPA bin.

$$BD^{epa} = FA\ RV\ ED^{epa}$$

where:

BD^{epa}	are scenario building damages;
CD^{epa}	are scenario contents damages;
REL^{epa}	are scenario relocation costs;
$RENT^{epa}$	are scenario rental income losses; and

VLS^{epa} is the scenario value of lost government services.

Building damages (BD^{epa}) are defined as the product of floor area of the buildings (FA), replacement value of the building per square foot (RV), and expected damage as a percentage of replacement value for earthquakes of each EPA bin.

where:

FA is the floor area of the building (in square feet);

RV is the replacement value of the building (per square foot); and

ED^{epa} is expected damage percentage for earthquakes of each EPA bin.

Contents damages (CD^{epa}) are defined as the product of floor area of the buildings (FA), replacement value of the building contents per square foot (RVC), and expected contents damage percentage for earthquakes of each EPA bin.

$$CD^{epa} = FA\ RVC\ ECD^{epa}$$

where:

RVC is the replacement value of the building contents (per square foot); and

ECD^{epa} is expected damage percentage for earthquakes of each EPA bin.

Relocation expenses (REL^{epa}) are defined as the product of relocation costs per month and the expected period for which the residence will be unusable (LOF^{epa}).

$$REL^{epa} = REL\ LOF^{epa}$$

where:

REL is the relocation cost per month; and

LOF^{epa} is the estimated period of loss of function for earthquakes of each EPA bin.

Rental income losses are also included if a portion of the building is rented. Rental income losses (RENT) are the product of gross leasable floor area (GLA), rental rate per month per square foot of gross leasable area (RR) and the expected number of days that the rental income will be lost (LOF^{epa}).

$$RENT^{epa} = RR\ GLA\ LOF^{epa}$$

where:

RR is the rental rate per month; and

GLA is gross leasable floor area.

For public sector buildings, the value of government services lost (VLS^{epa}) when the building becomes unusable during an earthquake must be included. Government services are valued using the Quasi-Willingness to Pay (QWTP) model. QWTP is a simple methodology that assumes that government services are worth what we pay to provide the services. QWTP are the product of agency wages (WAGE) plus benefits (BENEFIT) and support budget (SUPPORT) per day, multiplied by the period of agency disfunction ($LOAF^{epa}$). The period of lost services depends on the agency's ability to find alternative quarters and to establish normal functions. This period may vary depending on the structure, size and function of the agency and the availability of suitable quarters after the earthquake.

$$VLS^{epa} = (WAGE + BENEFIT + SUPPORT) LOAF^{epa}$$

where:

VLS^{epa}	is the value of lost agency services;
WAGE	is the total wages paid to the resident work force per day;
BENEFIT	is the total benefits paid to the resident work force per day;
SUPPORT	is the support expenditures per day; and
$LOAF^{epa}$	is the period of loss of agency function for earthquakes in each EPA bin.

1.3.3 Detailed Economic Assumptions and Equations: With the Value of Life

The benefit-cost 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 seismic hazard rehabilitation projects. The model can be modified to include the value of expected deaths avoided by retrofitting 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 expectéd 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:

$$VDA = \sum_{mm=VI}^{XII} EAE^{mm} \left[FA_{sf} \, OCP_{sf} \, (DR^{mm} - DRR^{mm}) \right] VOL$$

where:

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

EAE^m is the expected annual probability of an earthquake of MMI m;

FA_{sf} is the floor area of the building in square feet;

OCP_{sf} is the average occupancy rate per square foot;

DR^m is the expected death rate;

DRR^m is the expected death rate after rehabilitation; and

VOL is the dollar value of one statistical human life.

Similarly, the value of injuries (minor and major) avoided, ***VIA***, is computed:

$$VIA = \sum_{m=VI}^{XII} EAE^m \left[FA_{sf}\, OCP_{sf}\, (IR^m - IRR^m) \right] VOI$$

where:

IR^m is the expected injury rate in the existing building;

IRR^m is the expected injury rate after rehabilitation; and

VOI is the dollar value of one statistical injury.

Benefit-cost results are presented both with and without including the value of life so that the benefits of avoiding physical damages and the benefits of avoiding deaths and injuries can be analyzed separately.

This chapter describes the input data parameters and the data entry process.

MENU TREES

The benefit-cost model is driven from a customized Quattro Pro menu tree. The main menu headings appear at the left of the menu line at the top of the display screen (after the model is loaded).
The main menu tree for the benefit-cost model includes:

Model Building Rehab Seismic Results Print Close File Edit ...

The underscored letter of the menu indicates that, in addition to clicking on the menu word, that this menu can be accessed by an /X keyboard command, where X is the underscored letter in the menu label.

The first seven menu labels above are custom labels for the benefit-cost software. Each menu accesses a range of information about the model:

Model	model version and date
Building	data about the existing building
Rehab	data about a specific rehabilitation project
Seismic	seismic risk data for the site under consideration
Results	summary of damages and losses, casualties, benefit cost results and summary of all data input parameters
Print	controls printing of all data and results pages
Close	controls saving and naming files and closing Quattro Pro

MODEL MENU

The model menu label has one submenu: **Version**. Clicking on **Model** brings up the **Version** submenu header. Clicking on **Version** brings up the title screen of the benefit-cost model. The title screen identifies the version number and date of the version being run.

BUILDING MENU

The Building menu label accesses data entry screens for the existing building (before seismic rehabilitation). There are two submenus: Engineering and Use & Function. The Engineering menu has five submenus: Facility Class, Building Description, Building Evaluation, Mean Damage Function, and Death, Injury Rates. The Use & Function menu has four submenus: Occupancy, Rental Income, Contents, and Relocation & Information.

INSERT GRAPHIC HERE (illustrating actual screen configuration) (and similarly below, throughout the data entry and results sections).

ENGINEERING MENUS

BUILDING ID and TYPE

Building Name
Address
City, State, Zip
Enter the basic identifying information about the building under consideration: building name, address, city, state and zip code.

Analyst
Enter the name of the analyst(s) conducting the benefit cost analysis.

Building Type

Building type denotes the primary structural systems of buildings. Select the building type most appropriate for the building under consideration from the building type table by entering the appropriate letter in the shaded box.

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The designation of building type is a very important input for the benefit-cost analysis, because, many of the default parameters in the analysis, including the building's damage function, depend on building type. Therefore, unless building specific input parameters are entered later in the data entry process, designation of building type will markedly affect the results of the analysis.

If none of the listed building typees are appropriate for the building under consideration, enter select the "OTHER" option by entering "R" in the building type selection box. If the "OTHER" option is selected, then default values cannot be provided by the program and all data parameters must be user-entered.

BUILDING DESCRIPTION

This section contains additional descriptive information about the building. Enter the total floor area of the building and the building replacement value per square foot. The total building replacement value is calculated automatically and thus cannot be entered by the user.

Replacement building value (per square foot) is the cost of replacing a building with a new building of equivalent function. Seismic damages are estimated as percentages of replacement value. In some cases, a distinction may be made between "reproduction" which is duplication of the previous building, and "replacement" which refers to duplicating a building's function with another (generally more modern) construction type. In most cases, however, the cost to replace a destroyed building with a similar building are readily identifiable. This value is for the building only, excluding contents.

For historic buildings, reproduction value, rather than replacement value, may be a more appropriate measure of building value. If desired, the reproduction value of a historic building can be entered in the "replacement value" data entry box.

The last three data entries under the Building Description section are for informational purposes only (i.e., they are intended to help guide the user in analyzing the building, but entries in these boxes do not affect the benefit-cost results calculated). These entries include: number of stories, date of construction, and historic building controls? (yes or no).

BUILDING EVALUATION

This comment box is intended for a brief synopsis of the seismic evaluation of the building or for any other comments relevant to the building's seismic performance. If a detailed engineering analysis is available for the building, this comment box may also be used to identify reports or other sources of information on the building.

MEAN DAMAGE FUNCTION

Building Mean Damage Function

Mean damage functions (MDF) indicate a building's seismic vulnerability by showing the expected levels of damage (as a percentage of building replacement value) for each MMI/PGA bin. For reference, up to four typical building mean damage functions are provided for the building type of the building under consideration.

The user may select one of these "default" mean damage functions by entering the appropriate letter in the green box or may enter a user-determined, building specific MDF for the building. For the MDF, as for all other data input parameters, better data input means better results and, therefore, users are strongly encouraged to enter building specific data whenever possible.

Demolition Threshold Damage Percentage

The demolition threshold damage percentage reflects the fact that many buildings will be demolished, rather than repaired, when the cost of repairing seismic damage exceeds some percentage of the replacement cost. For older, somewhat substandard buildings, the demolition threshold may be quite low (e.g., 20 or 30%). For typical, relatively modern buildings, the demolition threshold will be higher (e.g., circa 50%). For some particularly important historical buildings, the demolition threshold may be close to 100%.

The demolition threshold damage percentage is an important policy parameter which may significantly affect the benefit-cost results. Thus, demolition threshold damage percentages should be decided at the agency level.

DEATH & INJURY RATES (per 1,000 Occupants)

Life safety concerns are often one of the prime drivers of seismic rehabilitation projects. Therefore, estimating the life safety threat in the existing building (and the efficacy of the rehabilitation in reducing expected future casualties are particularly important data input decisions. For reference, default death and injury (minor and major) rates per 1,000 occupants are shown in this section. These values are from ATC-13 for the appropriate building type selected.

Users may accept the default values or enter user-specified estimates in the appropriate green boxes. Users are strongly encouraged to enter building-specific estimates.

The importance of entering building-specific estimates for death and injury rates whenever possible cannot be overestimated. User-entered casualty rates should be consistent with the mean damage function estimates entered previously. The life safety threat posed by individual buildings may vary drastically from the "typical" values from ATC-13. For example, if a "typical" building of a given building type as an expected damage of 20% in a given MMI/PGA bin, the expected deaths may be very low. However, if the particular building is expected to collapse at that level of ground shaking, then the building specific death rate may be close to 100%.

A comment box is provided at the end of the Death and Injury section for user comments and/or references to supporting documentation of casualty estimates.

USE & FUNCTION MENUS

The Use and Function submenu of the Building menu contains information on occupancy, value of government services, functional downtime, building rental income, building contents, and relocation information.

OCCUPANCY DATA

The OCCUPANCY page has three main categories of information: Occupancy, Value of Government Services and Functional Downtime.

OCCUPANCY

Enter the average number of persons (employees and visitors) per 1,000 square feet of floor area for both daytime and nighttime. Daytime means the 12-hour block of time encompassing normal business hours. Nighttime means the other 12-hour block in the day. The program calculates the total building occupancy for day and night. (NOTE: we will change this to have the user enter occupants directly rather than occupants per 1,000 square feet).

VALUE OF GOVERNMENT SERVICES

The value of government services, which may be lost due to seismic damage, is determined using the Quasi-Willingness To Pay (QWTP) model, which is described more fully in Chapter 1 of Volume 2. Briefly, QWTP assumes that government services are worth what it costs to provide them. For example, if an agency spends $1,000,000 per month to provide services from a given building, then the loss of these services for one month is valued at $1,000,000. For QWTP evaluation, the full costs of providing government services must be counted, including salaries and benefits, utilities and other non-wage operating costs, and either rent or a rent-proxy (if the building is agency owned).

In compiling costs for the QWTP evaluation, pass through costs such as Social Security payments or other transfers should not be counted. Only the direct costs of providing the government services should be counted.

Enter **either** the total annual operating budget for the building (in box 1a) **or** the more detailed breakdown in boxes 2a, 2b, and 2c (number of fulltime equivalent employees, average wages and benefits, average annual utilities and other non-wage operating costs). If total annual operating costs are entered in box 1a, it is not necessary to fill in boxes 2a, 2b, and 2c. If all boxes are filled in, the program uses the more detailed values from boxes 2a, 2b, and 2c.

The proxy annual rent is calculated from the building's replacement value and the discount rate; this value (shown in Box 3a) is used if a user-entered annual rent is not entered in Box 3b. Otherwise, the user-entered value is used to calculate the daily cost of providing government services from the building. If a value for total operating costs is entered in box 1a, and a "1" is included in box 1b (total operating costs includes rent), and boxes 2a, 2b, and 2c are not filled in then the rental values in boxes 3a or 3b are not used to calculate the daily cost of providing government services from the building.

POST EARTHQUAKE CONTINUITY PREMIUM

The above QWTP calculation if for "normal" government services (i.e., not in the post-earthquake environment). Some government services, such as emergency response or emergency medical care, may be more valuable than normal in the post-earthquake time period. The "

FUNCTIONAL DOWNTIME

For the QWTP evaluation of the value of lost government services, it is necessary to estimate how long government services will not be provided as a result of seismic damage. Default values, which are based on the building's Mean Damage Function. The default functional downtime estimates are capped at 30 days, because it is assumed that government services will be reestablished within 30 days, in temporary quarters if necessary.

Users may accept the default estimates of functional downtime, or enter user-specified estimates in the boxes provided.

Functional downtime is distinct from relocation time (see Relocation Information section). Functional downtime and relocation time estimates will generally be quite different. Relocation time refers to the amount of time that agencies will be relocated out of a damaged building, and, thus, relocation time may be significantly longer than functional downtime.

BUILDING RENTAL INCOME

This data entry screen enables the user to enter building specific rental income information.

For reference, the top of this data entry screen has boxes to enter identifying information: managing agency for the building and a contact person with address and telephone number.

The main portion of this data entry screen is for rental income data. For reference, the total building space is shown (not user-entered here) and the total space rented is shown next to the total building space (after rental data are entered).

Rental data for both government and non-government building tenants should be entered in the appropriate boxes. Rental rates may be entered either aggregated or disaggregated depending on the degree of detail desired and on whether or not different tenants have different rental rates and/or different rental uses. If desired, a whole building aggregate (average) rental rate can be entered.

From the entered rental data, the program calculates average rental rates for government and non-government tenants and computes total monthly rental revenues.

BUILDING CONTENTS (Damage as a % of replacement value)

First, enter the estimated value of total building contents (per square foot) in the $/sf box. The total building contents value is calculated automatically.

Second, an estimate for the contents mean damage function must be made. The default assumption is that the contents MDF is the same as the building MDF. The building MDF (entered previously) is shown for reference.

Users may either accept the default contents MDF estimate, or enter a building-specific estimate. Because the seismic fragility of contents may differ significantly (either higher or lower) than the building fragility, users are strongly encouraged to enter building specific contents MDF estimates.

RELOCATION INFORMATION

Seismic damage to a building may necessitate relocation while the building is repaired. Default estimates of the number of days of relocation necessary, based on the building MDF, are provided for reference.

Users may accept the default relocation estimates or enter a building specific estimate. As always, users are strongly encouraged to enter building-specific estimates whenever possible.

Total relocation costs (dollars per square food per month) are calculated as the sum of the added costs of relocation per day plus the costs of renting alternative space. The costs of relocation per day include extra operating costs (transportation, communications, etc.) incurred as a result of a forced relocation due to seismic damage. Such costs are highly locality-specific and agency-specific and thus no default values are provided.

REHABILITATION MENUS

REHABILITATION PROJECT DESCRIPTION

All of the previously discussed input data are applicable to the existing building, and thus are applicable to any rehabilitation project(s) under consideration. The following rehabilitation project data, however, are project-specific (i.e., they apply to a specific project with defined objectives, engineering design and construction, and costs). A range of alternative rehabilitation schemes can be analyzed sequentially by entering appropriate data and obtaining benefit-cost results for each in turn.

This section provides spaces for a brief description of the rehabilitation project under evaluation and a statement of the objective of the rehabilitation.

The benefit cost model is applicable to all types of Federal building seismic rehabilitation projects.
Projects with objectives covering the full range of seismic performance enhancements can be analyzed, including:

risk reduction:	any measure to lower seismic risk;
collapse prevention:	the minimum structural strengthening to avoid collapse;
substantial life safety:	collapse prevention and ensuring post-earthquake access and egress;
damage control:	limiting the extend of seismic damage; and
continued functionality:	immediate occupancy, with virtually no disruption of function.

REHABILITATION PROJECT COSTS

This section allows input of the full range of rehabilitation project costs. Data entry boxes are provided for: direct construction costs, indirect costs such as architectural and engineering fees, testing, permits, etc. and for project management. For reference, data entry boxes are provided for the base year of costs and for the expected duration of construction.

To estimate relocation costs associated with the rehabilitation project (which are included in the total costs of the project), the user must enter the estimated number of months of relocation necessary. Relocation costs are then calculated automatically from relocation cost information entered previously.

Total project costs are calculated from a summation of the above costs.

EFFECTIVENESS OF THE REHABILITATION

The effectiveness of a seismic rehabilitation project is the extent to which the project reduces expected future damages and losses. Effectiveness is characterized by the percentage reduction in expected damages.

Effectiveness in Avoiding Building Damage

The effectiveness of a specific rehabilitation project in avoided future building damages may be viewed from two perspectives. One perspective is to consider the mean damage function (MDF) of the rehabilitated building compared to the MDF of the existing building. Several MDFs for the building type under consideration are shown for reference. The user may select one of these or enter a user-specified, building specific estimate of the MDF for the rehabilitated building. Percentage effectiveness of the prospective seismic rehabilitation project are calculated from the MDFs for the existing and rehabilitated building.

The effectiveness of seismic rehabilitation projects in avoided future damages may vary markedly from very small percentages for minor risk reduction projects to nearly 100% for projects designed to ensure continued functionality and immediate occupancy in the largest earthquake considered. In general, the effectiveness of many types of rehabilitation projects declines as the intensity of ground shaking increases.

Effectiveness in Avoiding Contents Damage

The effectiveness of the proposed rehabilitation project in avoiding contents damage must also be estimated. The default assumption is that the effectiveness for contents is the same as the effectiveness for the building.

Users may accept this default assumption (which may not always be a good assumption) or enter building- and contents-specific estimates in the appropriate data entry boxes. As always, users are strongly encouraged to enter building-specific estimates whenever possible.

Effectiveness in Avoiding Casualties

The effectiveness of the proposed rehabilitation project in avoiding casualties (deaths, major injuries and minor injuries) must also be estimated. For reference, the casualty rates for the existing building (entered previously) are shown. Default estimates are provided based on the assumption that the rehabilitation project reduces minor injuries by a factor of 10, major injuries by a factor of 100, and deaths by a factor of 1,000.

The effectiveness of rehabilitation projects in avoided casualties may vary markedly depending on the type of building and on the objective and implementation of the rehabilitation. Therefore, it is very important to enter building-specific, project-specific estimates whenever possible.

In some cases, where occupancy is high and a building is expected to undergo partial or full collapse at moderate levels of ground shaking, benefit-cost results may be predominantly determined by the casualties avoided by the rehabilitation. Therefore, estimation of expected casualty rates for the existing building and the reduction in expected casualty rates for the rehabilitated bridling are among the most important data input decisions.

SEISMIC MENUS

SEISMIC RISK

Seismic risk, the expected annual number (or probability) of earthquakes for the range of MMI/PGA bins is the single most important determinant of benefit-cost results. Seismic risk may vary by several orders of magnitude from one location in the United States to another. All other factors being equal, benefit-cost results are directly proportional to seismic risk.

Seismic risk, the expected annual number of earthquakes as a function of the MMI/PGA bins, for a specific site may be estimated in four ways in the model:

1) from tabulated values in the Seismic Risk Table below,
2) by entering values of acceleration and exceedance probability from the 1991 NEHRP maps,
3) by entering values of acceleration and exceedance probability from any other available data source, or
4) by entering data from a site-specific geotechnical study.

The first three methods all provide approximate estimates of seismic risk, based on regional seismicity contours. These three methods all require entering two pairs of data for expected PGA (as a percentage of g, the acceleration of gravity) and recurrence interval (e.g., 50 years and 250 years). More accurate estimates can be obtained from a site-specific geotechnical study. Therefore, users are strongly encouraged to use site-specific geotechnical data whenever possible.

The expected level of ground shaking in any given earthquake event depends on the soil type at the site. The user must classify the site on a simple five point scale (S0, S1, S2, S3, and S4):

S0 hard rock
S1 rock
S2 very dense soil
S3 stiff soil
S4 soft soil.

Option 1: Tabulated Values

The Seismicity Estimates for 300 Cities Table (Table 3.1) contains seismic risk data for approximately 300 cities in the United States. These cities include the 200 largest cities, plus an additional 100 smaller cities in higher seismicity areas. For cities in this table, the user can copy the two tabulated spectral acceleration data points into the appropriate boxes on the Seismic Risk data entry screen. These data points were obtained from the spectral acceleration contours on the 1991 NEHRP maps (as described under Option 2 below). From these data points, the program automatically calculates the expected annual number of earthquakes shown in the "default estimate" line of the Seismic Risk Table.
Using the tabulated values in the Cities Tables is convenient; however, seismic risk estimates derived from these tables are subject to two significant uncertainties. First, the spectral acceleration contours on which the tabulated values may not fully reflect all local faults. Second, particularly for cities of large geographic extent, the average values for a city may not reflect important local differences, depending on the location of the major fault(s).

Table 3.1
Seismicity Estimates for 300(±) Cities

CITY	Spectral Acceleration (% of g) 10% exceedance probability in 50 years	Spectral Acceleration (% of g) 10% exceedance probability in 250 years
Aardvark, MI	10	32
Acorn Park, MA	12	40
Squirrel, ID	45	131
to be continued...		

Option 2: Spectral Acceleration Contours (NEHRP Maps)

The second option is to enter spectral acceleration contour data (i.e., as shown in Table 3.1) for the city of interest. This option may be useful for cities not shown in Table 3.1 or cities of large geographic extent where it may be possible to read the contours to a higher precision than the average city values shown in Table 3.1. This option is still, of course, subject to uncertainties in the contours, which may not accurately reflect all local faults.

Option 3: Spectral Acceleration and Recurrence Interval Data from Any Available Source

The third option is to enter spectral acceleration and recurrence interval for any available source. Under this option, the user would enter two pairs of spectral acceleration (% of g) and recurrence interval data. Such recurrence interval data could be for different recurrences (e.g., 50 and 100) than under option two where the recurrence intervals used are always 50 and 250 years. This option is still, of course, subject to uncertainties in the contours, which may not accurately reflect all local faults

Option 4: Site-Specific Geotechnical Estimate

If available, this is by far the preferred option, because it incorporates detailed site-specific information and analysis of local faults and is thus likely to produce more accurate results than any of the first three options, all of which are based on limited data sets.

Geotechnical estimates frequently do not present data in the form of expected annual numbers of earthquakes for each MMI/PGA bin, as required for the benefit-cost analysis. More commonly, results would be presented as PGAs with some exceedance probability (usually 10%) in a stated time period (10, 50, 100 years etc.). In such cases, the site-specific geotechnical data points (as long as there are two, could be entered into Option 3, discussed above. The program would then calculated the estimated annual numbers of earthquakes.

SEISMIC RISK: Regression Analysis

This section contains no user enterable parameters. The mathematical details of the regression analysis used to estimate the expected annual numbers of earthquakes from two pairs of PGA and recurrence interval data are summarized in this section. (technical details to appear in Volume 2).

SEISMIC RISK: Soil Multipliers

Site-specific soil conditions may markedly impact the actual ground shaking experienced during earthquakes. Therefore, to model seismic risk it is essential to consider the effects of soils at each site. Soil effects are modeled using a five step soil classification from the Uniform Building Code (check):

Seismic risk at a site is adjusted according to the consensus soils multipliers compiled by the Design Values Panel (1993) which is reviewing proposed NEHRP 1994 standards (check). (technical details to appear in Volume 2).

SEISMIC RISK: Probability Intervals

This screen, which does not contain any user enterable parameters, shows the annual probabilities of earthquakes in each MMI/PGA bin for S0, S1, S2, S3, and S4 sites. A given site will, depending on local seismicity, always experience the same annual number of earthquakes (independent of soil type), but the level of ground shaking experienced will depend on soil type. Therefore, the expected annual number of earthquakes in any given MMI/PGA bin will depend on the soil type.

The five tables in this section of the program illustrate the importance of soil types on expected annual numbers of earthquakes in a given MMI/PGA bin. The program automatically includes the effect of soil type on the seismic risk estimates under Options 1, 2, and 3 discussed above. Under Option 4, a detailed geotechnical analysis, soils affects are assumed to have been included in the geotechnical analysis.

RESULTS MENU

DAMAGES

The four tables in this section of the Results summarize four types of damages:

scenario damages,
expected annual damages,
expected avoided annual damages, and
expected residual annual damages.

These types of damages are defined as follows:

Scenario Damages:

the estimated damages and losses per earthquake event of a given MMI (or range of effective peak ground acceleration, PGA, at the building .

Expected Annual Damages:

the product of scenario damages and the expected annual probability of an earthquake of a given MMI or PGA

Expected Annual Avoided Damages:

the product of expected annual damages and the effectiveness of the rehabilitation measure in reducing expected damages.

Expected Annual Residual Damages:

the expected annual damages after rehabilitation (i.e., the difference between expected annual damages and expected annual avoided damages.

For each of these types of damages, damages and losses are subdivided into five major categories: building damage, property (contents), relocation expenses, rental income losses, and the value of lost government services. In each case the damages and losses are shown for each MMI/PGA bin.

Scenario damage estimates are useful for planning purposes because they indicate the magnitude of losses per earthquake event (independent of the probability of such events). For benefit-cost analyses, the expected annual damages (which include the annual probabilities of earthquakes are central: these are the expected damages and losses which are potentially avoidable (in full or in part).

DEATH LOSSES & INJURIES

In a manner analogous to the damage tables discussed above, casualty estimates are summarized in six tables which include estimates of the expected numbers of minor injuries, major injuries and deaths as follows:

Without Retrofit:

Scenario casualties (per earthquake event), and
Expected annual casualties (including the probabilities of earthquakes).

After Retrofit:

Scenario casualties (per earthquake event),
Expected annual casualties (including the probabilities of earthquakes),
Avoided annual casualties, and
Residual annual casualties (to be added).

BENEFIT-COST RESULTS

The tables in this page present the benefit-cost results. However, there are five user-entered parameters in this section: discount rate and planning period, which affect all of the results, and three estimates of the economic value of minor injuries, major injuries and deaths, which affect only the benefit-cost results including the value of life. The discount rate and planning period account for the time value of money and the useful lifetime of the rehabilitation, respectively. In combination, they determine the present value coefficient which is a multiplier on expected annual benefits which determines the net present value of such expected annual benefits. None of the compilations of damages and losses discussed previously depend on these parameters. However, the benefit-cost results presented below do depend strongly on the discount rate and planning period.

ECONOMIC PARAMETERS

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. Enter the discount rate as a percentage (i.e., 10%)

The choice of an appropriate discount rate is frequently one of the most difficult aspects of benefit/cost analysis. For Federally funded projects, a 10% discount rate was previously mandated by the Office of Management and Budget, OMB, (Executive Order 12291, 1981). Recently, however, this mandate has been lifted. On October 29, 1992, OMB issued Circular A-94, Revised (Transmittal Memo No. 64), Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. For "public investments" which are not "internal Federal government investments", the Circular recommends a discount rate of 7 percent. For internal Federal government investments, the Circular recommends a discount rate of 3 percent.

This OMB Circular is revised periodically and the most current discount rate should always be used in any benefit-cost analysis. For more detail, see Chapter 1 of Volume 2 of this report. (review to make this section a bit more accurate!)

Planning Period

The planning period (horizon) is the time period over which the economic benefits of strengthening programs are considered. 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. Appropriate planning horizons may be as short as one year for one time public education efforts which have no impact beyond the first year. Planning horizons of 5 to 10 years for equipment purchases, and 20 to 30 years for building projects are reasonable. For major infrastructure projects such as levees, planning horizons as long as 50 to 100 years may be appropriate. To ensure consistency, agencies should adopt uniform guidelines for planning horizons.

SUMMARY OF DAMAGES AND ECONOMIC LOSSES (WITHOUT VALUE OF LIFE)

This section summarizes three categories of expected damages and losses: annual expected, annual avoided, and annual residual. In each case breakdowns are given for the five damage categories: building damage, property (contents), relocation expenses, rental income, and value of lost government services.

The right hand column in this table is the present value of the avoided annual losses (for each of the five categories and it total). **These are the benefits of the rehabilitation project.**

The results compare the benefits (present value of total damages and losses avoided) and costs (total costs of the seismic rehabilitation project). Results are shown two ways: 1) as the total benefits minus the costs (present value criterion), and 2) as a benefit-cost ratio. Rehabilitation projects in which benefits exceed costs (on a present value basis) have present value criteria greater than zero and benefit-cost ratios above one.

VALUE OF INJURIES AND DEATHS AVOIDED

This section considers benefit-cost results including the economic value of avoided casualties in addition to the other damages and losses considered previously. The expected numbers of casualties were presented earlier in the section labeled "Death Losses & Injuries." To convert these estimates into economic losses, dollar values must be assigned to deaths and injuries.

For consistency, agencies should make agency-level decisions about appropriate economic values for deaths, minor injuries and major injuries.

Value of A Statistical Life

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

A consensus value for a statistical human life is approximately $1.74 million, based on several Federal Agency studies. A fuller discussion of the value of life issue is contained in Appendix 1 of Volume 2 of the recently published benefit-cost model.[1] The default value in the program is $1.7 million. Other values may be entered, if desired.

Value of Injuries

Similarly, economic values must be assigned to minor and major injuries. The default value for minor injuries (not requiring hospitalization) is $1,000. The default value for major injuries (requiring hospitalization is $10,000). Other values may be entered, if desired.

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[1]Federal Emergency Management Agency. "A Benefit-Cost Model for the Seismic Rehabilitation of Buildings". Volume 2: Supporting Documentation. Earthquake Hazards Reduction Series 62, FEMA 227. April, 1992.

SUMMARY

This section summarizes all of the input parameters used in the calculation and summarizes the benefit-cost results, both with and without the value of life being included.

Boxes at the top of the summary printout identify the building under consideration and the rehabilitation project being evaluated. A scenario run identification number may be entered to delineate multiple analyses of projects, with varying sets of assumptions.

Input data are summarized in two tables: a table of single-value items, and a table of items which are defined for each MMI/PGA bin.

Benefit-Cost Analysis:

Benefit-cost analysis provides estimates of the "benefits" and "costs" of a proposed project or change. The term "benefit-cost analysis" is used to denote economic analyses that apply either the maximum present value criterion or the benefit/cost ratio criterion to evaluate prospective actions. Both costs and benefits are discounted to their net present value. The maximum present value criterion subtracts costs from benefits to determine if benefits exceed costs. Benefit/cost ratios provide an alternative evaluation: prospective actions in which benefits exceed costs have benefit/cost ratios above one. The logic of benefit-cost analysis requires that benefit/cost ratios, and/or the present value criterion, be compared across competing alternatives.

Cost-Benefit Analysis:

Cost-benefit analysis has identical economic assumptions to benefit-cost analysis and differs only in the nomenclature used to describe the analysis. Subtle differences in meaning between benefit-cost and cost-benefit analysis have been discussed by Hurter et al. (1982). These authors prefer the term benefit-cost for three reasons: 1) determining benefits is often the most difficult aspect of the analysis; if costs are placed first, the emphasis is wrong; 2) when ratios are used to compare projects, the ratio used is benefit/cost, not cost/benefit; and 3) placing the word "costs" first seems to suggest a negative attitude toward projects. It should be noted, however, that economic concepts, particularly as reflected in benefit-cost analysis, are completely neutral with respect to the undertaking of projects.

Cost-Effectiveness Analysis:

Cost-effectiveness analysis identifies the least-cost way to achieve a stated objective; it is strictly a comparison among means to a given end (Andrews, 1982). Thus, cost effectiveness is the ability to achieve a given benefit at a minimum cost. In cost effectiveness analysis, the merits of the objective itself are not evaluated in economic terms. This approach is typically used to select methods of achieving specific environmental standards.

Economic Efficiency:

Economic efficiency is attained when the economy is functioning in a way that maximizes the value of society's consumption over time (Ward and Deren, 1991). Economic efficiency may also be viewed as the contribution to overall social welfare (Leman, 1989). It is generally accepted that a benefit/cost ratio above one indicates an improvement in economic efficiency. Benefit-cost analysis however does not indicate whether the project is the "most efficient" allocation of scarce resources for two reasons. First, benefit-cost analysis is an average rather than a marginal concept. The ratio indicates the relationship between benefits and costs for a given project size. Economic efficiency, however, requires that a project be sized where marginal benefits equal marginal costs, which maximizes the total net benefits. Second, the typical project benefit-cost analysis does not survey the complete array of spending alternatives for all public projects/programs unrelated to the project under analysis. Economic efficiency under a budget constraint would require that the marginal benefits for all public spending alternatives be equal.

Economic Impact Assessment:

Economic impact assessment is both simpler and broader than either benefit-cost analysis or cost-effectiveness analysis in that it does not necessarily require aggregation or even categorization of effects as costs or benefits. It requires only the projection of economic effects of proposed actions and the listing of these for consideration. Impact assessment is broader than benefit-cost or cost-effectiveness analysis because it includes identification of all economic impacts: the changes in total (direct, indirect and induced) regional employment and income created by the proposed project. The inclusion of indirect and induced regional economic benefits and costs in the formal benefit-cost analysis is not generally accepted by the economics profession. Many economists maintain that such indirect and induced economic impacts represent a change in the distribution of economic activity and should not be confused with true gains in economic efficiency.

Informal Benefit-Cost Analysis:

Informal benefit-cost analysis embraces an indefinite range of procedures for the general identification and balancing of desirable and undesirable effects of proposed actions on society. Thus, informal benefit-cost analysis simply approximates pure common sense, and it should not be compared with formal economic analyses of prospective projects.

Risk-Benefit Analysis:

Risk benefit analysis compares the economic benefits of a proposed project with the environmental and/or health-safety risks that are also created by the project. Ideally, the environmental and/or health-safety risks should be quantified in economic terms which in many cases is almost, if not impossible.

References for economic definitions:

Andrews, R.N.L. (1982) Benefit-Cost Analysis as Regulatory Reform, in Cost-Benefit Analysis and Environmental Regulations: Politics, Ethics and Methods, D. Swartzman, R.A. Liroff, and K.G. Croke (editors), The Conservation Foundation, Washington, D.C.

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Leman, C.K. (1989) The Forgotten Fundamental: Successes and Excesses of Direct Government, in Beyond Privatization: The Tools of Government Action, L.M. Salamon (editor), The Urban Institute Press, Washington, D.C.

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