FEDERAL EMERGENCY MANAGEMENT AGENCY

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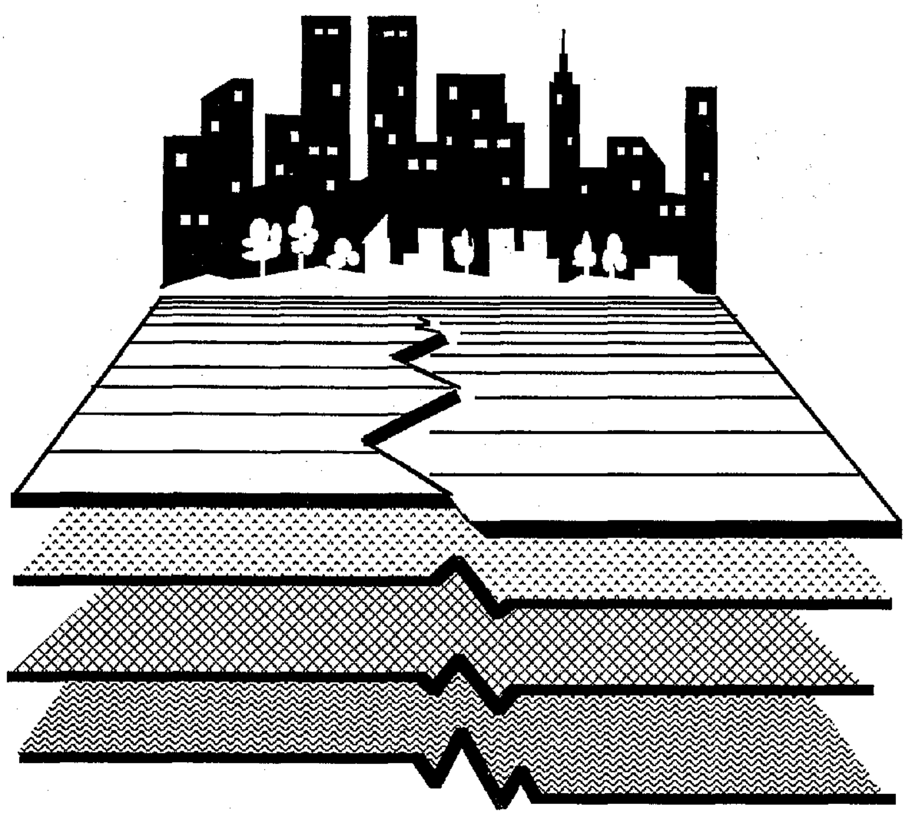
Second Edition
Typical Costs for Seismic Rehabilitation of Existing Buildings

Volume 2 - Supporting Documentation



EARTHQUAKE HAZARDS REDUCTION SERIES 39

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Second Edition—Typical Costs for Seismic Rehabilitation of Existing Buildings — Volume 2 - Supporting Documentation

NATIONAL EARTHQUAKE HAZARDS
REDUCTION PROGRAM

SECOND EDITION

TYPICAL COSTS FOR SEISMIC REHABILITATION OF BUILDINGS

VOLUME II - SUPPORTING DOCUMENTATION

FEDERAL EMERGENCY MANAGEMENT AGENCY

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PREFACE

Since 1984, The Federal Emergency Management Agency (FEMA) has had a comprehensive, closely coordinated program to develop a body of building practices that would increase the ability of existing buildings to withstand the forces of earthquakes. Societal implications and issues related to the use of these improved practices have also been examined. At a cost of about $17 million, two dozen publications and a number of software programs and audio-visual training materials have already been produced and distributed for use by design professionals, building regulatory personnel, educators, researchers and the general public. The program has proceeded along separate but parallel approaches in dealing with both private sector and Federal buildings.

Already available from FEMA to private sector practitioners and other interested parties is a "technical platform" of consensus criteria on how to deal with some of the major engineering aspects of the seismic rehabilitation of buildings. This technical material is contained in a trilogy, with supporting documentation, completed in 1989: 1) a method for the rapid identification of buildings that might be hazardous in case of an earthquake that can be conducted without gaining access to the buildings themselves; 2) a methodology for a more detailed evaluation of a building that identifies structural flaws that have caused collapse in past earthquakes and might do so again in future earthquakes, and 3) a compendium of the most commonly used techniques of seismic rehabilitation.

In addition to these engineering topics, the program has also been concerned with the societal implications of seismic rehabilitation. In addition to the report Typical Costs for Seismic Rehabilitation of Existing Buildings, the FEMA program has developed benefit/cost models and associated software for application to both private sector and Federal buildings and identified for decision-makers an array of socio-economic issues that are likely to arise in a locality that undertakes seismic rehabilitation of its building stock. FEMA programs have also provided ways to array the building stock and the methods to analyze it.

The culminating activity in this field will be the completion in late 1997 of a comprehensive set of nationally applicable guidelines with commentary on how to rehabilitate buildings so that they will better withstand earthquakes. This is a multi-year, multi-million dollar effort that represents a first of its kind in the United States. The guidelines will allow practitioners to choose design approaches consistent with different levels of seismic safety as required by geographic location, performance objective, type of building, occupancy or other relevant considerations.

Before being issued, the document will be given consensus review by representatives of a broad spectrum of users, including the construction industry, building regulatory organizations, building owners and occupant groups, academic and research institutions, financial establishments, local, State and Federal levels of government and the general public. This process is intended to ensure their national applicability and encourage widespread acceptance and use by practitioners. It is expected that, with time, this set of guidelines will be adopted by model building code organizations and standards-setting groups, and thus, will diffuse widely into the building practices of the United States.

Significant corollary products of this activity are expected. Principal among them will be an engineering applications handbook with refined cost data; a plan for a structural transfer of the technology embodied in the guidelines; and an identification of the most urgent research and development needs.

Recently completed is a set of technical criteria intended to provide Federal agencies with minimum standards for both the seismic evaluation and the seismic rehabilitation of buildings in their inventories. The performance level established in the standards is life-safety for building occupants and the general public. To facilitate the application of the standards by users, a commentary has also been prepared. In addition, an Executive Order to promulgate the standards has been drafted. These materials were given consensus approval by the Interagency Committee on Seismic Safety in Construction, which represents 30 Federal Departments and Agencies. They have been submitted to the Executive Office of the President for consideration and are awaiting signature by the President.

FEMA is pleased to have sponsored the development of these two new publications Second Edition: Typical Costs for Seismic Rehabilitation of Buildings - Volume I and Second Edition: Typical

Costs for Seismic Rehabilitation of Buildings - Volume II : Supporting Documentation, for inclusion in the series of documents dealing with the seismic safety of existing buildings that is discussed above. In this endeavor, FEMA gratefully acknowledges the expertise and efforts of the Hart Consultant Group and its subcontractors, H. J. Degenkolb Associates, Engineers, Inc. and Rutherford & Chekene Consulting Engineers, the Advisory Panel for the project, and Ms. Diana Todd of the National Institute of Standards and Technology, the Technical Advisor to FEMA for this project.

ACKNOWLEDGMENTS

The work described in this report was performed under a contract to the Hart Consultant Group. The work represents the collaborative efforts of the staff of the Hart Consultant Group and its two subcontractors : H. J. Degenkolb Associates, Engineers, Inc. and Rutherford and Chekene Consulting Engineers. Mr. Chris Poland and Mr. William Holmes were in every way co-project engineers with Dr. Gary C. Hart and their contributions are gratefully acknowledged.

The authors of this report would also like to thank the individuals listed in Appendix C for contributing seismic rehabilitation cost data and many helpful suggestions.

The project team would also like to acknowledge the efforts and support of Mr. Ugo Morelli, FEMA Project Officer, and Ms. Diana Todd of NIST. Their thoughtful and constructive suggestions during the course of the project and their careful reading of this report have improved its usefulness immeasurably.

Lastly, the authors would like to thank Dr. Rami Elhassan of Hart Consultant Group, Mr. Evan Reis of H. J. Degenkolb Associates, Engineers, Inc., and Mr. Jon-Michael Johnson of Rutherford and Chekene Consulting Engineers for their technical review and production of the final version of this report.

EXECUTIVE SUMMARY

GENERAL

This is the second edition of Typical Costs for Seismic Rehabilitation of Buildings, and represents a marked improvement over the first edition that was completed in 1988. The second edition combines extensive data collection with a rigorous quality control process in the creation of an extended database of 2088 data points. Sophisticated regression analysis techniques were applied to these data points to extract major behavioral trends inherent in the data points that were then used to formulate three different cost estimation options. A method for computing a confidence range for such cost estimates was also developed. As in the case of the first edition, there are two volumes, Volume I contains a summary of the report and Volume II, this volume, the supporting documentation.

OBJECTIVES

The goal of this report was to collect a large body of information on the costs of seismic rehabilitation and to develop tools for using the collected data to estimate the costs of rehabilitating other buildings. In the preparation of this second edition, two major prerequisites were established early in the life of the cost study:

1) There should be available to the user several cost estimation options that would differ in complexity to accommodate different levels of data availability.

2) Such options should be related to one another in direct and rational fashion, so that information from the development process of the most simple option would be part of the development process of the more complex options.

STUDY METHODOLOGY

The tasks that were performed in this project were:

1) Collection of the data from respondents and formation of the overall database.

2) Modification of the database to reflect cost normalization for time and location differences.

3) Application of strict quality control techniques to the modified database.

4) Ordering of the database into building groups.

5) Creation of a Super Database.

6) Development of equations for Cost Options 1, 2, and 3.

7) Development of confidence limits on cost estimates for Cost Options 1, 2 and 3.

Chapters 1 to 7 describe in detail the work performed in each of these tasks, including problems that were encountered, the solutions that were adopted, and the rationale for such solutions.

COST ESTIMATION

The typical costs addressed in this report are:

Type 1	Structural Costs
Type 2	Non-Structural Costs

Volume 1 of this report presented only the methodology used for determining structural costs. Non-structural costs are addressed in this volume.

In addition to non-structural and historic preservation costs, if any, there are three other factors that impact total costs. These are:

1) Disabled Access Cost - This is the cost to bring a building into compliance with the ADA by providing access for the disabled after the rehabilitation.

2) Hazardous Materials Cost - This is the cost required to rid the building site of hazardous materials as required by law. Examples of such materials can include asbestos, lead based paints and other contaminants in the vicinity of the site.

3) Project Management, Design and Testing Fees - This is the cost of utilizing the professionals needed to complete the project. They are usually a percentage of the cost of the total project.

These three costs must be addressed in any estimate of total seismic rehabilitation costs. However, there is no analytical technique described in this volume for the computation of these costs. The reason for this is that these costs are based upon the degree to which remedial measures are desired. Hence, these topics have been discussed but not quantified in terms of numbers. It is hoped that sufficient material exists in the discussions to help the user to make these decisions.

CHAPTER 1
SEISMIC REHABILITATION PROJECT COSTS

1.1 GENERAL

Volume I of this report provides users with a methodology to develop a range of "typical costs" and defines such costs as "the mean structural cost of the seismic rehabilitation of a building based upon the database gathered and does not include the cost of replacing architectural finishes." The architectural finishes whose costs are excluded are the architectural work done in normal buildings, those costs associated with the rehabilitation of historic buildings, and with upgrading buildings to current electrical, mechanical, accessibility, or hazardous materials removal code requirements that might become mandatory as a result of seismic rehabilitation. Also excluded are design, testing and management fees and costs associated with the occupancy conditions of the buildings that are to be rehabilitated.

For a variety of reasons, users may require information on these additional costs that are excluded from the definition of typical costs contained in Volume I of this report. Also, the database used in Volume1 for typical cost estimation did not include historic buildings in the analysis. Consequently, the first chapter of this volume discusses such additional costs and offers either specific values or general guidance for developing more comprehensive sets of rehabilitation costs. Worksheets from Volume I have been modified and combined into one new worksheet for use in computing those additional costs that are quantifiable. This worksheet is discussed in Section 1.7.

1.2 NON-STRUCTURAL COSTS

One type of non-structural cost that may be incurred is that of removing and replacing the various finishes that are affected by the installation of structural members during a seismic rehabilitation effort (architectural "cover-up"). Such efforts often will also include some amount of rehabilitation of internal non-structural elements, such as light fixtures or mechanical equipment. Although in a complete remodeling effort these additional non-structural costs may not be of great consequence, they may be a significant component of the costs under some circumstances.

Unfortunately, precise values for these non-structural costs cannot be provided because a rigorous approach for their determination is not available. Such costs depend upon a variety of factors that are not always known, especially when dealing with a large inventory of buildings. Using engineering judgment, therefore, and not the database developed for this report, tables providing additional costs associated with non-structural seismic rehabilitation have been developed and are presented below.

The tables which follow provide dollar per square foot allowances which are based on judgment and not analyses of the database. Table 1.1 provides values which can be used for all building types. Since the impact of the seismic work on architectural finishes in a commercial office building is generally more costly than in an industrial warehouse, occupancy specific values are provided in Tables 1.2, 1.3 and 1.4.

When developing cost ranges for a building inventory, the user must be aware that the costs associated with the seismic rehabilitation of those buildings may include much more than simply the cost of installing the structural elements which provide the lateral resistance to earthquake forces (this is the Typical Structural Cost derived in Volume I of this report). If a decision is made to seismically rehabilitate in conjunction with significant remodeling or rehabilitation of other systems, the added cost will be the Typical Structural Cost. If seismic rehabilitation is the primary driver of the construction work, it should be recognized that the total cost will include additional components. The minimum will be that of architectural "cover-up" which is basically the cost to remove and replace the various finishes which are affected during the installation of the structural elements.

In addition, many projects will include some amount of seismic risk mitigation to internal non-structural elements, such as light fixtures and mechanical equipment. In the case of a seismic rehabilitation associated with a complete architectural remodel, this non-structural mitigation premium may be of little consequence because new elements would automatically be installed with appropriate seismic details and, therefore, not necessary for the user to consider in developing typical costs attributable to seismic rehabilitation.

The tables presented in this chapter allow the user to develop a budget based on the extent of the two main variables affecting non-structural costs, the remodeling associated with the project and non-structural seismic mitigation. If non-structural seismic mitigation is not planned, the costs are solely those associated with a minimum "cover-up" of the structural work denoted as "Minimal costs for cover-up of structural work", or the costs of minor remodeling that might be done in conjunction with the structural work denoted as "Logical associated remodel" . There is no entry for a complete remodeling ("Gutted Building") in this case because it is assumed the non-structural seismic mitigation would be included with the new work.

On the other hand, if complete non-structural seismic mitigation is planned to be accomplished along with structural rehabilitation, the cost listed for no non-structural remodeling ("useful to find costs solely attributable to seismic work") can be used to determine total budgets for work associated with seismic mitigation; these costs would seldom represent actual total costs because there would always be at least minimal non-structural remodeling costs for cover-up purposes.

The user must therefore project the circumstances that will most accurately represent the average conditions associated with the seismic rehabilitation of the building or inventory and add the appropriate budget to the Typical Structural Cost.

1.3 DISABLED ACCESS IMPROVEMENTS

The requirements of the Federal Americans with Disabilities Act (ADA) may be triggered by the seismic rehabilitation work or the owner may voluntarily choose to improve accessibility for the disabled at the time that the seismic rehabilitation work is performed. If so, the user may wish to include such costs in developing a budget for a single building or a building inventory. The discussion below provides some guidance in determining the additional costs due to accessibility work.

The ADA contains various requirements which must be met when "alterations that affect the usability of, or access to, an area containing a primary function" are undertaken. "The path of travel to the altered area and the restrooms, telephones and drinking fountains serving the altered area" shall be made accessible to the maximum extent feasible "unless the cost and scope of such alterations is disproportionate to the cost of the overall alteration". Disproportionality is defined as 20 percent of the overall cost of the alteration.

Since elevators, restrooms and automatic doors are usually the most expensive accessibility items and they fall into the "path of travel" category, the largest increase that would occur for these and other related items is 20 percent of the seismic rehabilitation cost. For a large inventory of buildings, a 20 percent cost increase is highly unlikely, because it suggests that every building in the inventory will require the maximum accessibility improvements. A 20 percent increase would be unrealistic for very large buildings because the relatively fixed costs of installing an elevator or modifying a restroom do not necessarily increase linearly with an increase in square footage. Also, the ADA implements an elevator exemption for facilities that are less that three stories or have less that 3,000 square feet per story, unless the facility is "a shopping center, a shopping mall, the professional office of a health care provider, a terminal, depot, or other station used for specified public transportation, or an airport passenger terminal". The user should select an increase factor based on the above information and all other information available on the condition of the building or buildings being rehabilitated. For example, an extremely conservative approach would be to assume that all of the buildings in the inventory will require the maximum accessibility improvements resulting in a factor of 1.2 times the typical cost. Assuming that half of the buildings in the inventory (by area) will require about a ten percent cost increase for accessibility results in a factor of 1.05 times the typical cost.

1.4 HAZARDOUS MATERIAL REMOVAL

Hazardous materials may be encountered when performing seismic rehabilitation. When hazardous materials are present, extra costs may be incurred because they will have to be removed or special measures will have to be taken during construction to avoid risk to the workers or the occupants of the building.

Even though hazardous material removal is usually performed under a separate contract, the user may want to consider the possible impact of this work on the overall budget. A discussion is provided below to acquaint the user with hazardous materials that may be present in a building inventory and to provide some general guidelines on additional costs.

A common hazardous material that is encountered in buildings is asbestos. The wide use of asbestos for insulating materials was discontinued in the mid-1970's due to the promulgation of the asbestos National Emissions Standards for Hazardous Air Pollutants (NESHAP) by the Environmental Protection Agency beginning in 1973. Therefore, rehabilitation of buildings built after the mid-1970's is not likely to incur asbestos removal costs. The impact of asbestos in buildings built before the mid-1970's will vary according to the areas affected by the rehabilitation scheme and the extent of the asbestos in ceilings and walls, linoleum flooring, pipe and duct insulation, and fireproofing.

It is difficult to predict typical costs for asbestos removal considering the various factors which can influence such costs. First of all, the presence of asbestos and its extent is unknown without performing tests at each building. Secondly, even if asbestos is found to be present in the building, the extent to which it needs to be removed to install the structural elements is unknown until the rehabilitation scheme is designed. Finally, the owner may decide to remove all asbestos even though only specific areas will be affected. A reasonable upper bound to be added to the Typical Cost for asbestos removal is $5.00 per square foot. For an entire building inventory this amount is unrealistic considering the likelihood of encountering and then removing asbestos in all buildings in the inventory. More realistically, one might assume that ten percent of the buildings (by area) will contain asbestos which needs to be removed prior to rehabilitation.

Another common hazardous material that is still used today is lead-based paint which is used primarily to prevent rust on steel structures. The primary risk due to lead-based paint occurs when construction workers inhale the lead dust or lead fumes caused by blasting, welding or spray painting. An increase in the cost of rehabilitation is likely to occur because of the need to provide workers with proper protection and washing facilities when dealing with lead coated surfaces but a specific value cannot be provided because of the lack of data on this subject.

Soil contamination is yet another hazard that may be encountered in a seismic rehabilitation project. Possible sources of soil contamination are leaks from underground storage tanks, waste from factories, and contaminated land fill. A knowledge of the history of the site may help to determine whether the soil may be contaminated and thereby provide some basis for estimating additional costs.

1.5 DESIGN, TESTING, INSPECTION, AND MANAGEMENT FEES

Design fees cover the costs of design professionals such as architects, structural engineers, geotechnical engineers, civil engineers, surveyors, and cost estimators required to perform studies and design work. Somewhat unique to many seismic rehabilitation projects is the need to hire a testing agency to assess the strength of the existing materials during the design phase. Testing agencies and inspectors are also necessary during the construction phase to ensure compliance with building codes and contract specifications. The local building department will generally require permit fees to cover their review, inspection and any other involvement in the project.

In addition to these costs, as for any construction effort, the owner will need to manage the project. This can be done in-house or the owner may choose to hire a manager. In either case, time and money will be spent in order to complete the project. All of these non-construction project costs are grouped together for use in the development of typical costs. A reasonable estimate of these costs is thirty percent of the total construction cost (i.e. multiply the typical construction cost by 1.3).

1.6 HISTORIC PRESERVATION COSTS

Historic preservation costs are associated primarily with the architectural work involved with the seismic rehabilitation of historic buildings. Such buildings typically have features in them such as historic facades, architectural columns or special ceilings that cannot be moved or altered during the seismic rehabilitation work. These Historic Buildings are typically placed on a city, state or national register of historic buildings and any construction work done on these buildings is subject to regulation by the regulatory board. Buildings subject to such regulation are considered to have historic controls. These special considerations typically increase the overall cost of seismic rehabilitation. Due to the unique nature of each project, it is not possible to quantify the additional cost associated with historic preservation. During the collection of the cost data, it was found that fewer than 10 percent of all the data points had historic controls. For these data points, it was found that the mean cost of seismic rehabilitation was approximately three times that for the normal buildings (i.e. those without historic controls). In addition, it was found that the data points had a very large spread. The Project Advisory Panel felt that these values for the cost data reflected the unique nature of the respondent's projects and could therefore not be used to typify historic preservation costs in general. Due to these reasons, the cost database used to compute the typical costs of seismic rehabilitation did not include Historic Buildings. In general, Historic costs should be evaluated on a case-by-case basis with special attention being paid to the unique nature of each project.

1.7 WORKSHEET FOR PROJECT COSTS

The worksheet shown in Table 1.5 is similar to the Volume I worksheets with the addition of architectural and non-structural costs, disabled access improvement costs, hazardous material removal costs, and professional design fees and project management costs. The user is given the option of calculating a Typical Construction Cost or a Typical Project cost (which includes the professional design fees and project management costs). The intent of this worksheet is to provide a guide for planning for the seismic rehabilitation of many buildings in an inventory. Since the probable range of costs for a single building can vary dramatically, the results of the worksheet should be used only in a qualitative fashion in conjunction with estimating costs for individual buildings. Only as the number of buildings in the inventory increases does the variance in the range decrease (this is accounted for in the upper and lower bounds calculation in the worksheet). The user is reminded that these typical costs are based on the assumption that all buildings in the inventory under consideration have been determined to require some level of seismic rehabilitation.

The user will need to refer to Volume I as well as this chapter in order to complete the worksheet. For those cost categories which depend on specific characteristics of the buildings, (e.g. structural system or area), the inventory should be divided into groups based on buildings with similar characteristics and individual worksheets should be used for each of those groups. The non-structural modifiers should be applied to each of these groups of buildings to obtain the Typical

Construction Cost for that group. The total budget for the inventory can be determined by multiplying the Typical Cost for each group by the total square footage of the buildings in each group and them summing all group totals.

TABLE 1.1 NON-STRUCTURAL COST ALLOWANCES FOR ALL BUILDING TYPES ($/sq.ft.)

NON-STRUCTURAL SEISMIC MITIGATION	NON-STRUCTURAL REMODELING			
	None	Minimal	Moderate	Complete
	Useful Only to Find Costs Solely Attributable to Seismic Work	Minimal Costs for Cover-up of Structural Work	"Logical" Associated Remodel	Gutted Building
None	N/A	$3*	$13	N/A
Light	$3	$6	$16	N/A
Complete	$7	$10	$20	$50

N/A = Not applicable.

* Use this figure to get minimum actual structural construction cost with no non-structural mitigation.

TABLE 1.2 NON-STRUCTURAL COST ALLOWANCES FOR INSTITUTIONAL BUILDINGS ($/sq.ft.)

NON-STRUCTURAL SEISMIC MITIGATION	NON-STRUCTURAL REMODELING			
	None	Minimal	Moderate	Complete
	Useful Only to Find Costs Solely Attributable to Seismic Work	Minimal Costs for Cover-up of Structural work	"Logical" Associated Remodel	Gutted Building
None	N/A	$4*	$15	N/A
Light	$4	$8	$19	N/A
Complete	$10	$14	$25	$65

N/A = Not applicable.

* Use this figure to get minimum actual structural construction cost with no non-structural mitigation.

TABLE 1.3 NON-STRUCTURAL COST ALLOWANCES FOR COMMERCIAL BUILDINGS
($/sq.ft.)

NON-STRUCTURAL SEISMIC MITIGATION	NON-STRUCTURAL REMODELING			
	None	Minimal	Moderate	Complete
	Useful Only to Find Costs Solely Attributable to Seismic Work	Minimal Costs for Cover-up of Structural Work	"Logical" Associated Remodel	Gutted Building
None	N/A	$3*	$13	N/A
Light	$3	$6	$16	N/A
Complete	$7	$10	$20	$50

N/A = Not applicable.

* Use this figure to get minimum actual structural construction cost with no non-structural mitigation.

TABLE 1.4 NON-STRUCTURAL COST ALLOWANCES FOR INDUSTRIAL BUILDINGS
($/sq. ft.)

NON-STRUCTURAL SEISMIC MITIGATION	NON-STRUCTURAL REMODELING			
	None	Minimal	Moderate	Complete
	Useful Only to Find Costs Solely Attributable to Seismic Work	Minimal Costs for Cover-up of Structural Work	"Logical" Associated Remodel	Gutted Building
None	N/A	$1*	$2	N/A
Light	$2	$3	$4	N/A
Complete	$10	$11	$12	$20

N/A = Not applicable.

* Use this figure to get minimum actual structural construction cost with no non-structural mitigation.

TABLE 1.5 TYPICAL PROJECT COST FORM

1. GROUP MEAN COST (Table 4.3.2 in Volume I) ● Group: □ URM □ W1, W2 □ PC1, RM1 □ C1, C3 □ S1 □ S2, S5 □ S5 □ C2, PC2, RM2, S4	C_1 =
2. AREA ADJUSTMENT FACTOR (Table 4.4.1 in Volume I) ● Area □ Less than 10K sq. ft. □ 10K - 50K sq. ft. □ 50K - 100K sq. ft. □ 10K - 50K sq. ft.	C_2 =
3. SEISMICITY/PERFORMANCE OBJECTIVE FACTOR ADJUSTMENT ● SEISMICITY □ Low □ Moderate □ High □ Very High ● PERFORMANCE OBJECTIVE □ Life Safety □ Damage Control □ Immediate Occupancy ● COST ADJUSTMENT FACTOR C_3 (Table 4.4.2 in Volume I)	C_3 =
STRUCTURAL COST: $C_S = C_1 \times C_2 \times C_3$	C_S =
4. ARCHITECTURAL / NONSTRUCTURAL COST ● See Discussion in Chapter 1, Volume II (Default = 0)	C_{NS} =
CONSTRUCTION COST: $C_C = C_S + C_{NS}$	C_C =
5. OPTIONAL: DISABLED ACCESS IMPROVEMENTS COST ● See Discussion in Chapter 1, Volume II (Default = 1.0)	C_{DA} =
CONSTRUCTION COST MODIFIED BY DISABLED ACCESS COST	$C_C \times C_{DA}$ =
6. OPTIONAL: HAZARDOUS MATERIAL REMOVAL COST ● See Discussion in Chapter I, Volume II (Default = 0)	C_{HM} =
CONSTRUCTION COST MODIFIED BY HAZARDOUS MATERIAL COST	$C_C + C_{HM}$
7. PROJECT COSTS ADJUSTMENT FACTOR ● See Discussion in Chapter 1, Volume II	C_{PM} =
PROJECT COST : $C_P = C_C$ (modified) $\times C_{PM}$	C_P =
8. LOCATION ADJUSTMENT FACTOR ● City / State ________ (Table 4.3.4 - Vol I)	C_L =
9. TIME ADJUSTMENT FACTOR ● Budget Year ________ (Table 4.3.6 - Vol I)	C_T =
TYPICAL CONSTRUCTION COST: $C_{TC} = C_C$(modified) $\times C_L \times C_T$ TYPICAL PROJECT COST: $C_{TP} = C_P \times C_L \times C_T$	C_{TC} = C_{TP} =
10. CONFIDENCE RANGE ● Confidence Percentage: □ Very Narrow (90%) □ Narrow (75%) □ Moderate (50%) ● Number of Buildings in Group: □ 1 □ 2 □ 5 □ 10 □ 50 □ 100 □ 500 □ 1000 or more	C_{CRL} = C_{CRU} =

Range of Typical Construction Cost or Typical Project Cost ($C = C_{TC}$ or C_{TP})	Lower Bound = C x C_{CRL}	
	Mean Cost = C	
	Upper Bound = C x C_{CRU}	

CHAPTER 2
DATA COLLECTION AND QUALITY CONTROL

2.1 GENERAL

This report placed a strong emphasis on the collection and quality control of the cost data. Cost data was collected for over 2400 buildings from sources around the United States, on all model building types in all NEHRP seismic areas and for different levels of expected seismic performance. The net result of the collection effort yielded 1895 building seismic rehabilitation cost data points for use in the database. The collection and quality control checking of the data is described in this chapter.

2.2 DATA COLLECTION GUIDELINES

An initial project task was to develop, in conjunction with the other consultants, a worksheet which was universal enough to be used on any type of building but which had room to gather as much specific information as possible. It was determined that the critical data which had to be known about each building included its basic structural type, floor area, location, the level of performance which was proposed, and the costs associated with the rehabilitation scheme. Ancillary information on the building was also obtained, e.g. building age, to assist in the quality control phase of the data collection. A first draft of the worksheet, called the "Data Collection Guidelines", was developed and sent to the Project Advisory Panel for review. Comments were received and evaluated and the worksheet was revised into its present form. The Data Collection Guidelines consist of four pages. The first page, shown in Figure 2.2.1, asks for information which is most important for the statistical analysis of the database. The second page, shown in Figure 2.2.2, asks for detailed information on the building size, structural framing and codes used in the analysis. This page became a valuable tool in confirming the data on the first page of the worksheet and in locating trends. The last two pages of the form are shown in Figures 2.2.3 and 2.2.4 and contain explanatory notes to ensure consistency, completeness and accuracy in filling out the worksheet.

2.3 DATA COLLECTION

Data collection began with the creation of a large list of potential contributors. It was identified as critical that the contributors be geographically distributed around the country. The list started with each member of the Project Advisory Panel being responsible for providing at least ten building seismic rehabilitation cases for the database. Other potential data sources that were contacted were the FEMA Rehabilitation Guidelines and Commentary Project Panel members, various government agencies (FEMA, VA, DOE and the military), and engineers familiar to the project team members. A request for cost data was also placed in the EERI newsletter. A list was developed of over 100 groups, firms and individuals.

The potential contributors were contacted personally by an engineer on the project team who explained the project goals. Most potential contributors were sent several copies of the form described in Section 2.2. In some cases, the contributors were not able to fill out the worksheets but, instead, sent reports from which the project team extracted the needed data. In other situations, the contributor allowed a member of the team to visit their offices to research reports and fill out forms.

All told, almost fifty groups or firms contributed information, often with several engineers from an office providing data.

2.4 DATA PROCESSING

A major portion of the effort on the data collection task was directed at ensuring that the data collected was complete, consistent and accurate. Because information was being gathered from so many sources and from vastly different styles and qualities of reports, each piece of data was reviewed individually and in comparison to the aggregate database. Anomalies in the cost data were expected but in many situations the review justified such anomalies.

The information on each form was entered into the computerized database called Rbase. The list of data was reprinted weekly and back checked against the forms to ensure that the information was entered correctly.

2.5 QUALITY CONTROL

Once all the data had been collected and entered into the database a second level of quality control was performed by looking at the trends in groups of buildings. The data was sorted numerous times according to several different parameters including: building type and structural system, cost, age, historic controls, etc.. Trends developed and certain buildings showed up as anomalies. The records for these buildings were examined to see if mistakes had been made. Contributors were called by telephone where necessary to confirm or clarify these anomalies in the data.

A review of the data was performed to check for duplicate entries. This included cases where the same analysis was submitted by two different contributors. For example, the engineer and the client may be submitting the cost data for the same building. Also, in more than one case, a single building on a campus was studied and the results translated across the board to other buildings of "exactly" the same configuration. In this latter example, only the one building which was actually studied was used in the database. To determine which entries were duplicates, the data was sorted by location, area, model building type, age and cost. Where two or more buildings exactly or closely matched fields in all these areas the original Data Collection Guidelines were compared line by line. Duplicate entries were rejected. As a result, approximately 100 buildings were eliminated from the database during this quality control phase.

2.6 COST NORMALIZATION

The cost data that was collected varied in age and, by design, it was received from many different economic regions of the U.S. and Canada. A crucial aspect of this report was to convert all the cost data into the same relative time and location. Cost data was converted to 1993 dollars for the state of Missouri. Missouri was picked as a location in the geographic center of the U.S.

To make the adjustment in the cost data to correct for age differences, the team researched three widely used cost comparison indices: the Engineering News Record Index (ENR), the Means Construction Guide and the L. Saylor Index. The goal was to select an index to adjust the cost data which could be used for not only this project but also utilized by future users of the database, who would have to estimate costs in later years. For this reason the team selected the Engineering News Record (ENR) 20-city average index. To arrive at a relative building construction cost index, called the BCI, ENR takes three materials: cement, steel, and wood and determines the price for a given unit of each. It combines this with the labor costs for ironworkers, carpenters and concrete placers to arrive at a single value which incorporates labor and materials. The ENR tracks this value over time for twenty major U.S. cities and combines the data to obtain a nationwide average. Data is compiled and published each quarter.

The Means Construction Guide does not perform this tracking over time but does list each year the materials and labor costs for thousands of items and tasks. To track the change in costs over time, one must compare selected items in the various cost guides. The cost guides do not consistently list the same quantity of materials and labor each year, and thus, the analysis of this cost data is not straightforward and was not appropriate for this project.

After a considerable number of conversations between the project team and the staff from Hanscomb Associates, professional cost estimators who were part of the Project Advisory Panel, it was agreed by both parties that data before 1970 had a high degree of uncertainty. It was therefore decided to reject the 24 records which contained cost data for studies or actual rehabilitation construction prior to 1970.

The Hanscomb Associates staff was also concerned about the use of the ENR index for this report. They believed that for labor the rate of change over time would probably be accurate but that for materials the Means Construction Guide would probably be better. To study this matter three similar materials from the Means Construction Guide were tracked from 1972 through 1993. It followed that the differences between the Means Construction Guide and the ENR index ranged from 0 to 15%. Materials represent about one-half of the total construction costs with the labor costs representing the other half. When the Means Construction Guide materials index was combined with the ENR labor index the resultant difference was reduced to less than 8%. Based on the results of this review and considering the ease in obtaining and using the ENR index for most individuals it was decided to use the ENR index for both labor and materials.

To adjust the cost information by location the Means Construction Guide was initially selected because it provided relative costs across the U.S. and Canada for 150 cities; the ENR provides data on only 20 cities. Even though 150 cities is a large number, because the goal of this report was to obtain data from the U.S., the database contains costs from many cities not included in the 150. To group each city in the database with a city in the Means Guide would involve more knowledge about the regional economy than the project budget allowed and also more knowledge than future users of the database would likely have. Therefore, it was decided to average all the cities in a given state to calculate an average index for an entire state. Setting the Missouri index equal to 1.0, multipliers for the other states were developed to transform all costs to constant Missouri values. The rehabilitation cost for each building was multiplied by the appropriate factor for that state. Thus, building costs in South Carolina, which has a lower construction index than Missouri, would be multiplied by a number greater than one to transform them into Missouri dollars.

2.7 QUALITY CONTROL FOR COST ANOMALIES

Once the original cost data had been normalized to 1993 dollars for the state of Missouri an additional level of quality control was applied in this report. Bounds for acceptable values of the cost data for each building group were computed based upon the theory of probability. These bounds were calculated by assuming a lognormal probability density function (pdf) for the cost data. All data that lay outside these bounds (a total of 5% of the data points) were sent back for re-evaluation and possible elimination from the data set. The result was a data set whose spread or coefficient of variation (C.O.V) was fixed at an acceptable value of 50%.

<u>The Lognormal Cost Model</u>

The structural cost of seismic rehabilitation is itself the product of several factors. If the structural cost per square foot is called C and can be written as the product of several variables W_1 to W_n, then:

$$C = W_1 W_2 W_3 W_4 \ldots\ldots W_n \qquad (2.7.1)$$

Due to the inherent variability of the cost data, we can assume that C and the variables W_1 to W_n are also random variables.

Taking the natural logarithms of both sides of Equation (2.7.1) yields

$$\ln C = \ln W_1 + \ln W_2 + \ln W_3 + \ldots + \ln W_n \qquad (2.7.2)$$

Because each W_i is a random variable, the function $\ln W_i$ is also a random variable. From the theory of probability it can be shown that the sum of many random variables tends to be a normally distributed random variable. Therefore, ln C is a normally distributed random variable. If we define the natural logarithm of the cost C to be X then:

$$X = \ln C \qquad (2.7.3)$$

As we have shown, since ln C is normally distributed, X is normally distributed. If X and C are related as defined in Equation (2.7.3) then the random variable C is said to follow a lognormal distribution. The equation for the probability density function of C which is a lognormal distribution is given by :

$$f_C(c) = \frac{1}{c\sigma_X\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln c - m_X}{\sigma_X}\right)^2\right] \quad c \geq 0 \qquad (2.7.4)$$

where the parameters σ_X and m_X are the standard deviation and the mean of the random variable X. These variables can be related to the statistical parameters of C and this is now discussed.

Let m_C and σ_C be the statistical mean and standard deviation of the cost data sample. Then, it can be shown that

$$m_C = \exp(m_X + 0.5) \qquad (2.7.5)$$

and

$$\sigma_C = \exp(m_X + 0.5\sigma_X^2)\,[\exp(\sigma_X^2) - 1]^{1/2} \qquad (2.7.6)$$

Where m_X and σ_X are mean and standard deviation of the corresponding normal random variable, i.e X in Equation (2.7.3). From a statistical analysis of the cost data, the sample mean and sample standard deviation can be calculated and equated to m_C and σ_C, respectively, and thus, Equations (2.7.5) and (2.7.6) can be used to estimate the parameters σ_X and m_X for the lognormal distribution given in Equation (2.7.4). It can be shown that the median of the lognormal random variable C is equal to $\exp(m_X)$.

The first step in fitting a probability distribution to the cost data was performed by obtaining the histograms of the structural cost for each of the fifteen FEMA building model types. These building model types are given in Table 1.2.1 in Volume I of this report. The structural cost histograms are shown in Figures 2.7.1(a) and 2.7.1(b). The suitability of using the lognormal model for the cost data was studied by taking the logarithm of the cost data for these fifteen FEMA building model types and plotting their histograms. The histograms of the logarithm of the cost data are shown in Figures 2.7.2a and 2.7.2b. For these four figures, the histograms are shown as bars and also shown on the plot are the probability density function curves of the lognormal distribution based on parameters obtained from Equations (2.7.5) and (2.7.6) and the statistical mean and standard deviation for that building model type. It can be seen that the lognormal model is indeed a suitable model to represent the probabilistic behavior of the cost data and this was used in setting the parameters for the control and elimination of anomalous cost data.

The fundamental concept used in the elimination of anomalous cost data was that those buildings which lay outside a defined typical range of costs should be reviewed again to make sure the costs were accurate. Groups were sorted by zone, performance objective and building model type as these parameters typically have the most influence on costs. Figure 2.7.3 shows the procedure used for the development of the typical cost data set at this stage of the process. When evaluating the parameters for the lognormal distribution, one can use either the mean and the standard deviation of the cost data or the median and the coefficient of variation. One of the main advantages in using the median instead of the mean is that the median is relatively unaffected by changes in the tails of the distribution. Further, it was felt that cost data which had a coefficient of variation (denoted C.O.V) of greater than 50% was not acceptable for the analysis. Figure 2.7.4 shows the lognormal distributions for coefficients of variation of 50% and 100%. Based on the engineering experience of the consultants with other random variables in structural engineering, the coefficient of variation of the cost data was set at 50%. Using these two assumptions, the parameters of the lognormal distribution were computed for each data subset. Once the lognormal distribution curves were computed, the 2.5% and 97.5% percentiles for the data set were defined. This process is shown in Figure 2.7.5. All data lying outside this range (i.e. 5 percent of the total data set) were assumed to be anomalous. These screened data points were then sent back to the engineers for a re-evaluation. This re-evaluation was conducted by either conversations with the respondents in question or by a careful evaluation of the cost data sheet submitted for that point. From this re-evaluation, cost data points were either accepted or rejected.

Only in cases where the data was clearly in error were the records deleted from the database. It was believed that it was better to keep as much data in the database as possible, as anomalous entries at this point in the quality control process had already been checked twice for correctness. Less than 50 buildings were eliminated in this quality control step. The remaining buildings were then considered to be part of a data set that did not show unusual behavior in terms of its spread. This is because the objective of the cost study implicitly assumes that costs are influenced by a host of factors, some of which cause increases and some reductions. However, no trend can justify outliers in the data and, thus, this quality control step was necessary.

2.8 QUALITY FACTORS

The final step in the data collection process was to rate the quality of each record. While all the data at this stage had been checked for accuracy, it was believed by the project team that certain parameters related to the studies themselves which produced each record might make some data more valuable than others. The objective of the data review was to not eliminate any data except that which lacked so much information as to not be useful. To identify the most accurate cost data a quality factor was calculated for each building cost data point. The values of the quality factor ranged from 1 to 10 with 1 being the least accurate and 10 being the most accurate. The parameters which were determined to be the most important as it relates to a rating of the quality of the data were: the date of the cost data, the source of the cost information and the overall quality and consistency of the data. A point value was assigned to each of these parameters and the total summed for each cost data point to give the overall quality rating of that piece of cost data.

Date of the Study's Cost Estimate

Building codes have naturally developed over the years as engineers have become more familiar with earthquakes and the earthquake induced performance of buildings. For example, the year 1933 was a key year in masonry building construction because it marks the practical end of unreinforced masonry building construction in high seismic areas. Two other dates stand out as representing points of significant change in seismic design criteria and learning from earthquakes. In 1973, following the 1971 San Fernando Earthquake, engineers became more cognizant of the types of design which generally behaved well and those which behaved poorly in earthquakes. Significant first steps were made at this point, at least unofficially, to develop codes which looked beyond life safety to the functionality of buildings after a major earthquake. In 1987, as a result of the NEHRP program, a number of documents were produced which looked in greater detail at the design of buildings. Many of the provisions of these documents, including detailing, ductility, inelastic behavior and site specific dynamic response were incorporated into the later codes in an attempt to further refine the design process.

Based on this general characterization of a state of knowledge about how buildings perform in earthquakes, the project team members assigned the following rating to each cost data value according to the date of its cost study or construction:

DATE	RATING
BEFORE 1973	1 POINT
BETWEEN 1973 AND 1987	2 POINTS
AFTER 1987	3 POINTS

Source and Certainty of Cost Data

The source of the cost data was rated and given a value between zero and four points. All of the cost data used in this report were obtained from detailed structural engineering studies of buildings or from actual construction. Both can be valuable although one would expect the latter to be more accurate. The Data Collection Guidelines included space for the contributor to rate his or her confidence in the cost information provided. Based on this information, the project members assigned the following point values:

SOURCE	CONFIDENCE	POINT VALUE
UNKNOWN	POOR	0 POINTS
STUDY	POOR	1 POINT
STUDY	FAIR OR GOOD	2 POINTS
ACTUAL	POOR	2 POINTS
ACTUAL	FAIR	3 POINTS
ACTUAL	GOOD	4 POINTS

Quality and Consistency of the Data

The quality and consistency of the data was the factor with perhaps the most potential for subjectivity. In many instances, information provided for particular buildings or groups of buildings was sporadic and incomplete. Older or general studies of large groups of buildings often contained less information. The project members believed that the familiarity and experience with seismic rehabilitation of the person filling out the Guidelines form would, in general, affect the quality of the data. So that no single one of these characteristics would weigh too heavily on the point value given to this factor, the following procedure was used: seven characteristics were developed by which each record would be rated, either with a 1 (positive) or a 0 (unknown or negative). To be the most objective, the project members generalized where possible. These characteristics are explained below.

Were the Guidelines forms complete and clearly filled out?
Poorly filled out forms are expected to provide less accurate cost data than complete ones.

Did the person or office submit many records or only a few?
The project members believe that those individuals submitting data on many buildings would typically have been more familiar with seismic rehabilitation.

Were the reports from which the Guidelines forms were prepared specific and complete?
Often, when many buildings were analyzed by a firm for a single study, the only information available to the person filling out the Guidelines worksheet was in summary form. The project members

believed that the accuracy of such summaries was more difficult to verify than if a full and detailed report had been provided for each building.

Was the engineer located in a region of high seismicity?
The project members believed being located in a high or very high seismic location was an advantage and more accurate cost data could be expected because many more buildings have been seismically rehabilitated in these regions.

Was the person or office submitting the forms a member of the Project Advisory Panel?
Several people were selected to be on a Project Advisory Panel. Each was responsible for submitting data on rehabilitation projects with which he or she was familiar. The team believed that as members of the panel, these individuals would have the most clear and detailed knowledge of the information which was required.

Is the person filling out the Guidelines form a registered structural engineer?
In general, it was believed that being a registered structural engineer was an advantage because of the type of information required by the Guidelines forms.

Is the person or firm submitting the information well recognized in the earthquake engineering profession?
Professional recognition by the project members was believed to indicate past professional contributions or activity, and thus, better cost data.

Based on the total point value obtained from this list of characteristics (0-7), a rating was given for the consistency parameter as follows:

SUM OF CHARACTERISTICS	RATING
0-1	0 POINTS
2-3	1 POINT
4-5	2 POINTS
6-7	3 POINTS

Each of the cost data points has been given three ratings : for the date of the study's cost estimate, for the source and certainty of cost data and for the source and consistency of cost data. These three ratings were summed to give an overall factor for that cost data point which could vary between 1 and 10. This overall quality factor was used to develop the Super Database which is described in detail in Chapter 4.

FEMA - Data Collection Guideline | DO NOT USE| field number: C E V

A. Contributor ______________________ Phone ______________ Date ________

B. Building Identification (optional) ______________________

C. Site Location (county,state) ______________________ zone (if changed) ________

D. NEHRP/UBC Soil Type: S1__ S2 __ S3 __ S4__

E. Number of stories: above grade ________ below grade ________

F. Total Area (sq. ft.): ______________(see U.)

G. Approximate Year of Original Construction ________

H. Model Building Type: (before rehabilitation)

- wood light frame .... W1 __
- wood (commercial or industrial) .... W2 __
- steel moment frame .... S1 __
- steel braced frame .... S2 __
- steel light frame .... S3 __
- steel frame with concrete shear walls .... S4 __
- steel frame with infill shear walls .... S5 __
- concrete moment frame .... C1 __
- concrete shear walls .... C2 __
- concrete frame with infill shear walls .... C3 __
- precast concrete tilt-up walls .... PC1 __
- precast concrete frame with concrete shear walls .... PC2 __
- reinforced masonry w/ metal or wood diaphragm .... RM1 __
- reinforced masonry w/ precast concrete diaphragm .... RM2 __
- unreinforced masonry .... URM __
- other (please describe): ______________________

N. Occupancy Classification:

- assembly .... A __
- factory/industrial/warehouse .... F __
- institutional/educational .... I __
- residential .... R __
- commercial/office .... C __
- parking .... P __
- retail/mall .... M __
- other: ______________

O. Performance Objective:

- risk reduction .... RR __
- life safety .... LS __
- damage control .... DC __
- immediate occupancy .... IO __

P. Rehabilitation Method(s):

- added shear walls .... SW __
- added braced frames .... BF __
- added moment frames .... MF __
- modified existing walls .... EW __
- modified existing frames .... EF __
- isolation .... IS __
- added damping .... AD __
- strengthened diaphragm .... SD __
- strengthened foundations .... SF __
- parapet bracing .... PB __
- URM or tilt-up wall ties .... WT __
- strengthened soft-story only .... SS __

I. Historic building controls: YES__ NO__

J. BASE YEAR for cost: __________

K. TOTAL CONSTRUCTION COST: $ ______________ (see U.)

L. Source of cost: actual construction(AC) ___ study(S) ___

M. <u>Overall scope of non-seismic work</u>:

- minimum work required .... MIN ___
- additional improvements .... ADD ___
- complete renovation of interior .... COM ___
- added space (please give sq.ft.) ________

Q. <u>Non-seismic work included in total construction cost</u>:

- asbestos/hazardous material removal ..... YES __ NO __
- disabled access .... YES __ NO __
- system improvements (arch., M.E.P.) .... YES __ NO __
- repair of damage/deterioration .... YES __ NO __
- other: ______________________

R. <u>Condition of occupancy</u>:

occupants-in-place(IP)___ occupants temporarily removed(TR)___ vacant(V)___

S.

Scope of seismic rehabilitation work:	Not Evaluated(NE)	Evaluated and OK(OK)	Included in Cost(I)
1 Structure			
2 Exterior falling hazards			
3 Selected interior nonstructural			
4 All interior nonstructural			

T. STRUCTURAL COST (total of items 1 & 2 in S. including contractor's overhead & profit): ____________ (see U.)

U.

Estimate of uncertainty in data provided:	< 5% (G)	5-10% (F)	> 10% (P)
Area (see F.)			
Total Construction Cost (see K.)			
Structural Cost (see T.)			

<u>Additional information to be provided (if available)</u>:

V. Non-Construction Project Costs:

- occupant relocation .... ________
- A & E fees,testing, permits .... ________
- project management .... ________

W. Duration of Construction (months) ____________

X. Construction Costs ($ or % of cost in K.):

- repair of damage/deterioration .... ________
- hazardous material removal .... ________
- disabled access .... ________
- system improvements .... ________
- nonstructural mitigation .... ________

Figure 2.2.1

Y. Plan Shape: ▯ (R)__ L(L)__ E(C)__ ▣(O)__ Other(OT):______ Z. Base Dimensions:________________
AA. Typical Floor Plan Dimensions:______________ BB. Story Height:________ CC. Total Height:________

DD. Roof/Floor Framing (2nd Floor +): R F
- wood joists/gluelams .... W__ __
- truss joists/timber trusses .... TT__ __
- steel beams .... S__ __
- concrete beams .... C__ __
- flat slabs .... FS__ __
- other (please describe):____________________

EE. Diaphragms:
- wood (sheathing or plywood) .... W__
- metal deck w/ concrete fill .... MDF__
- metal deck w/o concrete fill .... MD__
- cast-in-place concrete .... C__
- precast concrete .... PC__
- steel truss .... ST__
- other (please describe):____________________

FF. Exterior Non-Load Bearing Cladding:
- curtain wall .... CW__
- precast .... PC__
- masonry .... M__
- other (please describe):____________________

GG. Evidence of Settling: .... YES__NO__

HH. Condition of Bldg: ... Good__ Fair__ Poor__

II. Columns/Bearing Walls: C BW
- timber .... W__ __
- concrete .... C__ __
- steel .... S__ __
- precast concrete .... PC__ __
- reinforced masonry .... RM__ __
- unreinforced masonry .... URM__ __
- other (please describe):____________________

JJ. Foundations:
- spread footings .... SF__
- concrete mat .... M__
- piles/caissons .... P__
- other (please describe):____________________

KK. Longitudinal Lateral System:
- moment frames .... MF__
- braced frames .... BF__
- shear walls .... SW__
- other (please describe):____________________

LL. Transverse Lateral System:
- moment frames .... MF__
- braced frames .... BF__
- shear walls .... SW__
- other (please describe):____________________

MM. Code or Design Guideline Used for Rehabilitation:____________________________

NN. Special Features (irregularities, interior partitions, etc.):____________________________

OO. Rehabilitation Work Completed (please describe):____________________

PP. Schematic Sketch of Building Plan:

Figure 2.2.2

Guideline Notes:

C. Location of building. Indicate seismic zone used for rehabilitation if it has been changed since the date of the rehabilitation project.

D. Soil profile type based on either NEHRP Handbook for the Seismic Evaluation of Existing Buildings (FEMA 178) or the Uniform Building Code.

E. Include new stories that were added.

F. Total area is the total square footage of the building including basements and added space.

H. Model building type is based upon the fifteen building types described in the NEHRP Handbook (FEMA 178). This applies to the original building, not the structural system used for rehabilitation.

I. Historic building controls refers to whether or not special consideration was taken for preserving the historic character of the building.

J. Base year for costs is the bid date for construction or the year used for the cost estimate in the study.

K. The total construction cost is the bid amount or the cost estimate from a detailed seismic study including the contractor's overhead, profit, and contingency costs. Also include change orders if known to add significant cost. If the cost due to change orders is unknown, indicate this in item U. Not included in this cost are the costs shown in item V.

L. Source of total construction cost is either an actual rehabilitation project which has been completed or an estimate from the study of the projected rehabilitation of a particular building. A study is a schematic design of a specific building. A study does not include a "cost per square foot" study as in FEMA 156/157 or a cost estimation based on the rapid screening process described in FEMA 154.

M. Overall scope of non-seismic work is divided into three categories: 1) minimum work is doing "just enough" to satisfy local code requirements; 2) moderate improvements are those done voluntarily without doing a 3) complete renovation of the interior, which implies that the seismic rehabilitation work does not increase the level of architectural work which is already a major portion of the project. Added space refers to additional stories or expansions of the bldg space.

N. Occupancy classifications are as follows:
- assembly - theatres, churches, or other assembly buildings.
- industrial/factory/warehouse - factories, assembling plants, industrial laboratories, storage, etc.
- institutional/educational - schools, hospitals, prisons, etc.
- residential - houses, hotels, and apartments.
- commercial/office - all buildings used for the transaction of business, for the rendering of professional services, or for other services that involve limited stocks of goods or merchandise.
- parking - parking garages or structures.
- retail/mall - retail stores or shopping malls.

O. The performance objectives are:
- risk reduction - rehabilitating parts or portions of a structure without considering the entire structure for life-safety or greater performance.
- life-safety - allows for unrepairable damage as long as life is not jeopardized and ingress or egress routes are not blocked.
- damage control - protect some feature or function of the building beyond life-safety, such as protecting building contents or preventing the release of toxic materials.
- immediate occupancy - minimal post-earthquake damage and disruption with some nonstructural repairs and cleanup

P. Rehabilitation method used for building.

Q. Non-seismic work included in total construction cost are those items which do not improve the seismic performance of the building. These may have been "triggered" by the seismic work or done voluntarily. The third item refers to architectural improvements, as well as mechanical, electrical, or plumbing (M.E.P.) improvements.

R. Condition of occupancy is the location of the occupants during the construction.
- occupants-in-place - work is scheduled around normal hours of occupancy
- occupants temporarily removed - occupants are moved to another room in the building during construction
- vacant - the building is completely vacated during construction

S. Scope of seismic rehabilitation work refers to any items which were rehabilitated: the main structure, exterior falling hazards such as precast panels and parapets, or interior elements such as equipment and light fixtures.

T. Structural cost is the cost of the construction of the structural elements necessary to rehabilitate the building and reduce exterior falling hazards. This cost includes the contractor's overhead and profit. It does not include items such as demolition and replacement costs for architectural finishes or M.E.P. systems. If the exact figure is not known, please approximate.

U. The estimate of uncertainty relates to the data collection process (not the uncertainty inherent in a cost estimate or study). If the area and/or costs provided are guesses, indicate >10% uncertainty. If the data is documented or recollection is very accurate, indicate <5%.

V. Non-construction project costs should be provided as an amount or percentage of the total construction cost for each of the items presented.

W. Please estimate duration of rehabilitation project.

X. Additional components of the construction cost. Please provide an amount or percentage of the total construction cost for each of the items presented.

Figure 2.2.3

Existing Standards and Performance Objectives

Existing Standard	Equivalent Performance Objective	Specific Concern of Standard
ATC-22/ATC-26-1	Life Safety	①Protect occupants and general public
ATC-14	Life Safety	①
'90 BOCA National Bldg. Code	Life Safety	①
CA Title 24 - Hospitals	Immediate Occupancy	②Use of building immediately following EQ
CA Title 24 - Schools	Damage Control	③Protect occupants that are not fully able to help themselves
FEMA 178	Life Safety	①
FEMA 95 - New Buildings	Damage Control	④Minimize the hazard to life in all buildings
GSA Seismic Design Manual	Damage Control	⑤Resist a minor earthquake without damage Resist moderate earthquake without structural damage but with some nonstructural damage Resist a major earthquake with damage but without collapse
H-08-8 (VA) - Hospitals	Immediate Occupancy	②
H-08-8 (VA) - most other buildings	Damage Control	⑤
City of Long Beach - Existing Bldgs.	Life Safety	①
Massachusetts State Code	Life Safety	①
Site Specific Response	Life Safety	①
Site Specific Response	Damage Control	⑤
Site Specific Response	Immediate Occupancy	②
SBCC Southern Bldg. Code	Life Safety	①
DOD Tri-Services - Essential Buildings	Immediate Occupancy	②
1992 Tri-Services Manual	Damage Control	⑤
'88,'91 UBC (I=1.0)	Damage Control	⑤
'88,'91 UBC (I=1.25)	Immediate Occupancy	②
<'88 UBC	Life Safety	①
UCBC	Life Safety	①
DOE-STD-1020-92 Moderate & High	Immediate Occupancy	⑥Use of building immediately following EQ and containment of hazardous materials
DOE-STD-1020-92 Low & General Use	Damage Control	⑦Protect occupants and prevent release of hazardous materials

For questions concerning the Data Collection Guideline, please call H.J. Degenkolb Associates, (415) 392-6952 (Jeff Soulages)

Please return the completed Guidelines to:

Jeff Soulages
H.J. Degenkolb Associates
350 Sansome St. #900
San Francisco, CA 94104

FAX # (415) 981-3157

Figure 2.2.4

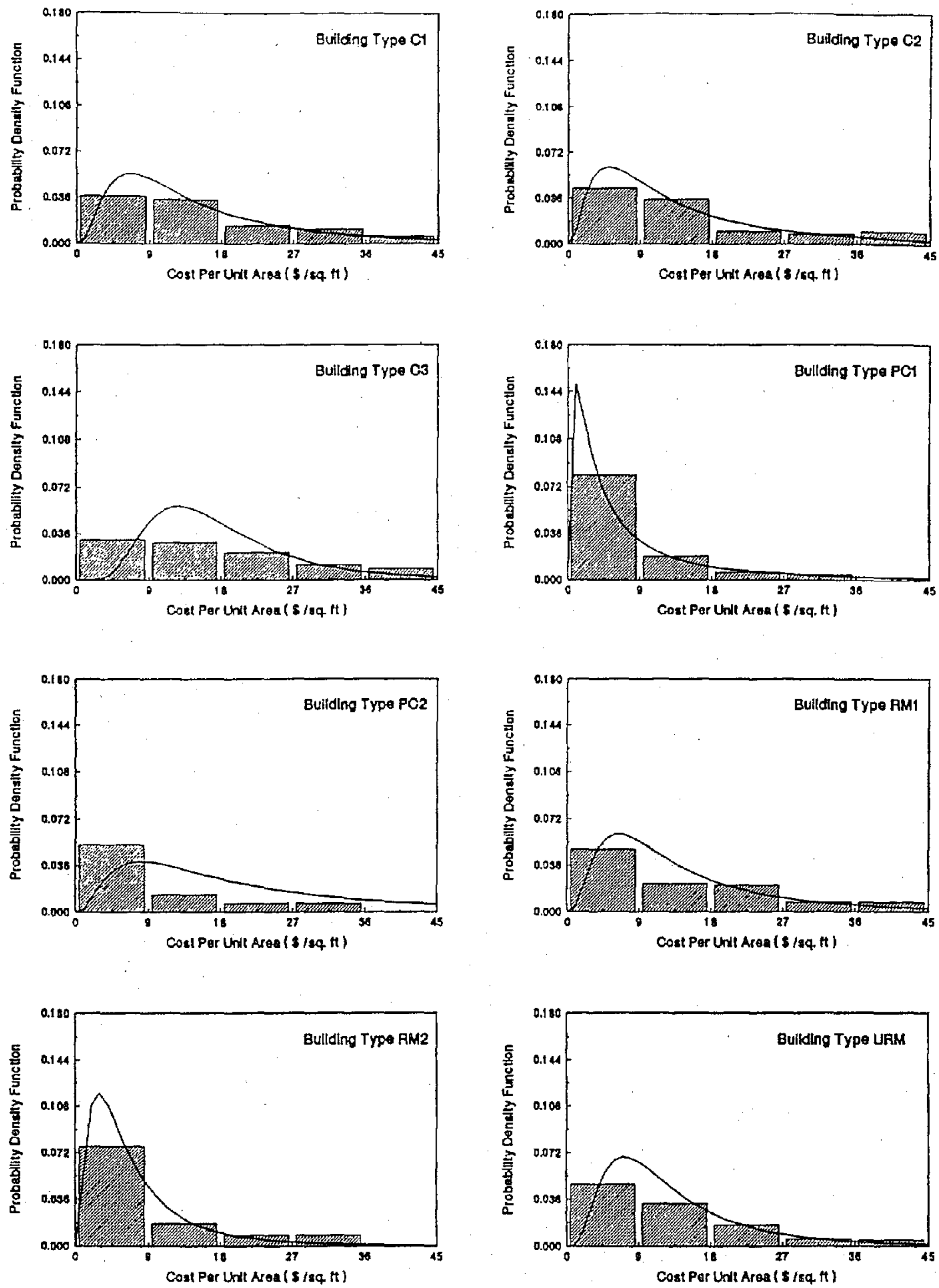

Figure 2.7.1 a Histogram of Cost for Building Types and Lognormal Fitting

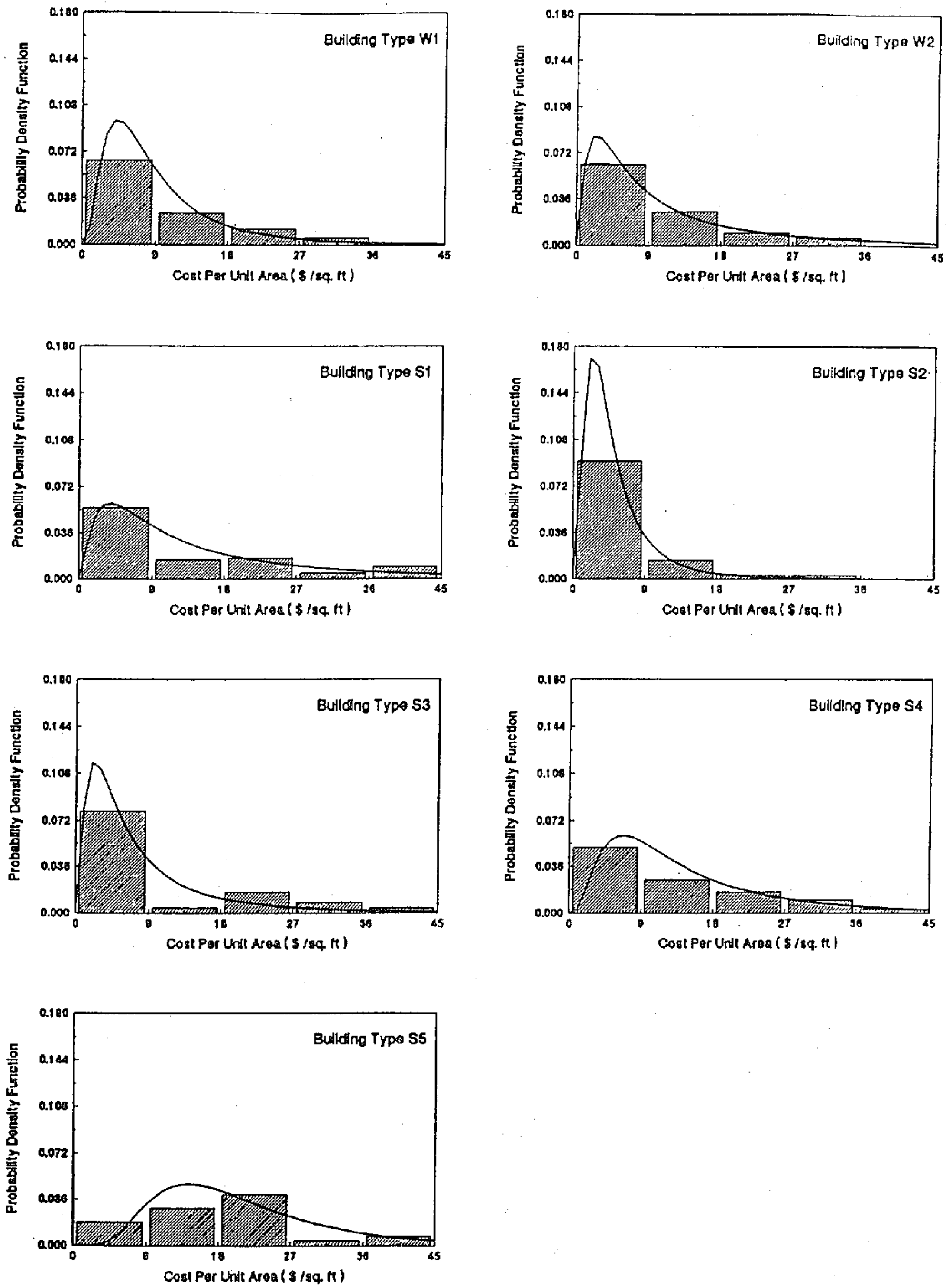

Figure 2.7.1b Histogram of Cost for Building Types and Lognormal Fitting

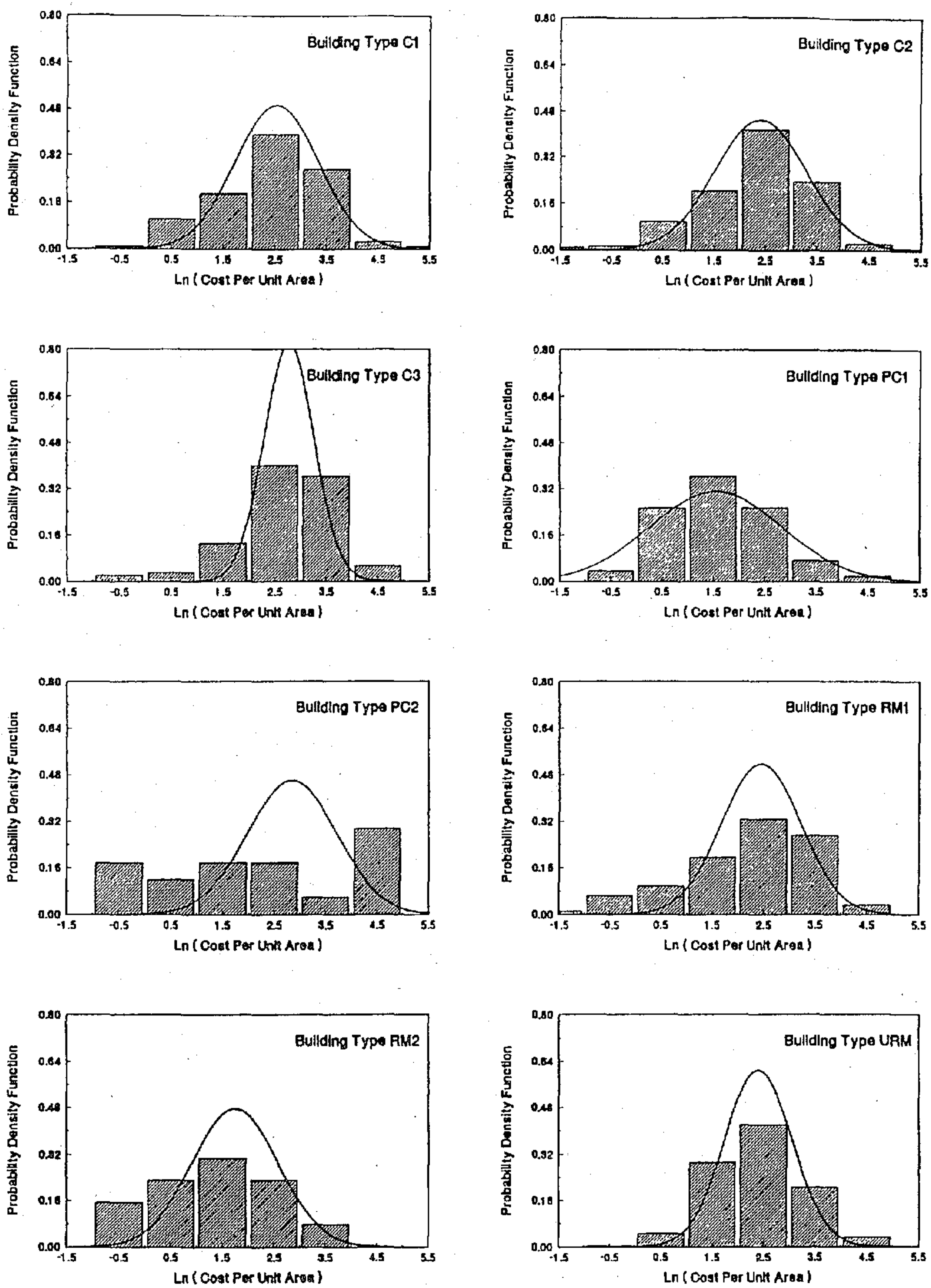

Figure 2.7.2a Histogram of Ln(Cost) for Building Types and Normal Fitting

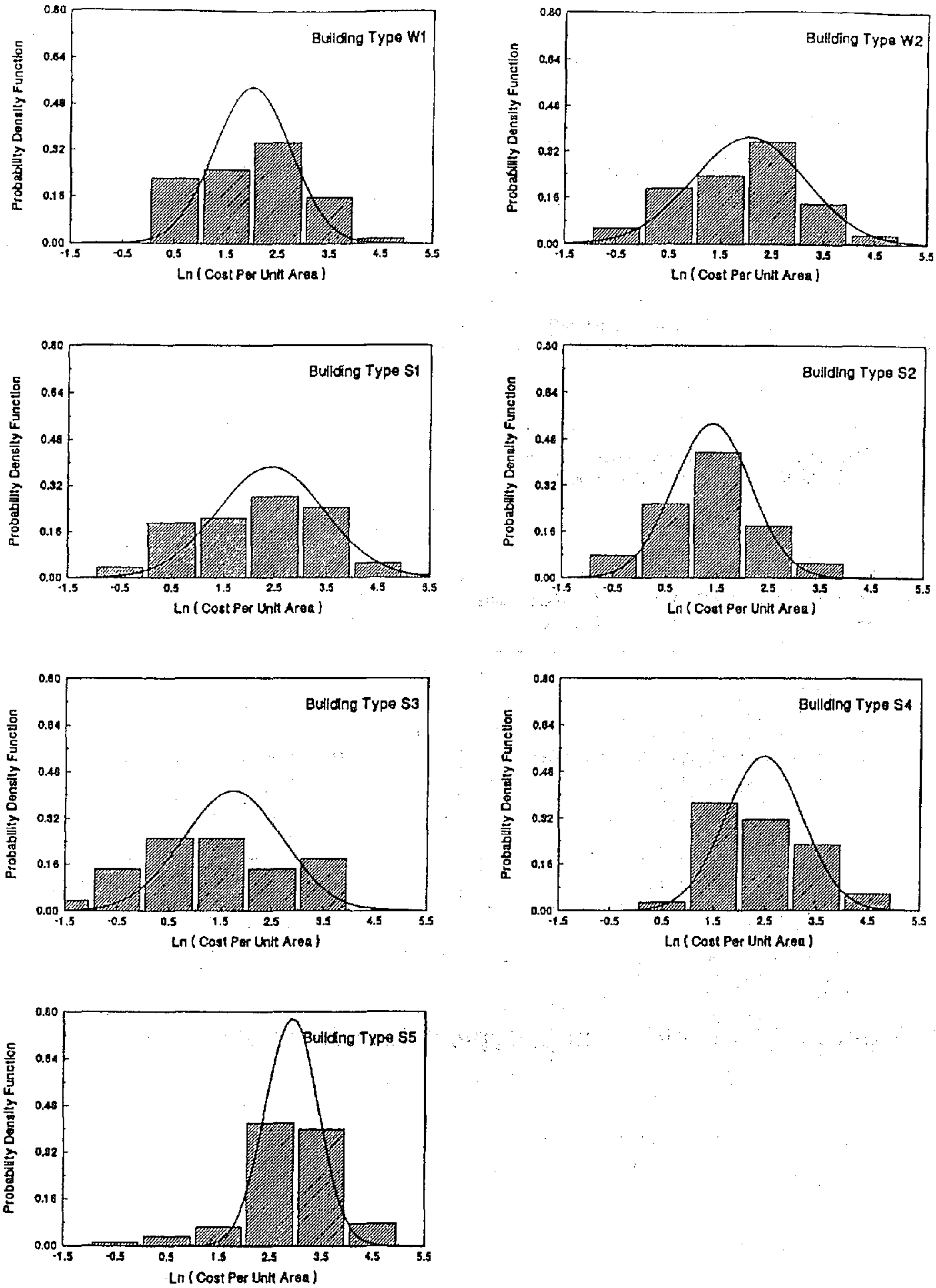

Figure 2.7.2b Histogram of Ln(Cost) for Building Types and Normal Fitting

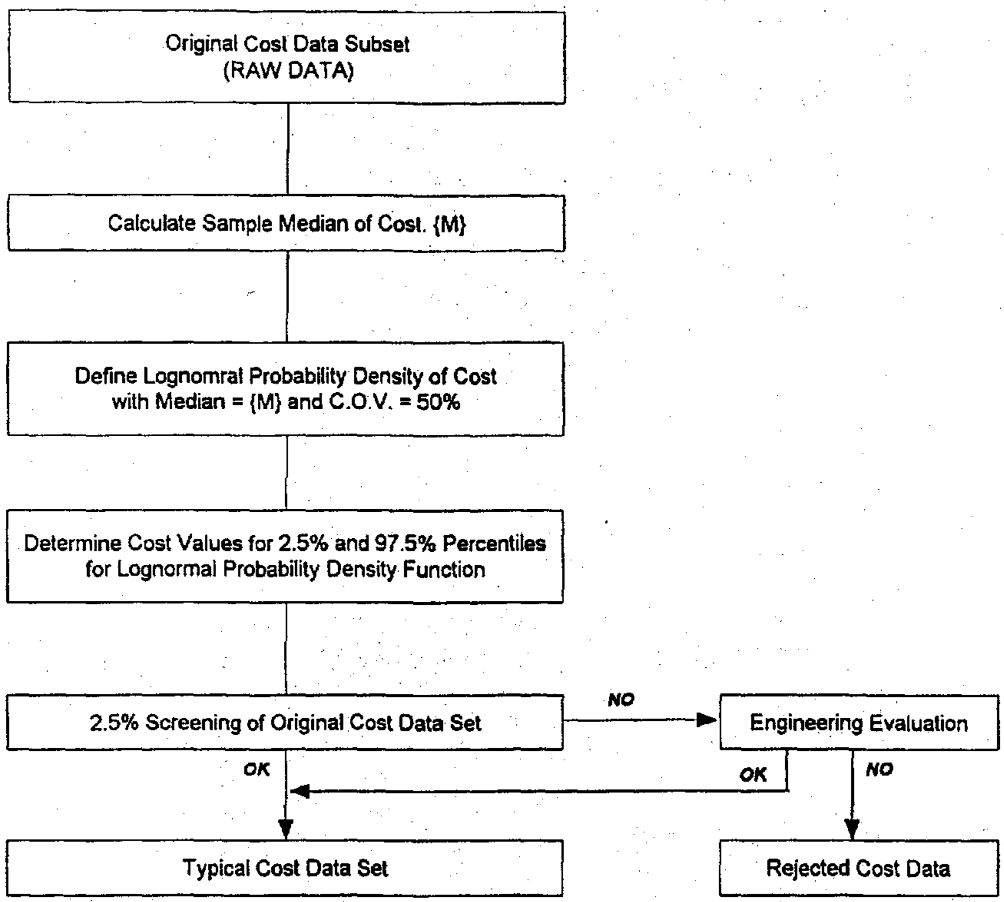

Figure 2.7.3 Development of Typical Cost Data Set

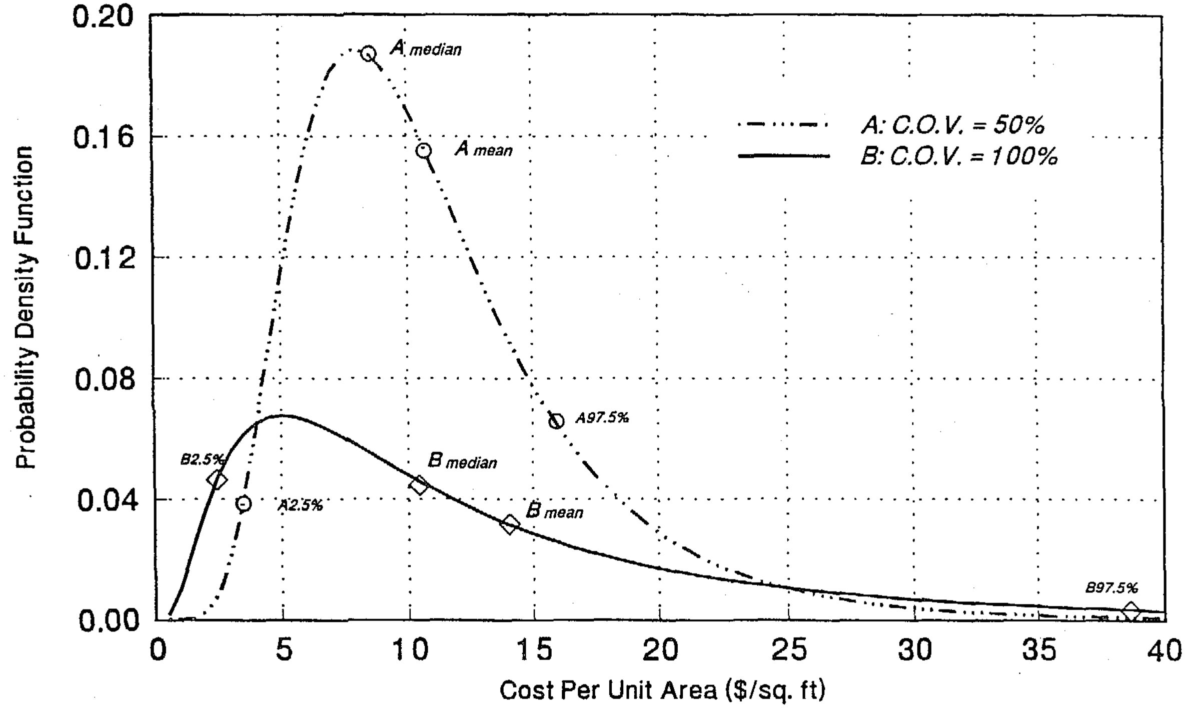

Figure 2.7.4 Probability Density Function of Cost for 50% & 100% C.O.V.'s

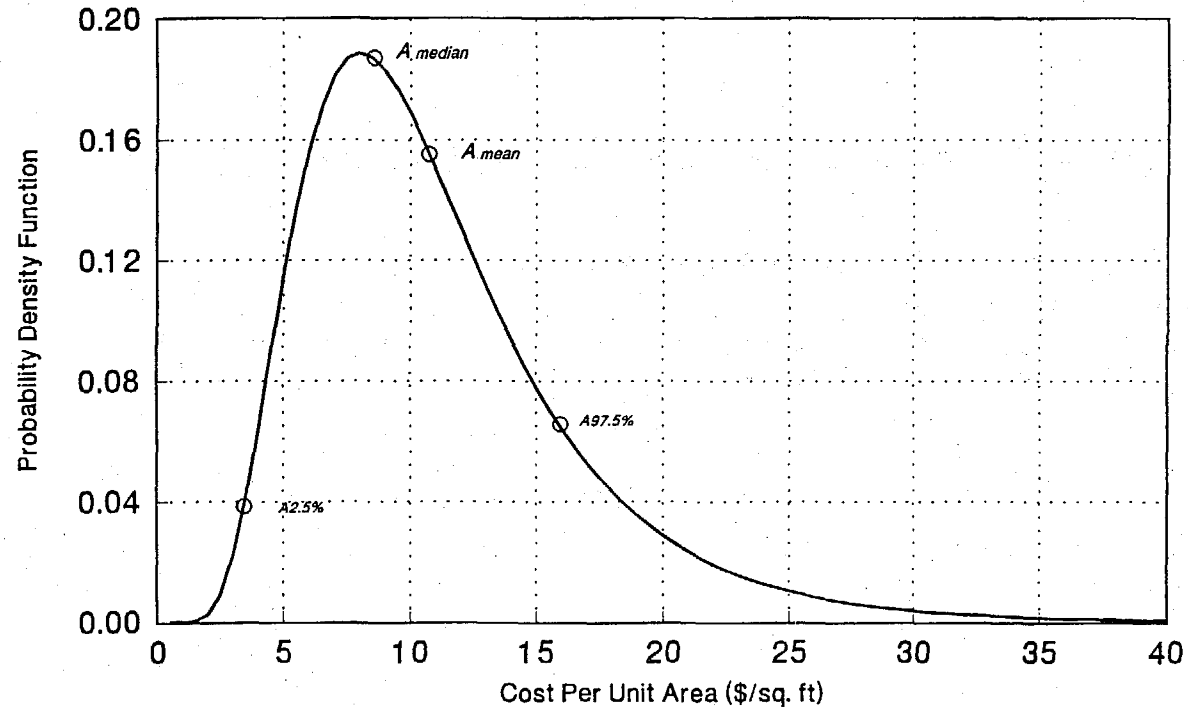

Figure 2.7.5 Probability Density Function of Cost for 50% C.O.V.

CHAPTER 3
DIVISION OF DATA INTO BUILDING GROUPS

3.1 GENERAL

The structural cost database classified each cost data point with one of the 15 FEMA building model types. These building model types are shown in Table 1.2.1 in Volume I of this study. For ease of analysis, it was assumed that some of these 15 building groups would behave similarly with respect to cost data. Grouping these together would result in a smaller number of building groups for use in the typical cost analysis. The objective of the data division procedure was to develop a rational and justifiable procedure for reducing the number of building groups.

Each building group chosen contains one or more of the FEMA building types. Each FEMA building type was first assigned to a building group based on a structural engineering judgment of the dominant type of lateral force resisting components. A detailed statistical analysis based on probability density functions of cost was then performed. Using the results of this statistical analysis, each FEMA building type either remained in the group it was first assigned to or was reassigned to a new group.

The procedure used in grouping the FEMA building types into different building groups was based on a comparison of the statistical behavior of the structural costs for these building groups. A Probability Density Function (PDF) of cost was created for each building group for every combination of Seismicity and Performance Objective. The PDF helps in visualizing the distribution of costs and is an important tool in judging if the costs for different FEMA building types behave similarly for various combinations of Seismicity and Performance Objectives. The analysis procedure is described in the following sections of this chapter.

3.2 HISTOGRAM AND PROBABILITY DENSITY FUNCTIONS OF COST

The first step in classifying the different building groups was to plot the histogram and the probability density function of the structural costs for the Life Safety Performance Objective and for buildings located in an area of very high seismicity. The probability density functions are shown in Figures 3.2.1 and 3.2.2 and the histograms are shown in Figures 3.2.3 and 3.2.4. It can be seen that some of the groups lend themselves to immediate grouping based on the closeness of their mean values as well as the total spread of the cost data. Although the figures shown are for a single level of Performance Objective, it was found that the curves did not vary significantly for the purposes of grouping the buildings if all the data were combined together. Accordingly, based on the histograms and the PDF curves, eight different building groups were created and are noted in the following section.

3.3 PROPOSED GROUPING OF BUILDING TYPES

The original cost data obtained from the data collection process was sorted into eight groups as shown in Table 3.3.1. The process is also shown graphically in Figure 3.3.1.

When the FEMA building categories were being assigned to the eight new building groups, the following criteria were used:

1) Do the statistical parameters of the various FEMA categories included in the building group lie close together?

2) Are there any engineering reasons for assuming that the costs for these categories would behave similarly? Such reasons could be based on past experience with seismic rehabilitation projects, theoretical reasons based on the similarity in the kind of rehabilitation techniques used for such buildings etc.

The process of combining the fifteen FEMA building model types into the eight building groups started with a study of the histogram of various combinations of these building model types. The probability density functions for the two building model types in the proposed Group 4 (Concrete Frames - C1, and Concrete Frames with Infills - C3) are shown in Figure 3.3.2. For each of these building model types, two cases are shown : with all cost data points and with cost data points from high Seismicity and Life Safety Performance Objectives only. The value of the mode (cost corresponding to the peak of the probability density function) of the cost data is quite close and so is the overall spread of the probability density function except at the upper tail values. Figure 3.3.3 shows the comparison between the probability density functions for the entire building group 4 (C1 and C3 model types combined) for two cases : all cost data points and only those data points corresponding to very high seismicity and life safety performance objectives. The probability density functions are seen to be very similar. It may also be noted that standard rehabilitation techniques for concrete frames and concrete frames with infills are not significantly different.

Similar probability density functions were computed for all of the cost data for the fifteen FEMA building model types. The comparison was performed between different building groups using all possible combinations of Seismicity and Performance Objectives (a total of twelve). The results were evaluated using a combination of statistical tools and engineering judgment as described in the two criteria used in the grouping process. The results of this analysis were the eight building groups shown in Table 3.3.1. The probability density functions and histograms of cost for these eight building groups are shown in Figures 3.3.4 and 3.3.5.

The advantages of this type of grouping of the cost data are twofold :

1) The total number of statistical calculations required is lowered.

2) The information obtained from this analysis will help engineers study the similarities and dissimilarities in the cost behavior of building structural systems.

The grouping of cost data into eight groups also helps to simplify the analysis required by the user who may not be an engineer.

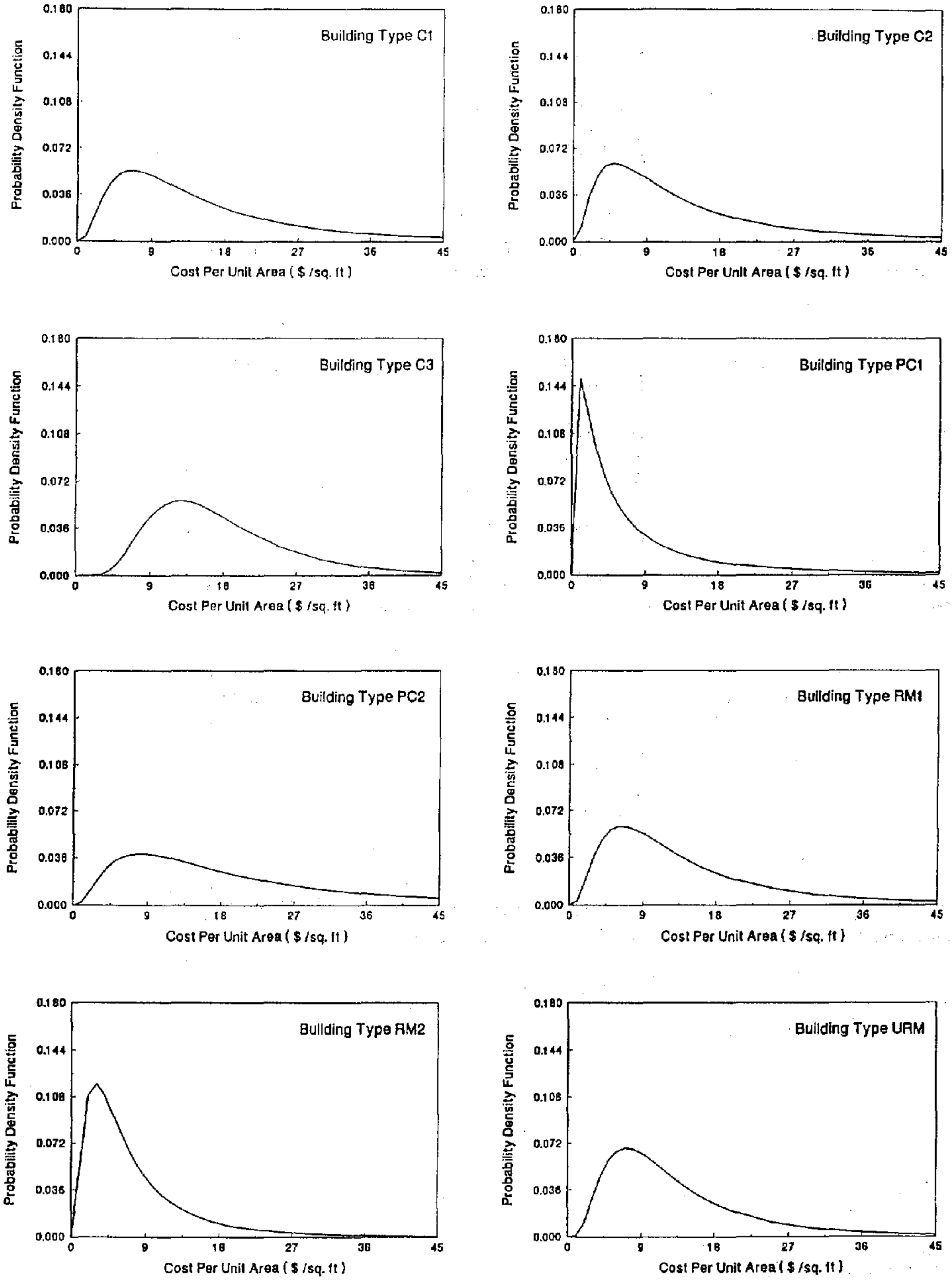

Figure 3.2.1 Probability Density Function of Cost for Building Types

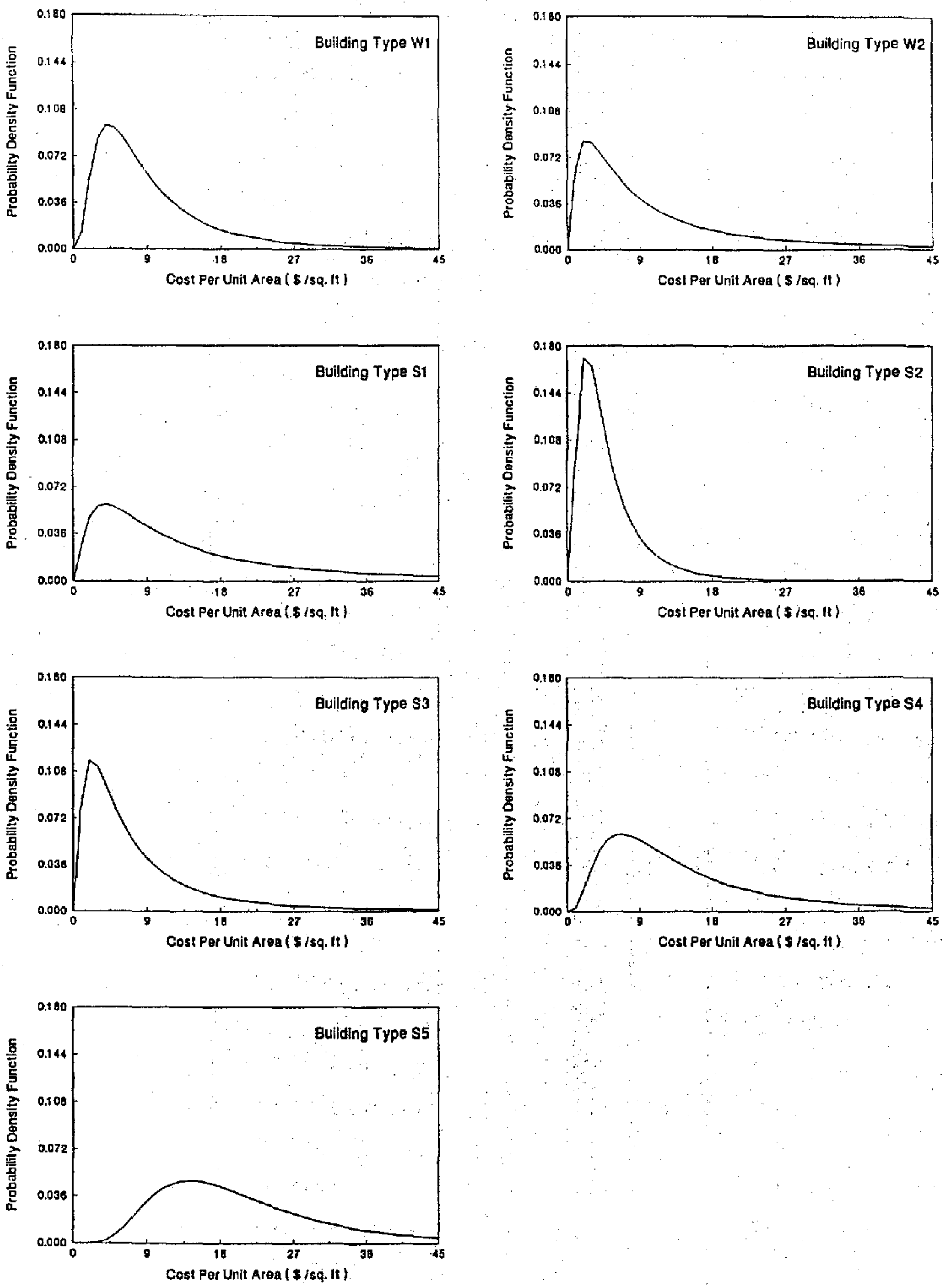

Figure 3.2.2 Probability Density Function of Cost for Building Types

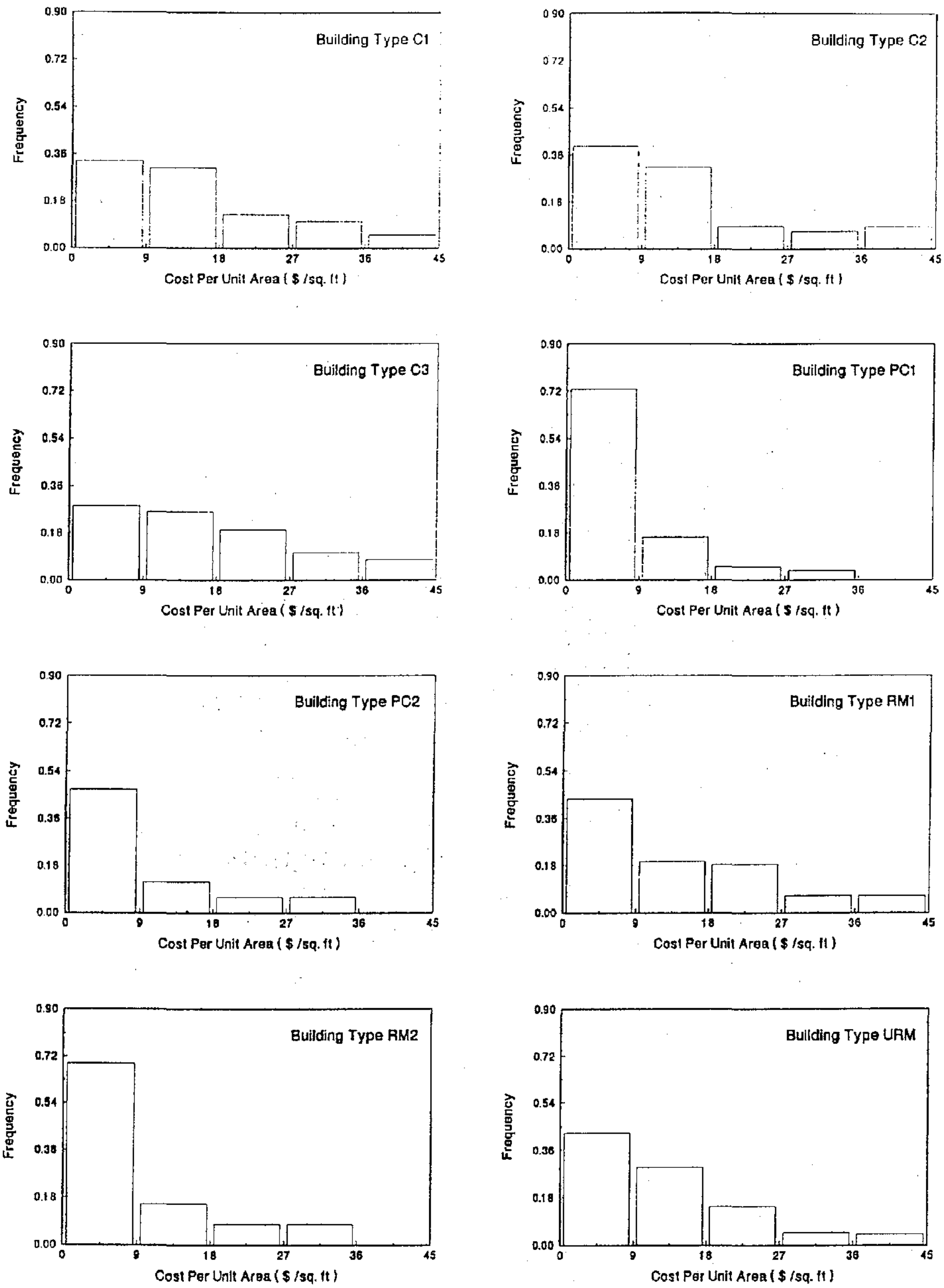

Figure 3.2.3 Histogram of Cost for Building Types

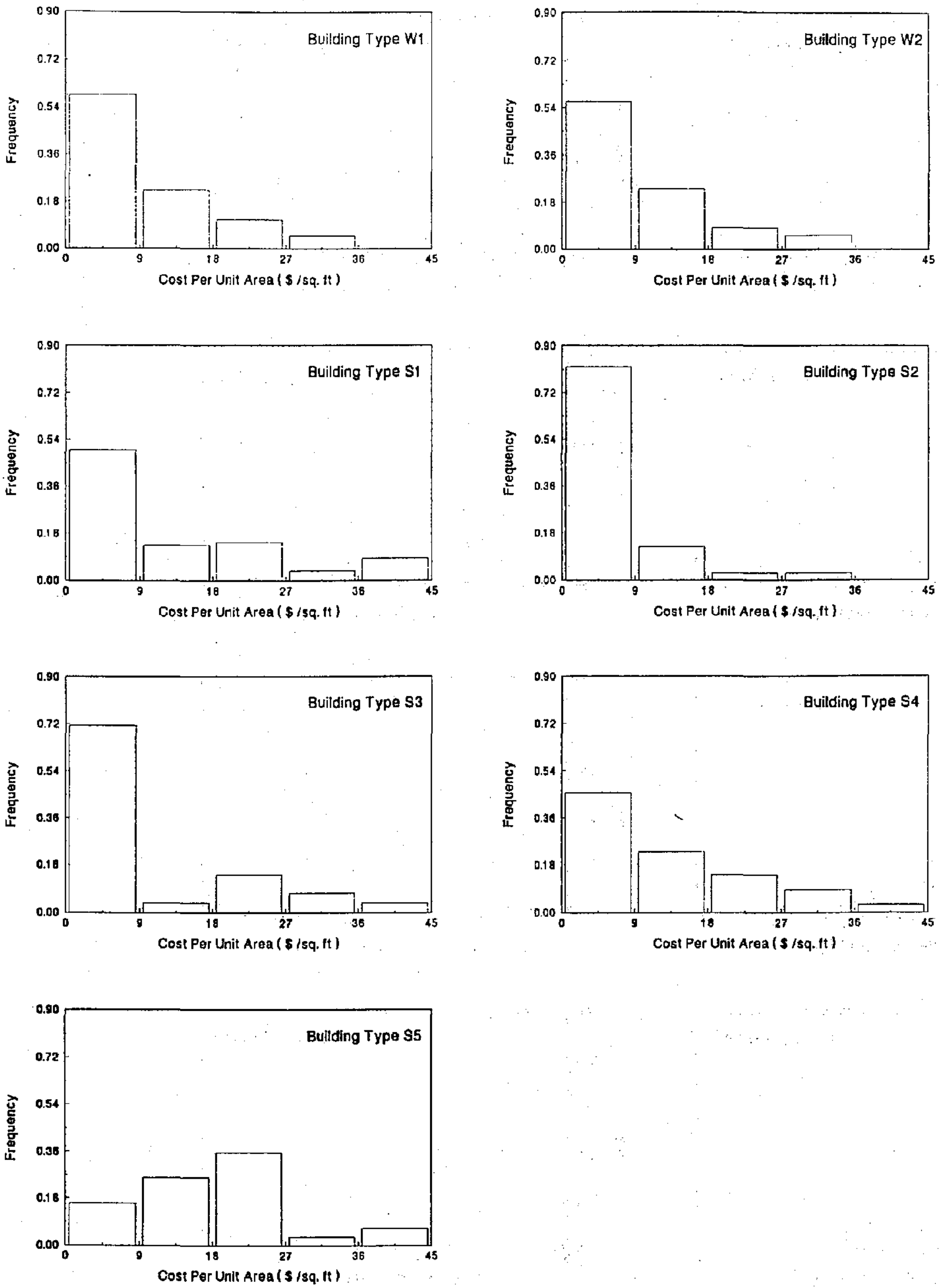

Figure 3.2.4 Histogram of Cost for Building Types

TABLE 3.3.1 FEMA BUILDING MODEL AND BUILDING GROUP TYPE

BUILDING GROUP	MODEL	FEMA 178 BUILDING TYPES
1	URM	Unreinforced Masonry
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)
3	PC1 RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphram
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls
5	S1	Steel Moment Frame
6	S2 S3	Steel Braced Frame Steel Light Frame
7	S5	Steel Frame with Infill Walls
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls

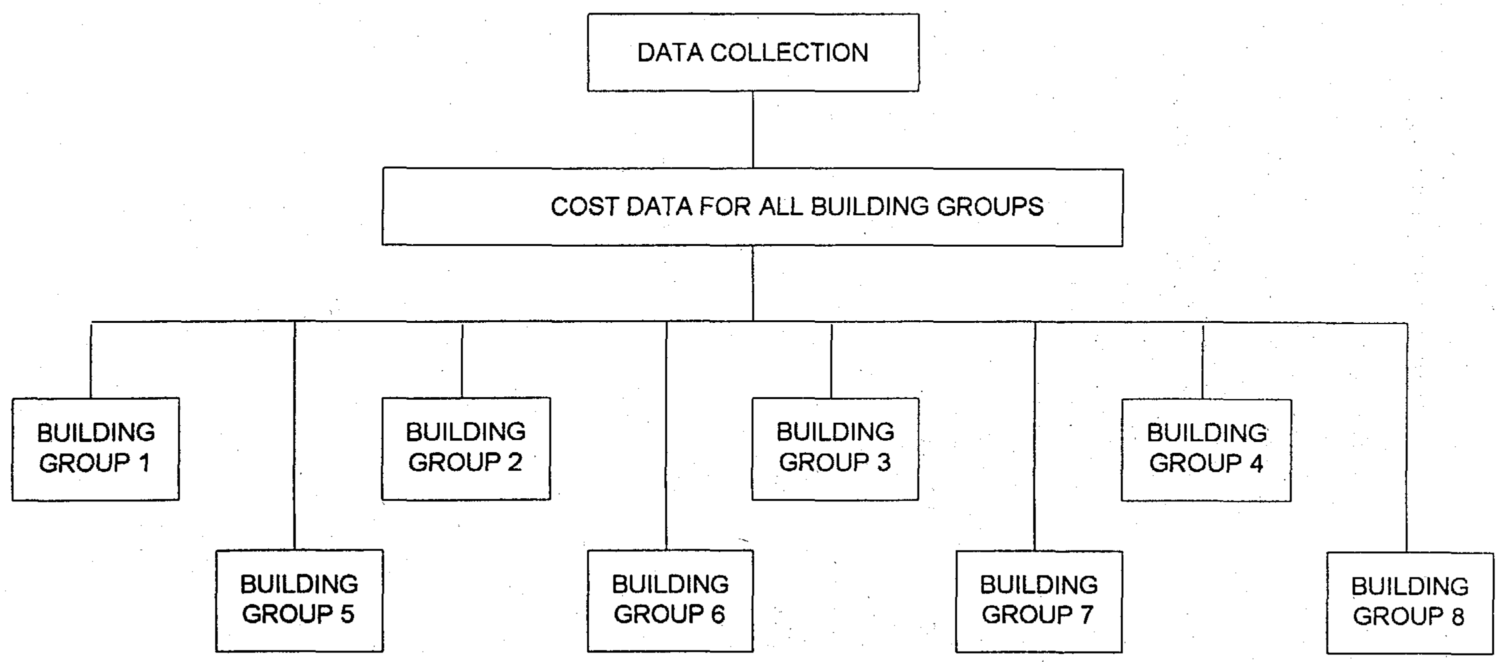

Figure 3.3.1 Division of Building Cost Data into Building Group Cost Data

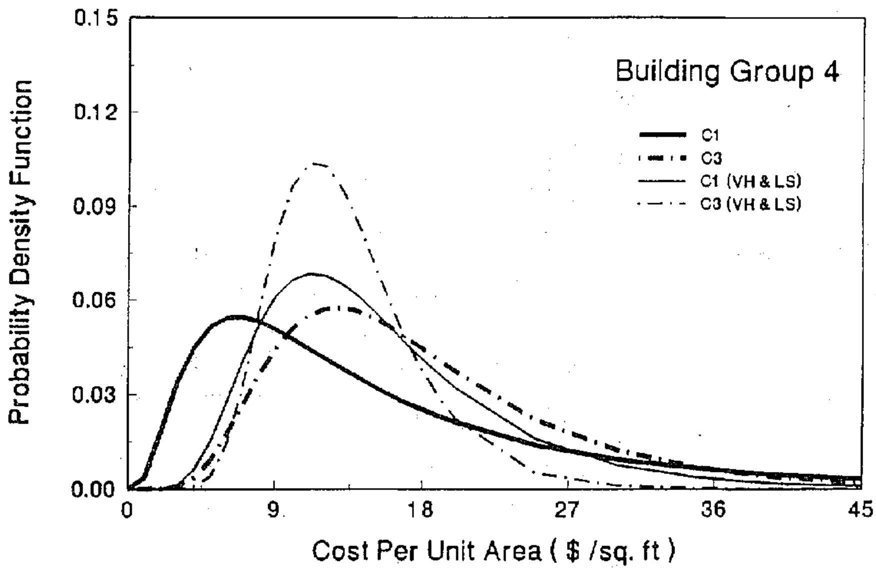

Figure 3.3.2 Probability Density Function of Cost for Group 4

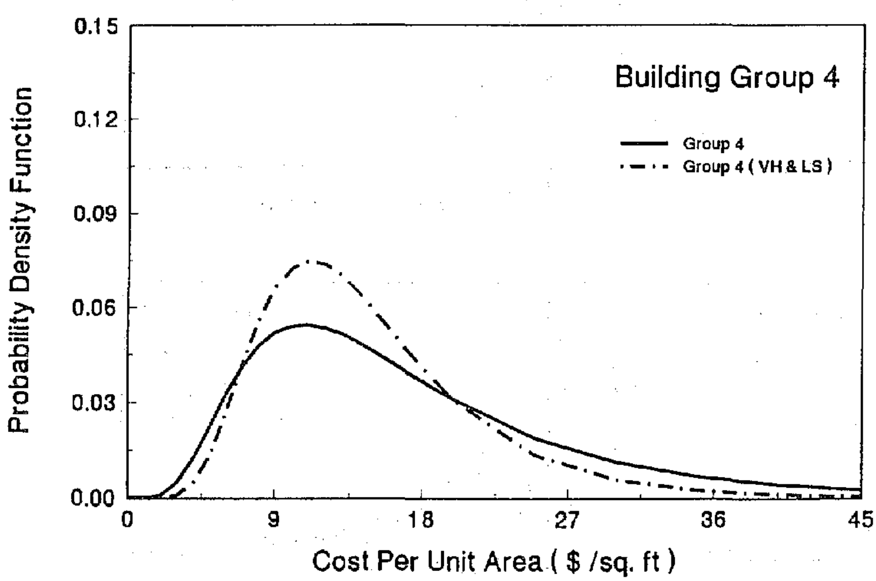

Figure 3.3.3 Probability Density Function of Cost for Group 4

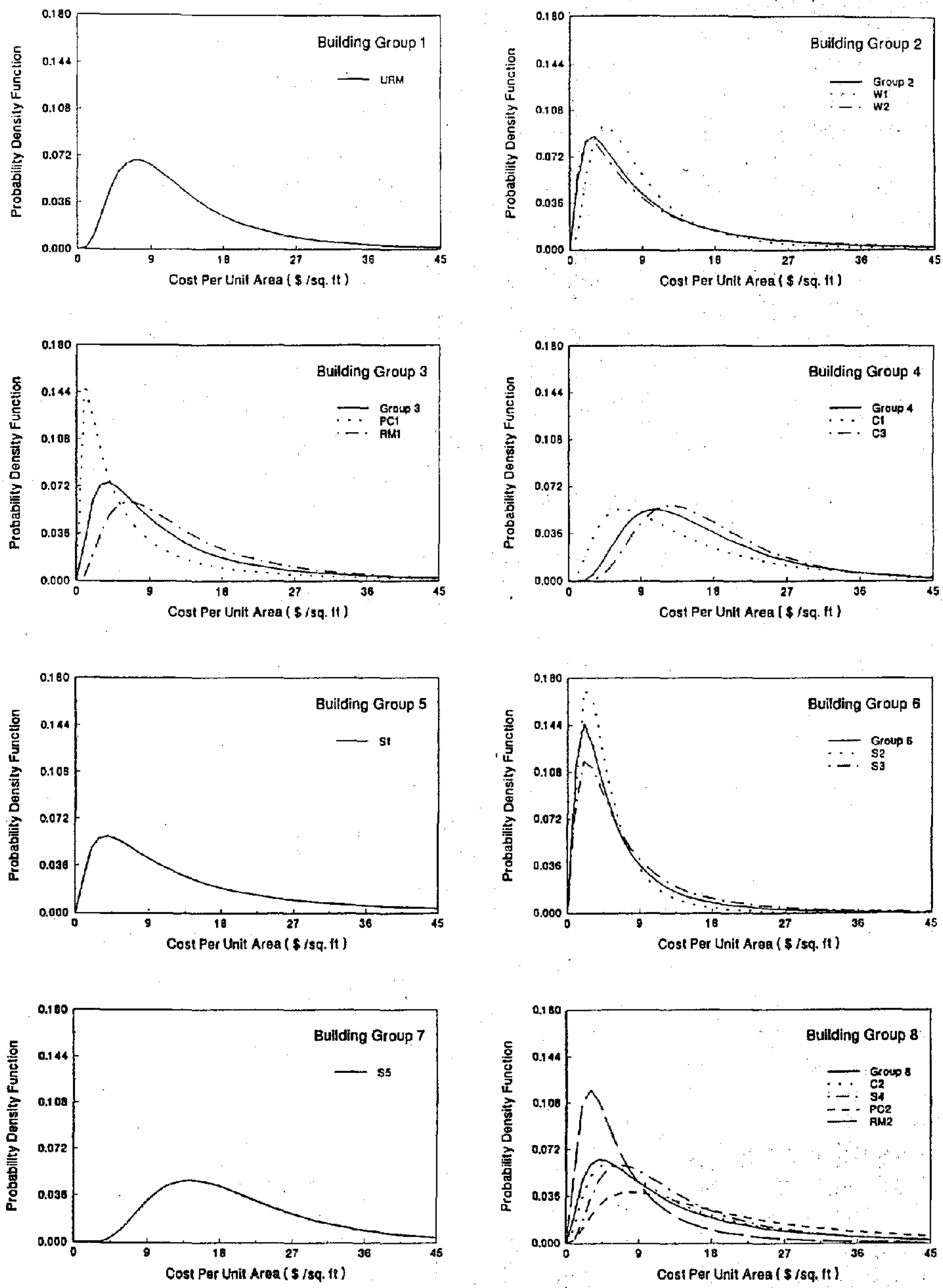

Figure 3.3.4 Probability Density Function of Cost for Building Groups

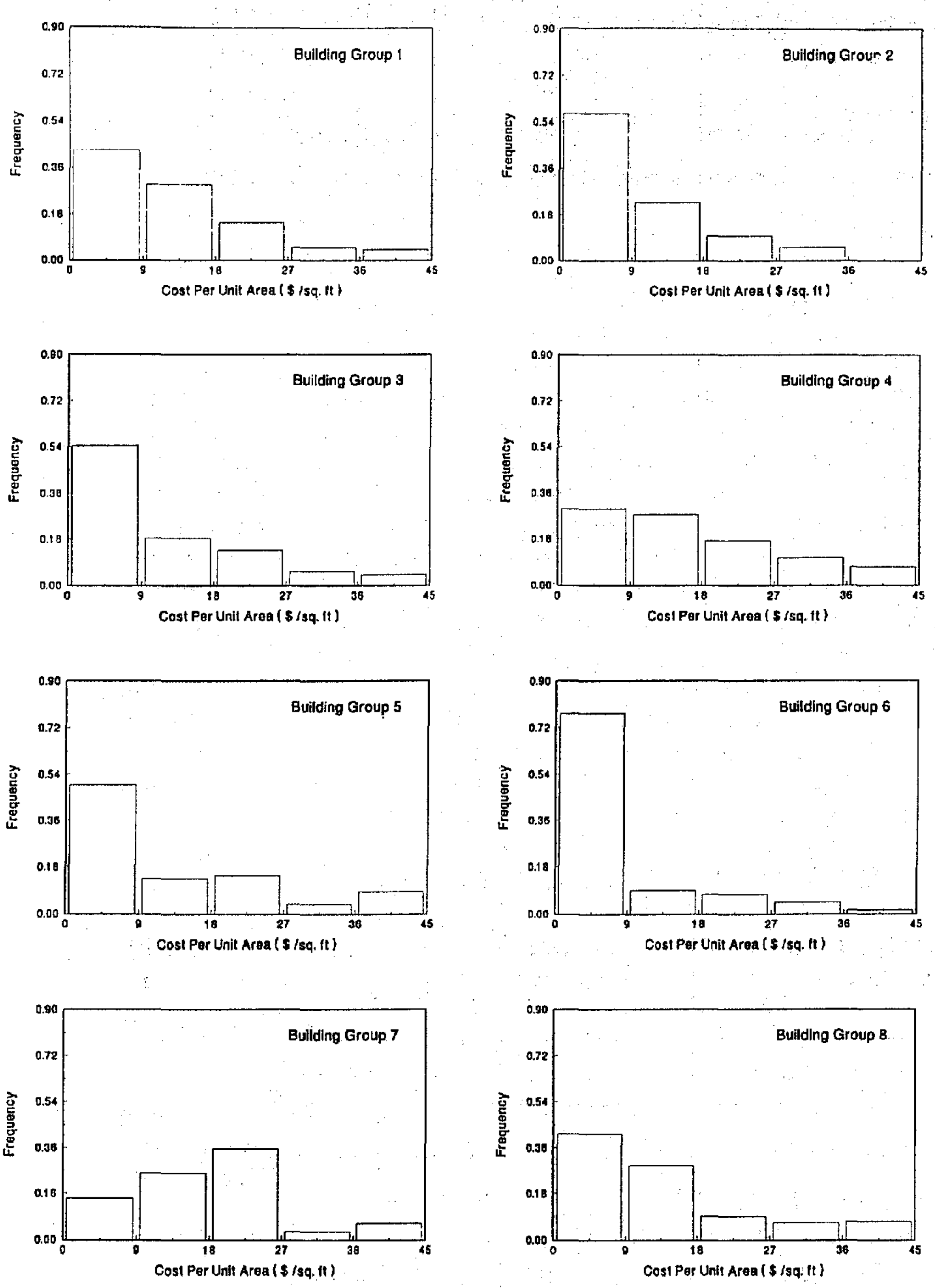

Figure 3.3.5 Histogram of Cost for Building Groups

CHAPTER 4
DEVELOPMENT OF THE SUPER DATABASE

4.1 GENERAL

An important part of the quality control process was the assignment of a quality factor to each cost data point in the database (See Chapter 2). With this quality factor, the methodology in this study was able to directly incorporate the degree of confidence associated with each cost data point. A data weighting approach was used to produce a Super Database and the method used was a Monte Carlo Simulation (MCS). This Super Database incorporates the quality of the data point in two ways. First, it incorporates the uncertainty in the cost data by generating random values for the cost data in the Super Database that uses the cost of the original data point as the mean with the coefficient of variation related to the quality rating. Second, the number of samples produced for inclusion into the Super Database for a given data point is a function of the quality rating. Therefore, the MCS analysis uses the actual cost data as the mean of the simulation sample and the uncertainty in the cost data (obtained from the quality rating) for the standard deviation of the simulation sample and proceeds to simulate a new database (i.e. the Super Database).

4.2 UNCERTAINTY IN INDIVIDUAL DATA SAMPLES

The quality rating expresses the degree of uncertainty associated with the cost data point. As the quality rating of the data point increases, the uncertainty associated with that point decreases. The cost data that is provided by the respondent can be said to be a single realization of the random variable that is the cost of rehabilitation. The cost variable, therefore, has a spread that can be represented quite conveniently using a coefficient of variation. If the cost data point comes from a sample, or respondent, with a large uncertainty, its probability density function has a large spread. Therefore, its coefficient of variation is also larger. Any simulation procedure to estimate the distribution of the cost must be able to relate the quality rating with the coefficient of variation (a statistical measure that can be used in the analysis to simulate the spread).

A quality rating versus coefficient of variation curve was drawn based on the opinion of the members of the project team and the Project Advisory Panel. In developing the relationship shown in Figure 4.2.1, values of the coefficient of variation in published literature for other random variables were noted and studied. For example, the coefficient of variation of the 50 year Fastest Mile Wind Speed at a given site is approximately 18%. The curve relating the quality factor and the coefficient of variation is monotonically decreasing. The curve in Figure 4.2.1 was used in the MCS procedure to set the value of the coefficient of variation of the simulated cost data.

4.3 NUMBER OF SAMPLES IN THE SUPER DATABASE FOR EACH ORIGINAL SAMPLE

The quality rating also indicates the degree of confidence in a given cost data point. Therefore, in the methodology developed in this project, the number of data points simulated using the MCS reflects this quality rating and confidence. Specifically, as the quality rating increases, the number of data points simulated for the Super Database from a single cost data point also increases. This has two effects:

1) The mean of the cost data simulated using MCS in the Super Database moves towards the values of the cost data points with higher quality ratings.

2) The shape of the frequency histogram of the Super Database cost data tends to concentrate around the points with higher quality ratings.

Five curves for computing the number of points generated in the MCS for each original data point were studied and they are shown in Figure 4.3.1. Table 4.3.1 shows a comparison of sample statistics of the simulated Super Database data for the five cases. Building Groups 1 and 8 are not shown in Table 4.3.1 but were also analyzed. Based upon these results and their own expert opinion, the Project Advisory Panel selected curve Type II for this typical cost study. Figure 4.3.2 shows the final choice of the quality rating versus number of MCS samples for this analysis. In this curve, the number of points simulated for the best quality data point (i.e. a quality factor of 10) was about twice as large as the number of points simulated for the worst quality data point (i.e a quality factor of 1). The Project Advisory Panel believed that because considerable effort was expended in this project to only use data that was reliable to begin with that the difference between a quality factor of 1 and 10 was not as large as might be expected.

4.4 SUPER DATABASE

The cost data in this extended Super Database was created following the tasks noted below and shown graphically in Figure 4.4.1. The tasks are:

(1) Select one Building Group

(2) Select one combination of Seismicity and Performance Objectives.

(3) Select a Data Collection Guideline for the Building Group in Task (1) and the combination of Seismicity and Performance Objectives from Task (2).

(4) The value of the cost is defined to be the mean value of a random variable denoted X.

(5) The value of the quality factor on the Data Collection Guideline was entered into Figure 4.2.1 and a value for the coefficient of variation of the random variable X was calculated.

(6) The value of the quality factor on the Data Collection Guideline was entered into Figure 4.3.2 and a value for the number of Monte Carlo Simulations was calculated. The number of Monte Carlo Simulations is denoted as NS.

(7) Using a Monte Carlo Simulation procedure, NS values of the random variable X are simulated. These simulated cost data points are then placed into the extended Super Database.

(8) Tasks 3 to 7 are repeated for each data collection form obtained in this study for the Building Groups defined in Task 1 and the Seismicity and Performance Objectives selected in Task 2.

(9) After the Monte Carlo Simulation Procedure is completed for all Data Collection Guidelines, the total number of cost data values in the Super Database is counted. If the number is greater than 1000, then the size of the database is reduced in proportion to the NS value for each simulation run. The simulated cost data is adjusted until it totals 1000 data points and this is the final extended Super Database for this combination of Building Group and Seismicity and Performance Objectives.

(10) Repeat Tasks 2 to 9 for each combination of Seismicity and Performance Objectives. The total number of times Tasks 2 to 9 are performed are 4 x 3 = 12. Therefore, the maximum number of cost data points created for the Super Database is 12,000 for this Building Group.

(11) Repeat Tasks 1 through 10 for each Building Group. The total number of Building Groups is 8. Therefore, the maximum number of cost data points in the extended Super Database is 96,000.

It must be pointed out here that not all combinations of performance objective and seismicity in a given building group had data points from the cost survey. Such cells were considered to have no information and no points were simulated from these blocks. The actual number of data points in the Super Database was 83,000.

At this point, the primary reason for the creation of the Super Database can be stated as follows:

<u>The creation of the extended Super Database is a weighting process that is used to incorporate the relative value of the cost data and the confidence in the value of the cost data.</u>

It is best to imagine that the Super Database has one Cost Guideline for each point in the Super Database. This Super Database retains on all new Cost Guidelines that are created from a given data form, the original age, area, occupancy etc. of the original Cost Guideline. A comparison of the statistics for the original cost data set and the Super Database cost data set for all eight building groups is shown in Tables 4.4.1 to 4.4.8.

It was found that for several groups, the sum of the simulated points for a specific combination of Building Group, Seismicity and Performance Objectives was less than 1000. In such cases, the number of simulated cost data points from each contributing Cost Guideline in the original cost database was scaled up or down so that the total number of cost data points totaled 1000.

The main reason for ensuring that each combination of Building Group, Seismicity and Performance Objectives had exactly 1000 points was to ensure a statistically large number of points and remove the confidence problems associated with predictions of cost data based on small sample sets. This was especially true for certain combinations of Building Group, Seismicity and Performance Objectives which had few cost data points in the original database.

The three cost estimation procedures that are presented in Chapters 5 to 7 all use parameters derived from the statistical analysis of the Super Database. These procedures, in general, computed parameters that were for a specific combination of Building Group, Seismicity and Performance Objectives and were therefore independent of the total number of samples in that combination in the Super Database. The primary exception to this rule was the Seismicity/Performance Objective Function which was computed using all of the eight building groups combined together. For this parameter, it was found that separating this function by building group did not increase the level of accuracy but instead in some cases led to results that were intuitively unacceptable.

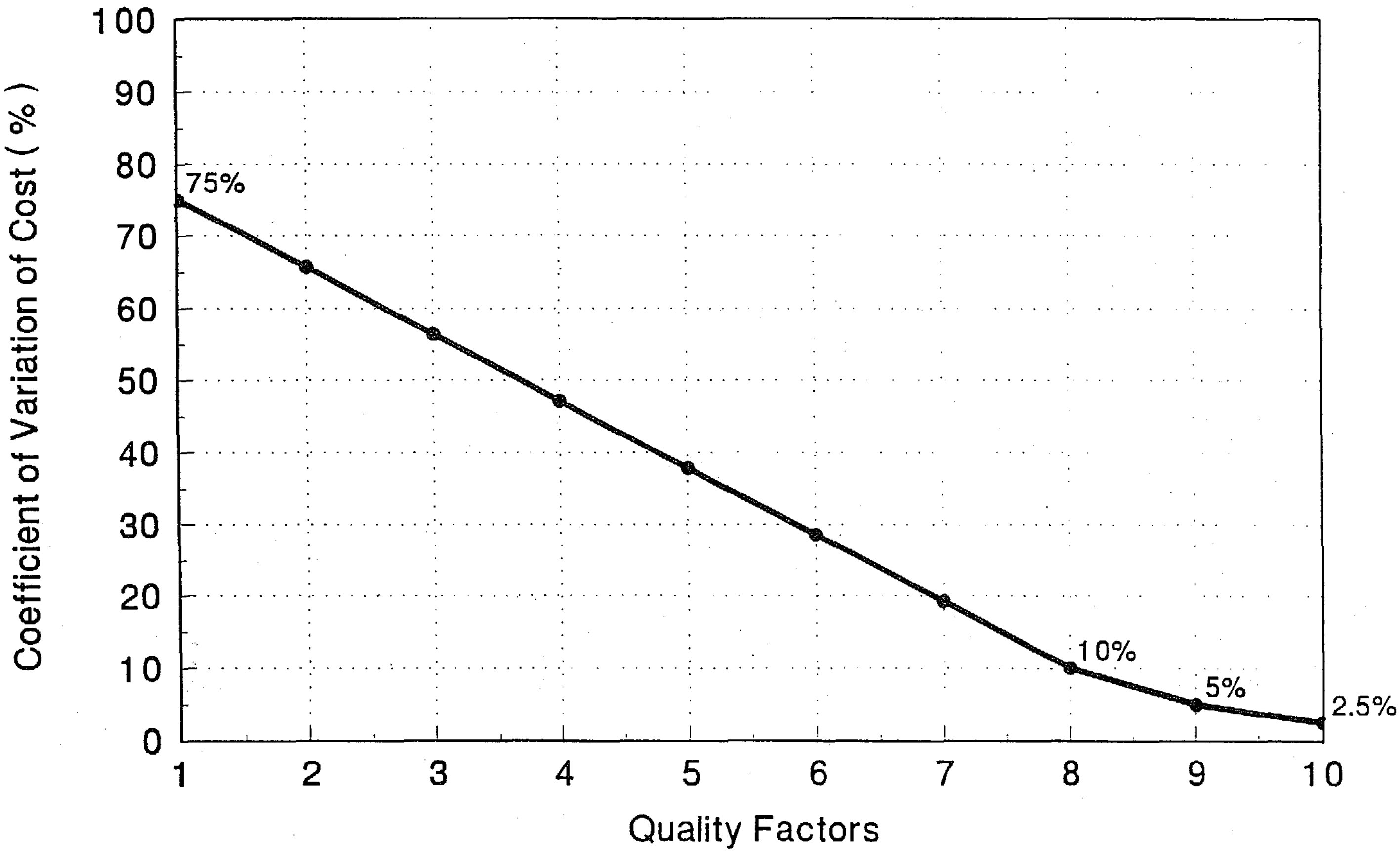

Figure 4.2.1 Coefficient of Variation of Cost for Development of Super Database

TABLE 4.3.1 COMPARISON OF SIMULATION METHOD STATISTICS

BLDG GROUP	BLDG TYPE	STAT.	RAW DBASE	SUPER DATABASE				
				Method-I	Method-II	Method-III	Method-IV	Method-V
2	W1 W2	NUM	28	2800	2157	1995	1603	974
		MEAN	19.63	21.21	19.23	18.74	16.59	14.86
		COV (%)	102	125	129	129	125	126
		C75%	24.29	25.49	22.97	22.39	19.94	17.83
		C50%	13.74	13.25	11.78	11.48	10.36	9.24
		C25%	7.77	6.89	6.04	5.89	5.39	4.79
3	PC1 RM1	NUM	40	4000	3385	3230	2855	1886
		MEAN	6.77	6.89	6.90	6.83	6.76	6.64
		COV (%)	104	108	110	108	108	99
		C75%	8.36	8.47	8.46	8.40	8.31	8.24
		C50%	4.69	4.68	4.64	4.64	4.59	4.72
		C25%	2.63	2.59	2.55	2.56	2.54	2.70
4	C1 C2	NUM	87	8700	6926	6467	5370	3171
		MEAN	18.76	19.22	19.52	19.51	19.45	19.00
		COV (%)	74	81	80	80	78	80
		C75%	23.55	24.11	24.50	24.48	24.42	23.84
		C50%	15.08	14.94	15.24	15.23	15.34	14.84
		C25%	9.66	9.25	9.48	9.48	9.63	9.23
5	S1	NUM	22	2200	1748	1633	1356	794
		MEAN	20.48	21.33	20.91	20.36	19.65	19.21
		COV (%)	85	97	98	96	92	91
		C75%	25.66	26.52	25.97	25.33	24.52	23.99
		C50%	15.60	15.31	14.93	14.69	14.46	14.21
		C25%	9.49	8.84	8.59	8.52	8.53	8.41
6	S2 S3	NUM	21	2100	1748	1659	1444	865
		MEAN	7.01	7.15	7.06	7.08	7.01	6.96
		COV (%)	154	157	154	154	152	161
		C75%	8.03	8.15	8.09	8.11	8.06	7.87
		C50%	3.82	3.84	3.84	3.86	3.85	3.67
		C25%	1.81	1.81	1.83	1.83	1.84	1.71
7	S5	NUM	13	1300	977	894	695	794
		MEAN	52.96	54.34	55.03	54.33	51.83	50.79
		COV (%)	59	72	79	77	67	63
		C75%	65.94	68.19	69.07	68.20	64.93	63.47
		C50%	45.61	44.10	43.18	43.05	43.06	42.97
		C25%	31.55	28.52	27.00	27.17	28.56	29.10

Note: Building Groups 1 and 8 were also analyzed but are not presented in this table.

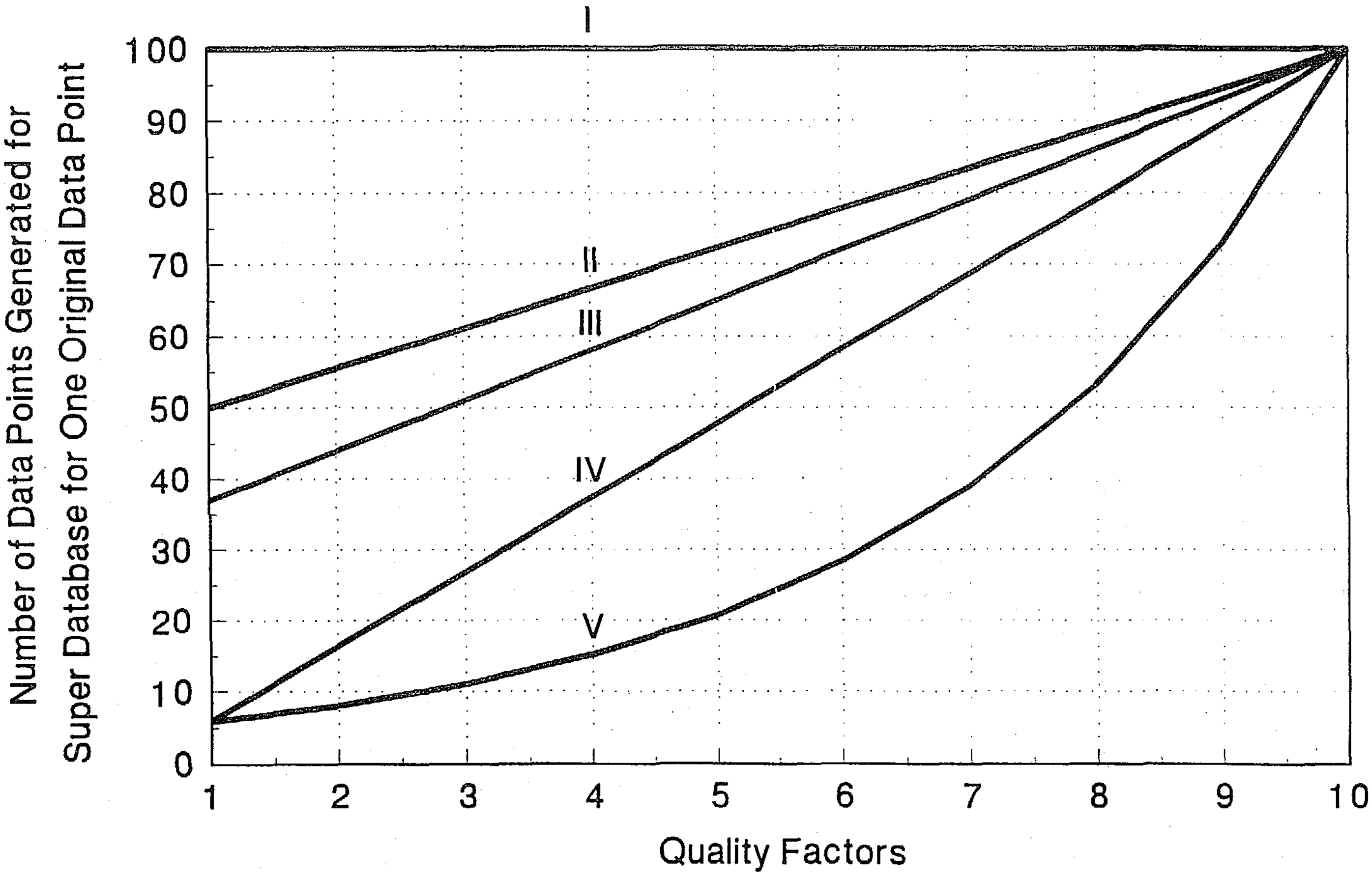

Figure 4.3.1 Proposed Curves Relating Number of MCS Data Points Generated for Super Database for Original Data Point with Quality Factor

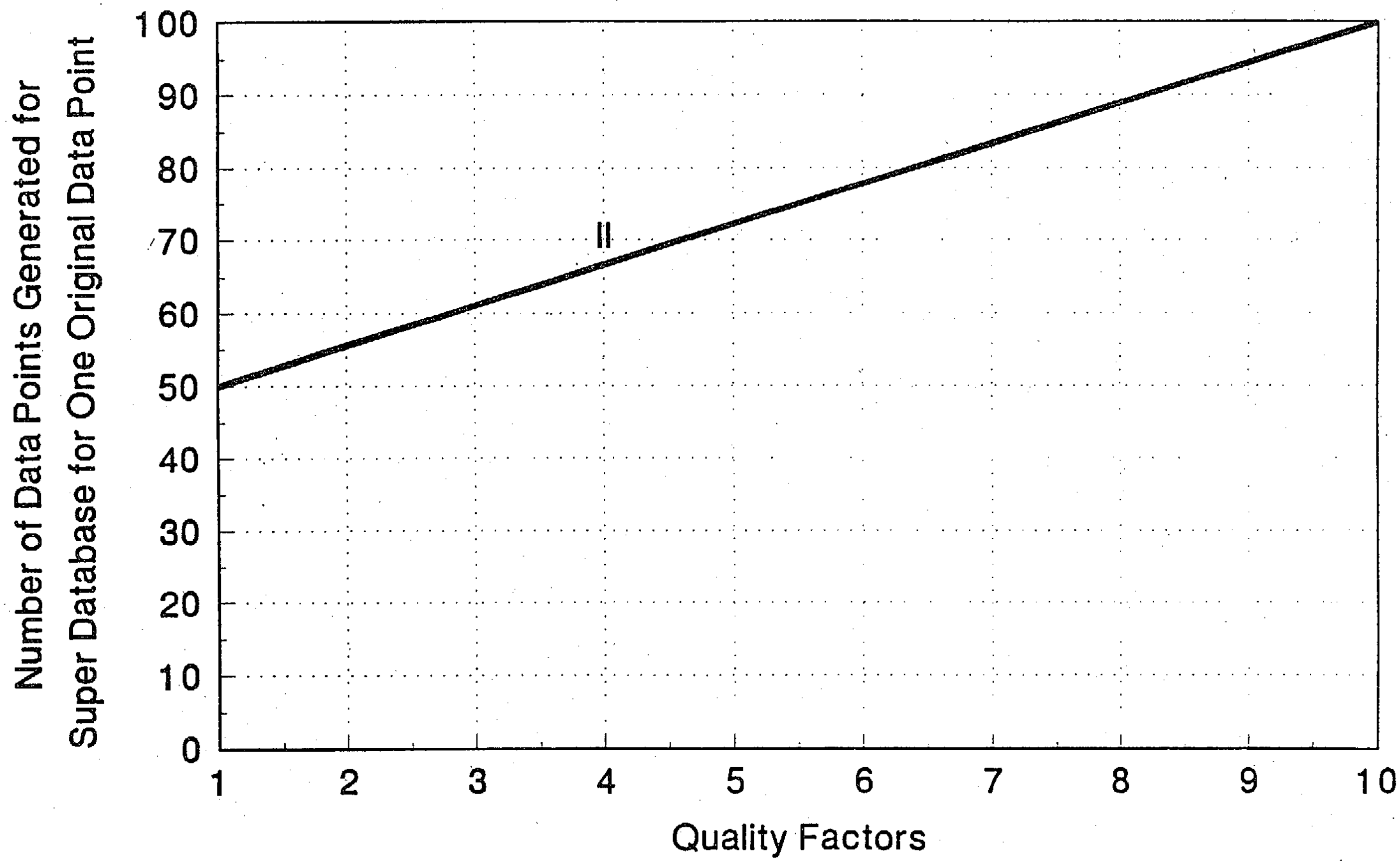

Figure 4.3.2 Proposed Curves Relating Number of MCS Data Points Generated for Super Database for Original Data Point with Quality Factor

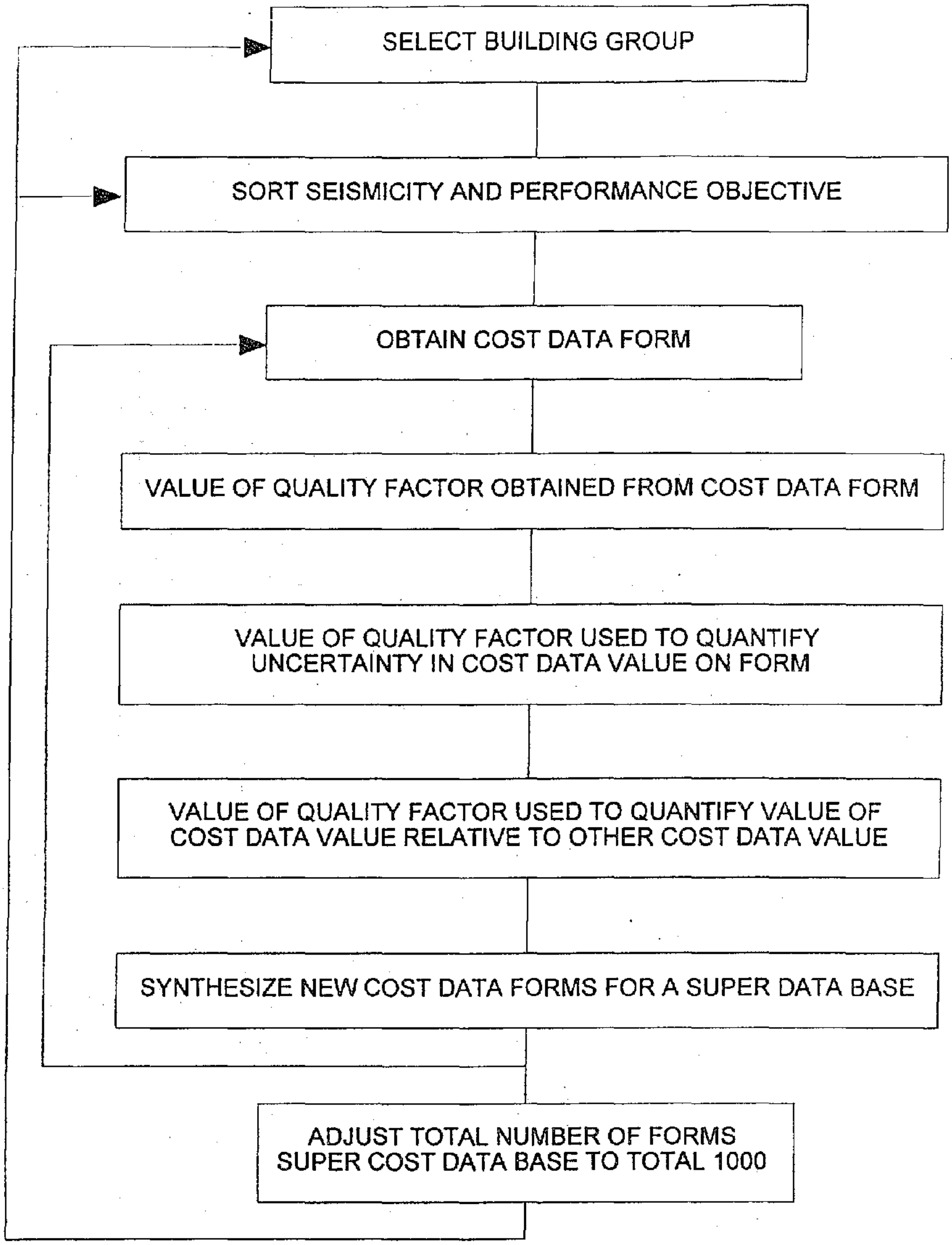

Figure 4.4.1 Extended Data Set Creation Process

TABLE 4.4.1 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR URM MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1, 2	MEAN	3.52	3.52	22.79	24.19	17.23	18.19
		COV (%)	40	36	72	89	30	47
		C75%	4.24	4.19	28.60	30.25	20.12	22.25
		C50%	3.27	3.31	18.49	18.07	16.50	16.46
		C25%	2.52	2.62	11.96	10.79	13.54	12.18
MODERATE	3, 4	MEAN	49.10	50.36	17.30	18.36	17.13	18.26
		COV (%)	98	78	81	95	61	70
		C75%	60.99	63.22	21.70	22.86	21.37	22.90
		C50%	35.07	39.71	13.44	13.31	14.62	14.96
		C25%	20.16	24.94	8.33	7.75	10.01	9.77
HIGH	5, 6	MEAN	22.64	23.05	20.05	21.13	40.51	40.71
		COV (%)	57	69	65	79	72	74
		C75%	28.13	28.90	25.09	26.52	50.84	51.10
		C50%	19.67	18.97	16.81	16.58	32.88	32.72
		C25%	13.75	12.45	11.26	10.37	21.26	20.96
VERY HIGH	7	MEAN	9.52	9.87	43.36	44.00	29.58	29.90
		COV (%)	96	103	78	85	-	20
		C75%	11.85	12.20	54.43	55.13	-	33.51
		C50%	6.87	6.88	34.19	33.53	29.58	29.32
		C25%	3.98	3.87	21.48	20.39	-	25.65

TABLE 4.4.2 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR W1 &W2 MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1 2	MEAN			4.97	5.10		
		COV (%)			108	114		
		C75%			6.11	6.22		
		C50%			3.38	3.36		
		C25%			1.87	1.82		
MODERATE	3 4	MEAN			6.94	7.25		
		COV (%)			85	98		
		C75%			8.70	9.01		
		C50%			5.29	5.18		
		C25%			3.22	2.98		
HIGH	5 6	MEAN	7.14	7.27	9.32	9.83	10.14	10.21
		COV (%)	121	123	64	77	102	110
		C75%	8.63	8.76	11.65	12.34	12.55	12.52
		C50%	4.55	4.59	7.85	7.79	7.10	6.87
		C25%	2.40	2.40	5.29	4.92	4.02	3.77
VERY HIGH	7	MEAN	17.54	17.14	25.38	26.21	6.29	6.11
		COV (%)	102	125	117	118	114	116
		C75%	21.70	20.60	30.85	31.82	7.68	7.44
		C50%	12.28	10.71	16.49	16.95	4.15	3.99
		C25%	6.95	5.57	8.81	9.03	2.24	2.14

TABLE 4.4.3 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR PC1 & RM1 MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1 2	MEAN			4.29	4.27		
		COV (%)			50	56		
		C75%			5.28	5.30		
		C50%			3.84	3.73		
		C25%			2.79	2.62		
MODERATE	3 4	MEAN	5.31	5.27	5.91	6.23	26.82	28.00
		COV (%)	61	65	-	39	134	134
		C75%	6.62	6.59	-	7.48	31.79	33.18
		C50%	4.53	4.42	5.91	5.80	16.04	16.75
		C25%	3.10	2.96	-	4.50	8.09	8.45
HIGH	5 6	MEAN	11.72	11.83	10.31	10.30	38.58	40.35
		COV (%)	76	85	97	103	63	72
		C75%	14.71	14.82	12.82	12.73	48.21	50.64
		C50%	9.33	9.01	7.40	7.17	32.64	32.75
		C25%	5.92	5.48	4.27	4.04	22.10	21.18
VERY HIGH	7	MEAN	6.05	6.11	12.37	12.48	27.21	27.08
		COV (%)	104	109	77	82	104	102
		C75%	7.47	7.50	15.53	15.65	33.60	33.51
		C50%	4.19	4.13	9.80	9.65	18.86	18.96
		C25%	2.35	2.27	6.19	5.95	10.59	10.73

TABLE 4.4.4 STATISTICS OF ORIGINAL AND SUPER DATABASE

(For C1 & C3 Model)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1, 2	MEAN			16.82	17.23	34.83	36.40
		COV (%)			100	115	58	73
		C75%			20.85	21.00	43.32	45.69
		C50%			11.89	11.31	30.13	29.40
		C25%			6.78	6.09	20.95	18.92
MODERATE	3, 4	MEAN	26.10	27.03	15.51	16.07	13.33	14.16
		COV (%)	65	73	105	112	67	80
		C75%	32.66	33.93	19.13	19.66	16.70	17.77
		C50%	21.88	21.83	10.70	10.70	11.07	11.06
		C25%	14.66	14.05	5.98	5.83	7.34	6.88
HIGH	5, 6	MEAN	15.74	15.74	21.46	22.16	25.86	26.87
		COV (%)	58	64	73	81	56	71
		C75%	19.58	19.68	26.94	27.80	32.09	33.71
		C50%	13.62	13.26	17.33	17.22	22.56	21.91
		C25%	9.47	8.93	11.15	10.67	15.86	14.24
VERY HIGH	7	MEAN	16.74	17.32	27.31	27.42	42.52	44.02
		COV (%)	74	80	127	130	48	62
		C75%	21.01	21.73	32.72	32.70	52.11	54.96
		C50%	13.46	13.52	16.90	16.72	38.33	37.41
		C25%	8.62	8.42	8.72	8.55	28.20	25.47

TABLE 4.4.5 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR S1 MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1 2	MEAN						
		COV (%)						
		C75%						
		C50%						
		C25%						
MODERATE	3 4	MEAN	7.98	8.20	3.32	3.52	35.26	35.57
		COV (%)	180	182	120	91	81	67
		C75%	8.72	8.92	4.02	4.40	44.24	44.56
		C50%	3.88	3.95	2.13	2.60	27.40	29.55
		C25%	1.72	1.75	1.12	1.54	16.97	19.60
HIGH	5 6	MEAN	10.10	10.26	33.28	34.92	12.52	13.03
		COV (%)	97	99	52	48	24	32
		C75%	12.56	12.73	41.07	42.80	14.28	15.32
		C50%	7.25	7.29	29.53	31.48	12.17	12.41
		C25%	4.19	4.18	21.23	23.16	10.38	10.05
VERY HIGH	7	MEAN	18.66	18.97	19.65	20.16	47.64	46.72
		COV (%)	79	88	93	92	122	119
		C75%	23.42	23.73	24.51	25.16	57.50	56.63
		C50%	14.64	14.24	14.39	14.84	30.20	30.06
		C25%	9.15	8.55	8.45	8.75	15.86	15.95

TABLE 4.4.6 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR S2 & S3 MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1, 2	MEAN						
		COV (%)						
		C75%						
		C50%						
		C25%						
MODERATE	3, 4	MEAN			3.47	3.66	11.07	12.30
		COV (%)			70	75	99	76
		C75%			4.35	4.59	13.74	15.44
		C50%			2.84	2.93	7.87	9.79
		C25%			1.86	1.87	4.50	6.21
HIGH	5, 6	MEAN	5.20	5.22	6.29	6.57	11.75	12.25
		COV (%)	108	107	122	104	96	102
		C75%	6.39	6.42	7.59	8.11	14.62	15.16
		C50%	3.53	3.56	3.99	4.55	8.48	8.58
		C25%	1.95	1.98	2.09	2.56	4.91	4.85
VERY HIGH	7	MEAN	6.25	6.39	7.46	7.79	15.29	15.17
		COV (%)	154	157	136	138	80	82
		C75%	7.16	7.28	8.81	9.17	19.19	19.03
		C50%	3.40	3.43	4.42	4.57	11.94	11.73
		C25%	1.62	1.62	2.22	2.28	7.43	7.23

TABLE 4.4.7 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR S5 MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1, 2	MEAN			24.33	25.55		
		COV (%)			-	39		
		C75%			-	30.68		
		C50%			24.33	23.80		
		C25%			-	18.47		
MODERATE	3, 4	MEAN	12.80	13.60	15.13	16.29	31.15	32.73
		COV (%)	127	99	88	104	43	48
		C75%	15.34	16.88	18.93	20.12	37.78	40.11
		C50%	7.92	9.66	11.36	11.29	28.62	29.51
		C25%	4.09	5.53	6.82	6.34	21.68	21.70
HIGH	5, 6	MEAN	17.69	18.20	16.58	17.42		
		COV (%)	41	52	32	49		
		C75%	21.35	22.46	19.49	21.39		
		C50%	16.37	16.15	15.79	15.64		
		C25%	12.55	11.61	12.79	11.44		
VERY HIGH	7	MEAN	47.31	49.12			55.79	56.25
		COV (%)	58	77			38	40
		C75%	58.85	61.66			66.81	67.72
		C50%	40.92	38.92			52.15	52.23
		C25%	28.46	24.56			40.71	40.28

TABLE 4.4.8 STATISTICS OF ORIGINAL AND SUPER DATABASE

(FOR C2, S4, RM2, PC2 MODEL)

SEISMICITY		STAT.	PERFORMANCE OBJECTIVES					
REGION	NEHRP AREA		LS		DC		IO	
			ORIGINAL	SUPER	ORIGINAL	SUPER	ORIGINAL	SUPER
LOW	1 2	MEAN	4.05	4.07	4.39	4.38	11.28	11.62
		COV (%)	64	70	85	85	55	46
		C75%	5.06	5.10	5.50	5.49	13.98	14.19
		C50%	3.41	3.33	3.34	3.34	9.88	10.56
		C25%	2.30	2.18	2.03	2.03	6.99	7.86
MODERATE	3 4	MEAN	1.79	1.84	16.25	16.82		
		COV (%)	58	52	18	31		
		C75%	2.23	2.27	18.04	19.71		
		C50%	1.55	1.63	15.99	16.07		
		C25%	1.08	1.17	14.18	13.10		
HIGH	5 6	MEAN	9.04	9.07	19.57	19.58	16.08	15.96
		COV (%)	105	111	93	96	124	131
		C75%	11.15	11.11	24.41	24.36	19.35	19.01
		C50%	6.23	6.07	14.33	14.12	10.09	9.68
		C25%	3.49	3.32	8.41	8.19	5.27	4.93
VERY HIGH	7	MEAN	13.54	14.46	24.77	25.98	29.90	31.23
		COV (%)	96	96	125	124	88	90
		C75%	16.85	17.99	29.77	31.27	37.41	39.03
		C50%	9.77	10.43	15.47	16.31	22.45	23.21
		C25%	5.66	6.05	8.04	8.51	13.47	13.81

CHAPTER 5
ESTIMATION OF TYPICAL COSTS USING OPTION 1

5.1 GENERAL

The first of the three cost estimation options developed in this study is presented in this chapter. The options increase in complexity as they incorporate more information about a building. The first estimation option is discussed below.

The information needed by the user of the Option 1 Cost Estimation Method is:

- FEMA Building Type
- Total Area of The Building
- Year for Which the Seismic Rehabilitation Cost is Desired
- State Where the Building is Located
- Number of Similar Buildings in the Inventory

The Option 1 Cost Estimation Equation is:

$$C = C_1 \, C_2 \, C_L \, C_T \qquad (5.1.1)$$

where

C_1 = Group Mean Cost ($/ sq. ft.)
C_2 = Area Adjustment Factor
C_L = Location Adjustment Factor
C_T = Time Adjustment Factor

The following sections of this chapter describe the development of the terms C_1, C_L, C_T and C_2

5.2 GROUP MEAN COST (C_1)

The coefficient C_1 is called the Group Mean Cost. Chapter 3 describes how the 15 FEMA building types were grouped into eight building groups and Table 3.3.1 provides the description of each group. Each of the 8 groups in Table 3.3.1 contains a significant number of buildings as shown in Table 5.2.1. As discussed in the previous chapter, each of the original data points and the associated quality rating factor were used to create the Super Database. The Group Mean Cost is the average or mean cost of all of the cost data points in the Super Database for the group under consideration. A value of a cost data point in the Super Database can be represented as C_{IK} where C_{IK} is the cost for the Kth sample in Building Group I with a total of 12,000 samples. Therefore, the Group Mean Cost for Building Group I is equal to:

$$GMC_I = \frac{\sum_{K=1}^{12000} C_{IK}}{12000} \qquad (5.2.1)$$

Table 5.2.2 gives the Group Mean Cost for each of the eight building groups using the Super Database cost data.

5.3 AREA ADJUSTMENT FACTOR (C_2)

The cost of the seismic rehabilitation per square foot of floor area is dependent on the size of the building. Based upon a statistical analysis of the cost data, this dependence was determined to be a function of the building group. The following procedure was followed in the development, for each building group, of an Area Adjustment Factor, C_2.

Imagine that Building Group I is under consideration. As noted in Section 5.2, C_{IK} is the cost for sample K in Building Group I.

The first analysis step divided the values of each cost point, C_{IK}, by the Group Mean Cost for the group identified with that cost point. That is,

$$CN_{IK} = \frac{C_{IK}}{GMC_I} \qquad (5.3.1)$$

Note that CN_{IK} is called the Group Normalized Cost of cost sample K in Building Group I. As discussed earlier, it is assumed to be a function of the building area only.

The second analysis step developed a linear regression equation relating the Group Normalized Cost to the area of the building corresponding to that cost. For a Group Normalized Cost sample CN_{IK} denote the area of that building as A_K. The linear regression equation relating the Normalized Group Cost to the building area is of the form :

$$CN_{IK} = b_0 + b_1 A_K \qquad (5.3.2)$$

A least squares fit using the cost data CN_{IK} and A_K was used to obtain the values for b_o and b_1. Table 5.3.1 gives the value of the regression constants for each building group.

The third analysis step divided, for Building Group I, the area into four ranges. It was decided, for the sake of simplicity of analysis, to divide the area of the buildings into several ranges rather than to use the actual values of area for each building in the estimation process. After a review of the cost data and using the professional experience of the project team, the following four area groups were selected for all building groups:

- SMALL Less Than 10,000 sq. ft.
- MEDIUM 10,000 to 49,999 sq. ft.
- LARGE 50,000 to 99,999 sq. ft.
- VERY LARGE Greater than 100,000 sq. ft.

The purpose in specifying ranges of areas was to both simplify the analysis procedure as well as to prevent errors in area estimation from strongly skewing the results.

The next analysis step sorted each cost data point into one of these four area groups. The final analysis step took each cost data point in an area group, e.g. SMALL, and for that point placed its value of area into Equation (5.3.2) to obtain a corresponding value for the Group Normalized Cost. Next, for that area group, the mean value of these cost values from Equation (5.3.2) was calculated and this mean was defined to be the Mean Group Normalized Cost. This value of the

Mean Group Normalized Cost is referred to as the Area Adjustment Factor C_2 in Table 5.3.2.

The typical cost estimate (excluding location and time effects) for a building in Building Group I, with an area A is then given by:

$$C = GMC_I * (MGNC_I) \qquad (5.5.3)$$

where the term $MGNC_I$ is the Mean Group Normalized Cost for Building Group I and is equal to the area adjustment factor C_2.

5.4 LOCATION ADJUSTMENT FACTORS (C_L)

Chapter 2 of Volume II describes how the team evaluated different cost adjustment options to account for geographic variations in cost. The Location Adjustment Factor C_L used in this study is shown in Table 5.4.1. Therefore, since each cost data value in the original study was translated to the state of Missouri in 1993 dollars a transformation from Missouri to the state where the building is located is required. The values in Table 5.4.1 are recommended for the coefficient C_L.

5.5 TIME ADJUSTMENT FACTOR (C_T)

The Group Mean Cost is for the year 1993. Future costs will change depending on the inflation rate and the variable C_T incorporates this cost change. Table 5.5.1 gives values for C_T for different future inflation rates. The user chooses this factor depending on the year that the seismic rehabilitation is to occur along with an estimate for the average inflation rate from the present to that year.

5.6 CONFIDENCE LIMITS

Once these values of the estimation parameters had been obtained, confidence limits for these parameters were computed. The confidence limits for the typical cost estimate were calculated for each building group. As the typical cost is assumed to be a lognormal random variable, with known statistical parameters, the confidence limits for this variable can be calculated using a transformation to the normal distribution. The confidence limits for the mean of a normally distributed variable are a function only of its coefficient of variation and the number of samples in the population. As the coefficients of variation for the eight building groups were similar, the upper and lower confidence limits as a ratio of the group mean were almost the same values. Therefore, it was decided to present the confidence ranges for the typical cost as a function only of the number of buildings in the inventory and the level of confidence desired in the estimate. Statistically, it can be shown that when the sample size increases, the confidence in the parameter estimates increases and this is seen graphically in Figure 5.6.1. Both upper and lower confidence bounds of the typical cost estimate were computed for three levels of confidence i.e. 50%, 75%, and 90%. If there is only one building to be studied, the spread of the cost estimate to rehabilitate the building is quite large. As the number of buildings in the inventory increases, the overall confidence in the prediction increases and this was borne out by the analysis. The confidence limits can be seen in Table 5.6.1.

In Cost Estimation Option 1, the user estimates the typical structural cost to seismically rehabilitate the building with the least amount of information. Hence, it is also seen that the confidence limits for this option show a larger spread than the confidence limits for Options 2 and 3.

TABLE 5.2.1 NUMBER OF BUILDINGS IN EACH GROUP

BUILDING GROUP NUMBER	DESCRIPTION	NUMBER OF COST DATA POINTS	
		Original	Super
1	URM	642	12000
2	W1, W2	164	8000
3	PC1, RM1	171	10000
4	C1, C3	372	12000
5	S1	160	11000
6	S2, S3	97	8000
7	S5	116	11000
8	C2, PC2, RM2, S4	366	11000

TABLE 5.2.2 GROUP MEAN COSTS

BUILDING GROUP NUMBER	DESCRIPTION	GROUP MEAN COSTS ($/sq. ft.)
1	URM	15.29
2	W1, W2	12.29
3	PC1, RM1	14.02
4	C1, C3	20.02
5	S1	18.86
6	S2, S3	7.23
7	S5	24.01
8	C2, PC2, RM2, S4	17.31

TABLE 5.3.1 REGRESSION CONSTANTS FOR AREA ADJUSTMENT FACTOR

BUILDING GROUP NUMBER	Constant b_0	Slope b_1
1	1.04	5.5×10^{-6}
2	0.67	7.8×10^{-6}
3	1.19	-2.0×10^{-5}
4	1.22	-5.7×10^{-6}
5	2.00	3.0×10^{-5}
6	1.31	2.1×10^{-6}
7	1.06	-8.2×10^{-6}
8	1.24	-1.7×10^{-5}

TABLE 5.3.2 AREA ADJUSTMENT FACTOR (C_2)

AREA (Sq. ft.)	BUILDING GROUPS							
	1	2	3	4	5	6	7	8
Small	1.01	0.97	1.13	1.09	1.16	1.18	1.04	1.11
Medium	1.00	1.02	1.07	1.06	1.14	1.12	1.03	1.08
Large	0.95	1.28	0.92	1.01	1.09	0.90	0.99	1.02
Very Large	0.80	1.64	0.57	0.84	0.83	0.51	0.87	0.83

TABLE 5.4.1 LOCATION ADJUSTMENT FACTOR (C_L)

STATE	LOCATION ADJUSTMENT FACTOR
ALABAMA	0.83
ALASKA	1.25
ARIZONA	0.91
ARKANSAS	0.83
CALIFORNIA	1.12
COLORADO	0.91
CONNECTICUT	1.05
DELAWARE	1.05
DIST. OF COLUMBIA	0.96
FLORIDA	0.86
GEORGIA	0.84
HAWAII	1.21
IDAHO	0.91
ILLINOIS	0.99
INDIANA	0.97
IOWA	0.90
KANSAS	0.86
KENTUCKY	0.88
LOUISIANA	0.85
MAINE	0.88
MARYLAND	0.98
MASSACHUSETTS	1.10
MICHIGAN	0.97
MINNESOTA	0.97
MISSISSIPPI	0.80
MISSOURI	1.00
MONTANA	0.90

STATE	LOCATION ADJUSTMENT FACTOR
NEBRASKA	0.84
NEVADA	1.03
NEW HAMPSHIRE	0.94
NEW JERSEY	1.14
NEW MEXICO	0.90
NEW YORK	1.07
NORTH CAROLINA	0.79
NORTH DAKOTA	0.80
OHIO	0.99
OKLAHOMA	0.88
OREGON	0.99
PENNSYLVANIA	1.01
RHODE ISLAND	1.09
SOUTH CAROLINA	0.80
SOUTH DAKOTA	0.80
TENNESSEE	0.86
TEXAS	0.86
UTAH	0.89
VERMONT	0.87
VIRGINIA	0.84
WASHINGTON	1.02
WEST VIRGINIA	0.99
WISCONSIN	0.97
WYOMING	0.86
OTHER: GUAM	0.67

TABLE 5.5.1 TIME ADJUSTMENT FACTOR (C_T)

YEAR	VALUE OF TIME ADJUSTMENT FACTOR				
	0 %	2 %	4 %	6 %	8 %
1993	1.00	1.00	1.00	1.00	1.00
1994	1.00	1.02	1.04	1.06	1.08
1995	1.00	1.04	1.08	1.12	1.17
1996	1.00	1.06	1.12	1.19	1.26
1997	1.00	1.08	1.17	1.26	1.36
1998	1.00	1.10	1.22	1.34	1.47
1999	1.00	1.13	1.27	1.42	1.59
2000	1.00	1.15	1.32	1.50	1.71
2001	1.00	1.17	1.37	1.59	1.85
2002	1.00	1.20	1.42	1.69	2.00
2003	1.00	1.22	1.48	1.79	2.16
2004	1.00	1.24	1.54	1.90	2.33

TABLE 5.6.1 CONFIDENCE LIMITS FOR OPTION 1 COST ESTIMATES

NUMBER OF BUILDINGS	CONFIDENCE LIMITS					
	90%		75%		50%	
	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}
1	0.18	5.57	0.27	3.69	0.40	2.48
2	0.38	2.63	0.51	1.97	0.67	1.49
5	0.54	1.84	0.65	1.53	0.78	1.29
10	0.64	1.54	0.73	1.35	0.84	1.19
50	0.82	1.21	0.87	1.15	0.92	1.08
100	0.87	1.15	0.90	1.10	0.95	1.06
500	0.94	1.06	0.96	1.04	0.96	1.03
1000	0.96	1.04	0.97	1.03	0.98	1.02

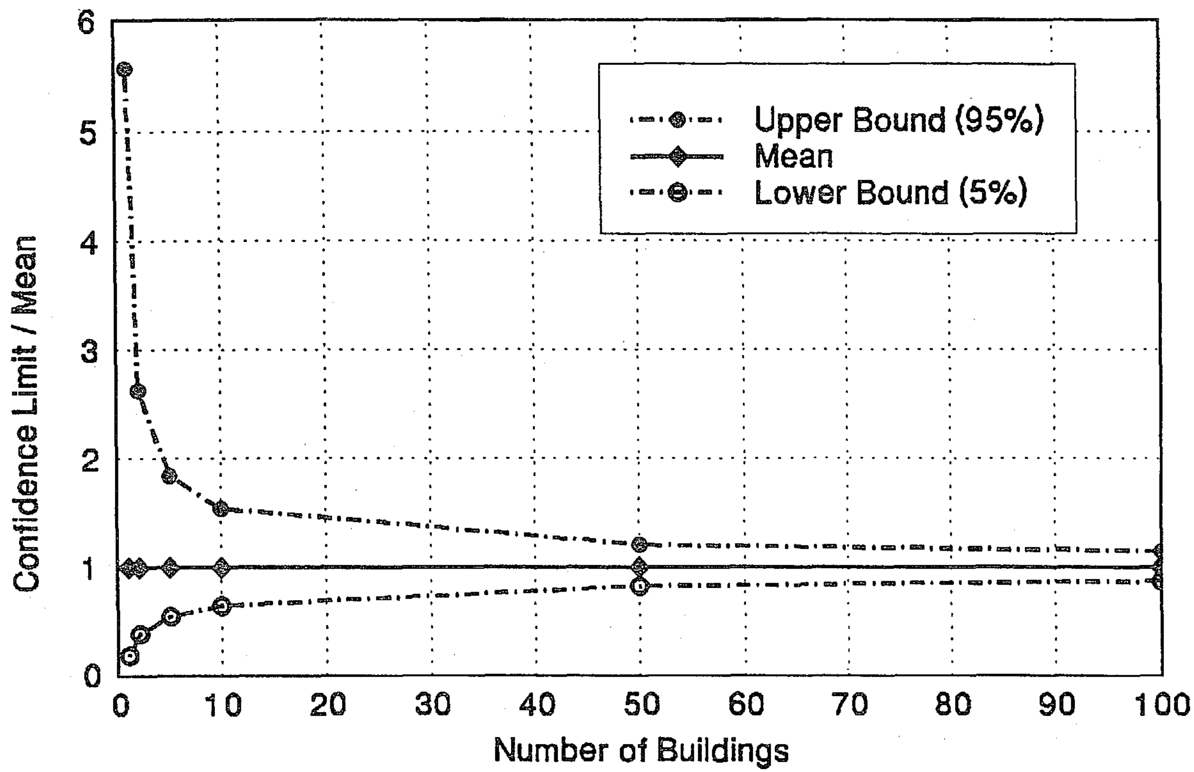

Figure 5.6.1 - Estimation of Confidence Limits for Option 1 Cost Estimates

CHAPTER 6
ESTIMATION OF TYPICAL COSTS USING OPTION 2

6.1 GENERAL

The second option for cost estimation is discussed in this chapter. Option 2 uses the information computed in Option 1 along with additional information to yield an improved estimate of the costs of seismic rehabilitation.

The Option 2 Cost Estimation Method is similar to the Option 1 Cost Estimation Method, except that the cost equation is modified to include the impact of seismicity and desired performance objectives in the cost estimate. The Option 2 Cost Equation is:

$$C = C_1 C_2 C_L C_T C_3 \qquad (6.1.1)$$

where C_1 , C_2 , C_L , C_T are the same coefficients as discussed in Chapter 5 and, therefore, will not be discussed in this chapter. The coefficient C_3 is a new coefficient that incorporates the influence of the building site seismicity and the user selected performance objective for seismic rehabilitation. This coefficient is called the Seismicity / Performance Objective Adjustment Factor.

As has been explained earlier in Chapter 5, the form of the Option 1 Cost Equation as well as the Option 2 Cost Equation (Equation 6.1.1) assumes that the cost is a product of several independent variables. Equation 6.1.1 is identical to Equation 5.1.1 except for the introduction of the coefficient C_3. The development of the parameters for the cost estimation process for Option 2 therefore proceeds in a manner similar to Option 1. Each cost data point is divided by the regression estimate of costs obtained from Option 1 by using Equation 5.1.1. The variable that is left is a function of the Seismicity and the Performance Objective only and is called the Reduced Cost Variable. A quadratic form for the Reduced Cost Variable as a function of the Seismicity/Performance Objective Function is then assumed and the coefficients for this function are calculated from regression analysis. The final cost estimate, therefore, is a product of the Group Mean

Cost, Location, Time, Area, and the Seismicity/Performance Objective Function. This procedure is consistent with the Option 1 Cost Estimation procedure. Further, it is in keeping in line with the basic methodology for cost estimation established for this study by the project members as explained in the Executive Summary.

6.2 SEISMICITY AND PERFORMANCE OBJECTIVE FUNCTION

The influence of site seismicity on the cost of seismic rehabilitation can be intuitively approached. Buildings in higher seismic zones have to meet more rigorous standards for rehabilitation. Consequently, the cost may be expected to increase with the increased seismicity. Similarly, the performance objective should increase the cost of seismic rehabilitation as the level of the rehabilitation goals increases. This intuitive feeling for the cost behavior was explored in the creation of the Seismicity and Performance Objective Function.

The variation of the costs of seismic rehabilitation with respect to the Seismicity and the Performance Objectives was expected at the start of this study to be similar for all building groups. Unfortunately, for several building groups there was little or no data for some combinations of Seismicity and the Performance Objectives. Table 6.2.1 shows one such building group and the number of cost data points in each group. Due to this lack of data, it was decided to group all of the building groups together and define C_3 to be the same for all building groups. To study that assumption an extended analysis was performed of the variation of the cost with the Seismicity and the Performance Objectives for each building group. The results of this analysis are discussed in the next section.

6.3 ESTIMATION OF THE SEISMICITY/PERFORMANCE OBJECTIVE FUNCTION

The Seismicity/Performance Objective Matrix is defined to enable the division of the cost data into four levels of Seismicity (Low, Moderate, High and Very High) and three levels of Performance Objectives (Life Safety, Damage Control and Immediate Occupancy). For a given set of data points corresponding to one building group, all the cost points will fall into a total one of 12 (i.e. 4 X 3) combinations of the Seismicity and the Performance Objectives. This sorting of the cost data points is the Seismicity/Performance Objective Matrix.

The Group Normalized Cost, CN_{IK} for a cost data point, is divided by the Mean Group Normalized Cost, MGNC, to yield a Reduced Cost Variable Y_{IK} that is not a function of the building area but is dependent upon the Seismicity and the Performance Objectives **only.**

$$Y_{IK} = \frac{CN_{IK}}{MGNC_I} \tag{6.3.1}$$

This is the same as dividing a cost data point by its estimated value as obtained from Equation 5.1.1.

These Reduced Cost variables were then computed for all cost data points. They were sorted and placed in the Seismicity/Performance Objective Matrix. This normalizing and sorting of data was first performed on the basis of building groups. It was immediately seen that certain combinations of building group, Seismicity and Performance Objectives did not contain any data points as there were no cost data points in the original data set. The **mean** value of the reduced cost variate for each of the twelve cells of the Seismicity/Performance Objective Matrix for a given building group was then computed.

Consider, for example, Building Group 4. There are 12 combinations of the Seismicity and Performance Objectives and, therefore, the Super Database for this group is a maximum of 12 times 1,000 or 12,000 points. This procedure was performed for each of the eight building groups, yielding a possible maximum of 8 x 12 = 96 data points of the Mean Reduced Cost Variate. In reality, some of the cells for many of the building groups did not have any data points and the actual number of points that were used in this analysis was 83. The actual number of points in the Super Database for each of the eight building groups is given in Table 5.2.1.

A three dimensional second order surface function was assumed to represent the behavior of the Mean Value of the Reduced Cost Variates, Y_m , as a function of the Seismicity and the Performance Objectives. This function is represented by the equation 6.3.2:

$$Y_m = c_0 + c_1 S + c_2 S^2 + c_3 P + c_4 P^2 + c_5 \, S.P \tag{6.3.2}$$

where S and P represent the Seismicity and the Performance Objectives. A quadratic function was assumed in Equation 6.3.2 and an interaction term between the Seismicity and the Performance Objectives was also assumed for completeness. A least squares fit for this shape was obtained using the Mean Value of the Reduced Cost Variate from the analysis and the values of the constants c_0 through c_5 were obtained. This process is shown graphically in Figure 6.3.1. The regression estimated values of the reduced cost variable Y_m for the Seismicity/Performance Objective Matrix are shown in Table 6.3.1. This table is called the Seismicity/Performance Objective Function and is the coefficient C_3 in Cost Option 2.

The costs for the seismic rehabilitation, excluding location and time effects, for a building in Group I, with an area of A, Seismicity S, Performance Objective P can be given as follows:

$$C = GMC_I \times GMNC_I \times Y_m(S,P) \qquad (6.3.4)$$

where $Y_m(S,P)$ is the Seismicity/Performance Objective Function (or the regression estimate of the Mean Reduced Cost Variate) and the other terms are as defined earlier. Since the term GMC_I is the Group Mean Cost C_1 , the term $GMNC_I$ is the Group Mean Normalized Cost or the Area Adjustment Factor C_2 and the term $Y_m(S,P)$ is the Seismicity/Performance Objective Matrix value or the coefficient C_3, this reduces back to Equation 6.1.1.

6.4 CONFIDENCE LIMITS

As with Option 1, confidence limits for three levels of confidence were computed for Option 2. The typical cost variable estimated using Option 2 is a product of the Group Mean, the Area Adjustment Factor and the Seismicity/Performance Objective Function. The Cost Equation 6.1.1 can be transformed into a linear regression equation and since the mean value of the typical cost is assumed to be lognormal variate, its confidence limits are a function of the number of buildings and the coefficients of variation of the Group Mean, the Area Adjustment Factor and the Seismicity/Performance Objective Function. The confidence limits for all eight building groups were computed using the theory of probability and it was found that the upper and lower bound confidence limits were very similar for all eight building groups. Therefore it was decided to present a single confidence bound table for Option 2, independent of the building group and this is shown in Table 6.4.1. The variation of the confidence limits with the number of buildings in the inventory is shown in Figure 6.4.1.

In Cost Estimation Option 2, the user estimates the typical structural cost to seismically rehabilitate the building with more information than Cost Estimation Option 1. Hence, it is also seen that the confidence limits for this option show a smaller spread than the confidence limits for Option 1 but are still larger than those for the most accurate method Option 3.

TABLE 6.2.1 NUMBER OF POINTS IN ORIGINAL DATABASE URM MODEL

SEISMICITY	STATISTICS	PERFORMANCE OBJECTIVES		
		LS	DC	IO
Low	Number	3	29	28
	Mean	3.52	22.79	17.23
Moderate	Number	3	82	31
	Mean	49.10	17.30	17.13
High	Number	75	29	14
	Mean	22.64	20.05	40.51
Very High	Number	328	17	3
	Mean	9.52	43.36	29.58

TABLE 6.3.1 SEISMICITY / PERFORMANCE OBJECTIVE MATRIX

SEISMICITY	PERFORMANCE OBJECTIVES		
	LS	DC	IO
Low	0.61	0.71	1.21
Moderate	0.70	0.85	1.40
High	0.89	1.09	1.69
Very High	1.18	1.43	2.08

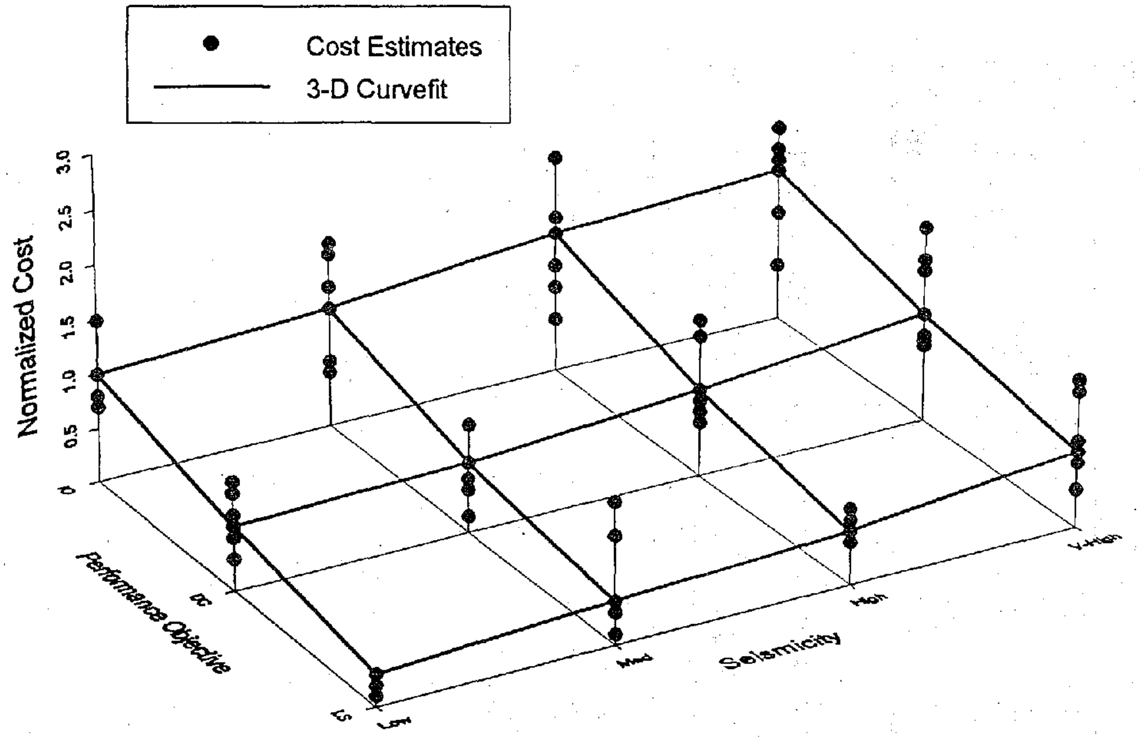

Figure 6.3.1 Shape of Seismicity and Performance Objective

TABLE 6.4.1 CONFIDENCE LIMITS FOR OPTION 2 COST ESTIMATES

NUMBER OF BUILDINGS	CONFIDENCE LIMITS					
	90%		75%		50%	
	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}
1	0.25	4.07	0.34	2.88	0.49	2.06
2	0.44	2.27	0.56	1.77	0.71	1.40
5	0.60	1.68	0.70	1.44	0.81	1.24
10	0.69	1.44	0.77	1.29	0.86	1.16
50	0.85	1.18	0.89	1.12	0.94	1.06
100	0.89	1.12	0.92	1.08	0.95	1.05
500	0.95	1.05	0.96	1.04	0.98	1.02
1000	0.96	1.04	0.97	1.03	0.99	1.01

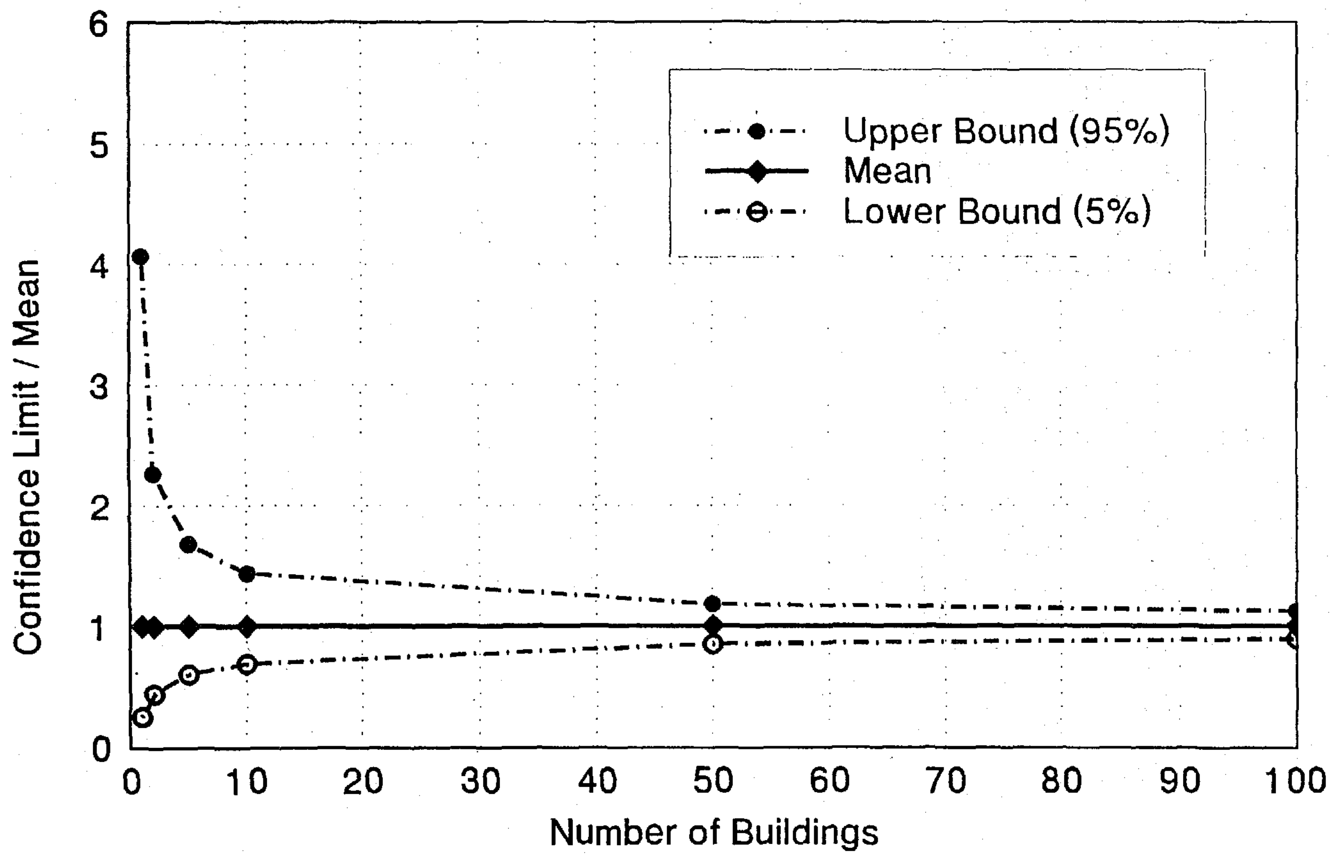

Figure 6.4.1 - Estimation of Confidence Limits for Option 2 Cost Estimates

CHAPTER 7
ESTIMATION OF TYPICAL COSTS USING OPTION 3

7.1 GENERAL

The third method of cost estimation is different from Options 1 and 2 in that it uses the results of multiple linear regression analysis to estimate costs. However, the data used by the project team to develop Option 3 is the same as that used for Option 2. In this respect, it follows the trend of using more information for each succeeding method of cost estimation.

Cost Estimation Options 1 and 2 rely on the use of step functions derived from compartmentalization of the data for their ease of use. This means that all data is sorted into groups of tractable size. All data within a given group is then assumed to behave identically. For example, for consideration of the building area, the data is grouped into four groups. Even data at the extreme ends of a given group are assumed to behave similarly. This may not reflect the true behavior of the costs. In Option 3, building area, the number of stories and building age were assumed to be continuous variables rather than step functions. The user can then employ the actual value of these variables to compute the typical cost of seismic rehabilitation for a specific building or group of similar buildings.

In Cost Estimation Option 3, the equation that is used to calculate the typical cost is :

$$C = C_C\,(\text{Area})^{X1}\,(\#\text{ of Stories})^{X3}\,(\text{Age})^{X2}\;X4\;X5\;X6 \qquad (7.1.1)$$

where

C_C	=	Statistically Based Constant
X1	=	Power Constant for Area
X2	=	Power Constant for the Building Age
X3	=	Power Constant for the Number of Stories
X4	=	Constant Based on Seismicity and Performance Objectives

X5	=	Constant Based on the Building Occupancy Class
X6	=	Constant Based on the Occupancy Condition

Each of these terms are dependent upon the building group and are described in greater detail later. The regression procedure will now be described.

7.2 MULTIPLE LINEAR REGRESSION

The primary objective of the Option 3 Cost Estimation technique was to match the computed costs and the costs in the database as closely as possible. This was done by using a Multiple Linear Regression (MLR) procedure.

Statistical studies typically arise out of a need to describe a large set of numbers called a population. Since populations are usually very large, a smaller representative sample is usually selected and the information contained in this sample is used to make statistical inferences on the population behavior. For the purposes of this study, the Super Database was used as the representative group in order to calculate the statistical properties of rehabilitation costs of the population which is all buildings under consideration. Such studies therefore, always indicate the degree of confidence in the results also through confidence intervals.

Regression analysis is a method that is used to relate two types of variables. The first is called the dependent or response variable and in our case is the typical cost of seismic rehabilitation. The second type of variable is called the independent or predictor variable and examples of these are the building area, the building age, the performance objective, etc.. The result of the regression analysis is the development of a model that is used to describe and then predict the dependent variable on the basis of the independent variables.

Regression models may employ both quantitative independent variables that have a numeric value and qualitative independent variables which are non-numerical or state. An example of a quantitative numeric variable is the area which is a number. An example of the latter type is the performance objective which is a state. The regression model used in this study employs both types of independent variables.

Regression models are typically described by equations. A linear regression model is of the form:

$$y = a_0 + a_1 x \tag{7.2.1}$$

where y is the dependent variable, x is the independent variable and the constants a_0 and a_1 are parameters of the model. If there is more than one independent variable, the process is called Multiple Linear Regression. Regression models can also be nonlinear such as:

$$y = a_0 (x)^{a_1} \tag{7.2.2}$$

where the terms are as before. In this case, the behavior of the dependent variable is nonlinear for a given change in the independent variable. However, such a nonlinear equation can be made linear by taking the natural logarithms of both sides. Doing so yields:

$$\ln(y) = \ln(a_0) + a_1 \ln(x) \tag{7.2.3}$$

This equation is therefore linear in ln(y) and ln(x). This technique was used to perform the multiple linear regression analysis for the cost data study.

The regression analysis procedure involves the computation of the model constants that best describe the sample behavior. In order to do this, some type of performance criterion has to be established. One of the most commonly used criterion is the minimization of the sum of the squared deviations of the sample from the model predictions. The best fit is attributed to that model whose sum of squared deviations from the actual sample is the minimum. Alternatively, this can be written as:

$$\text{Minimize}[S] = \sum_{\text{All K}} (y_K - y_K^*)^2 \tag{7.2.4}$$

where y_K is the Kth sample observation and y^*_K is the model estimate of the Kth sample observation. If the model is perfect, then the sum S will be zero. In practice, it rarely ever is. The procedure for computing the regression constants is easily obtained from the Calculus of Variations and involves the differentiation of the function S with respect to each of the parameters. The equations obtained from this procedure yield the required parameters.

As the model increases in complexity, the solutions of the regression equations also become more complicated and computer methods are preferred. Further, in cases involving qualitative variables with several alternative states (in this case, the seismicity/performance objective variable has 12 states), each state requires a dummy variable and a closed form solution may be intractable. For this study, the statistical analysis was performed using the IMSL (International Mathematical and Statistical Library) family of mathematical and statistical routines available from Visual Numerics Limited.

Once the best fit model has been obtained, it may be required to quantify the extent of the fit itself. For linear regression models, the extent of the fit is quantified through a parameter called the coefficient of linear regression and is usually denoted as r^2. The values of the coefficient of linear regression can lie between 0 and 1. A value of 1 indicates perfect linear correlation while a value of zero indicates that no linear relationship exists. It is preferable to have as high a value of r^2 as possible for a chosen model.

The steps to be followed in performing linear regression are as follows:

1. Identify the Dependent and Independent Variables
2. Set up the Proposed Model Equations with the Variables
3. Compute the Values of the Regression Constants
4. Compute the Coefficient of Linear Correlation to Ensure that the Fit is Acceptable.

These steps are shown graphically in Figure 7.2.1.

7.3 COST ESTIMATION PROCEDURE

The dependent variable in this study is:

1. The typical Cost of Seismic Rehabilitation

The independent variables in this study are:

1. The Building Area - Numeric Variable
2. The Building Age - Numeric Variable
3. The Number of Stories - Numeric Variable

4. The Seismicity/Performance Objectives - State Variable
5. The Occupancy Class - State Variable
6. The Occupancy Condition - State Variable

The model chosen for this analysis has already been given in Equation 7.1.1. Although this model is nonlinear, it can be converted to a linear model by taking the natural logarithms of both sides of the equation. This resultant equation is:

$$\ln C = \ln C_1 + X_1 * \ln(\text{area}) + X_2 * \ln(\#\text{ of stories}) + X_3 * \ln(\text{age}) + \ln X_4 + \ln X_5 + \ln X_6 \quad (7.3.1)$$

This is of the same form as Equation 7.2.3 and is therefore linear in the logarithmic values of the variables.

Dummy variables were used for each of the non-numeric variable states (occupancy condition, occupancy class, seismicity and performance objective). Once this was done, the linear regression procedure described earlier was followed in estimating the variables. This procedure was performed for each of the eight building groups. The regression coefficients were obtained for each building group and these values are tabulated in Table 7.3.1. A key table for the variables is given in Table 7.3.2.

In order to estimate the cost, the user specifies the values of the different parameters of the building or inventory of buildings. The appropriate regression constants are then obtained from Tables 7.3.1 and 7.3.2 and Equation 7.1.1 is used to compute the structural costs. In addition, the costs must be suitably altered for location and the planned date of rehabilitation using the Location and Time Adjustment Factors given in Chapters 5 or 6 (these are independent of the estimation option used). If desired, non-structural and other costs may be added in using the values or guidance outlined in Chapter 1.

7.4 CONFIDENCE LIMITS

Once the multiple linear regression equation parameters had been obtained, confidence limits for these parameters were computed. The typical cost is a function of the independent variables and, hence, its confidence limits can be given in terms of the statistics of the dependent variables as well as the sample size (the number of buildings in the inventory). The confidence limits were estimated for each of the eight building groups and were found to be similar. Therefore, the confidence limits were set to be independent of the building group to avoid added complexity in the cost estimation process. Both upper and lower confidence limits identifying bounds of the final cost estimate were computed for three levels of confidence i.e. 50%, 75% and 90%. The confidence limits are shown in Table 7.4.1. The dependence of the confidence limits upon the number of buildings in the inventory is shown graphically in Figure 7.4.1.

In Cost Estimation Option 3, the user estimates the typical structural cost to seismically rehabilitate a building with the maximum amount of information. Further, there is no compartmentalizing of data into groups (as was done for the area in Cost Options 1 and 2). Therefore, Cost Estimation Option 3 is the most accurate predictor of the cost data collected in this study. The confidence limits for this option consequently show the smallest spread of all three cost estimation options.

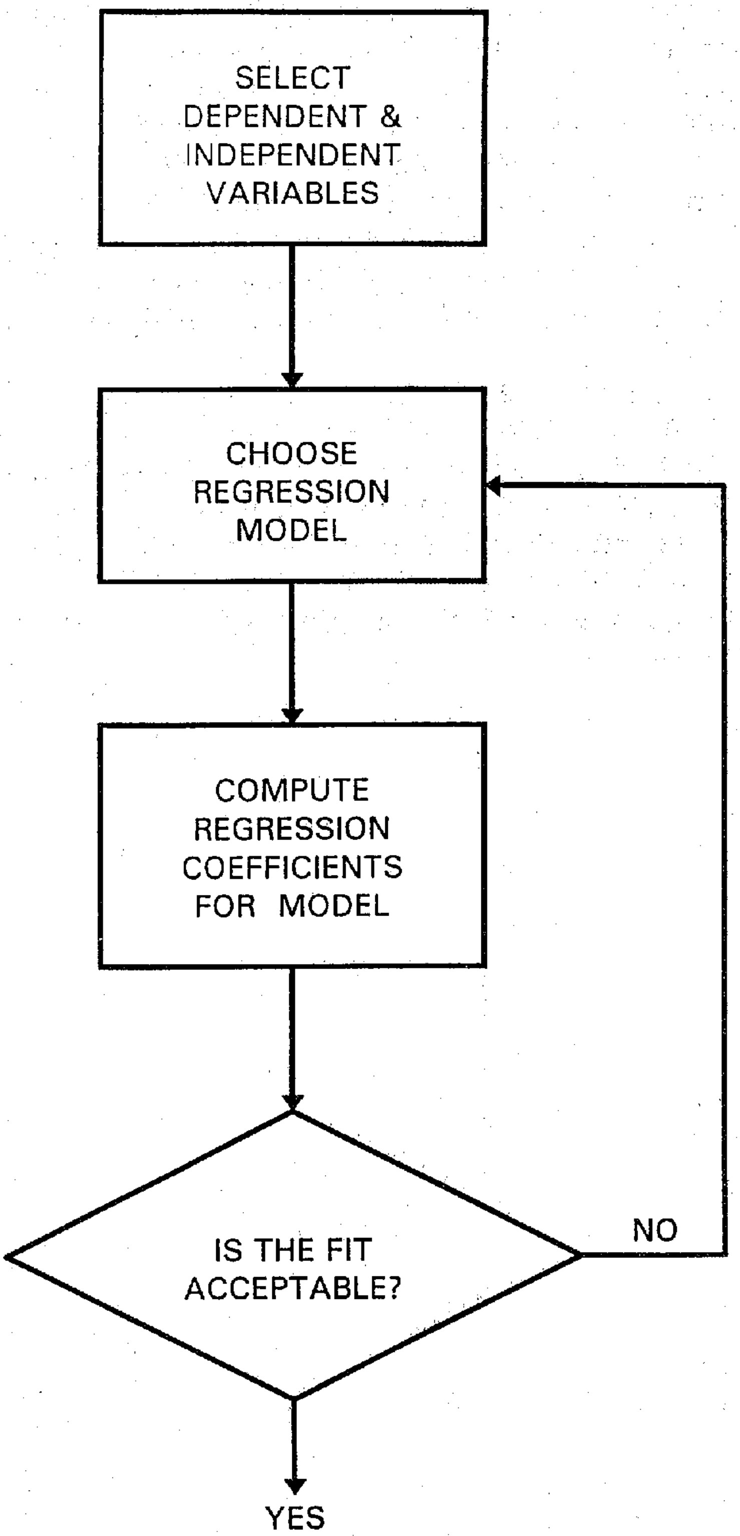

FIGURE 7.2.1 MULTIPLE LINEAR REGRESSION ANALYSIS

TABLE 7.3.1 VALUES OF REGRESSION VARIABLES

COEFF.	CATEGORY	BUILDING GROUP							
		1	2	3	4	5	6	7	8
C_C	-	151.9	1.2	13.5	36.9	182.5	137.6	59.2	86.5
X1	-	-0.23	-0.02	-0.26	-0.15	-0.30	-0.11	-0.26	-0.28
X2	-	0.02	0.52	0.60	0.18	0.19	-0.50	0.40	0.14
X3	-	0.28	-0.28	1.06	0.43	0.21	-0.71	0.40	0.53
X4 (See Table 4.5.2 below)	1	0.28	0.48	0.51	0.48	0.53	0.58.	0.47	0.61
	2	2.65	0.61	0.41	2.55	0.46	0.73	1.20	0.64
	3	1.16	0.72	1.25	0.72	1.07	1.27	0.97	0.43
	4	0.57	1.31	0.70	1.03	1.22	0.90	1.74	1.02
	5	0.69	0.40	0.35	0.52	0.76	0.83	0.67	0.44
	6	0.57	0.67	1.03	0.52	0.14	0.30	0.32	2.27
	7	0.76	1.17	0.96	1.01	1.23	0.42	0.81	1.42
	8	2.30	2.53	1.01	1.02	1.30	0.43	1.40	1.61
	9	1.48	1.12	1.20	1.17	1.25	1.35	1.10	1.86
	10	1.28	1.31	1.16	0.62	2.71	3.21	1.25	1.38
	11	1.60	1.24	3.23	1.28	1.89	2.12	1.57	0.46
	12	2.09	1.10	2.15	2.10	1.44	2.36	1.54	1.89
X5	P*	4.27	1.09	1.09	0.26	1.19	1.48	1.15	0.45
	M	0.76	0.43	0.59	4.50	0.45	0.56	0.85	0.36
	R	0.48	0.90	2.19	0.75	2.72	1.11	0.32	1.09
	F	0.98	0.91	0.99	1.03	0.39	0.54	0.96	2.21
	I	0.97	1.35	1.00	0.82	1.29	0.47	1.17	0.96
	C	0.82	0.94	1.47	1.01	0.81	0.73	2.48	1.25
	A	0.83	2.22	.53	1.33	0.91	4.77	1.33	2.16
X6	IP**	0.69	1.78	1.00	0.77	1.11	0.63	0.93	0.69
	TR	1.12	1.13	0.96	1.44	1.28	1.94	1.08	1.21
	V	1.30	0.50	1.04	0.90	0.70	0.81	0.99	1.20

Notes: * Occupancy Class: See Table 2.6.1 in Volume I
**Occupancy Condition: See Table 2.6.2 in Volume I

TABLE 7.3.2 CATEGORY FOR CONSTANT X4

	PERFORMANCE OBJECTIVES		
SEISMICITY	LIFE SAFETY	DAMAGE CONTROL	IMMEDIATE OCCUPANCY
Low	1	5	9
Moderate	2	6	10
High	3	7	11
Very High	4	8	12

TABLE 7.4.1 CONFIDENCE LIMITS FOR OPTION 3 COST ESTIMATES

NUMBER OF BUILDINGS	CONFIDENCE LIMITS					
	90%		75%		50%	
	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}
1	0.34	2.90	0.45	2.21	0.59	1.70
2	0.52	1.91	0.64	1.57	0.77	1.30
5	0.66	1.50	0.75	1.33	0.85	1.18
10	0.75	1.33	0.82	1.22	0.89	1.13
50	0.88	1.13	0.91	1.09	0.95	1.05
100	0.91	1.09	0.94	1.07	0.96	1.04
500	0.96	1.04	0.97	1.03	0.98	1.02
1000	0.97	1.03	0.98	1.02	0.99	1.01

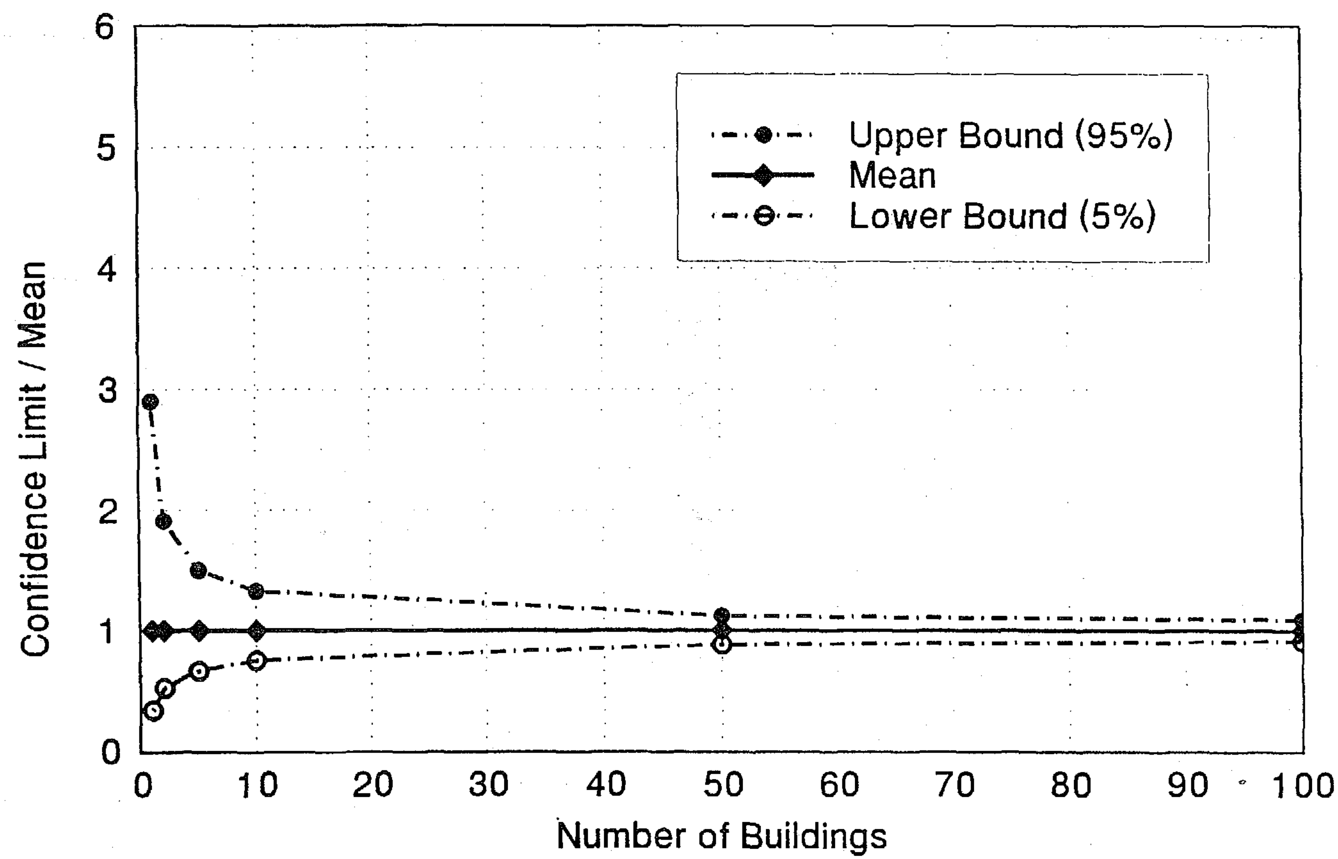

Figure 7.4.1 - Estimation of Confidence Limits for Option 3 Cost Estimates

APPENDIX A

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