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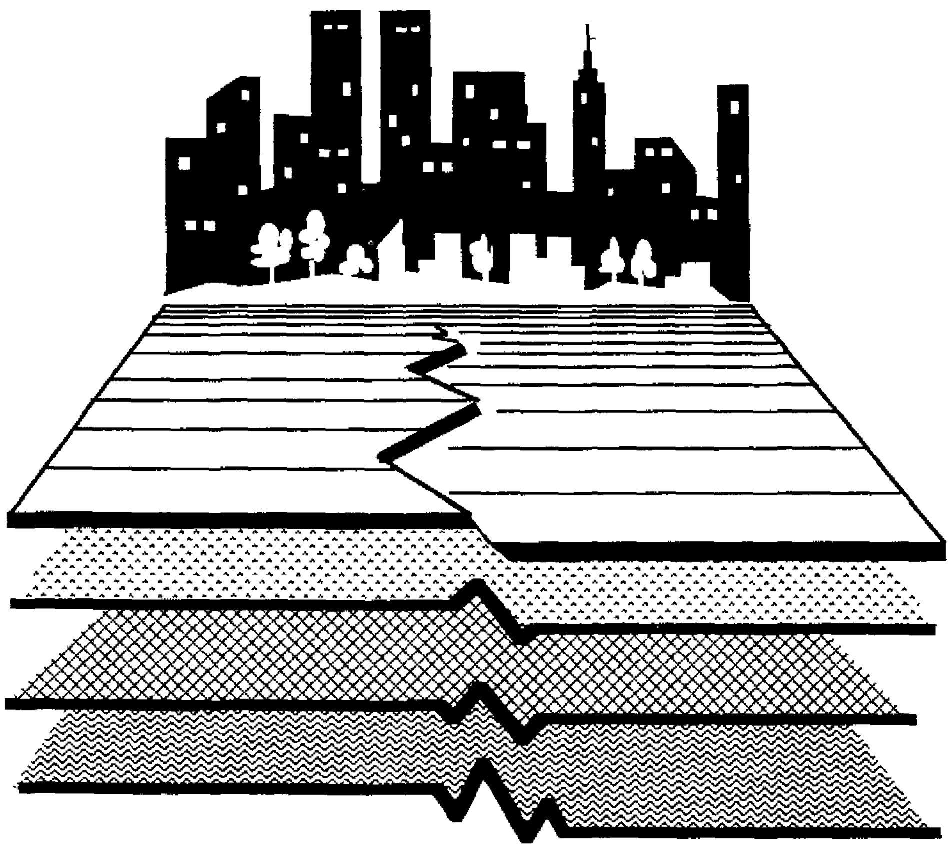
Second Edition Typical Costs for Seismic Rehabilitation of Existing Buildings

Volume 1 - Summary



EARTHQUAKE HAZARDS REDUCTION SERIES 39

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Decade for Natural Disaster Reduction.

NATIONAL EARTHQUAKE HAZARDS
REDUCTION PROGRAM

SECOND EDITION

TYPICAL COSTS FOR SEISMIC REHABILITATION OF BUILDINGS

VOLUME I - SUMMARY

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 $16 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 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 the event of an earthquake which can be conducted without gaining access to the buildings themselves; 2) a methodology for a more detailed evaluation of buildings 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 study <u>Typical Costs for Seismic Rehabilitation of Existing Buildings</u>, 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 socioeconomic 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 practioners 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 two documents 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 adapted or 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

In advance stages of preparation 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, and were submitted to the Executive Office of the President for consideration in September 1994.

FEMA is pleased to have sponsored the development of these two new publications 2nd Edition: Typical Costs for Seismic Rehabilitation of Buildings - Volume 1 and 2nd Edition: Typical Costs for Seismic Rehabilitation of Buildings - Volume 2 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 effort 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 this report.

CHAPTER 1 SUMMARY RESULTS

1.1 GENERAL

The first attempt at gathering a comprehensive set of costs for the seismic rehabilitation of buildings was completed in 1988 (Typical Costs of Seismic Rehabilitation of Existing Buildings-Volume I - Summary and its companion Volume 2: Supporting Documentation, FEMA 156 and 157, respectively) Although these volumes were based on a relatively small sample and employed a simplified analytical methodology, they nonetheless served the twin objectives of focusing the attention of decision makers and providing useful, general guidance on this very significant topic.

In the intervening six years, the tempo of improving the seismic safety of buildings in both the private and public sectors has accelerated. Further, such activities have spread from the region west of the Rocky Mountains to other parts of the country and more cost data on this subject has become available. Increasing the availability of this new data for use in seismic rehabilitation initiatives is the principle motive behind the preparation of a Second Edition of Typical Costs for Seismic Rehabilitation of Existing Buildings.

The Second Edition, which also consists of a summary and a supporting documentation volume reflects:

- A clear definition of "costs",
- A rigorous data collection procedure;
- A written data collection protocol;
- Intensive follow-up efforts to verify the data, and
- A stringent quality control process, including a quality rating for each data point.

This collection effort and the application of quality control procedures has resulted in the creation of a computerized database of 2088 data points, each data point being the cost of rehabilitation for one building. Each data point represents the cost of either an actual rehabilitation project or the estimated cost of rehabiliation of a building subjected to a detailed analysis by an experienced design professional. Cost estimates based on mere studies were excluded from the database. The database is, therefore, not only extensive but also objective and reliable. Further, it comprises a rather broad distribution of buildings in terms of types and location, as shown later in this chapter.

A sophisticated statistical methodology was developed to analyze this database, with one very significant result; **the quality and reliability of the cost estimation of seismic rehabilitations become significantly improved as more and more details of a building or a building inventory are available to the user and employed in the estimation process. Guidance is also provided to calculate a range of uncertainty associated with this process.** The variation of costs of seismic rehabilitation is large. However, the reliability of an estimation using the results of this analysis will improve if more characteristics of the building or inventory are known, and the reliability of the estimate will improve dramatically when used to obtain the average costs of many buildings.

Further, users are presented with the opportunity to apply any one of three typical cost estimation techniques, from a very simple to a rather complex one, depending on their needs or availability of information. Instructions on how to use the various techniques are contained in Chapter 4 of this volume. Depending on the cost estimation technique that the user selects, it is also possible to link costs to:

- One of three seismic performance objectives;
- Regional seismicity levels;
- Variations in the cost of labor and materials in any location in the United States and its Territories;
- Any one of 15 common building types, rearranged into eight groups; and
- Construction in the future using projected ENR indexes or estimated inflation
- Additional characteristics of the building

1.2 DEFINITION OF TERMS

In order to facilitate the understanding of the major results of this effort, it is first necessary to clarify a few of the most significant concepts used in both volumes.

- "Typical costs" is 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. Volume 2 contains a detailed discussion of this topic and provides data on costs that are not included in this definition, principal among which are those associated with architectural work in normal buildings, rehabilitating historic buildings, or upgrading a building to current electrical, mechanical or accessibility code requirements that might become mandatory as a result of seismic rehabilitation. Instructions on how to add allowances for these costs are also presented in that volume.

- The unit cost is **expressed in terms of dollars per square foot ($/sq.ft.) (One square meter equals 10.76 square feet).**

- All unit costs have been normalized to **1993 dollars for the State of Missouri** to represent an average national level. Information on how to apply this normalized cost to any location in the United States and Guam, or to any year in the next decade, is found in Chapter 4 of this volume.

- Buildings are categorized by **15 common building types.** These are identified and described in NEHRP Handbook for Seismic Evaluation of Existing Buildings, FEMA 178, pp. 14-16. For this effort, they have been clustered into eight groups. The groups are based on cost distribution similarities that have been identified based on physical similarities as well as similarities in costs. (See Table 1.2.1)

- The seismicity of the building location is categorized as **low, moderate, high** and **very high.** The four categories are correlated to the Map Areas shown in Map 1 of the 1991 Edition of the NEHRP Recommended Provisions for the Development of Regulations of New Buildings. (See Table 1.2.2 and Figure 1.2.1).

- Performance levels associated with the cost data are **life safety, damage control** and **immediate occupancy**. These levels are functionally described in Table 1.2.3.

TABLE 1.2.1 FEMA BUILDING MODEL TYPES AND BUILDING GROUP TYPES USED IN THIS STUDY

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 Diaphragm
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 Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls

TABLE 1.2.2 SEISMICITY CATEGORIES

SEISMICITY	NEHRP MAP SEISMIC AREA
Low	1,2
Moderate	3,4
High	5,6
Very High	7

DOCUMENTO ORIGINAL EN MAL ESTADO

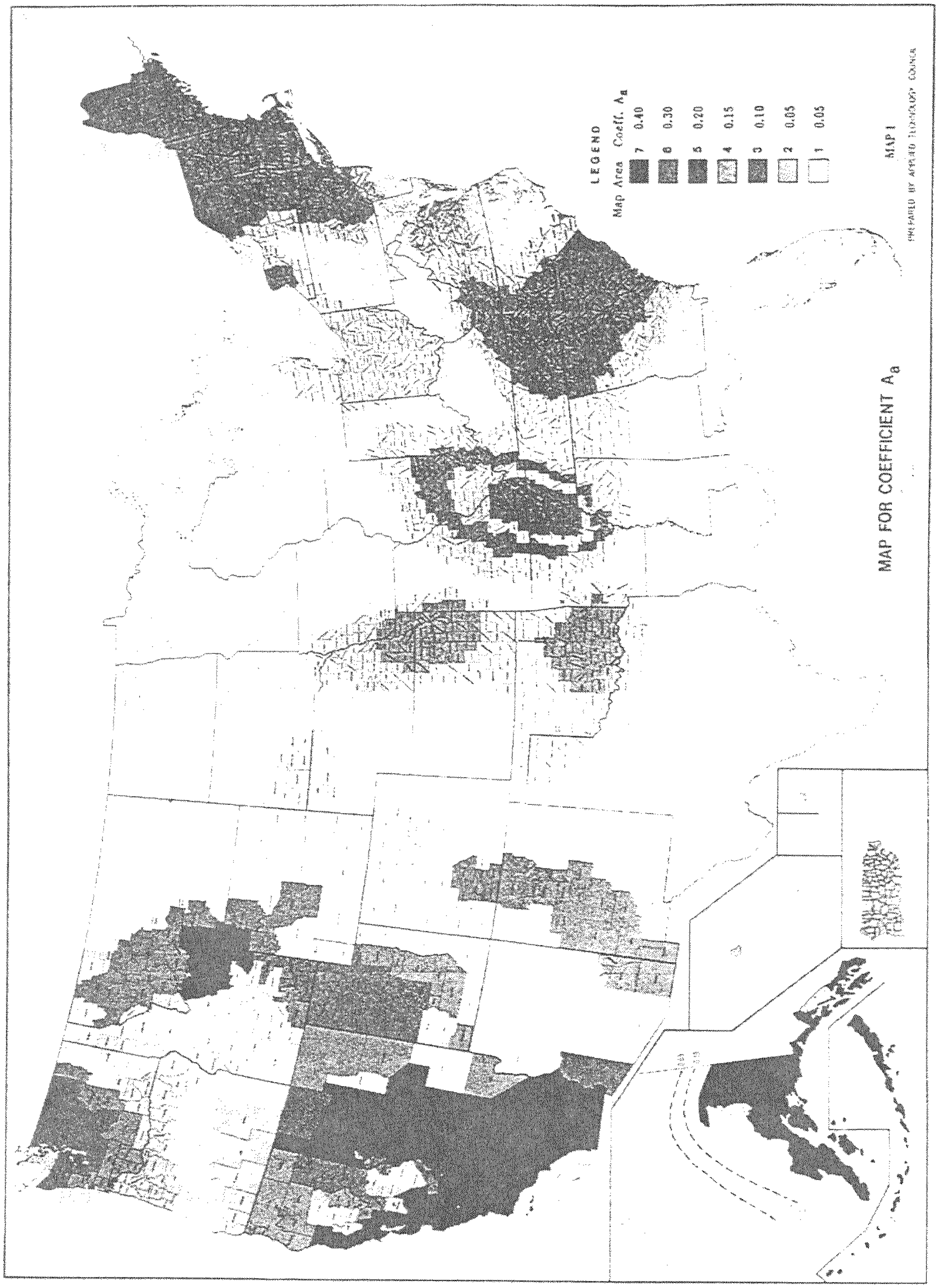

Figure 1.2.1 - NEHRP SEISMICITY MAP

TABLE 1.2.3 PERFORMANCE CATEGORIES

PERFORMANCE CATEGORY	DESCRIPTION
Life Safety (LS)	Allows for unrepairable damage as long as life is not jeopardized and egress routes are not blocked.
Damage Control (DC)	Protects some feature or function of the building beyond life-safety, such as protecting building contents or preventing the release of toxic material.
Immediate Occupancy (IO)	Allows only minimal post-earthquake damage and disruption, with some nonstructural repairs and cleanup done while the building remains occupied and safe.

1.3 DATABASE CHARACTERISTICS

As was indicated earlier, a rigorous collection effort coupled with stringent quality control measures resulted in the creation of a large database of exceptional reliability. Major characteristics of the 2088 data points (buildings) that were judged to be of high enough quality to be included in the database are summarized below.

Figure 1.3.1 shows the distribution of the building cost database as a function of the building groups defined in Table 1.2.1. Figure 1.3.2 shows the distribution of the data by NEHRP map seismic area. Figure 1.3.3 is similar to Figure 1.3.2 but URM buildings have been omitted because their large number tends to skew the data. Figure 1.3.4 shows the distribution of cost data by three performance categories. The number of URM buildings by performance objective was 442 Life Safety, 167 Damage Control and 71 Immediate Occupancy. Figure 1.3.5 shows a three dimensional plot of

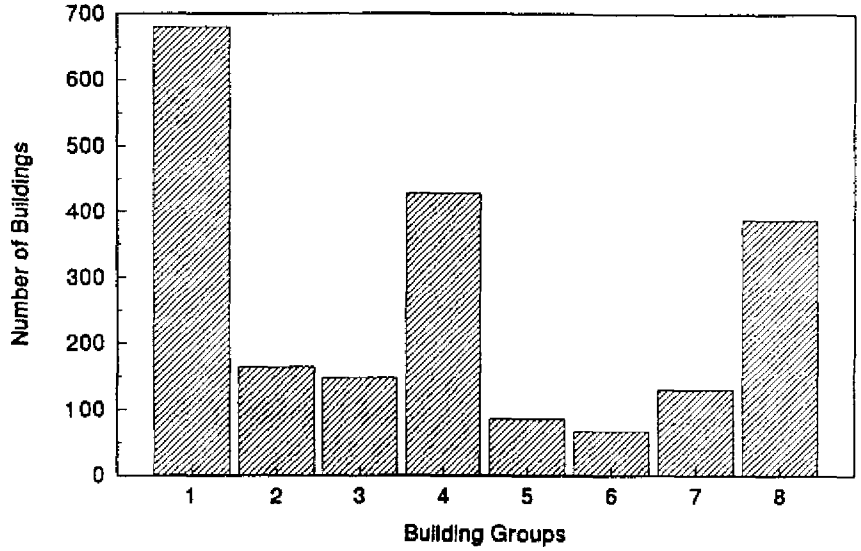

FIGURE 1.3.1 NUMBER OF BUILDINGS IN DIFFERENT BUILDING GROUPS

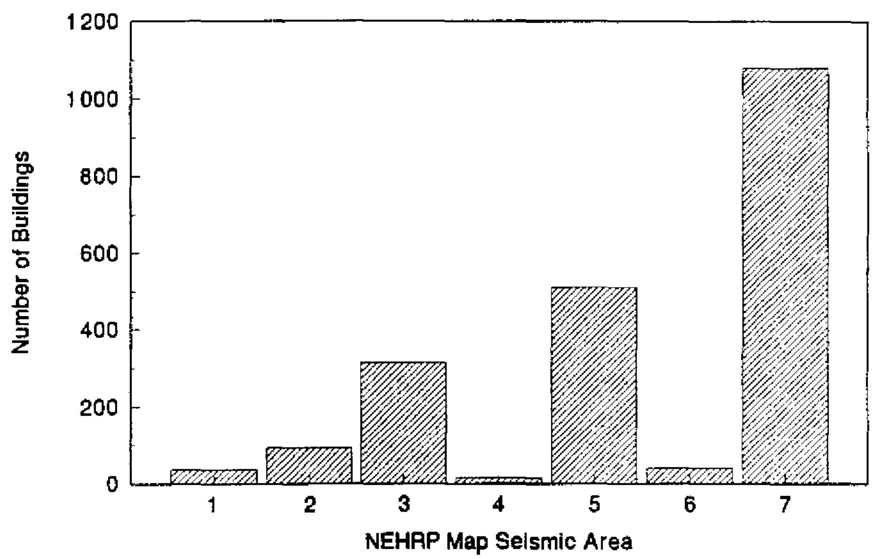

FIGURE 1.3.2 NUMBER OF BUILDINGS IN DIFFERENT NEHRP MAP SEISMIC AREAS (WITH URM BUILDINGS)

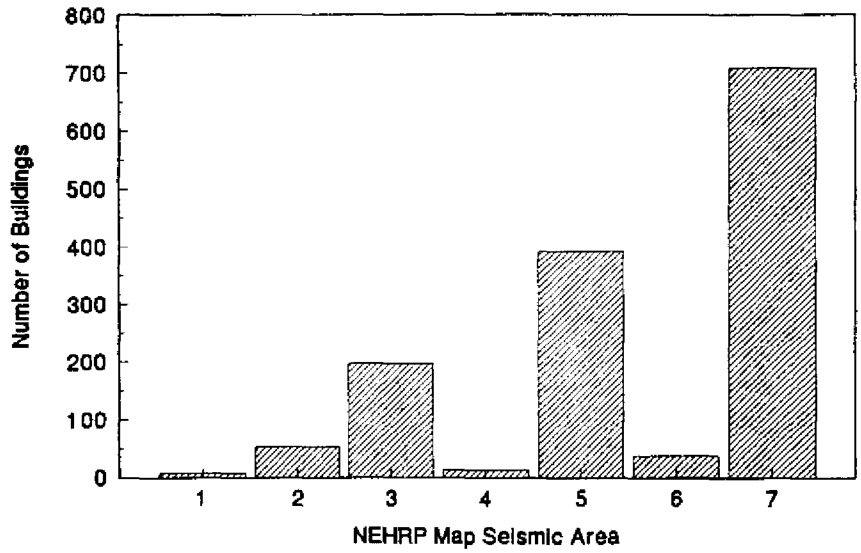

FIGURE 1.3.3 NUMBER OF BUILDINGS IN DIFFERENT NEHRP MAP SEISMIC AREAS (WITHOUT URM BUILDINGS)

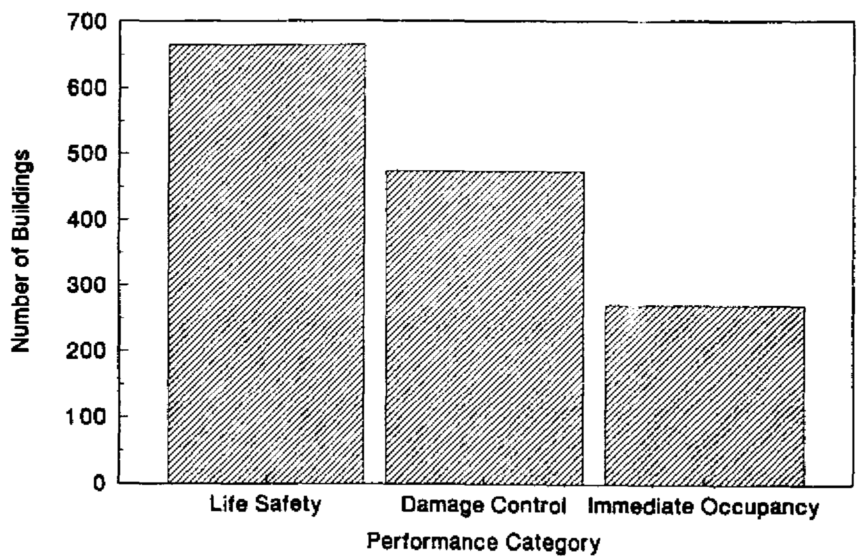

FIGURE 1.3.4 NUMBER OF BUILDINGS IN DIFFERENT PERFOMANCE CATEGORIES (WITHOUT URM BUILDINGS)

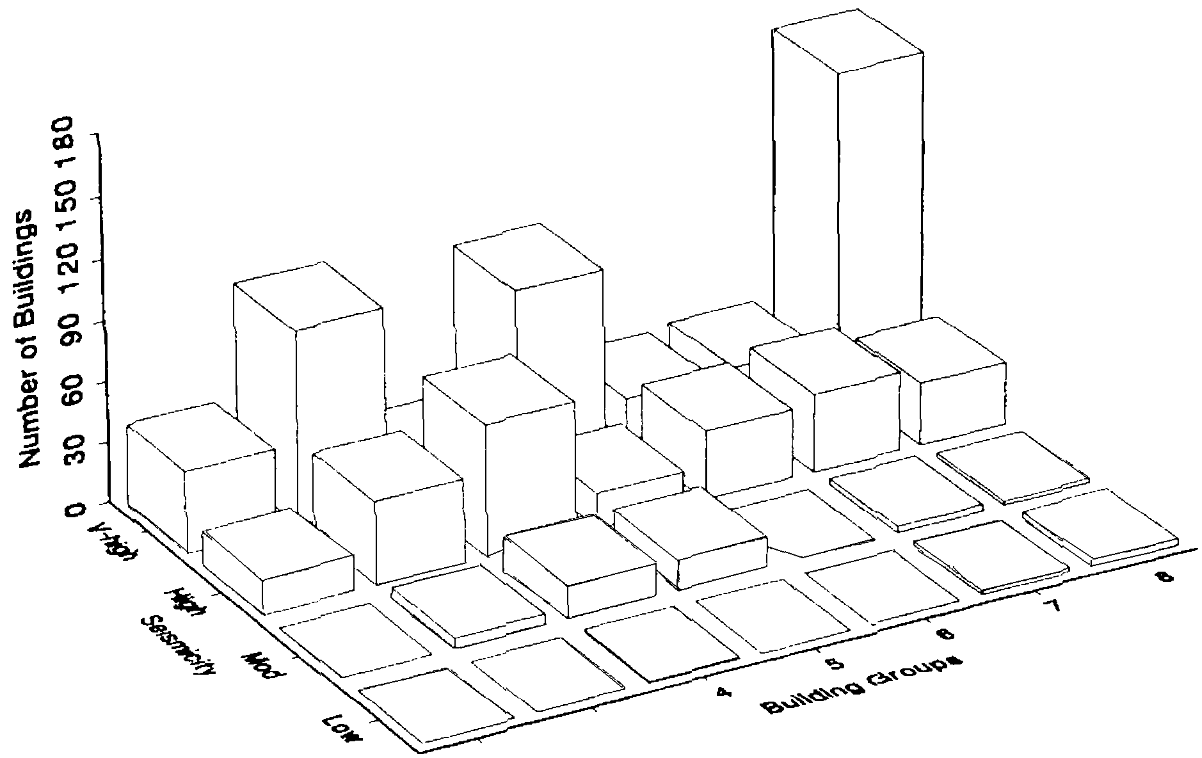

FIGURE 1.3.5 NUMBER OF BUILDINGS FOR DIFFERENT BUILDING GROUP/SEISMICITY COMBINATIONS

(LIFE SAFETY PERFORMANCE WITHOUT URM BUILDINGS) the number of buildings with a life safety performance category as a function of building group and seismicity Figure 1 3.6 shows a similar plot as a function of performance category and seismicity.

1.4 DATABASE LIMITATIONS

As previously noted, the data represents the most extensive and accurate cost data available to users However, because of the diversity of reasons for performing the rehabilitations and also the diversity of objectives of the users of this database there are some limitations that are important to note. Many, and perhaps all, of these limitations can be removed from the database if the presented methodology is modified to meet the specific needs of a specific user. The noted limitations are:

- **Architectural Renovation**: The cost data does not include costs associated with extensive removal and replacement of architectural finishes or other nonstructural aspects that must always be considered during seismic rehabilitation. The cost of rehabilitation of large architectural features (e g cladding) is not included.

- **Distribution of Buildings in the Database**: The building cost data was collected and placed in one of the eight building groups. Within each group there was typically more than one FEMA building type. The cost data for that group will therefore reflect the distribution of buildings within the group. Considerable effort was taken to group the NEHRP types with similar cost mean values and distribution. However, if a user has a different mix of buildings within a group (e.g only C2 buildings in Group 8 and no PC2, RM2 or S4 buildings), then a unique cost database that included only C2 building types would be more representative. If such a situation exists, the users can use Method 3 or analyze the data themselves.

- **Single Building Cost Estimation**: For a single building type, e.g. C1, there is a significant variation in rehabilitation costs even for buildings of the C1 type within a single structural engineering design office. The methods presented in Chapter 4 for deriving typical costs must be interpreted when used with a single building

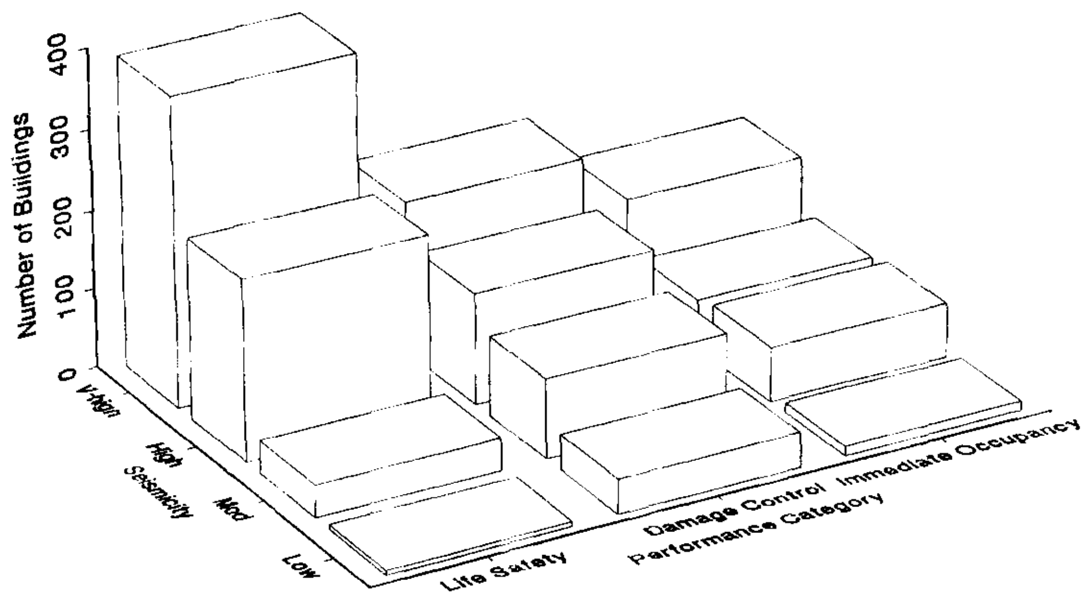

FIGURE 1.3.6 NUMBER OF BUILDINGS FOR DIFFERENT PERFORMANCE CATEGORY / SEISMICITY COMBINATIONS
(WITHOUT URM BUILDINGS)

Because of the wide variation in costs for individual buildings with similar characteristics, mean costs are less variable as the number of buildings in an inventory increases. This limitation is overcome by specifying a range of costs for a single building.

- **Rehabilitation Following a Damaging Earthquake**: The database does not differentiate between costs associated with a rehabilitation performed as a direct response to observed structural damage after an earthquake and costs associated with a planned rehabilitation. Very few, if any, data points represent damaged buildings. The cost of rehabilitation when structural damage exists and/or when there are pressures to reopen or re-occupy the building as fast as possible after an earthquake will be significantly greater than for a planned pre-earthquake rehabilitation.

1.5 METHODS TO DERIVE TYPICAL COSTS

Chapter 4 of this volume contains a detailed discussion of the methodology that was used to derive from the database three different options for deriving typical costs. Each option was designed to provide cost data that is as reliable as possible given the information available. As more information is available, the cost data becomes more refined.

Figure 1.5.1 shows a schematic overview of the options and required information. A brief description of each option follows.

- **OPTION 1** : This option requires knowledge by the user of the building group, the size in square feet of the building or buildings in the group under consideration, and the year for which typical costs are desired. The user can stop at this point but may want to learn the confidence range that can be assigned to the typical cost estimation, in which case the number of buildings in an inventory is also required. The typical costs obtained from Option 1 are deemed adequate only for very general discussions of potential seismic rehabilitation costs for large inventories.

- **OPTION 2** : The user of Option 2 needs to know the information required for Option 1, the seismicity of the location (by NEHRP Map Area), and the desired performance objective. Typical costs derived from the use of Option 2 are deemed accurate enough for planning purposes and only when considering multiple buildings .

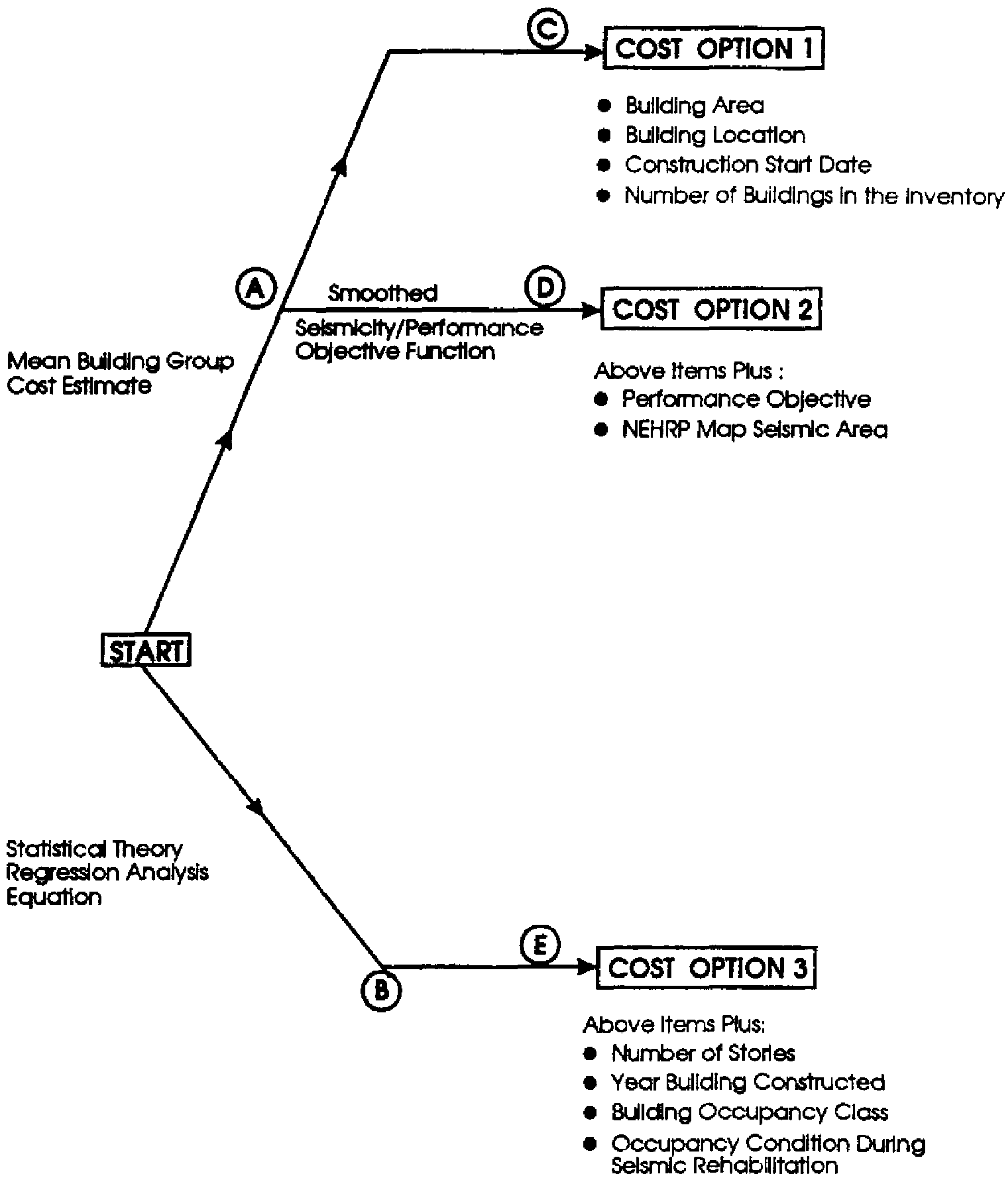

FIGURE: 1.5.1 SCHEMATIC OF COST OPTIONS

• **OPTION 3** - In addition to the information required for Option 2, the user of this option must know the age of the building(s), the number of stories, the occupancy type (office, residential) and occupancy condition (vacant, in use during rehabilitation). In return for investing a greater effort to gather this additional information and to perform some mathematical calculations, the user obtains the most mathematically rigorous definition of typical costs possible through the use of this database. Further, the computerized database is available in its entirety to a user for whatever calculation may be desired. The database is available from Birch and Davis Associates, Inc., at (301) 589-6760 (phone) or (301) 650-0398 (fax). A description of the database can be found in Appendix D of this volume.

1.6 TYPICAL COSTS EXAMPLE

As an example of the results that can be obtained by the use of Option 2, following are four tables; Tables 1.6.1 through 1.6.4, one for each seismicity level. They present the 1993 structural costs per square foot for a single building of one of four sizes (square footage), assuming that the materials and labor costs are those of the State of Missouri and the performance objective is life safety. The four categories identified correspond to the following ranges:

• Small	Less than 10,000 sq.ft.
• Medium	10,000 sq.ft. to 49,999 sq.ft.
• Large	50,000 sq.ft. to 99,999 sq.ft.
• Very Large	100,000 sq.ft or greater

The typical cost of all buildings in the database that can be used for general cost estimation purposes is $16.50/sq ft .

TABLE 1.6.1 TYPICAL STRUCTURAL COSTS FOR VERY HIGH SEISMICITY AND LIFE SAFETY ($/sq. ft.)

BUILDING GROUP	MODEL	FEMA BUILDING TYPES	AREA			
			SMALL	MEDIUM	LARGE	V-LARGE
1	URM	Unreinforced Masonry	18.22	18.04	17.14	14.43
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)	14.07	14.79	18.56	23.78
3	PCI RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphragm	18.69	17.70	15.52	9.43
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls	25.75	25.04	23 86	19.84
5	S1	Steel Moment Frame	25.82	25.37	24.26	18.47
6	S2 S3	Steel Braced Frame Steel Light Frame	10.07	9.56	7.68	4.35
7	S5	Steel Frame with Infill Walls	29.47	29.18	28.05	24.65
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls	22 67	22.06	20.83	16.95

TABLE 1.6.2 TYPICAL STRUCTURAL COSTS FOR HIGH SEISMICITY AND LIFE SAFETY ($/sq. ft.)

BUILDING GROUP	MODEL	FEMA BUILDING TYPES	AREA			
			SMALL	MEDIUM	LARGE	V-LARGE
1	URM	Unreinforced Masonry	13.74	13.61	12.93	10.89
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)	10.61	11.16	14.00	17.94
3	PCI RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphragm	14.10	13.35	11.48	7.11
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls	19.42	18.89	18.00	14.97
5	S1	Steel Moment Frame	19.47	19.14	18.30	13.93
6	S2 S3	Steel Braced Frame Steel Light Frame	7.59	7.21	5.79	3.28
7	S5	Steel Frame with Infill Walls	22.22	22.01	21.16	18.59
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls	17.10	16.64	15.71	12.79

TABLE 1.6.3 TYPICAL STRUCTURAL COSTS FOR MODERATE SEISMICITY AND LIFE SAFETY ($/sq. ft.)

BUILDING GROUP	MODEL	FEMA BUILDING TYPES	AREA			
			SMALL	MEDIUM	LARGE	V-LARGE
1	URM	Unreinforced Masonry	10.81	10.70	10.17	8.56
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)	8 34	8.78	11.01	14.11
3	PCI RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphragm	11.09	10.50	9.03	5.59
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls	15.28	14.86	14.15	11.77
5	S1	Steel Moment Frame	15.31	15.05	14.39	10.96
6	S2 S3	Steel Braced Frame Steel Light Frame	5.97	5.67	4.55	2.58
7	S5	Steel Frame with Infill Walls	17.48	17.31	16.64	14.62
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls	13.45	13.09	12.36	10.06

TABLE 1.6.4 TYPICAL STRUCTURAL COSTS FOR LOW SEISMICITY AND LIFE SAFETY ($/sq. ft.)

BUILDING GROUP	MODEL	FEMA BUILDING TYPES	AREA			
			SMALL	MEDIUM	LARGE	V-LARGE
1	URM	Unreinforced Masonry	9.42	9.33	8.86	7.46
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)	7.27	7.65	9.60	12.30
3	PCI RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphragm	9.60	9.15	7 87	4.87
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls	13.31	12.95	12.33	10.26
5	S1	Steel Moment Frame	13.35	13.11	12.54	9.55
6	S2 S3	Steel Braced Frame Steel Light Frame	5.20	4.94	3.97	2.25
7	S5	Steel Frame with Infill Walls	15.23	15.09	14.50	12.74
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls	11.72	11.40	10.77	8.76

1.7 COMPARISON WITH TYPICAL COSTS IN THE FIRST EDITION

In the First Edition of Typical Costs of Seismic Rehabilitation of Existing Buildings, completed in 1988, the database consisted of 614 data points, or fewer than one-third as many as the 2088 that comprise the database for this effort, and most of the original data points were derived from rather limited studies. Unreinforced masonry buildings were by far the most predominant building type. Further, the "typical cost" in the First Edition, expressed in California 1988 dollars, was calculated by deleting the lower and upper one-sixth of the data points, so as to reduce the influence that extreme data points would have had on the mean values.

For historical reasons only, Table 1.7.1 presents a comparison of costs between the two editions in as similar a manner as feasible, including the elimination of the lower and upper one-sixth of the data points in each respective database. Both sets of costs assume the performance objective of the rehabilitation work to be life safety. The costs in the First Edition were for California buildings in the late 1970's and the costs for the Second Edition are all for buildings located in Missouri for 1993 in the database.

TABLE 1.7.1 FIRST AND SECOND EDITION COST COMPARISONS
LIFE SAFETY PROTECTION ONLY
($/sq. ft.)

BUILDING GROUP	FIRST EDITION	SECOND EDITION
Unreinforced Masonry	$ 6.40	$ 12.82
Reinforced Masonry	$ 3.70	$ 10.80
Reinforced Concrete	$ 10.60	$ 14.70
Precast Concrete	$ 12.90	$ 5.58
Wood	$ 12.30	$ 8.77
Steel	$ 10.25	$ 14.23