BSSC PROGRAM ON
IMPROVED SEISMIC SAFETY PROVISIONS

SOCIETAL IMPLICATIONS: SELECTED READINGS

Prepared for the
Federal Emergency Management Agency
by the
Building Seismic Safety Council
Committee on the Societal Implications
of Using New or Improved
Seismic Safety Design Provisions

BUILDING SEISMIC SAFETY COUNCIL
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Societal Implications: A Community Handbook, 1985
Societal Implications: Selected Readings, 1985

Overview of Phases I and II, 1984
Appendixes to the Overview, 1984

NEHRP Recommended Provisions for the Development of Seismic Safety Provisions for New Buildings (draft version for ballot by the BSSC membership), 1984:
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- Part 2--Commentary,
- Appendix--Existing Buildings

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PREFACE

This volume of selected readings is intended to accompany the volume Societal Implications: A Community Handbook, one of a series of publications prepared by the Building Seismic Safety Council (BSSC) under contract to the Federal Emergency Management Agency (FEMA). The objective of the handbook is simply to provide between two covers a synthesis of what is known about the most significant societal implications of adopting new or improved seismic regulations for new buildings in those communities across the land that are considering such a step. This accompanying volume of selected readings provides a sampling of more detailed information.

The handbook is a companion publication to the NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings. Both are intended for voluntary use by interested parties in the nonfederal sector. Comments and suggestions for improvement of the handbook are earnestly solicited. Similar publications are scheduled for completion in the next several months.

FEMA is grateful to the BSSC Board of Direction and its Executive Director, to the BSSC committee members and consultants who prepared the handbook and assembled the selected readings, and to the many other volunteers whose contributions to and participation in the BSSC study have enriched the content of these publications. Similar acknowledgment is due the U.S. Geological Survey for the geotechnical information and the National Bureau of Standards for the structural engineering and cost information contained in the handbook as well as for their support at the four BSSC meetings with building process participants (in Charleston, South Carolina; Memphis, Tennessee; St. Louis, Missouri; and Seattle, Washington) during which many useful insights were obtained.

Federal Emergency Management Agency

FOREWORD

This volume of selected readings and the handbook it accompanies have been developed to provide participants in the building process at the local, state, and regional levels with the information they need to adequately address the potential effects on their communities of using new or improved seismic safety design provisions in the development of regulations for new buildings. It represents one product of an ongoing program conducted by the Building Seismic Safety Council (BSSC) for the Federal Emergency Management Agency (FEMA). A brief description of this program is presented below so that readers of the handbook and these selected readings can approach their use with a fuller understanding of their purpose and limitations.

BSSC PROGRAM ON IMPROVED SEISMIC SAFETY PROVISIONS

The BSSC was established in 1979 as an independent, voluntary body with a membership of 57 organizations representing the full spectrum of building community interests. Its fundamental purpose is to enhance public safety by providing a national forum that fosters improved seismic safety provisions for use by the building community in the planning, design, construction, regulation, and utilization of buildings. The BSSC Program on Improved Seismic Safety Provisions is structured to assist FEMA in achieving national seismic safety goals.

Phases I and II

Phases I and II of the BSSC program have focused on new construction. During these phases Tentative Provisions for the Development of Seismic Regulations for Buildings, originally developed by the Applied Technology Council (ATC), were reviewed and revised (in cooperation with the National Bureau of Standards). To assess the economic impact, usability, and technical validity of the amended provisions, 17 design firms in 9 major cities,[1] where the seismic risk varies from high to low, were retained to prepare trial designs of the structural systems of various types of buildings. The trial design effort included 46 buildings and each was designed twice--once according to the amended ATC document and once according to the prevailing local code for the particular location of the design.

The amended ATC document was further revised in light of the results of these trial designs and in late 1984 was submitted by the BSSC for ballot

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[1] Charleston, South Carolina; Chicago, Illinois; Ft. Worth, Texas; Los Angeles, California; Memphis, Tennessee; New York, New York; Phoenix, Arizona; St. Louis, Missouri; and Seattle, Washington.

to its members (see inside back cover) as The NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions for the Development of Seismic Regulations for New Buildings.

Phase III

During Phase III of the BSSC program, modifications are being made as a result of this first ballot. The document that results, NEHRP Recommended Provisions--1984, will reflect the consensus approval of virtually all segments of the building community and its publication is expected in late 1985. Since the NEHRP Recommended Provisions document is to present the most up-to-date data and technology in the context of a rational, nationally applicable approach to seismic safety design, its continuous revision and the issuance of subsequent editions are to be expected.

The BSSC also has examined the societal implications that could be expected as a consequence of utilizing the NEHRP Recommended Provisions as a source document in the development of local regulations, especially in communities east of the Rocky Mountains that have, to date, been largely unconcerned about the seismic safety aspects of building design. The handbook and this accompanying volume of selected readings present the results of that study.

Related Efforts

In related efforts the BSSC is examining the likely impact of the NEHRP Recommended Provisions on building regulatory practices and is developing materials and plans for encouraging maximum use of the NEHRP Recommended Provisions. In a joint venture with the Applied Technology Council and the Earthquake Engineering Research Institute, the BSSC is also examining the issues involved in improving the seismic safety of existing buildings and critical facilities. Information on these subjects will be published separately.

SCOPE OF THE HANDBOOK

The potential societal impacts of using new or improved seismic safety design provisions in developing regulations for new buildings are varied and difficult to quantify definitively. Nevertheless, after meeting with building process participants and seismic safety experts and pooling the expertise of its members, the BSSC Committee on Societal Implications has identified a number of potential impacts that require community consideration. The emphasis is on new buildings, and existing facilities are discussed only to the extent that seismic safety provisions for new buildings affect them.

DEVELOPMENT OF THE HANDBOOK

To develop the needed information, the BSSC Societal Implications Committee attempted to identify the many principal concerns, issues, and problems connected with utilization of the NEHRP Recommended Provisions by meeting with building process participants in four selected areas:

- Charleston, South Carolina
- Memphis, Tennessee
- Seattle, Washington
- St. Louis, Missouri

Charleston and Seattle already enforce seismic safety provisions for new buildings while Memphis and St. Louis do not. Although these four communities have somewhat different physical, social, and economic characteristics and different degrees of seismic risk, they are representative of a broad range of seismic conditions and urban characteristics that exist in the United States.

The committee supplemented the information it gathered in the four communities with information from the literature and with the expertise and experience of its individual members so that it could present the users of the handbook with relatively authoritative, if not completely comprehensive, guidance.

CONTENT OF THE HANDBOOK AND THESE SELECTED READINGS

In the chapters included in the handbook:

- The potential impacts identified by the committee are described.

- Information sources and data bases that may be able to provide communities with general as well as specific information and guidance are listed.

- General terms related to earthquakes are defined and the modified Mercalli intensity (MMI) scale and the Richter magnitude scale are described.

In this accompanying volume of selected readings, the committee has assembled a series of papers that address various aspects of the seismic safety issue. A number of these papers were prepared specifically for the BSSC study and several were presented at the BSSC committee meetings with building process participants. Several other papers were originally presented at a 1984 FEMA workshop but were not published. One other paper was suggested for inclusion by a BSSC committee member. Included are:

- An estimate of the impact of the NEHRP Recommended Provisions on design and construction costs developed for the BSSC study

  "Cost Impact of the NEHRP Recommended Provisions on the Design and Construction of Buildings" by Stephen F. Weber, National Bureau of Standards

- Descriptions of the seismic hazard in various areas of the United States developed for the BSSC study

  "Earthquake at Charleston in 1886" by G. A. Bollinger, Virginia Polytechnic Institute and State University

  "Earthquake Hazards in the Memphis, Tennessee, Area" by Arch C. Johnston and Susan J. Nava, Tennessee Earthquake Information Center

  "Evaluation of the Earthquake Ground-Shaking Hazard for Earthquake Resistant Design" by Walter W. Hays, U.S. Geological Survey

  "Introduction to Seismological Concepts Related to Earthquake Hazards in the Pacific Northwest" by Stewart W. Smith, University of Washington

  "Nature of the Earthquake Threat in St. Louis" by Otto W. Nuttli, St. Louis University

- Explanations of seismic safety codes

  "Development of Seismic Safety Codes" by Robert M. Dillon, American Council for Construction Education

  "The Purpose and Effects of Earthquake Codes" by Theodore C. Zsutty, San Jose State University, and Haresh C. Shah, Stanford University

- Descriptions of current seismic hazard mitigation practices and programs

  "Current Practices in Earthquake Preparedness and Mitigation for Critical Facilities" by James E. Beavers, Martin Marietta Energy Systems, Inc.

  "Management of Earthquake Safety Programs by State and Local Governments," by Delbert B. Ward, Structural Facilities, Inc.

- A description of recent seismic safety policy research developed for the BSSC study

  "Summary of Recent Research on Local Public Policy and Seismic Safety Mitigation" by Claire B. Rubin, George Washington University

- A summary of the BSSC committee meetings with building process participants in Charleston, Memphis, St. Louis, and Seattle

- A relatively extensive set of references to serve as the basis for more detailed research

- The list of information sources and the glossary of terms that also appear as Chapters 7 and 8 of the handbook

Although the readings presented herein are far from comprehensive, they are intended to give the handbook user some idea of the sorts of information that are available. In addition, the set of references and the list of information sources, which are included in both the handbook and the selected readings volume, will give interested readers some guidance about what to look for and where to find it when they pursue topics of special interest.

ACKNOWLEDGMENTS

The BSSC and its Committee on Societal Implications is grateful to the many individuals who contributed to this project. The committee is especially grateful to the building process participants in Charleston, Memphis, St. Louis, and Seattle who attended its meetings and so articulately identified issues for committee attention. Special thanks go to those who spoke at and/or developed presentations for the committee's meetings: in Charleston, Charles Lindbergh of the South Carolina Seismic Safety Commission, G. A. Bollinger of Virginia Polytechnic Institute and State University, and Joyce B. Bagwell, of Baptist College; in Memphis, Warner Howe of Gardner and Howe Structural Engineers and Arch Johnston and Susan Nava of the Tennessee Earthquake Information Center; in St. Louis, Otto Nuttli of St. Louis University and John Theiss of Theiss Engineers, Inc.; and in Seattle, Bruce Olson, Consulting Engineer, and Stewart Smith of the University of Washington. The committee also wishes to thank Stephen Weber of the National Bureau of Standards for conducting an economic analysis of the cost impact of the NEHRP Recommended Provisions and for presenting a summary of his findings at each of the four meetings. Walter Hays of the U.S. Geological Survey deserves special recognition for arranging for the speakers and for preparing a special background paper for their use. Finally, the committee wishes to acknowledge the contribution of its consultants and the other authors who graciously allowed their work to be included in the selected readings volume.

REQUEST FOR FEEDBACK

Because every community is unique in some way, FEMA and the BSSC urge those using the handbook and these accompanying readings to provide feedback on their experiences. If the handbook is to serve its purpose as one means for providing up-to-date, experience-based seismic design information, reports from its users are essential.

A "Feedback Sheet" is included at the back of both the reports to make the response process easier and to permit users to request additional information. Every attempt will be made to integrate what is learned into future publications and to inform those who respond about the experiences of other communities and about subsequent BSSC and FEMA efforts.

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COST IMPACT OF THE NEHRP RECOMMENDED PROVISIONS
ON THE
DESIGN AND CONSTRUCTION OF BUILDINGS

STEPHEN F. WEBER

ABSTRACT

This paper provides some information on the approximate cost impacts resulting from implementation of the NEHRP (National Earthquake Hazards Reduction Program) Recommended Provisions (Building Seismic Safety Council 1984 a) and proposes research to obtain improved estimates of cost impacts. The information is derived from the 52 case studies of the Building Seismic Safety Council (BSSC) trial design program conducted in 1983-84 and based on an amended version of the Applied Technology Council's Tentative Provisions for the Development of Seismic Regulations for Buildings (ATC Tentative Provisions). The NEHRP Recommended Provisions are the result of the revisions and amendments to the ATC Tentative Provisions that were recommended during the trial design program. For the 29 trial designs conducted in the 5 cities (Chicago, Ft. Worth, Memphis, New York, and St. Louis) whose local building codes currently have no seismic design provisions, the average projected increase in total building construction costs was 2.1 percent. For the 23 trial designs conducted in the 4 cities (Charleston, Los Angeles, Phoenix, and Seattle) whose local codes currently do have seismic design provisions, the average projected increase in total building construction costs was 0.9 percent. The average increase in cost for all 9 cities combined was 1.6 percent. Although these case study results cannot be directly projected to the U.S. building population, they do reflect the order of magnitude of the cost impacts.

INTRODUCTION

This paper provides information on the approximate cost impacts resulting from implementation of the National Earthquake Hazards Reduction Program NEHRP Recommended Provisions and proposes research to obtain improved estimates of these cost impacts. The information presented here summarizes the results of 52 case studies which compared the costs of constructing the structural components of a wide variety of buildings designed according to two distinct criteria: (1) the prevailing local

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Dr. Weber is an Economist for the Center for Applied Mathematics, National Bureau of Standards, Gaithersburg, Maryland. He developed this paper for the BSSC Study of Societal Implications and presented this information at the BSSC meetings in Charleston, Memphis, St. Louis, and Seattle.

building code; and (2) a proposed set of improved seismic safety provisions similar to the NEHRP Recommended Provisions. Some of the case studies also compared the structural engineering design time required for the two design criteria. The case studies included multifamily residential, office, industrial, and commercial building designs in nine U.S. cities.

The case studies that serve as the primary data source for this paper are the result of the Building Seismic Safety Council (BSSC) trial design program that was conducted in 1983-84. This trial design program was established to evaluate the usability, technical validity, and cost impact of the application of a somewhat amended version the Applied Technology Council (ATC) Tentative Provisions for the Development of Seismic Regulations for Buildings. The NEHRP Recommended Provisions, which currently are being balloted by the BSSC membership, include additional amendments made in response to the results of the trial design program.[1] It is important to note, therefore, that the trial design program data on potential cost impacts of seismic design summarized here are based on the amended Tentative Provisions and not directly on the NEHRP Recommended Provisions themselves and that, as noted by the BSSC: "Some buildings showing high cost impacts will be significantly affected by new amendments to the amended Tentative Provisions that should tend to reduce the impact (BSSC, 1984 b)."

The framework for selecting the specific building designs included in the trial design program is first described. The major factors considered in that selection framework include building occupancy type, structural system, number of stories, and the cities for which the designs were developed. The types of cost data reported by the participating engineering firms also are described. The cost impact data results of the trial designs then are presented in summary form by building occupancy type and by city as well as in detail for each of the four cities visited by the BSSC Committee on Societal Implications (Charleston, South Carolina; Memphis, Tennessee; St. Louis, Missouri; and Seattle, Washington). In presenting the cost data, a distinction will be made between two separate cases: (1) building communities not currently using a seismic code of any kind (e.g., Memphis and St. Louis) and (2) building communities that currently are using a seismic code (e.g., Charleston and Seattle). The paper closes with some conclusions regarding the cost impact of seismic design and suggestions for further research.

DESCRIPTION OF THE TRIAL DESIGN DATA

The construction cost impact of the amended Tentative Provisions generally depends on two major groups of factors: those related to characteristics of the building itself and those related to the location in which the building is to be constructed. The first group includes such

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[1] See Volume I, Overview of Phase I and II, of the 1984 BSSC report, BSSC Program on Improved Seismic Safety Provisions, for a full description of the trial design effort.

factors as the planned occupancy of the building, the structural system used to support the building, the general shape of the building in terms of number of stories and floor plan, and the total size of the building. The second group includes such factors as the seismic hazard of the building site and the degree to which that hazard is reflected in the current local building code. Because each of these six cost impact factors can assume several different values, the number of potentially unique trial designs is very large indeed. A statistically valid experimental design that would adequately sample from each of these unique cases (combinations of cost impact factors) would have required a total sample size that was well beyond the budget and time available for the trial design program.

Framework for Selecting Trial Designs

Because of the necessary limit on the number of trial designs, the case study approach was used as an alternative to statistical sampling. In order to make the case studies as representative as possible, a framework was developed distributing the trial designs over the broad range of values for each of the cost impact factors mentioned above. This overall framework used for selecting the specific building designs included in the trial design program is best illustrated by referring to Table 1. Beginning with the left-hand column, there are four types of building occupancy included in the framework: residential, office, industrial, and commercial. As the next four columns show, the structural system was divided into four elements, each of which has a number of different types: vertical load system, seismic resisting system components, other vertical components, and floor or roof components. For example, the vertical load system could use either bearing walls or a complete vertical load carrying frame. The method of resisting seismic forces could employ such systems as plywood walls, concrete masonry walls, brick walls, precast concrete walls, reinforced concrete shear walls, prestressed moment frame, or steel braced frame. The number of stories varied from single-story to a high-rise building with 40 stories. Between these extremes there were buildings with 2, 3, 5, 10, 20, and 30 stories. As indicated in the far right-hand columns, the trial designs were distributed over nine cities: Los Angeles, Seattle, Memphis, Phoenix, New York, Chicago, Ft. Worth, Charleston, and St. Louis. These cities cover the range of seismic hazard levels found in the United States and they vary in the degree to which seismic provisions are contained in their local building code. For example, Los Angeles is in a very high seismic hazard area while New York City is in a low hazard area. Similarily, Seattle has adopted the Uniform Building Code (1979) seismic provisions while the city of Memphis, although exposed to considerable seismic hazard, has no seismic provisions in its building code.

There are a total of 468 possible combinations of the 9 cities with the 52 building types. Each of these combinations constituted a potential candidate for inclusion in the trial design program. Each candidate is represented by one of the cells in the nine columns on the right-hand side of Table 1. From all these potential candidates, 46 were selected as the building design/city combinations used in the trial design pro-

TABLE : Framework for Selecting BSSC Trial Designs

Plan Form	Vertical Load System	Seismic Resisting System Components	Other Vertical Components	Floor or Roof Components	Bldg No.	No. of Stories	Cities: Phase I Los Angeles	Seattle	Memphis	New York	Phase II Phoenix	Charleston	Ft. Worth	Chicago	St. Louis
Residential	Bearing Walls	Plywood wall		Wood + plywood diaphragm	1	3	●	●							
		Concrete masonry wall		Wood + plywood diaphragm	2	3				●					
		Brick and concrete masonry		Wood + plywood diaphragm	2A	3						●			
		Concrete masonry wall		Prestressed slab	3	5				●			●		
		Brick wall		Reinforced concrete slab	4	3									
				Reinforced concrete slab	5	11	●				●				
				Reinforced concrete slab	5A	10									●
		Brick and concrete masonry wall		Steel joist	6	5								●	
				Steel joist	7	12									
		Reinforced concrete wall		Reinforced concrete slab	8	5			●						
				Reinforced concrete slab	9	12						●			
				Post-tensioned slab	10	5				●					
		Precast concrete wall		Prestressed slab	11	5									
				Prestressed slab	12	12									
	Complete Vertical Load Carrying Frame	Steel, braced frame (transverse)/ moment frame (longitudinal)	Steel Framing	Steel joists	13	10									
			Steel Framing	Steel beam & RC slab	14	20			●						
		Reinforced concrete shear wall	RC framing	RC flat plate	15	10	●						●		
			RC framing	Post-tensioned flat plate	16	20						●			●
			RC framing	Post-tensioned flat plate	17	30									
		Reinforced concrete moment frame (perimeter)	RC framing	RC flat plate	18	10	●		●						
			RC framing	RC flat plate	19	20									
		RC, MF (perimeter) & SW (dual)	RC framing	RC flat plate	20	20									
			RC framing	RC flat plate	20A	20					●				
Office	Bearing walls	Reinforced concrete wall (core)	RC framing	RC flat slab	21	10									
			RC framing	RC flat slab	22	20				●	●				
		PC wall (interior & exterior)	PS framing	Prestressed slab	23	10									
	Complete Vertical Load Carrying Frame	Reinforced concrete shear wall	Steel framing	Steel beam & RC slab	24	10		●						●	
			Steel framing	Steel beam & RC slab	25	20									
		Steel braced frame	Steel framing	Steel beam & RC slab	26	20									
			Steel framing	Steel beam & RC slab	26A	5									●
		Steel moment frame	Steel framing	Steel beam & RC slab	27	10	●		●						
			Steel framing	Steel joist	27A	5					●				
			Steel framing	Steel beam & RC slab	27A	5							●		
			Steel framing	Steel beam & RC slab	28	40									
			Steel framing	Steel beam & RC slab	28A	30					●				
		Steel MF & RC SW (dual)	Steel framing	Steel beam & RC slab	29	20	●								
		Steel MF and BF (dual)	Steel framing	Steel beam and RC slab	30	20		●							
		Reinforced concrete moment frame	RC framing	Post-tensioned flat slab	31	10									
			RC framing	RC pan joist & waffle	32	10				●	●				
			RC framing	PT pan joist	33	20									
		RC, MF & SW (dual)	RC framing	RC pan joist & waffle	34	20	●								
Industrial	Bearing walls	Concrete masonry wall	Steel framing	Steel joist	35	L				●					
		PC wall (maybe PS)	PS framing	Prestressed slab	36	H									
			PS framing	PC double tees girders & beam	36A	H						●			
		PC tilt-up wall	Wood framing	Wood (plywood)	37	L	●								
	Complete Vertical Load Carrying Frame	PC tilt-up wall	Steel framing	Steel joist	38	L			●						
		Steel moment frame (transverse)/ braced frame (longitudinal)	Steel framing	Steel purlins & deck	39	L	●							●	
			Steel framing	Steel long-span truss	40	H		●							
		Concrete masonry wall	Steel framing	Steel joist	41A	2					●				
Commercial	Complete Vertical Load Carrying Frame	Concrete masonry wall	Steel framing	Steel joist	41	2	●								
			Steel framing	Steel joist (irregular plan form)	42	2			●						
		PS moment frame	PS framing	Prestressed slab	43	2									

1 - All office buildings will have a high first story, the industrial buildings are all on one story (with the exception of Building No. 41A) and for them the L indicates a low clearance, and H indicates a high clearance.

2 - BF = braced frame — MF = moment frame — RC = reinforced concrete
PC = precast concrete — PT = post-tensioned concrete — SW = shear wall (non-bearing)
PS = prestressed, precast concrete

3 - With the exception of the industrial building with purlins and steel deck (the metal building) all moment frames in Los Angeles, Seattle and Memphis are to be Special. All moment frame in dual systems must also be Special. All other moment frames may be Ordinary.

gram. These selected combinations are represented by dots that appear in the cells of Table 1. For 6 of these 46 buildings, alternative designs were also developed to provide 6 additional cost impact estimates. As a result, there are 52 data points for which cost impact estimates are available.

For each of the 52 building designs included in the trial design program, a set of building requirements or general specifications was developed and provided to the responsible design engineering firm. An example of such building requirements specifications is presented in Table 2. Within these requirements designers were given latitude to assure that building design parameters such as bay size were compatible with local construction practice. The designers were not permitted, however, to change the basic structural type. For example, they could not change from a reinforced concrete frame system specified in the building requirements to a reinforced concrete shear wall system. Such changes were not permitted even if an alternative structural type would have cost less under the amended Tentative Provisions than the specified type. This constraint may have prevented the designer from selecting the most economical system for the amended Tentative Provisions, and consequently may have resulted in overestimates of the cost impacts for some of the trial designs. The 17 design firms involved in the trial design program and the building designs for which each was responsible are identified by city in Table 3.

Data Reported for Trial Designs

For each of the trial designs, the engineering firms developed two individual designs for the structural components of the buildings. One design was based on the prevailing local building code and the other was based on the amended Tentative Provisions for the city in which the building was to be located. The former will be referred to as the Local Code Design and the latter will be referred to as the Tentative Provisions Design. Both of these designs are described in considerable detail for each trial design in the engineering reports submitted by the firms (BSSC, 1984c). It should be noted that only structural components were included in the analysis for the 52 trial designs summarized here. Consequently, the Tentative Provisions Design did not include those requirements for nonstructural elements described in Chapter 8 of the amended Tentative Provisions. The engineering reports also include detailed estimates of the construction costs for the structural components of each of the two designs (Local Code Design and Tentative Provisions Design). These cost estimates were derived using standard, nationally recognized cost estimating guides that take into account local cost factors. The estimates were made on the basis of current construction costs at the time the designs were completed, which ranged from early 1983 through the middle of 1984. The percentage differences in these structural component cost estimates for the two designs (i.e., cost of the Tentative Provisions Design minus cost of the Local Code Design divided by cost of the Local Code Design times 100) provide the

TABLE 2 Typical Building Requirements[a]

- Plan Form - as per that shown for each building type
- Number of Stories - 20
- Clear Structural Height - 11 feet except that: (a) the first story shall have a 20 - foot clear structural height, and (b) the clear structural height does not apply along the perimeter
- Plan Story Area - 7,500 to 25,000 sq ft
- Plan Aspect Ratio - 1:1 to 2:1
- Bay Size - 20 foot minimum dimension; 600 sq ft minimum area (minimum bay size does not apply to perimeter column spacing)
- Roof - nominally flat but with a 1/4 in 12 slope for drainage
- Window Areas - 30 to 40 percent of exterior wall areas
- Core Size - proportional to the building height
- Core Walls and Floors - include openings for doorways, stairs, and elevators; core wall may be structural
- Foundation Conditions - selected as representative of those that could be anticipated in the local, consistent for all designs, and included in design presentations
- Vertical Load Systems - complete vertical load-carrying frames
- Seismic Resisting Systems Components - dual system[b] - steel moment frame (Special) and braced frame
- Other Vertical Components - steel framing
- Floor and Roof Components - steel beams and reinforced concrete slabs
- Similarity should be maintained in paired studies, such as local requirements for live loads and assumed dead loads
- Other - not applicable

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[a] Requirements vary with building type.
[b] As defined in Chapter 2 amended Tentative Provisions.

TABLE 3 Design Firms and Types of Building Designs

City/Design firm	Type of Building/No.
Seattle	
Abam Engineers, Inc.	o 10-Story Steel Frame with RC Shear Wall (O)/S-24
Bruce C. Olsen	o 3-Story Wood with Plywood Walls (R)/S-1 o 1-Story Long Spa Steel, 30′ Clear Height-MF and Braced Frames (I)/S-40
Skilling, Ward, Rogers, Barkshire	o 20-Story Steel Frame-Dual Special & Braced Frames (0)S-30
Los Angeles	
S. B. Barnes & Associates	o 3-Story Wood with Plywood Walls (R)LA-1 o 1-Story Wood Frame with Precast Concrete Tilt-Up Walls (I)/LA-37 o 1-Story Steel with Moment and Braced Frames (I)LA-39 o 2-Story Steel Frame with RC Block Walls (C)/LA-41
Johnson & Nielsen	o 20-Story Steel Moment Frame with Shear Walls (Dual) (O)LA-34
Wheeler & Gray	o 12-Story Reinforced Brick Bearing Wall with RC Slabs (R)LA-5
Phoenix	
Magadini-Alagia Associates	o 5-Story RC Bearing Wall (R)/P-10 o 20-Story RC Bearing Wall with Core Shear Walls (O)P-22 o 10-Story RC Frame (Ordinary) (O)/P-32
Read, Jones, Christoffersen Inc.	o 3-Story RC Block Bearing Wall (R)/P-2 o 5-Story RC Block Bearing Wall (R)/P-3 o 1-Story Steel Frame with RC Block Shear Walls (I)/P-35

TABLE 3 Continued

City/Design Firm	Type of Building/No.
Allen & Hoshall, Inc.	o 5-Story Bearing Wall (R)M-8 o 1-Story Steel Frame with RC Tilt-Up Exterior Shear Walls (I)/M-38 o 2-Story Steel Frame with Non-Bearing RC Block Walls (C)M-42
Ellers, Oakley, Chester & Rike, Inc.	o 20-Story Steel Moment and Braced Frame with RC Floors (R)/M-14 o 10-Story RC Moment Frame (Perimeter) (R)/M-18 o 10-Story Steel Moment Frame (Special) with RC Slabs (O)/M-27
Ft. Worth, Texas	
Datum-Moore Partnership	o 5-Story RC Block Walls with Prestressed Slabs (R)/FW-3 o 10-Story RC Frame with RC Shear Walls (R)FW-15 o 5-Story Steel Moment Frame (O)FW-27A
St. Louis	
Theiss Engineering	o 10-Story Clay Brick Bearing Wall (R)/SL-5A o 20-Story RC Frame with RC Shear Walls (R)SL-16 o 5-Story Steel Frame with Braced Framed at Core (O)/SL-26A
Chicago	
Alfred Benesche & Co.	o 3-Story Brick and RC Block Bearing Walls with Plywood Floor & Roof Diaphragms (R)/C-2A o 20-Story RC Frame with RC Shear Walls (R)/C-16
Klein & Hoffman	o 12-Story RC Bearing Wall (R)/C-9 o Parametric Study of Steel Moment and/or Braced Frames (O)C-26, C-27, & C-30 o 1-Story Precase RC Bearing Walls with PC Double Tee Roof (I)/C-36A

TABLE 3 Continued

City/Design Firm	Type of Building/No.
Klein & Hoffman	o 12-Story RC Bearing Wall (R)/C-9 o Parametric Study of Steel Moment and/or Braced Frames (O)/C-26, C-27, & C-30 o 1-Story Precast RC Bearing Walls with PC Double Tee Roof (I)/C-36A
New York City	
Weidlinger Associates	o 12-Story Brick Bearing Wall (R)/NY-5 o 30-Story RC Moment Frame and Non-Bearing Shear Wall (Dual) (R)/NY-20A o 10-Story RC Moment Frame (O)/NY-32
Robertson and Fowler	o 20-Story RC Bearing Wall (O)/NY-22 o 5-Story Steel Moment Frame (O)/NY-27A o 30-Story Steel Moment Frame (O)/NY-28A o 2-Story Steel Frame with RC Block Walls (I)/NY-41A
Charleston, S.C.	
Enright Associates	o 5-Story Brick and RC Block Bearing Walls (R)/CSC-6 o 10-Story Steel Frame with RC Shear Walls (O)/CSC-24 o 1-Story Steel Moment and Braced Frame (I)/CSC-39

R = Residential
O = Office
I = Industrial
C = Commercial

primary raw data on which this paper is based. Because the focus of this paper is on percentage cost differences rather than absolute estimates, the slight changes in construction costs during the study period can be reasonably ignored.

In addition to the estimates of the construction costs for the structural components of the two designs, the engineering firms also submitted rough estimates of the additional design time that would be required to use the amended *Tentative Provisions*. Typically these estimates were reported as percentage changes in design time required for the structural components assuming the design engineer was already familiar with the amended *Tentative Provisions*. These design time cost percentage change estimates are also summarized below.

SUMMARY OF COST IMPACTS

This section summarizes the cost impact data reported by the 17 design engineering firms that participated in the trial design program. The first subsection provides an overview of the construction cost impacts organized first by type of building occupancy and then by city. In the overview by city, the data are presented in two groups: cities not currently using any seismic provisions in their local building codes and cities currently using seismic provisions in their codes. The first subsection also summarizes the design time percentage change estimates provided by the engineering firms. The second subsection reports the construction cost impacts for each individual trial design in the four cities that were visited by the BSSC Committee on Societal Implications (Charleston, Memphis, St. Louis, and Seattle).

Overview of Cost Impacts

Table 4 presents an overview of the construction cost impacts by type of building occupancy. The five classes of buildings were derived from the orginal four classes found in the framework for selecting trial designs by dividing the residential designs into low-rise (five stories or fewer) and high rise (more than five stories). Because only three of the office building designs have fewer than ten stories (and those three have five stories), the office building class is not divided. Similarly, all seven of the industrial building designs have just one story and the three commercial designs all have two stories. The third column in Table 4 presents the percentage change in construction costs for the structural components of the building, with the Local Code Design as the base, as estimated by the BSSC trial design engineering firms. As can be seen, the average change for the structural costs is 5.6 percent, with by far the largest change (11.2 percent) reported for the high-rise residential designs. This high average for residential buildings is significantly influenced by the extremely high estimates reported for four of these building designs: LA18 (17 percent); M14 (16 percent); M18 (46 percent); and NY20A (20 percent).

TABLE 4 Percentage Changes in Structural Cost and Total Building Cost for the Trial Designs by Building Occupancy Type

Building Occupancy	Number of Designs	Estimated Change In Structural Cost (%)[a]	Projected Change in Total Cost (%)[b]
Low-rise residential[c]	9	3.6	0.7
High-rise residential[d]	12	11.2	3.3
Office	21	4.7	1.3
Industrial	7	1.5	0.5
Commercial	3	5.6	1.7
Average Percentage Change		5.6	1.6

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[a] Percentage change in structural construction cost from the local code to Amended _Tentative Provisions_, as estimated by the BSSC trial design engineering firms, 1983-1984.

[b] Projected percentage change in total building construction cost from the local code to Amended _Tentative Provisions_, derived from estimated structural cost changes by using the following McGraw-Hill's, _Dodge Construction Systems Cost_ (1984) data on structural cost as a percent of total building cost:

Low-rise residential	18.1%
High-rise residental	30.0%
Office	28.1%
Industrial	33.7%
Commercial	29.5%

[c] Five or fewer stories.

[d] More than five stories.

The fourth column of Table 4 presents the projected percentage change in total building construction costs for each building occupancy type. These total cost changes were projected from the structural cost percentage changes by using data on structural cost as a percentage share of total building cost for each building occupany type. The percentage shares are based on data from McGraw-Hill's, Dodge Construction System Costs (1984), which reports the structural percentage share of total building cost for a large number of typical building designs. The shares for three of these typical building designs were averaged for each of the building occupancy types to derive the percentage shares used in Tables 4 and 5 and reported in the footnotes to the tables. The average projected change in the total construction cost over all 52 of the trial designs is 1.6 percent. The high-rise residential building designs have the highest total building cost impact with 3.3 percent, both because of the four outliers mentioned above and the relatively high structural percentage share used for this type of building (30.0 percent).

Table 5 presents the same type of data as Table 4 but reported for each city grouped according to whether the city currently has a seismic building code or not. As expected, the average estimated change in the structural cost is considerably higher (more than twice as high) for those cities with no seismic provisions in their local codes than for those with seismic provisions: 7.6 percent versus 3.1 percent. A similar relationship holds for the projected change in total building cost: 2.1 percent for cities without seismic provisions versus 0.9 percent for those already having some seismic provisions in their local codes.

Table 6 summarizes the estimates made by the engineering firms of the change in structural design time that is expected to be required once the firms are familiar with the amended Tentative Provisions. The 52 responses are divided into the four categories: negligible change, positive but unspecified change, positive specified change, and negative specified change. The fourth category means that the amended Tentative Provisions, once adopted and familiar to the design firms, would require fewer design hours than the current codes do. The first response category of negligible change was the most common with 28 designs.

Detailed Cost Impacts for Selected Cities

Tables 7 through 10 present the cost impact data for each of the individual trial designs in the four cities visited by the BSSC Committee on Societal Implications. The first two cities (presented in Tables 7 and 8), Memphis and St. Louis, are examples of cities with no seismic provisions in their current building code even though the amended Tentative Provisions place them in relatively high seismic hazard zones. The last two cities (presented in Tables 9 and 10), Charleston and Seattle, are two examples of cities that do have seismic provisions in their local building codes. The point made in reference to Table 6 regarding greater cost impact for the cities without seismic codes can also be

TABLE 5 Percentage Changes in Structural Cost and Total Building Cost for the Trial Designs, by City and City Group With and Without Seismic Provisions in Current Local Codes

City	Number Of Designs	Estimated Change in Structural Cost (%)[a]	Project Change in Total Cost (%)[b]
		Cities Without Seismic Provisions	
Chicago	10	2.5	0.7
Fort Worth	3	6.1	1.5
Memphis	6	18.9	5.2
New York	7	7.3	2.1
St. Louis	3	4.5	1.3
Average Percentage Change		7.6	2.1
		Cities With Seismic Provisions	
Charleston	3	-2.5	-0.6
Los Angeles	10	4.2	1.3
Phoenix	6	6.9	1.9
Seattle	4	-1.1	-0.3
Average Percentage Change		3.1	0.9
Overall Average Percentage Change		5.6	1.6

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[a] Percentage change in structural construction cost from the local code to the amended _Tentative Provisions_, as estimated by the BSSC Trial Design engineering firms, 1983-1984.

[b] Projected percentage change in total building construction cost from the local code to Amended _Tentative Provisions_, derived from estimated structural cost changes by using the following McGraw-Hill's, _Dodge Construction Systems Costs_ (1984) data on structural cost as percent of total building costs:

Low-Rise Residential	18.1%
High-Rise Residential	30.0%
Office	28.1%
Industrial	33.7%
Commercial	29.5%

TABLE 6 Possible Effects of the Amended *Tentative Provisions* on Structural Engineering Design Time as Reported by the Trial Design Firms[a]

- For these 28 building designs negligible change was reported:

  LA1, S1, P2, P3, LA5, SL5A, CSC6, C9, P10, LA15, FW15, SL16, LA18, NY20a, S24, CSC24, SL26A, LA27, FW27A, NY28A, NY32, P35, C36A, LA37, CSC39, S40, LA41

- For these 11 building designs positive but unspecified change was reported:

  C2A, FW3, NY5, C26A, C26, C27, C27A, S30, C30A, C30, NY41A

- For these 11 buildin designs positive specified change ranging from 5% to 50% was reported:

  M8, M14, C16, M18, P22, NY22, M27, NY27A, P32, M38, M42

- For these 2 building designs negative specified change of -5% was reported:

  LA29, LA34

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[a] For descriptions of the individual building designs listed here, see Table 3.

TABLE 7 Design Description and Percentage Changes in Structural Cost and Total Building Cost for the Trial Designs of Memphis

Design Code	Stories	Structural Cost Change (%)[a]	Total Building Cost Change (%)[a]	Design Code Description
M8	5	25.0	4.5	Residential, reinforced concrete wall and slab
M14	20	16.0	4.8	Residential, steel frame/ moment frame, composite floor
M18	10	46.0	13.8	Residential, reinforced concrete moment frame, flat plate
M27	10	11.0	3.1	Office, steel moment frame, composite floor
M38	1	5.4	1.8	Industrial, tilt-up shear wall, steel framing
M42	2	10.0	3.0	Masonry shear wall, steel framing

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[a] See note on Tables 4 and 5 for definition.

TABLE 8 Design Description and Percentage Changes in Structural Cost and Total Building Cost for the Trial Designs of St. Louis

Design Code	Stories	Structural Cost Change (%)[a]	Total Building Cost Change (%)[a]	Design Description
SL5A	10	6.0	1.8	Residential, masonry walls, reinforced concrete slab
SL16	20	3.8	1.1	Residential, reinforced shear wall, flat plate
SL26A	5	3.6	1.0	Office, steel braced frame, composite floor

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[a] See note on Tables 4 and 5 for definition.

TABLE 9 Design Description and Percentage Changes in Structural Cost and Total Building Cost for the Trial Designs of Charleston, S. C.

Design Code	Stories	Structural Cost Change (%)[a]	Total Building Cost Change (%)[a]	Design Description
CSC6	5	-3.5	-0.6	Residential, masonry walls, steel joists
CSC24	10	-4.0	-1.1	Office, reinforced concrete shear wall, composite floor
CSC39	1	0.0	0.0	Industrial, steel braced frame/moment frame

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[a] See note on Tables 4 and 5 for definition.

TABLE 10 Design Description and Percentage Changes in Structural Cost and Total Building Cost for the Trial Designs of Seattle

Design Code	Stories	Structural Cost Change (%)[a]	Total Building Cost Change (%)[b]	Design Description
S1	3	-1.1	-0.2	Residential, wood frame, plywood walls & dDiaphragms
S24	10	-4.6	-1.3	Office, reinforced concrete shear wall, composite floor
S30	20	1.3	0.4	Office, dual steel braced frame/moment frame, composite floor
S40	1	0.0	0.0	Industrial, steel braced frame/moment frame (metal building)

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[a] See note on Tables 4 and 5 for definition.

made here by comparing the average projected change in total building costs for Memphis (the highest at 5.2 percent) and St. Louis (1.3 percent) with the corresponding percentages for Charleston and Seattle (both negative).

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The results of the BSSC trial design program presented here provide some idea of the approximate cost impacts expected from implementation of the NEHRP Recommended Provisions. For the 29 trial designs conducted in the 5 cities (Chicago, Ft. Worth, Memphis, New York, and St. Louis) whose local building codes currently have no seismic design provisions, the average projected increase in total building construction costs was 2.1 percent. For the 23 trial designs conducted in the 4 cities (Charleston, Los Angeles, Phoenix, and Seattle) whose local codes currently do have seismic design provisions, the average projected increase in total building construction costs was 0.9 percent. The average increase in costs for all 9 cities combined was 1.6 percent. Although these case study results cannot be directly projected to the U.S. building population, they do reflect the order of magnitude of the cost impacts of the NEHRP Recommended Provisions.

In spite of the limited sample size of the trial design program, these data do offer several avenues for further research. The first is an analysis of variance test to see whether the difference in the cost impact estimates for the cities with and without current seismic provisions is statistically significant. Because of the rather large variance in the cost impact estimates, it may be that the difference between the two categories (2.1 percent versus 0.9 percent) is not significant. Other analyses could be conducted to see whether the factors such as building occupancy type and number of levels have a significant effect on the cost impact estimates.

Another major effort could be undertaken to normalize the data by controlling for the effect of the local seismic hazard and the presence of seismic provisons in the current code from city to city. If a seismic design value could be established for the Local Code Design cases that is comparable (i.e., on the same numeric scale) to the Seismic Design Coefficient used in the amended Tentative Provisions cases, then such a normalization could be accomplished. This would make possible the use of regression analysis techniques to develop a statistically valid method for estimating seismic design cost impacts for any city.

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