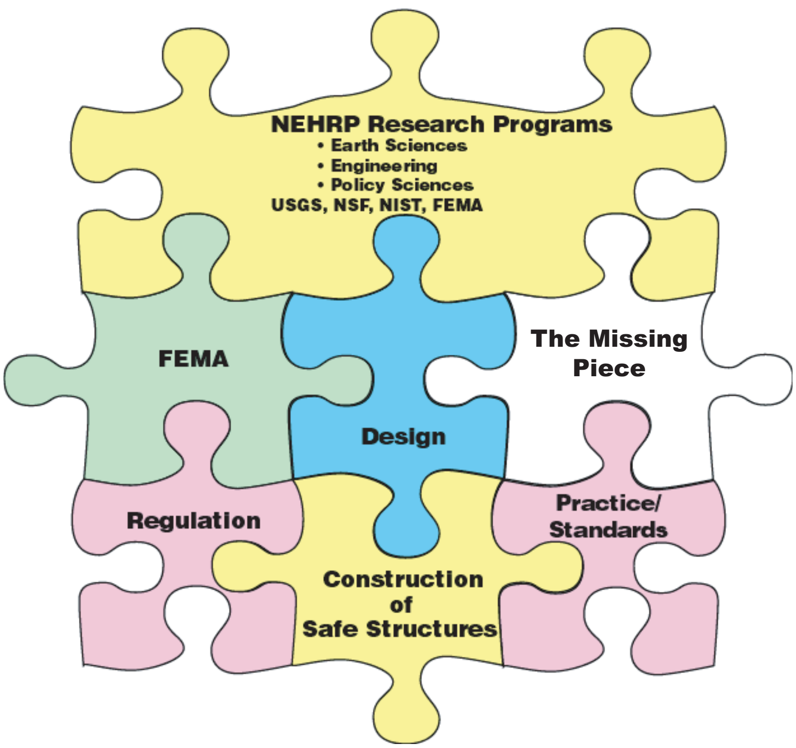
ATC 57

The missing piece: improving seismic design and construction practices



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The work reported herein is the direct result of the significant contributions of time and effort of the community of earthquake engineering professionals who participated in this project, with additional support provided by the Applied Technology Council and the National Institute of Standards and Technology, on behalf of the National Earthquake Hazards Reduction Program.

Applied Technology Council

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ATC-57

The Missing Piece: Improving Seismic Design and Construction Practices

by

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2003

PREFACE

In 2001, the Applied Technology Council (ATC) commenced a broadly based effort to define a problem-focused knowledge development, synthesis and transfer program to improve seismic design and construction practices. Input was sought from seismic design and construction industry leaders, and a Workshop was convened in the summer of 2002 to develop the program. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is the result of an industrial collaboration. It provides a framework for creating a knowledge bridge and allows the nation to more fully realize its NEHRP (National Earthquake Hazards Reduction Program) investment in practical terms—safer buildings.

THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES had its genesis in the strategic planning process for NEHRP, which was undertaken by the Federal Emergency Management Agency (FEMA) from 1998 to 2001. In the course of that strategic planning process, representatives from the design and construction industry determined and documented, as one of their major findings, that a technology transfer gap has emerged within NERHP, and that it limits the adaptation of basic research knowledge into practice. To resolve this problem, industry participants recommended that NEHRP agencies develop a much-expanded, problem-focused knowledge development, synthesis and transfer program that will:

1. Develop standards and guidelines that incorporate the best knowledge available in a practical way.
2. Facilitate the development of new mitigation technologies.
3. Improve the productivity of the engineering and construction industries.

Included in this report are:

- A definition of what needs to be done;
- Background information on the impetus for THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES program, on how technology transfer works, and a history of the decline in engineering and construction productivity in the United States; and
- THE MISSING PIECE program plan

THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES program emphasizes two subject areas, with a total of five Program Elements proposed:

- ***Systematic support of the seismic code development process.***

  Program Element 1 Provide technical support for the seismic practice and code development process.

  Program Element 2 Develop the technical basis for performance-based seismic engineering by supporting problem-focused, user-directed research and development.

- ***Improve seismic design and construction productivity.***

  Program Element 3 Support the development of technical resources (e.g., guidelines and manuals) to improve seismic engineering practice.

  Program Element 4 Make evaluated technology available to practicing professionals in the design and construction communities.

Program Element 5 Develop tools to enhance the productivity, economy and effectiveness of the earthquake resistant design and construction process.

Also included in this report are six issue papers commissioned to develop the basis for the proposed program, along with a list of project participants and other supplementary information.

ATC gratefully acknowledges the broad range of industry representatives who participated in the process. Charles C. Thiel Jr. served as the report editor and is the principal architect of the report. The project Steering Committee consisted of James E. Beavers, Lloyd Cluff, James M. Delahay, Robert D. Hanson, James Harris, Richard E. Neal, Christopher Rojahn, Paul Somerville, Charles C. Thiel, Jr., and Charles H. Thornton. The issue paper authors consisted of Edwin T. Dean, Ronald T. Eguchi, Ronald O. Hamburger, Roberto Leon and selected Steering Committee members. Workshop participants consisted of the above named individuals as well as Daniel Abrams, Gerald Brady, Joe Brewer, James Cagley, Alan Carr, Gene Corley, Ian Friedland, John Gillengerten, Melvyn Green, Gayle Johnson, H. S. Lew, Lee Marsh, Ed Matsuda, Peter McDonough, Bernadette Mosby, Chris Poland, Maurice Power, Woody Savage, Charles Scawthorn, Tom Schlafly, Paul Senseny, Daniel Shapiro, Shyam Sunder, Susan Tubbesing, and Ray Zelinski. Gail H. Shea served as Production Editor and Michelle Schwartzbach served as the Report Production Specialist.

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ATC Executive Director

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1 THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES

When the National Earthquake Hazards Reduction Program (NEHRP) was established in 1976, our knowledge of when and where earthquakes occurred and how to engineer structures to provide a life-safe environment was limited. It was limited by our scientific understanding of earthquake physics and hazards, the nature of earthquake forces on structures, and of how engineering materials and systems respond. Twenty-five years later, the base of earth sciences and engineering knowledge has been expanded significantly through NEHRP efforts. In the summer of 2002, thirty-seven national leaders in earthquake engineering design, practice, regulation, and construction fields met to assess the state of knowledge and practice. Their assessment was guarded as to whether full advantage was being made of this increased knowledge. The consensus of these recognized leaders was that the gap between engineering and scientific knowledge and its practical application (for design and construction of economical, earthquake-safe structures) has dramatically widened because so much more is now known. As a result, the amount known and developed during the last 25 years of NEHRP exceeds the knowledge put into practice. While there have been notable successes, e.g., the FEMA-sponsored SAC[1] effort to develop guidelines for the seismic design, evaluation, upgrade, and repair of welded steel moment frame buildings, such achievements have been sporadic and generally narrowly focused. The informational link between theory, research results, and practice is weaker than it should be. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES proposes to correct this weak link in the chain and thereby improve seismic safety.

The engineering professions recognize this weakness and seek its correction. THE MISSING PIECE program is intended to be a giant step towards (1) achieving a safer and acceptably functional earthquake structural environment through bringing the latest technical research and results to practicing engineers and (2) improving the productivity of the seismic design and construction community. The goal is to realize—in real life and in real buildings—the potential of the significant investment the nation has made in the past 25 years. We are at the juncture where the knowledge base has been sufficiently expanded that we can now reap the rewards in improved practice—achieve better earthquake safety, adequate post-earthquake functioning, and more economy in construction. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES establishes a framework through which the practicing engineering professions can form a permanent link with the information and research resources of the federal government and universities and colleges, so that what is known can be put into practice.

1.1 WHAT IS TO BE DONE

The goal of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is development of more efficient, effective, and technically reliable practice for earthquake engineering design and construction. Two subject areas with a total of five Program Elements are proposed:

- ***Systematic support of the seismic code development process.***

  Program Element 1 Provide technical support for the seismic practice and code development process.

  Program Element 2 Develop the technical basis for performance-based seismic engineering by supporting problem-focused, user-directed research and development.

[1] SAC is a joint venture partnership of the Structural Engineers Association of California, the Applied Technology Council, and Coalition of Universities for Research in Earthquake Engineering

- ***Improve seismic design and construction productivity.***

Program Element 3	Support the development of technical resources (e.g., guidelines and manuals) to improve seismic engineering practice.
Program Element 4	Make evaluated technology available to practicing professionals in the design and construction communities.
Program Element 5	Develop tools to enhance the productivity, economy and effectiveness of the earthquake resistant design and construction process.

The purpose of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is simply to make the above Program Elements full partners in the NEHRP program and provide a framework to bridge the research-practice gap so that the earthquake safety goals set by NEHRP legislation can be achieved.

The actions recommended in THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES are necessary if the National Earthquake Hazards Reduction Program is to be as successful in reducing the national vulnerability to earthquake-caused death and destruction as it could be. This is the last major element of the NERHP program needed to respond to the lofty goals set by Congress in 1976. Without THE MISSING PIECE effort, it will take too long to achieve the results we need—that is, improved seismic design and construction practices.

IT IS TIME TO ACT!

2 BACKGROUND

2.1 NEHRP AND THE NATIONAL EARTHQUAKE RISK

At the center of the National Earthquake Hazards Program (NEHRP) is the Congressional Goal to reduce the lives lost in earthquakes and their impact on the U.S. economy. Earthquakes represent an enormous threat to the nation (Figure 1). Significant earthquakes have occurred since the nation's founding in every area of the United States—Northeast, Southeast, Southwest, Midwest, Mountain, Northwest, Alaska—and the Caribbean, and Pacific Islands. When these faults slip again, and they will with certainty someday, death and destruction will be all the greater in this era of significantly greater population and increased building density and value. Not only will more lives and structures be lost, but, depending on the location of the earthquake, entire regions and the whole nation could be affected economically. To differing degrees, portions of most regions of the United States face the risk of a catastrophic earthquake and the entire country bears the economic burden when one occurs. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES seeks to enhance the likelihood that those damages are mitigated.

Although damaging earthquakes occur infrequently at any location, their consequences can be staggering. As recent earthquakes around the world have demonstrated, high population densities and development pressures, particularly in urban areas, are increasing the exposure and vulnerability of people, buildings, and the economy. Unacceptably high life loss and enormous economic consequences are associated with recent global earthquakes (1999 Koaceli Turkey, 1999 Chi Chi Taiwan, and 2001 Bhuj India earthquakes caused 17,000, 2,400 and 20,000 deaths respectively and economic losses of $5, $14 and $6 billion). It is only a matter of time before the United States faces a similar experience with economic losses significantly larger than we have ever experienced. The 1989 Loma Prieta and 1994 Northridge, California earthquakes are harbingers of much greater U.S. earthquake-caused catastrophes yet to happen. Imagine what the results would be if one of these earthquakes was centered under a major population center instead of in an outlying area, as was the case for both of these events.

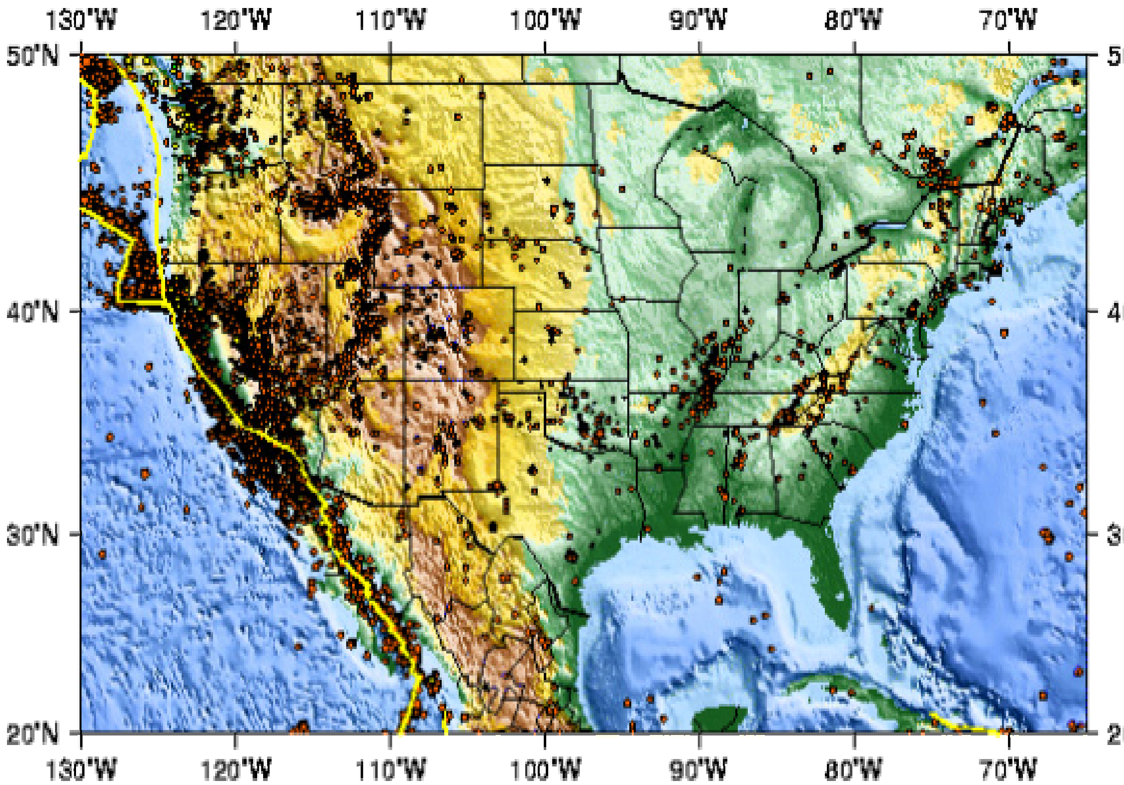

Figure 1. Seismicity of the conterminous United States (source: USGS).

Earthquakes cannot be prevented, but their impacts can be managed to a large degree so that loss to life and property can be reduced. To this end, NEHRP seeks to mitigate earthquake losses in the United States through both basic and directed research and implementation activities in the fields of earthquake science and engineering. NEHRP is authorized and funded by Congress and is managed as a collaborative effort among the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF), and the United States Geological Survey (USGS). These four Federal organizations work in close coordination to improve the Nation's understanding of earthquake hazards and to mitigate earthquake effects. The programs of the USGS in monitoring earthquakes, assessing seismic hazards, and basic earth science research, NSF in advancing fundamental knowledge in earthquake engineering, earth sciences processes, and societal preparedness and response, NIST in evaluating advanced technologies and developing measurement and prediction tools, and FEMA's efforts with states, local governments, and the private sector to develop tools and improve hazard mitigation policies and practices—all will achieve greater effectiveness, earthquake safety, and reduce losses when put to their fullest use and application in the engineering design office.

These programs have been ongoing for over 25 years and have budgetary levels of approximately $100 million per year, but the weak link has always been putting this storehouse of information out to practitioners, where it will ultimately do the most good. This deficiency is widely recognized by the design community and others, including those involved in the most recent NEHRP Strategic Planning process, which was conducted from 1998-2001 under the leadership of FEMA. Among the major findings of that strategic planning effort, currently in draft stage, are that (1) a technology transfer gap has emerged that limits the adaptation of basic research knowledge into practice, and (2) this gap is expected to widen as NEHRP embarks on the development of a new generation of performance-based seismic design provisions and guidelines for buildings and lifeline systems, including bridges, ports, airports, and utility lifeline systems for the distribution of power and water. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES will change all that. It will provide a permanent framework for putting theory and research results into general engineering and construction practice.

2.2 DECLINE IN CONSTRUCTION PRODUCTIVITY

The productivity of the construction industry (as measured by constant contract dollars per hourly work hour) has gradually declined (with some exceptions) over the past 35 years (Figure 2). The United States led worldwide construction productivity as late as 1970, but in the ensuing decades, it has been steadily declining and has been consistently down in the past nine years. This is alarming when compared to the *increasing* labor productivity in all other non-farm industries, which have enjoyed an increasing productivity of 1.77% per year over the same time period. The spread between these two productivity indices became even more pronounced during the 1990s, confirming that the seismic design and construction communities seriously lag other industries in productivity.

Figure 2 shows that the design/construction industry productivity seriously lags other industries and suggests that there are significant opportunities to improve the quality and efficiency of facility design and construction practices. Studies from the U.S. Department of Commerce show that productivity in the United States construction industry has fallen when compared to other

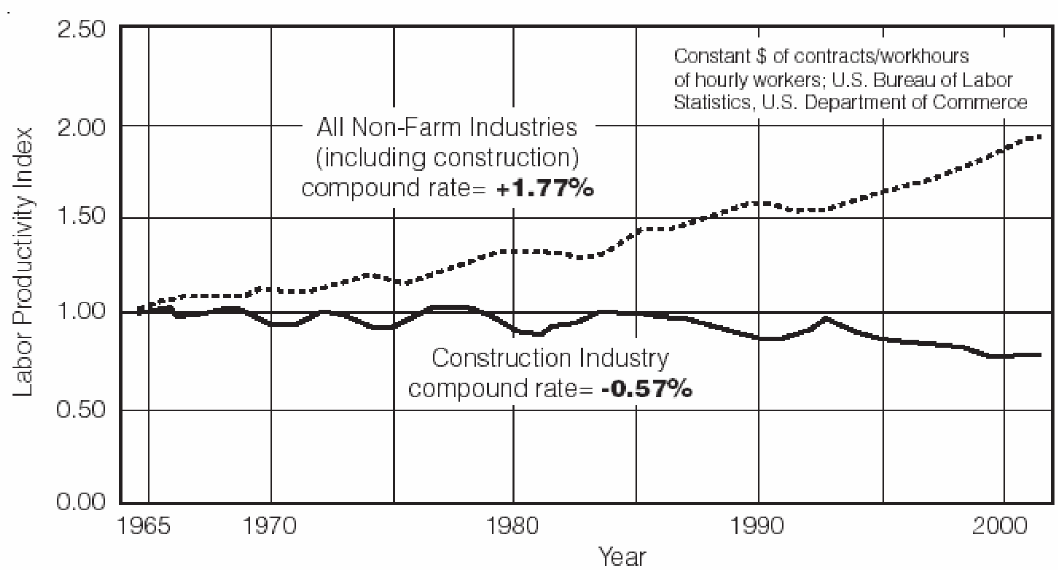

Figure 2. Labor productivity index for U.S. construction industry and all non-farm industries from 1964 through 2001.

industrialized countries. Construction industry executives blame their lack of improving efficiency on the fragmented nature of the industry. This fragmentation is present, but other industries face the same challenges and have increased their efficiency and productivity.

Despite the fact that there has been a significant adoption of new information technology (IT) by the construction industry over the past 35 years, these applications tend to run in a *stand-alon*e mode that does not permit improved collaboration by the project design and construction team. For example, each designer uses a separate computer-aided design (CAD) or computer-aided engineering system, and computerized project management is independent of cost control, which is independent of project changes to the drawings and specifications. Thus, while computers now generate much information, they ultimately produce a paper output, which then must be manually reviewed so that relevant data can be entered into another program (for example, CAD drawings are plotted so that estimators can use them for making a cost estimate). This fragmentation causes increased effort and time and has greatly reduced the ability of the project team to respond quickly and effectively to changes in scope, site conditions, and other parameters—not to mention change orders. Thus, despite the widespread use of IT, it has not resulted in better overall productivity performance.

The building industry is characterized by a large number of small clients, vendors, suppliers, designers, and contractors who are often not in a position to provide leadership for the adoption of new technology and practice. In other industry segments, such as process and power, this is not the case and there has been more rapid change and a significant increase in the productivity of both design and construction. For example the capital cost per kilowatt-hour of output from a power plant has steadily declined over the past decade. The opposite is true in commercial construction.

This inability to communicate effectively has created tremendous waste and inefficiency, estimated at up to 30% of the total cost of a building project. In the United States this amounts to $240 billion of annual savings, or 3.9% of the U.S. gross domestic product. Additional large potential savings are directly linked to the lack of effective communications, coordination, and data sharing in building operations. For example, in the United States commercial building stock uses energy valued at approximately $100 billion per year. Field data show that exceptional buildings designed by skilled designers using appropriate systems and products can reduce energy use by 50%. These potential savings are not captured due to numerous factors, many of which are connected to IT problems and the lack of effective data exchange, including coordination between architectural and engineering teams and communication of design intent to facility operations. If the lack of effective interoperability accounts for only 20% of this total in energy use, the savings opportunity is $10 billion/year. The same holds for design inefficiency costs that cause construction to accommodate gravity and lateral loadings of structures, particularly extreme loads, e.g., those due to earthquakes.

Providing adequate seismic life safety requires structural systems that are strong and durable, and their cost increases with the degree of threat. The Midwest, Southeast and Northeast all have experienced significant damaging earthquakes in the past, and are now known to be at sufficient seismic hazard to warrant specific earthquake-resistant design. A major impediment in these regions to implementing life-safety seismic design is the incremental cost over conventional non-seismic design. Increases in building costs of up to 5% for seismic design compared to non-seismic design are not unexpected. Such increases have a major impact on attitudes and on the likelihood of implementing seismic safety practices in regions where the perception of the seismic hazard is low. In the West, seismic design coefficients have increased 50% or more from what they were 25 years ago, and the requirements for material detailing have become more restrictive. The net impact of these changes is the perception that the cost of seismic design has increased, notwithstanding that good design to the new requirements can cost less than mediocre design to the older requirements.

2.3 Inter-Organizational Design Process

Design and construction of buildings is a technically demanding and competitive endeavor, with significant cost and schedule constraints. Practices are dominated by small organizations; there are no major or dominant organizations in any aspect of practice. The process of design is one that merges science and art with a professional's judgment. A project typically proceeds through several distinct steps:

Planning

- Goal and program determination, project conceptualization
- Financing

Design

- Schematic determination of the form of the structure and its geometric form, structural system, and structural materials to be used
- Design of the structure
- Production of construction documents, including plans and specifications
- Permit application and review

Construction

- Shop drawings
- Construction, including design modifications and alterations, observation, inspection, and materials testing
- Job completion
- Leasing and operation

The design team consists of architects, engineers (geotechnical, structural, mechanical, electrical, and plumbing), contractors, materials suppliers, and specialty consultants on many specific issues. All of these groups have specific areas of responsibility that merge in the completed structure, under the ultimate direction of the owners or their representatives. The design and development team is, in modern management sciences terminology a *virtual corporation*, in that for each project, a large number of organizations team together to realize a project and disband when it is completed.

The process of design is often sequential, with the architect setting the configuration and massing of the structure, the geotechnical engineer setting the foundation conditions, the structural engineer arraying the structural elements and materials, the mechanical, and the electrical and plumbing engineers providing the schematic design of the utility services of the building. In some cases, particularly mechanical and electrical systems, and often for cladding and roof truss systems, the actual design is completed by a specialty contractor as part of a design/build effort during construction. At each of these design steps, plans will be altered based on the architect/owner/developer's vision of the resulting project. One of the challenges to the design team is to efficiently accommodate the needs of others in the preparation of its plans. Too often, the process of integration is an afterthought. The opportunities for improved efficiency and economy are potentially large.

It is instructive to examine how other industries have progressed. In the 1970s, General Dynamics Electric Boat division was designing and manufacturing nuclear submarine structures using state of the art CAD/CAM (Computer Aided Design/Computer Aided Manufacturing). Engineers sitting at CAD stations performing analytical calculations, detailing, design and drafting were immediately linked to machine tools cutting out sections of the submarine. Twenty years ago submarine construction at General Dynamics was paperless.

While the automotive, shipping, and aircraft industries, as well as electronic manufacturers have continued over the last 25 years to significantly increase their productivity through the use of computers, business-to-business internet, and interoperability, the construction industry has lagged far behind, with an actual decline in productivity averaging almost 2% per year for the last 30 years. Construction industry executives blame their lack of improving efficiency on the fragmented nature of the industry. While this fragmentation is present, it is not a reason, it is an excuse.

2.4 TECHNOLOGY TRANSFER

Improvements in seismic design and construction will depend on increasing the use of both existing information and new knowledge developed from research and experience. It is clear that simply publishing the results of research, and depending on the end user to find and interpret it is not a particularly effective method of getting information to those who need it.

A key Program Element of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is effective technology transfer. In order to truly change the way structures are built so that they can better withstand earthquakes, the knowledge gained from earthquakes and through research must be placed in the hands of the practitioners who are actually designing them. In this way, future losses of life and property can be avoided through improving the design process. The mechanisms of this technology transfer must consider the participants in the process and be structured in a way that best fits that group and also takes into consideration the industry's needs. An effective approach to technology transfer is to place the potential user in a prominent position. Under THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES program, potential users will have primary input to both identification of needs and to the evaluation of effectiveness of the actions taken.

Research suggests that the most effective approaches to increase use of technical innovations and change are those that focus on involvement of the non-researcher (that is, those whose actions are to be influenced, or individuals representative of those groups). These influential individuals include decisionmakers, consultants, and advisors who are viewed within their communities as leaders. Means of involvement include workshops, prototype studies, priority-setting exercises, advisory groups and any other approach that exposes them to the problem, approaches to resolution and the details of problem resolution. Experience is the key to affecting their future actions. Successful utilization depends both on the careful selection of individuals to participate and on constant rotation, bringing new individuals into the process.

Four groups in United States society play key roles in shaping, promoting, and implementing the use and development of technology in the engineering design and construction professions:

- **Private sector.** The private sector is comprised of the owners, designers, consultants, builders and occupants/users. The underlying fabric of the private sector is economic. The private sector garners many economic benefits through the implementation of new technologies.
- **Academia.** Academia consists of the universities, colleges, and individual researchers who educate, and develop new knowledge, through science and applied research.

Academic research is fundamental to shaping new technology and fulfilling academia's roles as educators and a depository of knowledge.

- **Government.** Government, primarily at the state and federal levels, plays both a regulatory role in standardizing and codifying technology as well as advancing science and technology to protect the public welfare. Government has the financial resources and mandate to fund basic and applied research, mitigate the hazards posed by earthquakes, and provide emergency response after earthquakes. Local governments also take on the role of regulators, but in the form of the local community building officials who must enforce the building code requirements that often develop from the new technology.
- **Collaborative organizations.** Collaborative organizations are the professional and technical societies, trade groups, and not-for-profit organizations that work as consensus networks in advancing technological development. Collaborative organizations provide the vehicle for the effective synthesis and distribution of technology from research into practice—technology transfer.

Individually, each group fosters different incentives for advancing seismic engineering technology. Collectively, all of these groups and society at large will benefit through technological advancements.

Each of these groups plays a role and shares in the responsibility for advancing the progress of technical innovation. The challenge of moving technical innovation in seismic engineering into mainstream professional engineering practice requires the focused effort of all of these groups. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES proposes a coordinated, goal-oriented, cooperative technology transfer effort as an integral part of every action.

Technology transfer is accomplished where specific needs or limitations in current technology are identified and the best resources are targeted to be brought to the challenge of bringing applicable research into practice to address these needs. The technology transfer process is continuous and dynamic, and THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES will provide a permanent structure and framework for accomplishing this and for adjusting to ongoing changes in priorities, earthquake events, and funding availability. Resources are drawn from the four groups that play the most significant roles in shaping the development of technology. From these resources, researchers and practitioners are drawn together to meld the latest research into practical application in a consensus process under a collaborative organization assisted, advanced, and funded by the government.

THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is a problem-focused program, and promotes a technology transfer agenda as an integral focus within all of it activities. The advances of the past 25 years have shown that basic research does not always provide the information needed to fully support the development of all the new technologies that could be directly utilized in improving general engineering practice. To this end, a technology transfer master plan will need to be established as an integral part of THE MISSING PIECE. The program will succeed only if the needed technology is transferred to the general practice of seismic engineering. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES proposes to do just that.

3 PROGRAM PROPOSAL—THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES

The goal of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is development of more efficient, effective, and technically reliable practice for earthquake engineering design and construction. As indicated at the outset of this document, two subject areas with a total of five Program Elements are proposed:

- ***Systematic support of the seismic code development process.***

  Program Element 1 Provide technical support for the seismic practice and code development process.

  Program Element 2 Develop the technical basis for performance-based seismic engineering by supporting problem-focused, user-directed research and development.

- ***Improve seismic design and construction productivity.***

  Program Element 3 Support the development of technical resources (e.g., guidelines and manuals) to improve seismic engineering practice.

  Program Element 4 Make evaluated technology available to practicing professionals in the design and construction communities.

  Program Element 5 Develop tools to enhance the productivity, economy and effectiveness of the earthquake resistant design and construction process.

These action areas were determined through a workshop of 37 leading earthquake engineers, regulators, and contractors in the summer of 2002. The Workshop meet for two days in San Francisco to assess the state–of-the-art and state-of-practice in earthquake resistant design, regulation, and construction. Six background papers were commissioned and distributed to the participants to form the basis for Workshop deliberations. The topics and authors of the papers were selected by a Steering Committee through several preparatory meetings and discussions. The six background papers are:

1. *Productivity Tools* by Charles C. Thiel Jr. and Charles H. Thornton
2. *Systematic Technical Support for the Seismic Code Development Process* by James R. Harris and Charles C. Thiel Jr.
3. *Problem-Focused Study in Performance-Based Seismic Engineering* by Ronald O. Hamburger and Roberto T. Leon
4. *Development of Technical Resources and Associated Problem-Focused Research for Improved Seismic Engineering Practice* by Christopher Rojahn and Ronald T. Eguchi
5. *Technology Transfer Mechanisms and Programs* by Edwin T. Dean and James M. Delahay
6. *Program Management* by Robert D. Hanson and James E. Beavers

The six commissioned papers are reproduced, as revised, in Appendices 1 through 6. These papers formed the basis for Workshop discussions and were a resource for the drafting of this main report. The Program Elements proposed in this report are distinct from these papers, but derived significant value from the thoughts and opinions expressed therein. Also at the end of this report, in Appendix 7, are brief resumes of the principal individuals involved in formulating the recommendations herein. These resumes are provided as background to better understand the breadth and perspective of the project participants.

3.1 SYSTEMATIC SUPPORT OF THE SEISMIC CODE DEVELOPMENT PROCESS

3.1.1 Background

Public safety, as embodied in the police power of a government, is not a power that the U.S. Constitution enumerates for the federal government. Rather, this power is reserved to the individual states, which in turn delegate it to local governments. Locally enacted laws governing building construction have traditionally been called "building codes," and there are thousands of such codes in the United States. In the past half century, there has been a move toward states reclaiming their authority with statewide building regulations. In some states, these statewide requirements encompass most forms of construction, while in others it is of limited scope, for example, covering schools or for manufactured housing only.

Preparation and maintenance of a building code requires substantial creative and collaborative effort. Few local governments can, in fact, devote such resources to this process. Furthermore, the interests of interstate commerce advocate a commonality among building codes. Therefore, model building codes have become popular in the United States. A local or state government can adopt a model code with amendments appropriate for local conditions. This has currently evolved to two model codes of nationwide scope: one promulgated by associations of building regulatory officials, and one promulgated by an association of individuals interested in fire safety.

Most of the technical provisions in model codes are not actually written by the developers of the model codes. A large number of voluntary national and international consensus standards and guidelines exist that are developed and maintained by organizations interested in a particular technical sphere. Model codes incorporate many technical provisions from such volunteer-developed standards, and in many other cases they simply cite accredited standards by reference. Accredited voluntary national/international standards are documents developed by groups with scopes of (at least) nationwide interest and with procedures that ensure general agreement on the technical contents of the standard. With respect to earthquake engineering, there are several standards of interest. A very short list includes:

1. ASCE 7 *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers
2. ACI 318 *Building Code Requirements for Structural Concrete*, American Concrete Institute
3. AISC LRFD/ASD *Design Specifications for Steel Buildings* and its supplement, *Seismic Provisions for Structural Steel Buildings*, American Institute of Steel Construction
4. AF&PA/ASCE 16 LRFD *Engineered Wood Construction* and its Allowable Stress Design companion *National Design Specification for Wood Construction,* American Forest and Paper Association and ASCE
5. TMS 401/ACI 530/ASCE 5 *Building Code Requirements for Masonry Structures,* The Masonry Society, with ACI and ASCE

A particularly important guidance document for earthquake engineering has been *Recommended Lateral Force Requirements and Commentary*, the SEAOC "Blue Book," (Structural Engineers Association of California). Similarly, the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, produced by the Building Seismic Safety

Council with partial NEHRP/FEMA support, has played a significant role in the development of seismic provisions in model codes and standards.

The volunteer-supported model code development process has been aided by FEMA's support to prepare the NEHRP *Recommended Provisions for Seismic Regulation of New Buildings and Other Structures* and its efforts in specific areas such as wood framed housing and seismic rehabilitation of existing buildings (e.g., preparation of the FEMA 273 *Guidelines for the Seismic Rehabilitation of Buildings*). These efforts have addressed large, pressing needs, but have not generally involved basic, practical research that would form the basis of individual technical decisions, or provide a basis for advancing the structure of the code.

There are two pressing needs if the effectiveness of this process is to be improved, as it must be to achieve the NEHRP goals:

- Provide specific technical support to the committees that develop model codes and the documents upon which the model codes depend. This support is needed to address in a timely manner critical, highly specific technical issues and problems encountered in the code development process. This will foster development of more effective, efficient, and technically reliable design regulations. The result will be safer buildings that are more functional following an earthquake and fewer lives lost in an earthquake.
- Support problem-focused studies in performance-based seismic engineering that can form the technical basis of future code development. Current codes are specification based, that is, specific prescribed and proscribed steps to be followed and verified. The goal of performance-based design is to focus on structural performance and provide means to evaluate whether a design objectively meets these performance objectives.

The building code development and publication cycle is a regular process in which the provisions are considered and revised to reflect changes in understanding and knowledge. Typically, the cycle is that a new edition is published every three years. Figure 3 shows how this process proceeds and its ongoing, regenerative process. The current edition is evaluated, and over a period of two years or so, revisions are suggested, balloted for approval, and ultimately considered by the code-writing body for acceptance. Following publication of the new code communities at interest consider its recommendations and modify their code (as/if appropriate) in the next few years—usually not less than one, and on average, about three years.

The work of the code development process is voluntarily performed, with members and their organizations contributing the effort, generally with no compensation for time or expenses. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES proposes to support the code development practice by:

- Short-term practical or research projects intended to directly support making sound technical decisions for the current revision cycle.
- Long-term projects or research intended to supply technical answers for future code revision cycles.

These recommended activities are described below in Program Elements 1 and 2, and discussed in more detail in Appendix 2, "Systematic Technical Support for the Seismic Code Development Process" and in Appendix 3, "Problem-Focused Study in Performance-Based Seismic Engineering."

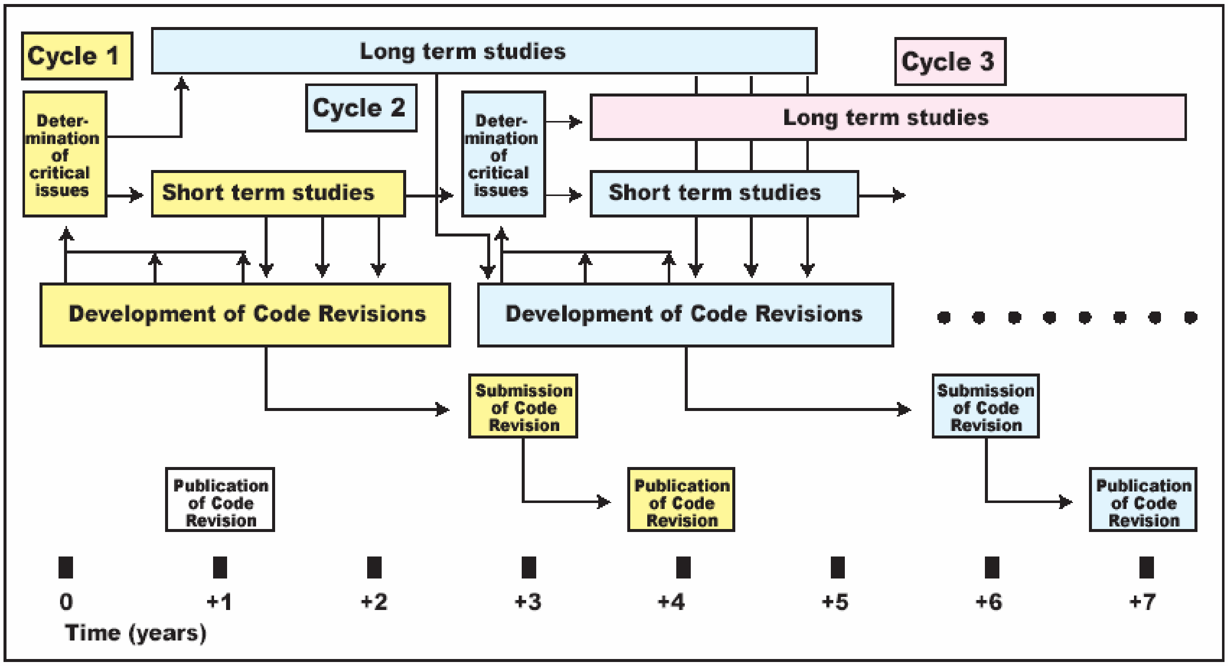

Figure 3. The code development cycle showing where the short-term and long-term projects fit into the development process. Short- and long-term projects are currently either not performed, completed at a rudimentary level, or completed by those with vested interests that may not be consistent with the community's best interests. Each code publication cycle starts anew about one year after publication of the previous code.

3.1.2 Program Element 1: Technical Support for Seismic Practice and Code Development

The objective of this Program Element is to support short-term practical, applied research projects to better realize the goals of NEHRP in improved seismic design practice and code development. The objective is not to restructure existing standards development processes. Program Element 1 will be accomplished by systematically identifying needs and resources, then prioritizing, designing, conducting, vetting, and communicating the results of the studies intended to answer the needs.

A short list of current research and development needs is identified in Appendix 2, "Systematic Technical Support for the Seismic Code Development Process." Examples from the larger list of Appendix 2 are:

- Examination of the consequences no longer restricting particular structural systems in high hazard areas, particularly in light of modern interpretations of favored systems that conflict with older interpretations.
- A rational method of accounting for geometric instability in a linear static analysis where the real behavior is dynamic and nonlinear (the P-delta problem).
- Methods to identify circumstances in which the torsional response of structures is significant, and how best to account for such response in linear analyses.
- Methods to approximate nonlinear response when designing by with a linear analysis (the R factor problem).

- Simple methods for predicting the nonlinear dynamic response of components supported by structures.
- The need for and utility of quantitative design provisions to account for the redundancy in a structural system, specifically focusing on the effect of such provisions on the reliability of performance (the rho factor problem).
- The reliability implications of the present methods for linear analysis and design that incorporate load and resistance factors calibrated for gravity and wind loads.

3.1.3 Program Element 2: Problem-Focused Research to Support Development of Performance-Based Seismic Design Concepts and Guidelines

The objective of this Program Element is to support longer-term projects that focus specifically on performance-based seismic engineering and its application in the next generation of seismic codes. Performance-based seismic engineering (PBSE) is an area of engineering practice that is rapidly developing, and which will have wide application to the evaluation and upgrade (rehabilitation and retrofit) of existing structures and the design and construction of new structures. Described broadly, performance-based seismic engineering envisions a related series of technologies, that:

- Enable the development of structures that will provide predictable and desirable performance in future earthquakes.

From this perspective, performance-based seismic engineering may be thought of as closely related to performance-based engineering for other hazards including, for example, fire and blast.

FEMA has recently initiated a major effort to develop performance-based seismic design guidelines for buildings. The effort is broadly based and will produce next-generation guidance on a broad range of issues pertaining to the performance of structural components, the performance of nonstructural components, and risk management strategies. Ultimately, this guidance will be converted into provisions that can be incorporated directly into the NEHRP *Recommended Provisions for Seismic Regulation of New Buildings and Other Structures* and the FEMA 273 *Guidelines for the Seismic Rehabilitation of Buildings*, or the FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*. FEMA is also supporting the American Lifelines Alliance project to develop guidance addressing earthquake and other hazards for lifelines (utilities an transportation systems). This Program Element is intended to support the FEMA effort by conducting needed problem-focused research studies to advance performance-based engineering concepts and criteria. Work on Program Element 2 would be coordinated so as to complement, and not duplicate, research on similar topics being carried out in association with Network for Earthquake Engineering Simulation (NEES) and other NSF programs, and to take advantage of the earthquake data collection system, particularly in buildings and other structures, carried out under the USGS-supported Advanced National Seismic System (ANSS).

The primary emphasis of Program Element 2 is to support incorporation of performance-based design concepts into the guidance documents and standards developed by the standards and practice development community. The focus of activity is expected to include all types of structures, not just buildings. Program Element 2 would include development of:

- Standard measures of performance
- Systems for qualifying the performance capability of construction components
- Tools for predicting performance
- Performance translation tools for experimental data

- Construction systems capable of providing desired performance
- Sensors, including their calibration
- Systems for monitoring performance
- Appropriate simulation and experimentation projects

Additional information about the FEMA program and detailed recommendations on needed studies is provided in Appendix 3, “Problem-Focused Study in Performance-Based Seismic Engineering” and in Appendix 4, “Development of Technical Resources and Associated Problem-Focused Research for Improved Seismic Engineering Practice.”

3.2 IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRODUCTIVITY

3.2.1 Background

The productivity and effectiveness of the interaction between the seismic design and construction communities is affected by a variety of factors. These include (1) the makeup of the engineering design and construction industry, which consists of a large number of small clients, vendors, designers and contractors; (2) the complexity and wide variety of construction types, including buildings of varying height, size, and construction materials, and a wide range of transportation and utility infrastructure facilities; (3) the availability of modern tools to improve efficiency; and (4) the availability of new technology and information for reducing the effects of earthquakes on the built environment. Given the decline in productivity of the United States design and construction industry over the last decade and the widening gap between NEHRP-developed engineering knowledge and its application, THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES encompasses both a major technology transfer effort and a major effort to improve productivity of the design and construction industry.

THE MISSING PIECE program responds directly to conclusions of the recent NEHRP *Strategic Plan*, which recommends (1) a “much-expanded problem-focused research and guidelines development program to develop future design, construction, evaluation, and upgrade guidelines and standards of practice, and to facilitate the development of new mitigation technologies,” and (2) that NIST, in partnership with FEMA, USGS, and NSF, should develop a coordinated NEHRP plan to support an expanded level of problem-focused applied research and development.

THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is intended to address the following needs:

- Provide technical resources, such as tutorials, primers, code commentaries, guidelines, and design manuals that reflect new knowledge and standards of practice. These resources are needed for a wide range of existing prevalent structure types and elements, including buildings and lifelines systems and their structural and nonstructural components. In many instances, the development of such resources will require problem-focused research studies to advance the basis for understanding new methods of practice.
- Evaluate and synthesize available seismic hazard mitigation information and technology, including the wealth of NEHRP-funded research results that have become available over the last 25 years. In some cases, initial results must be updated and revised. Everything should be made available in a format that can be used by practicing professionals in the design and construction communities.
- Reduce inefficiencies in design and construction practice by integrating and advancing existing computer systems and tools used by the various segments of the design and

construction industry. There is a clear need to reduce inefficiencies and duplication of effort in document and record keeping, to make more efficient the development and transfer of drawings, and to develop standardized component definitions and details.

Recommended activities to fill these needs are encompassed in Program Elements 3, 4, and 5. Program Elements 3 and 4 involve significant technology transfer activities. Therefore, it is proposed that a technology transfer master plan (see Section 2.4) be developed that defines products, milestones, schedules, review mechanisms, and dissemination strategies.

Additional information about the activities proposed for Program Elements 3, 4, and 5 is provided in Appendix 1, "Productivity Tools," Appendix 4, "Development of Technical Resources and Associated Problem-Focused Research for Improved Seismic Engineering Practice," and in Appendix 5, "Technology Transfer Mechanisms and Programs."

3.2.2 Program Element 3: Problem-Focused Research and Technical Resources Development to Improve Seismic Engineering Practice (Guidelines and Manuals Development)

The conduct of this Program Element recognizes and considers the related efforts of all NEHRP agencies, including:

1. The NSF role in funding studies to advance fundamental knowledge in earthquake engineering, which is carried out in large part by the three NSF-funded earthquake engineering research centers (MAE, the Mid-American Earthquake Engineering Research Center; MCEER, the Multidisciplinary Center for Earthquake Engineering Research; and PEER, the Pacific Earthquake Engineering Research Center).
2. FEMA's role in developing tools to improve seismic engineering practices, including model code provisions for the seismic design of new buildings, and guidelines and standards of practice for the seismic evaluation and rehabilitation of existing buildings and for the seismic evaluation and design of utilities and transportation systems.
3. NIST's current limited program of problem-focused research and development in earthquake engineering aimed at improving building codes and standards for both new and existing construction, and advancing seismic practices for structures and lifelines.
4. The USGS Earthquake Hazard Program, which provides the earth science foundation for NEHRP, and which includes earthquake hazards assessments and maps, seismic monitoring, rapid earthquake information, and research on earthquake physics, occurrence, and effects.

Of special relevance to the program of technical resources development and associated problem-focused research proposed herein is the highly successful FEMA program to develop guidelines, model code provisions, code commentaries, practice handbooks, and other technical resources. Products from the FEMA program, known as the "Yellow Book series," have been broadly accepted by the seismic engineering profession and model code development bodies because leading design professionals, researchers, and regulators were involved in their development. FEMA-funded publications in the Yellow Book series include:

- The *NEHRP Recommended Provisions for the Seismic Regulation of New Buildings and Other Structures* (FEMA 368 and FEMA 369). These have been updated every three years since their initial publication in 1985.
- A *Manual for Reducing the Risks of Nonstructural Earthquake Damage* (FEMA 74).

- The first and second editions of FEMA 154, *Rapid Screening of Buildings for Potential Seismic Hazards: A Handbook*.
- The *NEHRP Handbook for the Seismic Evaluation of Buildings* (FEMA 178), and its successor document, *Prestandard for the Seismic Evaluation of Buildings* (FEMA 310).
- The *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273), and its successor document, the *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (FEMA 356).
- *Procedures for the Evaluation and Repair of Earthquake-Damaged Concrete Wall and Masonry Wall Buildings* (FEMA 306, FEMA 307 and FEMA 308).

FEMA also sponsors and funds the American Lifelines Alliance (ALA), a five-year-old public/private partnership. The goal of the ALA is to reduce risks to utilities and transportation systems from earthquakes and other hazards. Projects undertaken by ALA produce guidelines that are provided to standards developing organizations for consensus development and dissemination. ALA maintains a tabulation of the current status of U.S. natural and manmade hazards. This tabulation is available as a reference for use by lifelines industries and regulators and as a means to identify needs for guidance development or updating.

Program Element 3 is intended to:

1. Expand NEHRP's current responsibilities for the conduct of problem-focused research and development in earthquake engineering.
2. Complement the existing highly successful FEMA effort to develop guidelines, handbooks, standards of practice, and other technical resources for reducing the seismic vulnerability of new and existing buildings.
3. Utilize new understanding and knowledge developed on seismic hazards from research in the earth sciences. The Advanced National Seismic System (ANSS) network may provide a new level of understanding of earthquake ground motion that will allow reconsideration of how earthquake loadings are incorporated into performance-based design.
4. Encompass the broad range of existing structures and newly designed structures needed and used by society today, including:
   - Problem-focused research to advance the state of knowledge relating to needed seismic engineering technical resources.
   - Systematic development of needed guidelines, manuals, and other technical resources for advancing seismic engineering practices.

Problem-focused research conducted under Program Element 3 may be initiated by observations of the performance of building and lifeline structures during severe earthquake-induced ground shaking, or researchers or practitioners may recommend topics with a specific technical resource in mind (e.g., specific guideline or manual). The intent of THE MISSING PIECE program is not to duplicate the NSF research program, but rather to develop specific problem-focused research information for those who develop guidelines, manuals, and other technical resources for advancing seismic engineering practices, and, in the process, put NSF and NEHRP research to practical use.

Examples of high-priority problem-focused research needs include:

- Identify seismic capacities of existing nonductile concrete frame buildings and the number and distribution of such buildings nationwide.

- Test and evaluate the use of carbon fiber for rehabilitation of buildings and lifelines.
- Research innovative connections and systems for buildings.
- Research advanced technologies (e.g., remote sensing, ground penetrating radar) for damage assessment of buried lifelines.

The technical resources development process will necessarily include the review of current standards of practice, and the synthesis and reformatting of available research information from NEHRP-funded investigations, as well as other sources (e.g., NSF, or international efforts). Program Element 3 should focus on design and construction issues complementary to similar efforts already being carried out by FEMA to reduce the seismic hazards of new and existing buildings and certain lifelines. Among the issues with the highest expected impacts are specialized types of facilities (often utility service-related), and specialized construction techniques for which seismic design guidance is not available. Constant communication between NEHRP agencies and FEMA will be needed to eliminate any duplication of effort. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES will provide the conduit through which this information will flow.

Needed technical resources include: tutorials; primers; design guidelines for different structure types and different audiences (ranging from engineers to construction inspectors); manuals of design (for existing as well as new codes and standards); and code commentaries. Examples of high-priority needs include guidelines for the seismic design of:

- Fossil fuel power plants
- Oil and gas pipeline systems
- Port and harbor facilities
- New municipal landfills

3.2.3 Program Element 4: Evaluated Technology for Practicing Professionals in the Design and Construction Communities

One of the critical needs for improving the economy and efficiency of professional earthquake mitigation practice is to provide the design and construction community with relevant, information that can make a difference in a practical way. There is a wealth of information available—much from NEHRP-sponsored activities and not directly available to the practicing professional (or, at least, it is not reaching this audience). The technical literature is becoming too large and technically difficult for most practicing professionals to examine, much less evaluate for use. Furthermore, as the technical literature becomes more complex, designers are reluctant to employ the principles conveyed out of concern that building officials who have jurisdiction may not sanction the ideas.

The goal of this Program Element is to evaluate and synthesize available seismic hazard mitigation data, information, and technology, including the wealth of NEHRP-funded research results that have become available over the last several decades, and to make this information available in a format that can be used by practicing professionals in the design and construction community.

The proposed format for reporting the results of each activity undertaken as part of this Program Element is the technical brief format (*TechBriefs*) pioneered by the Applied Technology Council (ATC) to spearhead distribution of technical information on earth-science research results to practicing design professionals. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND

CONSTRUCTION PRACTICES recommends that ATC continue to take the lead in disseminating, through *TechBriefs*, technical advances of the problem-focused activities conducted under Program Element 3 and the results of the past 25 years of government-funded research. Each *TechBrief* would address a single, focused topic, and its contents would be actionable. Nominally 4-to-12 pages in length, *TechBriefs* are not research papers, but topical, tightly written, and well-illustrated discussions of practical problems faced by many engineering design and construction practitioners. Target audiences are:

- Project engineers, designers and detailers
- Building department personnel who review plans and field construction documents
- Inspection service field personnel
- Construction trades personnel

TechBrief topics will be varied and would likely include the following categories:

1. Distillations of research findings, particularly experimental research, that lead to specific conclusions on structural detailing.
2. Findings of professional committees and task groups on particular seismic design and regulation issues.
3. Results of testing programs for existing materials and assemblies that may have broader application than the reason for the test.
4. Comparative evaluations of typical detailing practice. Most individuals who engage in extensive peer review or building evaluations comment that many commonly used practices are not particularly effective. These include, for example, extending confined collectors in thin concrete slabs, or placement of reinforcing bar curtains in special moment resisting frames. The issue is essentially that many repetitively used details of construction could be significantly improved if they were reviewed and commented upon by knowledgeable designers, and better, more effective details suggested, with a discussion of why they are better. Hence, comparative evaluations of typical detailing practice should provide specific recommendations for typical details and a discussion of when they are good to use, and when they are not, as well as preferred alternatives.
5. Code clarification and interpretation. Building codes are often ambiguous on particular applications or particular circumstances. There needs to be an effective way to communicate clarifications and the basis for them to the design and regulation professions.
6. Guidance on how to utilize real-time earthquake monitoring of structures to evaluate their safety for continued use.
7. Construction means and methods evaluation of options for selected applications.
8. Case studies of typical design decisions to determine a building's expected seismic performance.
9. Observations from what we have learned from earthquakes and performance of structures that bear on specific design practice, observations, and improvements. The NEHRP-funded postearthquake investigations, including the Learning From Earthquakes program of the Earthquake Engineering Research Institute, will be major resources.

3.2.4 Program Element 5: Tools to Enhance the Productivity, Economy, and Effectiveness of the Earthquake-Resistant Design and Construction Process

Program Element 5 is a major programmatic effort under which the National Earthquake Hazards Reduction Program would seek to improve productivity in the design and construction industry by taking the lead in incorporating and integrating all seismic design codes, analysis tools and methods into the International Alliance for Interoperability (IAI) effort.

The global architectural, engineering, and construction community has initiated steps to improve its productivity for economic reasons. One way is to use object based computer systems. IAI is developing industry foundation classes (IFCs) for all products. Industry foundation classes are an object-based approach to defining all of the attributes of the component, and all of its interfaces with all of the other building systems within a particular construction project. Furthermore, interoperability permits the linking of analysis, design, codes, standards, cost estimating, scheduling, maintenance, lifecycle costing, and all other activities of the construction industry. When completed, architects, engineers, and contractors will have object-based databases to fully automate the process from start to finish. The United States participation in this effort has been limited, with no incorporation of seismic design and construction issues to date. This effort could improve significantly the efficiency and economy of the design and construction for structural systems.

At the present time, there are approximately nine international IAI councils around the world. The leadership councils have been in Singapore and the Scandinavian countries of Finland, Sweden, and Norway. Some of the present initiatives are energy simulations, facilities management domains, Construction Specifications Institute (CSI) standardization of specifications, project management domains, steel projects, structural analysis models, reinforced concrete and foundation construction, drafting extensions, precast concrete construction, code compliance support, and building owners' requirements.

This IAI initiative can have significant implications for improving productivity within the seismic community. The entire NEHRP seismic code provisions and their interface with all products and components of a building—some with mass, some without mass—could form an industry foundation class (IFC). This could allow the huge interoperable database in which all industries around the world could use the same object definition and interface. This would go a long way to improve and reduce fragmentation in the design and construction community and could provide a mechanism for more effective competition of U.S. firms in the international design and construction markets.

NEHRP participation in the IAI initiative would add a set of IFCs for structural and seismic components, thus providing IFCs for all components of buildings, bridges and the constructed environment so that they can be incorporated directly into the seismic design, analysis and construction processes.

The effort will likely require systematic and careful planning for implementation, as well as a feasibility study to explore how to best encourage utilization of the completed interoperability capability by the design and construction community. Other tools for improving productivity could also be explored, and implemented, if feasible, as part of this Program Element. Additionally, process oversight should be implemented where major areas of the technology would be evaluated and recommended for implementation. Areas where the technology required significant improvement would be identified for future work.

3.3 PERSONNEL REQUIREMENTS

The personnel to complete THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES are available and are expected to be willing to participate. Indeed, Workshop participants expressed eagerness to participate. The structural engineering professions are well-known for their wide and extensive participation in code and standards development. The wide participation by the membership associations of structural engineers associations (e.g., the Structural Engineers Association of California, the National Council of Structural Engineers Associations, the Western Council of Structural Engineers Associations) in the technology and standards development efforts of the Applied Technology Council, the Building Seismic Safety Council and other model code groups is an indicator of the capacity and willingness of the professions to work when there is a *perceived* benefit in better earthquake resistant design and construction practices. This below-cost, or voluntary, participation includes all aspects of seismic-design research and code and standards development. The planned level of effort in the work proposed in THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is a natural extension of what has been done to date.

Through the efforts of FEMA, NIST, NSF and USGS over the past 25 years, NEHRP has proven that the academic and professional communities can perform the types of investigations needed to implement THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES, and can willingly contribute to such efforts.

There are no market place limitations to accomplishing the goals of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES.

3.4 BUDGETARY REQUIREMENTS

The budgetary requirements for THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES for the first three years of its operation, and for the sustaining effort, all in constant dollars, are summarized in Table 1.

The amounts recommended were determined by the assessment and evaluation of Workshop participants as necessary to make significant accomplishments in the intended areas. These amounts are evaluated as realistic to achieve the original Congressional objective of increasing public seismic safety. The amounts recommended in this section are considered the minimum required to achieve the goal of each Program Element. The program starts at a level of $5.25 million, grows to $8.25 million and is recommended for a sustaining level of $6.25 million, adjusted annually for the cost of inflation. It is recommended that if fewer total resources are available, then every effort should be made to fund the individual Program Elements of the program at the indicated levels, and reduce the total amount expended by eliminating some Program Elements, not a proportional reduction of all. It would be better, from both economic and technical standpoints, to stagger initiation of Program Elements rather than to fund them at below-critical levels.

The code development activities of Program Elements 1 and 2, both for short- and long-term (performance-based seismic engineering) efforts, will continue over time and require long-term support. This level of support is consistent with the perceived needs for technical support of the code development process for all building and structural types. The support level for Program Element 3, the development of technical resources (e.g., guidelines and manuals of practice) is modest. It assumes that the major issues in this area continue to be undertaken by FEMA, as they have in the past, and that THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES focus on those types of facilities and applications that are not large enough to engage the concern of the emergency response community, but are sufficiently important to others at interest to attempt to resolve the technical issues before an earthquake exposes them as important.

Table 1. Budgetary Requirements (millions of dollars)

Program Element: ($millions)	Year 1	Year 2	Year 3	Sustaining
▪ ***Code development support program***				
Program Element 1 Technical support for short-term projects that support practice and code development	1.0	1.0	1.0	1.0
Program Element 2 Long-term problem-focused research on performance-based seismic engineering	1.5	2.0	3.0	2.0
▪ ***Improving design and construction productivity***				
Program Element 3 Problem-focused research and technical resources development (guidelines and manuals)	1.0	2.5	2.5	2.0
Program Element 4 Evaluated technologies distilled and distributed through TechBriefs	0.5	1.0	1.0	1.0
Program Element 5 Productivity and interoperability	1.25	1.00	0.75	0.25
Total	5.25	7.5	8.25	6.25

Support of Program Element 4 for the evaluated technologies (*TechBriefs*) development effort is essentially constant. It is anticipated that the perceived need for TechBriefs will increase, as will the number of topics warranting consideration. The proposed budget assumes that other NEHRP agencies will observe the utility of this approach to dissemination of technical information and will initiate similar projects to supplement this effort in other technical areas. Program Element 5, the productivity and interoperability effort, is possible to complete within three years. Following this initial three-year effort, it is anticipated that there will need to be a standing effort to maintain the database system and supplement and augment it as required to meet the needs of the seismic design and construction communities.

There have been other planning efforts within the earthquake hazards reduction community that have addressed these programmatic issues in the context of larger, more comprehensive efforts. The Earthquake Engineering Research Institute (EERI) has vigorously supported the immediate need to fund ANSS and NEES and proposes a sustained, 20-year effort to reduce the nation's earthquake vulnerability. The EERI-recommended program consists of research and development funded at approximately $358 million per year. The NEHRP strategic plan, in draft and not yet finalized, similarly provides a comprehensive program to address the NEHRP legislative objectives. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES is a small element in support of both these proposed efforts and draws strength from them. Workshop participants expressed support for these larger efforts, but focused their recommendations on the narrower objectives presented herein. Potential budgetary resources for THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES are consistent with current NEHRP expenditures.

3.5 SCHEDULE AND MANAGEMENT

It is recommended that THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES program be implemented at the earliest possible moment. Start-up should be rapid, since there has already been a significant amount of effort in defining what is to be done and how it can be accomplished. This report and its appendices will serve as a roadmap.

THE MISSING PIECE recognizes that current NEHRP funding emphasizes the fundamental research programs of the National Science Foundation and the seismic monitoring, hazard assessments, and research of the U.S. Geological Survey and the earthquake engineering codes and practices of FEMA-supported efforts. New funds for problem-focused and applications research are necessary.

It was recommended by Workshop participants that this problem-focused research and development program be user- and needs-driven. Further, it must include appropriate project, task, and personnel evaluations and a willingness to terminate projects not achieving the desired goals and individuals not meeting agreed deadlines. *That is, it should be run like a business enterprise rather than as an academic program.*

To gain the support of the design and construction communities, and for the advocacy of this problem-focused research and development program, it is important that the needs of these design and construction communities be addressed. On this basis, the following recommendations for management are offered:

- Establish a formal external review mechanism, drawing on experts with leadership experience, to assist in identifying and prioritizing problem-focused topical areas and review of program progress. Such reviews should be a regular part of maintaining and updating the program plan, evaluating project effectiveness and direction, and supporting managerial decisions on program implementation.
- For each significant programmatic undertaking, an appropriate project plan, management structure and technical team should be in place, and should be regularly reviewed for effectiveness so that mid-course modifications can be made to assure successful project completion. Management of the activity must consider both the work done, and its relationship to its goals and its specific interim plan.
- The level of effort provided by government, academic and private sector personnel should be balanced to best achieve the objective of the specific project.
- The success of this program depends upon being efficient and effective in reducing earthquake losses by supporting the seismic code development process and improving seismic design and construction productivity. Therefore, at the core of program management must be a focused and dedicated effort to measure the benefits of programmatic outcomes against their costs. Programmatic actions should be based on this independent benefit-cost assessment. To the extent practical these should be concrete, not hypothetical, specific not generalized, and focused on both intended and unintended beneficiaries and costs.

3.6 FEASIBILITY

There are no known impediments that would prevent achievement of the goals set forth in THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES. A principal concern is to keep Program Elements focused on practical "actionable" results that are user- and needs-driven.

Program Element 5, the productivity/interoperability effort, represents the only undertaking with any technical or applicability risk. The risk is associated with the possibility that the global integration goal cannot be achieved at this time, or that it provides tools that are not ready for applications use; that is, it is ahead of its time. The risks of failure are counterbalanced by the extraordinary benefits of success as discussed below.

That the productivity/interoperability framework can be successfully implemented has already been proven. The technologies and information required to implement it are all stable and known to exist. The principal feasibility issue is whether the design and construction community will use the system developed. It is clear, however, that other design and construction industries have successfully implemented these procedures to great economic and societal profit. It is expected that marketplace economics will force use of these productivity and interoperability tools, and that seismic design and construction can only benefit from this increased use of specifications that are interconnected and standardized to the very best of our research knowledge.

3.7 BENEFITS OF IMPLEMENTING THE MISSING PIECE

The benefits of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES can be significant to earthquake safety. Impacts will be in three basic areas:

1. Reduced investment required to achieve acceptable earthquake performance of the built environment.
2. Reduction in the traumatic life loss, injury damage, and economic impacts when earthquakes occur.
3. More rapid recovery and restoration of the physical community and economic activity following an earthquake.

Reductions are hard to quantify at this time. Projections are that earthquakes with over $100 billion and thousands of lives lost can occur at many locations in the United States. Current incremental investment in seismic resistant construction is in excess of $10 billion per year. Reducing the funds directed toward restoring the built environment following an earthquake will free funds for other societal uses that are more productive.

Major benefits may accrue to the construction economy— a one-trillion-dollar segment of the economy and a $3 trillion global market. As much as 50% of all construction is in seismic hazard areas, as determined by USGS hazard maps, so there is opportunity to directly impact construction in seismic regions.

In summary, the benefits of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES are assessed as:

- Better, more technically sound earthquake-resistant engineering design and construction practices.
- More reliable structures that perform better in earthquake shaking.
- Fewer lives lost in a destructive earthquake.
- Lower initial seismic and retrofit construction expenses.
- Mitigation of the consequences of earthquake shaking.
- Increased productivity and interoperability in engineering and construction.
- Better, less intrusive, code enforcement.

If the total cost savings of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES are only 0.1% of annual construction expenditures in seismic regions, then the return will be over 30 times the investment proposed herein. The actual return in reduced costs is expected to be much greater. The rewards of the other non-monetary benefits (e.g., reduction in life loss and injury, maintenance of facility use) are even larger. These benefits are clear in their form, because they are targeted specifically at the people and institutions of the construction economy. THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES could become a major source of *benefits* from the whole NEHRP program, with clearly defined and traceable results that can be directly demonstrated to have impacted practice.

The big unknown in the program is the huge, upside potential of the interoperability Program Element on how all construction is realized, not just that small portion that is dictated by seismic safety and performance concerns—which even in high seismic hazards areas accounts for only a few percent of total construction costs. It is uncertain how quickly or to what degree productivity and interoperability will impact the overall construction industry for nonseismic issues. If it succeeds for all construction issues, then the rewards of THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES will apply not just to productivity of seismic construction, but also to productivity of all construction, whether for gravity and service loads, or those of wind, snow, water, and blast.

If there is but a 1% improvement in efficiency of the construction industry, the benefit will exceed $1 billion annually—and more may be possible. The stakes are huge, but so are the opportunities for significant, systematic productivity improvements. Even if the possibility of success is only 10%, the annual rewards are estimated to be over 50 times the investment proposed for the entire THE MISSING PIECE: IMPROVING SEISMIC DESIGN AND CONSTRUCTION PRACTICES.

APPENDIX 1
Issue Paper 1: Productivity Tools

by
Charles Thiel[1] and Charles Thornton[2]

1.1 BACKGROUND

An initiative to enhance the economy and effectiveness of earthquake resistant design and construction.

The National Earthquake Hazards Reduction Program (NEHRP) seeks to mitigate earthquake losses in the U.S. through both basic and directed research and implementation activities in the fields of earthquake science and engineering. The 2001 NEHRP Plan (Draft) states four basic goals, consistent with the underlying legislation:

A. Develop effective practices and policies for earthquake loss-reduction and accelerate their implementation. *Promote earthquake loss-reduction activities and support those who adopt, implement, and enforce such policies and practices.*

B. Improve techniques to reduce seismic vulnerability of facilities and systems. *Develop, improve, and disseminate products that guide design and construction practices and land-use planning, and improve professional practice.*

C. Improve seismic hazards identification and risk-assessment methods, and their use. *Develop, improve, and disseminate products that portray earthquake-related hazards accurately and quantify seismic risk.*

D. Improve the understanding of earthquakes and their effects. *Support research to understand the processes that lead to earthquakes and associated hazards and to advance engineering, social, behavioral, and economic knowledge.*

The NEHRP program supports basic and applied research programs in earthquake hazards reduction. Much of this work is completed for earthquake engineering and earth sciences supported by NSF and USGS by universities and government personnel. An integral part of the program is the FEMA NEHRP efforts in development of guidelines and standards for regulation and practice. In the final analysis mitigating the threat and impacts of earthquakes will be through better engineering and construction practices by those designing and constructing buildings and other structures. The draft plan states:

> *The knowledge gained from this basic research is utilized by NIST to help industry adopt and use innovative technologies through problem-focused research and development aimed at removing technical barriers, evaluating advanced technologies, and developing measurement and prediction tools underpinning performance standards for buildings and lifelines.*

NIST is a key player in achieving the NEHRP goals. This program initiative in PRODUCTIVITY TOOLS implements the portion of the NIST assignment in the NEHRP directed at helping industry, that is the design professions, regulators, and construction industry improve economy and effectiveness, do a better job.

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The goal of this element of the NIST program is to support more efficient, effective and technically reliable practice of earthquake engineering design and construction by:

- Assessing the way in which structures are designed and constructed to identify opportunities to improve efficiently, economics and technical reliability of the resulting designs. This will focus on recent inter-professional efforts to integrating design methods support, documents and records, making them interactive and transparent during design.
- Providing design tools and practice recommendations that
  - Will improve economy of design and construction and the reliability of the resulting structural elements and systems
  - Evaluate the efficacy of research finding applications to practice and recommend their application in practice where appropriate.
  - Study examples of construction means and methods to identify opportunities for improved economy and effectiveness of construction to meet intended seismic performance goals.
  - Synthesize experience

The first initiative seeks to improve the efficiency, economy and effectiveness of achieving predictable seismic performance for designed structures. The second fills the gap of NEHRP activities between the generation of knowledge and design practice by providing to the practicing professional specific tools to improve their practice. These are discussed below.

1.2 IMPROVING THE DESIGN PROCESS

1.2.1 Opportunities to Improve Construction Industry Productivity

The productivity of the construction industry (as measured by constant contract dollars per hourly work hour) has gradually declined (with some exceptions) over the past 35 years (see Figure 1-1), and has been consistently down in the past nine years (see Figure 1-2). This is particularly alarming when compared to the increasing labor productivity, in all other non-farm industries that have enjoyed an increasing productivity of 1.77% per year over the same time period. During the 90s, this trend has not improved for construction and the spread between the productivity indices is even more significant. This confirms that the design construction industry seriously lags other industries and indicates that there are significant opportunities to improve the quality and efficiency of facility design and construction practices. Studies from the U.S. Department of Commerce show that productivity in the U.S. construction industry has fallen when compared to other industrialized countries. The U.S. construction industry led worldwide productivity as late as 1970, but in the ensuing decades it has been falling rapidly.

Despite the fact that there has been a significant adoption of new information technology (IT) by the construction industry over the past 35 years, these applications tend to run in a standalone mode that does not permit improved collaboration by the project team, e.g., each designer uses a separate computer-aided design or computer-aided engineering (CAD/CAE) system; computerized project management (CPM) is independent of cost control which is independent of project changes to the drawings and specifications. Thus, while computers now generate much information, they ultimately produce a paper output, which then must be manually reviewed so that relevant data can be entered into another program. For example, CAD drawings are plotted so that estimators can use them for making a cost estimate. This fragmentation causes increased effort and time and has greatly reduced the ability of the project team to respond quickly and effectively to changes in scope, site conditions, etc.

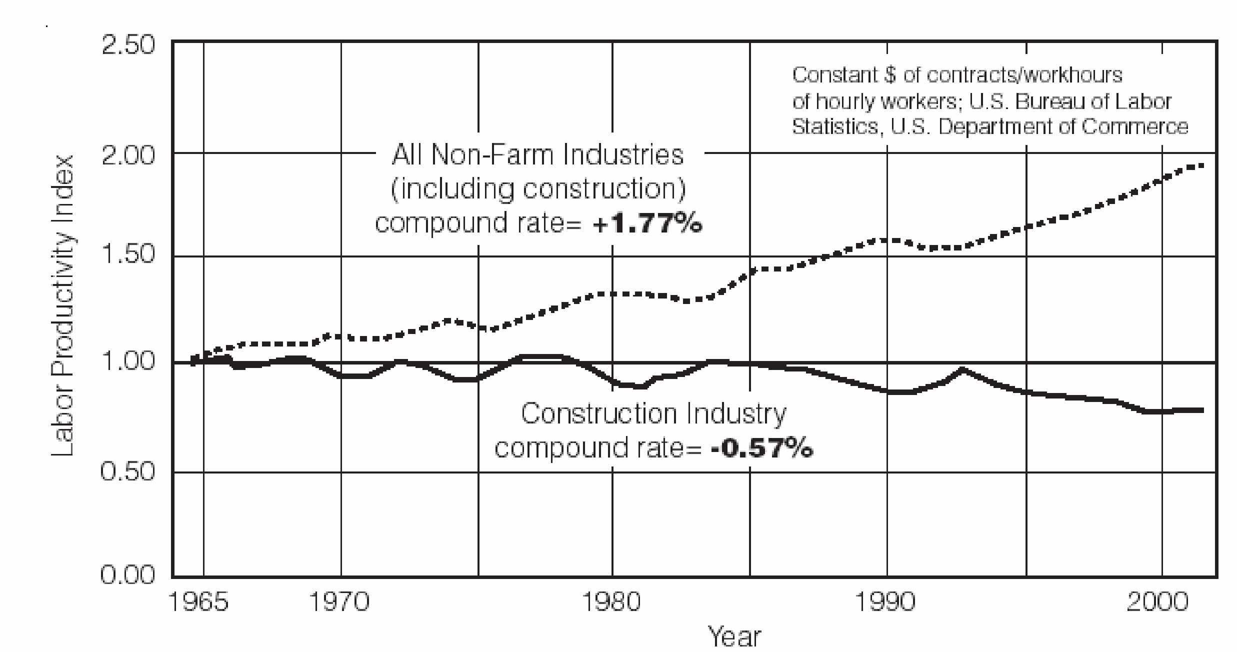

Figure 1-1. Labor productivity index for US Construction Industry and all non-farm industries from 1964 through 2001. See also Figure 2 for recent data.

Thus, despite the widespread use of IT, it has not resulted in better overall performance.

The building industry is characterized by a large number of small clients, vendors, designers and contractors who are often not in a position to provide leadership for the adoption of new technology and practice. In other industry segments where this is not the case, such as process

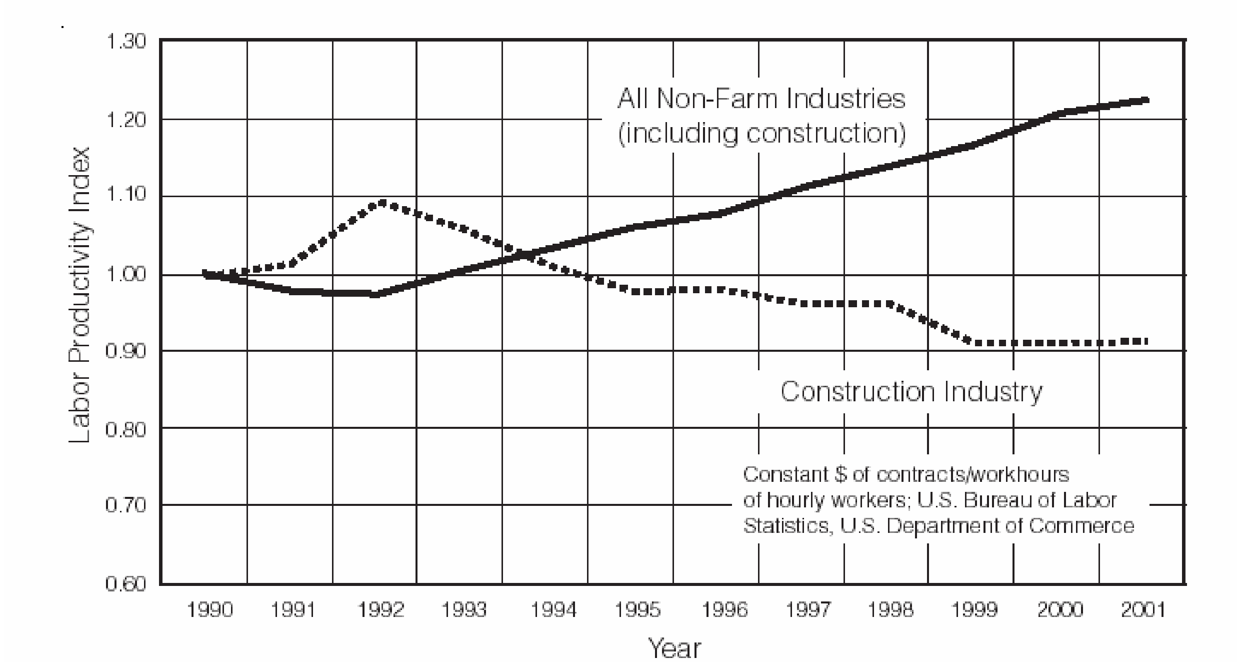

Figure 1-2. Labor productivity index for US Construction Industry and all non-farm industries from 1990 through 2001

and power, there has been more rapid change and a significant increase in the productivity of both design and construction. For example the capital cost per KWH of output from a power plant has steady declined over the past decade. The opposite is true in commercial construction.

Improvements in the ability to communicate, share, and re-use data among the different facility design/construction/operation related activities throughout the life cycle of a facility could dramatically reduce today's inefficiencies and increase the overall performance of the U.S. building community.

From designers to contractors to product manufacturers to facility managers, each sector of the building industry has a different set of software applications that focus on its distinct function and speaks its own language. There is no standard method for integrating these varied and numerous functions in a single building model. In fact, despite technological advances, much of the transfer of information from one building discipline to another is performed manually, leaving the information subject to loss, multiple interpretations, and errors.

This inability to communicate effectively has created tremendous waste and inefficiency, estimated at up to 30% of the total cost of the building project. In the U.S. this amounts to $240 billion of annual savings potential or 3.9% of the U.S. Gross Domestic Product. Additional large potential savings are directly linked to the lack of effective communications and data sharing in building operations. For example in the U.S., commercial building stock uses energy valued at approximately $100B per year. Field data shows that exceptional buildings designed by skilled designers using appropriate systems and products can save 50% of energy costs. These potential savings are not captured due to numerous factors, many of which are connected to IT problems and the lack of effective data exchange including coordination between architectural and engineering teams and communication of design intent to facility operations. If a lack of effective interoperability accounts for only 20% of this total, the savings opportunity is $10B/year in wasted energy expenses.

One of the impacts of the NEHRP is that there is now a recognition of the degree of seismic risk in different regions. This has been through identifying risk where little was understood before, and through increased design coefficients to accommodate the true hazard where it was known. Providing adequate seismic life safety requires structural systems that are strong and durable, and their cost increases with the degree of threat. The Midwest, Southeast and Northeast all have experienced significant damaging earthquakes in the past, and are now known to be at sufficient seismic hazard to warrant specific earthquake resistant design. A major impediment in these regions for implementation of life-safety seismic design is the incremental cost over conventional non-seismic design. Increases in building costs of up to 5% for seismic design compared to non-seismic design are not unexpected, and have a major impact on attitudes and likelihood to be implemented. In the west the seismic design coefficients have increased 50% or more from what they were 25 years ago, and the requirements for material detailing have become more restrictive. The net impact of these changes is the perception that the cost of seismic design has increased, notwithstanding that good design to the new requirements can cost less than mediocre design to the older requirements. Improvements in the efficiency of the structural design process under the NEHRP aegis can counter balance the perception that improved seismic design to achieve acceptable life safety and enhance implementation of better seismic performance in structures.

The collected data and analysis of this initiative will identify and document the types of saving opportunities identified and how they can be realized.

1.2.2 How the Construction Process Proceeds

Design and construction of civil structures is a very technically demanding and competitive endeavor, with significant cost and schedule constraints. The practices are dominated by small organizations, and there are for almost all areas of practice no major or dominant organizations. The process of design is one that merges science and art with professional judgment. Typically a project proceeds through several distinct steps

- Goal and program determination, project conceptualization,
- Schematic determination of the form of the structure and its geometric form, structural system, and structural materials to be used
- Production of construction documents, including plans, specifications, and engineering calculations
- Permit application
- Shop drawings
- Construction observation, inspection, and materials testing
- Modification during construction
- Job completion

The design team consists of project managers, architects, geotechnical, structural, and mechanical engineers, contractors, and materials suppliers, specialty consultants on many specific issues consultants. All of these groups have specific areas of responsibility that merge in the completed structure. The development team is in the modern management sciences termed a virtual corporation, in that for each project a large number of organizations team together to realize a project, and then disband when it is completed.

The process of design is often sequential, with the architect setting the configuration and massing of the structure, the geotechnical engineer setting the foundation conditions, the structural engineer arraying the structural elements and materials, the mechanical, electrical and plumbing engineers providing the utility services of the building, penetrating the structural system and modifying the envelope of the spaces. At each of the design steps the plans will be altered based upon the architect/owner/developer's vision of the resulting project. One of the challenges to the design team is to efficiently accommodate the needs of others in the preparation of their plans. Too often, the process of integration is an after thought, except at the gross level. The opportunities for improved efficiency and economy are potentially large.

The practice of engineering depends upon making choices of:

- Configuration and massing of the structure
- Structural systems and materials
- Evaluation criteria for evaluating options
- Analysis procedures and techniques
- How different building systems interact
- When to provide information to and involve other design disciplines design decisions
- How to "detail" a particular element
- Approval of a contractor proposed variation to the plan

Usually the choices are from an inexhaustible list of possibilities, some articulated, and some not; some selected by choice, others by external factors; some purposefully made and some by habit; some without understanding the consequences of the decision, and others with full knowledge; some with a firm analytical understanding, and some with only professional opinion; some based on experience and others based on whim. Design is not a clean process; it is a sequence of decisions made, only some of which are considered carefully for the specific applications. Fortunately most of these decisions can be made once and then repeated in other applications without deleterious consequence. There are more options for a design of a particular facility than there are designers.

It is instructive to examine what has progressed in other industries. In the 1970s General Dynamics Electric Boat division was designing and manufacturing nuclear submarine structures using state of the art CAD/CAM (Computer Aided Design/Computer Aided Manufacturing). Engineers sitting at CAD stations performing analytical calculations, detailing, design and drafting were immediately linked to machine tools cutting out sections of the submarine. Twenty years ago submarine construction at General Dynamics was paperless.

While the automotive, shipping, and aircraft industries, as well as electronic manufacturers have continued over the last twenty years to increase their productivity by several magnitudes through the use of computers, business to business internet, and interoperability - the construction industry has lagged far behind, with an actual decline in productivity. Construction industry executives blame the lack of improving efficiency on the fragmented nature of the industry. This is true, but so were these other industries! Let's take a look at Boeing 777 aircraft; Boeing has to use either of three major engine manufacturers, Rolls Royce, GE or Pratt and Whitney for political and socio-economic reasons. To sell aircraft in Asia, Europe or South America, individual countries have preferences to buy aircraft that can use components which are manufactured in their own or other countries - As a result the Boeing 777 is truly an international design, engineering, and manufacturing activity. The use of interoperability, or like standard bar code approach to all the components makes this possible. It truly allows the world community to participate in the design and construction of an aircraft. So even though it's called an American Boeing 777, 20-30 different countries participate in the actual construction of the aircraft. While they all look alike, no two 777s are really alike and they are all designed for specific requirements, either for passenger comfort, climate in which it flies, runway roughness, and a myriad of other reasons to have a standardized aircraft that is never the same. This could only happen through interoperability.

1.2.3 How Will It Be Accomplished?

The global architectural, engineering, and construction community must figure out a way to improve its productivity, whether for achieve seismic safety or for economic reasons. One way is to use object based computer systems. The International Alliance for Interoperability (IAI) is developing industry foundation classes (IFC) for all products. Industry foundation classes (IFCs) are an object-based approach to defining all of the attributes of the component, and all of its interfaces with all of the other building systems within a particular project. Furthermore, interoperability allows the process to link analysis, design, codes, standards, cost estimating, scheduling, maintenance, lifecycle costing, and all other activities of the construction industry. Architects, engineers, and contractors will have object-based databases to fully automate the process from start to finish.

At the present time there are approximately nine international IAI councils around the world. The leadership counsels have been Singapore and the Nordic countries of Finland, Sweden, and Norway. Some of the present initiatives are energy simulations, facilities management domains, CSI standardization of specifications, project management domains, steel projects, structural analysis models, reinforced concrete and foundation construction, drafting extensions, precast concrete construction, code compliance support, and building owners' requirements.

Where does all this lead for NEHRP's and NIST's initiatives in improving productivity within the seismic community? The entire NEHRP code and its interface with all products and components of a building - some with mass - some without mass - could form an IFC. This would allow a huge interoperable database in which all industries around the world could use the same object definition and interface. This would go a long way to improve and reduce fragmentation in our worldwide community.

We propose that NIST and NEHRP take the lead in incorporating and integrating all seismic design codes, analysis tools and methods and IFCs *for* all the components of buildings, bridges and infrastructure so that we can allow the seismic community to improve its productivity.

1.2.4 Personnel

The personnel to complete this effort are available and are expected to participate. The structural engineering professions alone are well known for the wide and extensive participation of practicing engineers in code and standards development. The wide participation in the Structural Engineers Association of California (SEAOC), the Western Council of Structural Engineers Association (WCSEA), the Building Seismic Safety Council (BSSC), the International Conference of Building Officials (ICBO), etc. is an indicator of the capacity and willingness of the professions to work when there is a *perceived* benefit in better earthquake resistant design and construction practices.

It is proposed that NIST play the principal organizational role in this initiative. It is expected that NIST engineering personnel will engage others from industry in the process. The technical development will be performed by firms whose specialty is system architecture and software development.

1.2.5 Resources

It is expected that leadership of this effort will require:

- One full-time professional leader of the effort for the duration of the effort.
- Three technical support personnel for the duration of the effort.
- An external Advisory Council of 15 professionals, meeting at least three times per year.
- External contracts in total amount of approximately $3,000,000 to prepare the software to incorporate seismic structural engineering capabilities into the interoperability system; the majority expended within three years.

1.2.6 Schedule

It is highly recommended that this effort begin as soon as practical to assure that decisions made in the system architecture be capable of easily and efficiently incorporating seismic capabilities into the interoperability system.

It is recommended that the first year’s efforts focus on developing basic system architecture and requirements, and that subsequent efforts to directed at their implementation.

1.2.7 Feasibility

There are no known impediments that would prevent achievement of the goal. Work is already underway internationally, and the US IOP is active, but with limited structural engineering participation.

On the Federal level the Corps of Engineers and NIST at this time have participated. The AIA, IAI, the DBIA, and AGC are also involved. There are several NIST staff who are technically experienced and knowledgeable in this area that can lead the US effort to incorporate seismic engineering issues into the process.

1.2.8 Benefits If Successful

The benefits if successful include: better practices, more reliable structures, less expense in construction to get reliable structures, and mitigated consequences when earthquakes occur. As discussed above, the construction industry over the past three decades has actually decreased in efficiency, unlike any other US industrial area. While this is but one approach to reversing this trend, it cannot be doubted that improvements in design efficiency can and will lead to improved economics, and thereby, productivity of the construction industry.

It is uncertain how quickly or to what degree this initiative can impact the overall industry. About 25% of all construction is in seismic hazard areas, so there is opportunity to impact this part. But in a larger sense the seismic elements of this initiative are comparable to what would be required for the whole of structural engineering. So the rewards apply not just to productivity of seismic design, but also to productivity of all structural design, whether for gravity and service loads, or those of wind, snow and water. If there is but a 1% improvement in efficiency of the construction industry, the benefit will exceed $1 billion annually. The stakes are huge, but so are the opportunities for significant, systematic productivity improvements.

In a more parochial view, it is often argued, usually without merit, that improvements in seismic design add to the cost of a structure.

1.3 TECHBRIEFS —DISSEMINATING ADVANCES IN EARTHQUAKE RESISTANT DESIGN AND CONSTRUCTION

1.3.1 What Needs to Be Done

One of the critical needs for improving the economy and efficiency of professional earthquake mitigation practice is to provide to the design and construction community relevant, information that can alter actions. There is a wealth of information available, much from the NEHRP, that is not directly available to the practicing professional, or at least not reaching this audience. The technical literature is too large and difficult to examine for most practicing professionals to examine, much less evaluate it for use. TechBriefs are intended to be a vehicle to provide in a directly usable form information directed to the design professional. It can act as the translating medium from research results and professional experience into practice realization.

A TechBrief addresses a single, focused topic, and its contents are actionable. They are expected to be from 4 to 8 pages in length and to be tightly written and well illustrated. They are not research papers, but topical discussions of practical problems that are faced by many designers. A TechBrief will typically contain the following elements:

- Issue
- Background
- Discussion of alternative practices or approaches
- Pros and cons of alternatives
- Recommended practice for specific circumstances
- Further reading and references
- Acknowledgements, including references to any institutions that provided financial or material support to the preparation of the TechBrief

The target audiences are principally the technical persons who implement design and construction:

- Project engineers, designers and detailers
- Building department personnel who review plans and field construction
- Inspection service field personnel
- Construction trades

This effort is modeled after the ATC TechBrief series that has to date addressed only earth sciences issues, but expanded to a wider coverage of earthquake mitigation issues and a wider audience.

Technical reliability and quality of these documents is of the first importance. They will be developed with a strict Quality Assurance program to assure quality contents. All TechBriefs will be peer reviewed to assure technical reliability of the contents and the recommendations. Multiple peer reviewers will be selected that represent the required technical experience and knowledge required for reliable evaluation of the document.

The topics will be varied and might include the following categories:

1. *Distillations of research findings*, particularly experimental research, that leads to specific conclusion on structural detailing. An example might be on the detailing of dog-bone sections for steel special moment-resisting frames.
2. *Findings of professional committees* and task groups on particular seismic design and regulation issues. For example, the SEAOC Seismology Committee is addressing the issue of how staggered truss structural systems should be approached in Zones 3 and 4. This was prompted by the innovative system's use in the eastern US for wide span structures, and by the December 2001 AISC report on recommended seismic design practices.
3. *Results of testing programs* for existing materials and assemblies that may have broader application than the reason for the test. For example, recently AME, Tipping+Marr Associates, and Telesis Engineers had a series of tests performed on bent steel wall anchors typically used in URM buildings at the turn of the 20th century to attach walls to embedded wood joists during construction. These tests indicate significant out-of-plane capacity that was unexpected, and usually assumed to be not reliable. There is no current forum to provide the profession with such findings, yet they could be useful to many.
4. *Comparative evaluations of typical detailing practice*. Most individuals who engage in extensive peer review or building evaluations comment that many commonly used practices are not particularly effective. For example, extending confined collectors in thin concrete slabs where the corridors are staggered without consideration of maintaining the slabs integrity in combined loading. Or, placement of reinforcing bar curtains in shear walls, or any of a variety of detailing practices. The issue is essentially that many repetitively used details of construction could be significantly improved if they were reviewed and commented upon by knowledgeable designers, and better, more effective details suggested, with a discussion of why they are better.
5. *Code clarification and interpretation*: The Building Code is often ambiguous for some particular applications or circumstances, and there needs to be an effective way to communicate to the design and regulation professions clarifications and their basis. It is expected that a major source of manuscripts will be the companion initiative on code development support.

6. *Construction means and methods evaluation* of options for selected applications. For example, quality of workmanship and inspection procedures to assure adequate shotcrete application.
7. *Case studies* of typical design decisions to determine their expected seismic performance. For example, technical discussion of the practice of some designers to use post-tensioning strands in diaphragms or beams to serve also as collectors to deliver lateral loads to shear walls.
8. *Learning from earthquakes* recommendations that bear on specific design practice, observations, and improvements. For example, in 1994 Northridge it was observed that conventional welded steel moment frame construction practices were deficient. SAC, a joint venture partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering, addressed the problem, but in the interim period between the earthquake and the publication of its interim report, many buildings were constructed. When conclusions were reached in evaluation methods, they could have been issued as TechBriefs and be available in a timely manner to the profession. Or, 1994 also demonstrated that certain types of embedded bent metal straps are not very effective wall attachments for tilt-up construction and should not be used as a primary means of out-of-plane connections of roof elements to walls. Some findings in earthquake performance are too important to wait for code adoption to legitimize incorporation in to practice. It is expected that organizations like SEAOC will continue to be very agile in the identifying these changes. The TechBriefs give a rapid means of communication to the professions of their actionable findings.

It is expected that there will be many potential authors for TechBriefs—researchers, practicing professionals, professional organizations, code committees, materials providers, etc. It is not expected that TechBriefs will be publication sources for original research, but it may be the principal publication source for technical reviews by professional engineering committees addressing seismic performance issues. There are many issues that are likely to be raised by the design professions that are not easily and readily answered without research and consideration. Some TechBrief issues will be the result of specific, small-scale research and investigation efforts; in essence these will be commissioned, reviewed, and if acceptable, published.

It is expected that the collection of TechBriefs will become a principal resource for the technical professions to be informed of practice improvements. It is intended that over time the collection of TechBriefs will become an important resource for training and development of design professionals in good earthquake resistant design and construction. They also could provide one of the bases for performance-based design advances in practice.

1.3.2 How Will It Be Accomplished

The following discussion reviews a course of action that could implement this recommendation. There are five essential elements to implementing this effort, whose implementation strategy is discussed

1. It is proposed that there be a *General Editor* of the TechBrief series that is principally responsible for the publication. An Editorial Board of Advisors would advise the Editor on priorities, acceptability of documents, etc. The Editorial Board would be appointed to represent the several technical interests in earthquake engineering practice, with selected Professional Organizations asked to nominate members. The Editor and Board would

need to actively work with a large number of existing organizations, which will require some considerable dexterity.

2. Identifying topics and issues that should be addressed. There are two ways TechBriefs can be developed. First, by submission of an unsolicited manuscript, which is reviewed prior to decision on its merits. Second, by commissioning a review/development individual or team to address a specific issue.

   - Topics, by this it is meant narrow, highly focused issues or evaluations, for example a particular detail of reinforcement placement in a beam-column-wall assembly, can be obtained from a variety of sources. It is hoped and expected that professional code committees will use the TechBrief series as a principal means of communication to the professions on technical issues.
   - It is not the purpose of a TechBrief to compete with scholarly, trade, or professional publications. It is proposed that when a TechBrief is published that any professional journal may reprint the TechBrief, with acknowledgement, or contact the authors to prepare a version appropriate to their specific publication.
   - The world wide web may be the primary method of publication and distribution.

3. Preparing the manuscript
   - Potential authors will be provided with an editorial guide for preparation of the manuscripts.
   - It is proposed that there be a modest honorarium for publication of unsolicited manuscripts.
   - It is expected that for some topics NIST professional staff will conduct studies to resolve the issue that is posed. Such studies may also be commissioned from other organizations.

4. Reviewing the manuscript to assure technical quality and reliability of recommendations.
   - It is proposed that an Editorial Board member be the responsible lead peer reviewer of all documents proposed managing the process.
   - Multiple peer review of all documents is required. The review process is expected to be conducted with revisions of text proposed if these can change the decision. Where the manuscript addresses code interpretation issues, the principal peer review will be from those individuals and professional groups judged to have definitive opinions on the issue.
   - The Editor will be charged with ensuring the text is of adequate technical and presentation quality before a peer review is conducted. Following completion of peer review, the Editor will work with the author(s) to refine the presentation quality of the document as required.
   - Peer reviewers would receive an appropriate honorarium to complete reviews.
   - Advocacy, either directly or indirectly, of specific products will not be accepted.

5. Publication
   - The target audiences are members of: state structural engineers associations (e.g., SEAOC, Western Council of Structural Engineers Associations), Building Official

groups (e.g., CALBO), materials groups (e.g., Western States Masonry Association), etc. Three approaches to implementation are proposed:

– Printed copies of the TechBrief could be distributed in numbers from the current ATC distribution of about 5,000 to 10,000 or more, if all Structural Engineers Association of California members in about 10 states are included.

– Internet distribution to addresses supplied by professional organizations, and by those asking to be added to the list. This could either be a notice of availability or a distribution of the document.

– Downloadable files, say Adobe PDFs, that can be accessed on demand through the Internet. Relying on this channel may be too limiting since we want to cut down the transaction cost of considering the content. If it takes a specific effort to receive the document, then many who would benefit may not seek it.

- It may be advisable to have several different distribution lists, responsive to different professional interests, although this may defeat the purpose of impacting the total design process.
- It is suggested that ATC could provide the publication venue for these TechBriefs, with the support of NIST. It is expected that NIST personnel will either perform the commissioned studies or administer other organizations so doing.

1.3.3 Personnel

The personnel to complete this effort are available and are expected to participate. The structural engineering professions alone are well known for the wide and extensive participation of practicing engineers in code and standards development. The wide participation in SEAOC, the Western Council of Structural Engineers Associations, BSSC, the International Conference of Building Officials, etc. is an indicator of the capacity and willingness of the professions to work when there is a perceived benefit in better earthquake resistant design and construction practices.

It is proposed that ATC play an important role in this initiative. ATC was formed to provide the bridging from research and development into professional practice. Its Board is comprised of representatives of many of the nations major structural engineering professional organizations; it is national in its membership and activity. ATC has the stature and ability to recruit the necessary personal and organizations to assist in accomplishment of the goals of the Productivity Initiative. ATC has in the past 30 years consistently been able to call upon the best and brightest in the engineering professions to assist it in its projects, including not only structural engineers, but the balance of the engineering and technical professions active in earthquake mitigation design, regulation and construction. Almost all of its projects have included contributions from professional participants far in excess of the honorariums paid or expenses reimbursed.

It is expected that NIST engineering personnel will be engaged in many of the commissioned studies. Their staff is known for their professionalism and capability. NIST has been involved in pivotal ways in ATC efforts since the very first project, ATC-1, and has maintained their involvement for the past thirty years.

1.3.4 Resources

The Editor and Board would receive honoraria for their efforts. It is expected that the average cost per TechBrief will be about $15,000 per issue where the manuscript is unsolicited, and about $25,000 to $30,000 when it is commissioned. The plan is:

Startup Editor and Editorial Board appointed within six weeks of initiation.

Year 1:	6 TechBriefs, starting with the first publication six months after initiation of the process, and one per month thereafter. An estimated 8 studies will be commissioned.
Year 2	18 to 24 TechBriefs, one about every three weeks, but issued when appropriate, not on a specific schedule. An estimated 12 studies will be commissioned.

With this schedule, it is expected that the cost will be approximately $500K the first year and about $1,000K the second and subsequent years. The total resources required can be adjusted most readily by limiting the number of commissioned studies initiated per year, and by choosing to distribute the documents by internet access only. If the number of commissioned studies is halved and publication by Internet is adopted, the resources required are estimated to be: $300K in the first year and $500 for subsequent years.

1.3.5 Schedule

- Proposal completed in three months from the date of request.
- Editor and Editorial Board appointments completed within three months of authorization to proceed.
- Notice to profession soliciting recommendations issued three months after notice to proceed
- First TechBrief issued about six months after notice to proceed.

1.3.6 Feasibility

There are no known impediments that would prevent achievement of the goal. The one issue is whether there will be an adequate number of issues to be addressed, and whether review engineers will be willing to criticize details and actions taken by others. It is one thing to do so in private, quite another to do so in print. Most professional engineers are not good writers, and are sometimes reluctant to prepare manuscripts. The availability of NIST staff with appropriate technical experience and good writing skills mitigates some of this problem.

A principal management issue is to keep the focus on practical “actionable” results, and not allow it to become an academic research forum.

1.3.7 Benefits If Successful

Better practices, more reliable structures, less expense in construction to get reliable structures, and mitigated consequences when earthquakes occur.

This could become a major source of “benefits” of the whole NEHRP program, with clearly defined results that can be directly demonstrated to have impacted practice. It will be particularly beneficial to the NSF engineering program, which as a basic research supporting program, could point to the research selected for discussion in a TechBrief as evidence of its “worth” and utility.

APPENDIX 2
Issue Paper 2:
Systematic Technical Support for the Seismic Code Development Process

by
James Robert Harris[1] and Charles Thiel[2]

This initiative proposes that NEHRP systematically support the voluntary code drafting process by providing technical support to the committees that develop model codes and the documents upon which the model codes depend. This support is intended to address in a timely manner critical technical issues and problems encountered in the code development process. This will foster development of more effective, efficient, and technically reliable design regulations.

2.1 BACKGROUND

Public Safety, as embodied in the police power of a government, is not a power that the U.S. constitution enumerates for the federal government. Therefore, this power is reserved to the individual states. The regulation of building construction traditionally was not exercised by the states, but abdicated to the local governments. Locally enacted laws governing building construction have traditionally been called building codes, and there have been tens of thousands of such codes. In the past half century there has been a move toward States reclaiming their authority with statewide building regulations. In some states, these encompass most forms of construction, while in others, it has been of a very limited scope, for example, for schools or for manufactured housing only.

The preparation and the maintenance of a building code require substantial creative effort. Few local governments can in fact devote such resources. Furthermore, the interests of interstate commerce advocate a commonality among building codes. Therefore, model building codes became popular in the U.S. Any given local or state government found it convenient to adopt a model code with amendments appropriate for local conditions. This has currently evolved to two model codes of nationwide scope: one promulgated by associations of building regulatory officials and one promulgated by an association of individuals interested in fire safety.

Most of the technical provisions in model codes are not actually written by the developers of the model codes. A large number of voluntary national and international consensus standards exist that are developed and maintained by organizations interested in a particular technical sphere. Model codes incorporate many technical provisions from such standards, and in many other cases they simply cite accredited standards by reference. Accredited voluntary national/international standards are documents developed by groups with scopes of (at least) nationwide interest and with procedures that assure general agreement on the contents of the standard. With respect to earthquake engineering there are many standards of interest. A very short list includes:

1. ASCE 7 *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers (ASCE)
2. ACI 318 *Building Code Requirements for Structural Concrete*, American Concrete Institute (ACI)
3. AISC LRFD/ASD *Design Specifications for Steel Buildings* and its supplement, *Seismic Provisions for Structural Steel Buildings*, American Institute of Steel Construction (AISC)

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4. AF&PA/ASCE 16 LRFD *Engineered Wood Construction* and its Allowable Stress Design companion *National Design Specification for Wood Construction,* American Forest and Paper Association and ASCE
5. TMS 401/ACI 530/ASCE 5 *Building Code Requirements for Masonry Structures,* The Masonry Society (TMS), with ACI and ASCE

A particularly important standard for earthquake engineering has been *Recommended Lateral Force Requirements and Commentary*, the SEAOC "Blue Book," (the Structural Engineers Association of California). Although not national in scope nor produced under the common rules for accreditation, it was extremely influential and was directly incorporated in the model code predominantly used in the regions of higher seismic hazards.

Today, the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* produced by the Building Seismic Safety Council (BSSC) play a very significant role in the development of seismic provisions in model codes and standards. This particular document is often referred to as a prestandard, because its recommendations generally find a place in standards and codes and because it is produced by a process that resembles the accredited standards producing processes.

Since well before the establishment of the National Earthquake Hazards Reduction Program the federal government has actively supported research in earthquake engineering and seismology. Furthermore, the private sector, states, and others conduct and support substantial amounts of pertinent research. Some portion of that research eventually finds application in design and construction, and building codes and standards are a sometimes-effective vehicle to promote that application. However, those in the process of developing and maintaining seismic codes and standards frequently voice the opinion that more research is needed to resolve recognized and hidden deficiencies in seismic codes and standards.

The dilemma is that research sponsoring and performing organizations are not necessarily interested in the issues of paramount importance to the code developers and almost always cannot meet the time frame in which the developers are working.

It is the opinion here that there are three dominant reasons for the perception that the seismic research community is not meeting the needs of the developers of seismic codes and standards:

- Some of the needed research is extremely applied, being more *development* than *research*, which is not as highly regarded in the rewards system of the research community.
- The code development process is driven by schedules to an extent that is nearly incompatible with the research community.
- The issues requiring resolution often are difficult to frame in a fashion relevant to conventional academic research in earthquake engineering.

2.2 An Unmet Need: Systematic Technical Support for Seismic Code Development

All the forgoing defines a need for a coordinated program to support research and development directed at providing technical support for future development of seismic codes and standards. Furthermore, the process by which seismic codes and standards move forward is complex, and the effort must be structured with an appreciation of the cyclical nature and the complexity of relations between various entities involved.

2.3 WHAT NEEDS TO BE DONE?

The objective is to support existing processes to better realize the goals of NEHRP. The objective is not to restructure existing standards development processes. It will be accomplished by systematically identifying the needs and the resources, then prioritizing, designing, conducting, vetting, and communicating the results of the studies intended to answer the needs.

Identifying the needs: The first and most obvious method is to ask the participants. As the BSSC produced a new edition of the NEHRP Recommended Provisions each three years, it was common practice to develop a research needs list at the conclusion of each cycle. This has not been done as systematically in recent cycles, due to the seeming lack of interest on the part of NEHRP agencies funding research. Some high profile issues, such as the problems with the conventional welded joint in steel frames exposed by the Northridge earthquake were adequately studied. However, many other problems were ignored, perhaps because they were thought either insignificant or intractable.

Following is a short list of such issues, although it is dominated by global issues that are complex to resolve and will involve significant effort. There are other issues that are more “compact” in scope that also need to be done but that require more effort than is reasonable to ask volunteers to complete. These tend to be efforts that take a man-month or less to complete by persons knowledgeable of the base literature and design procedures. While it is the global issues discussed above that limit the longer-term development of the code, it is these smaller tasks that limit development in the short-term.

- Establishing realistic limits that exclude the use of common simplistic methods (for example linear static analysis for design) to estimate the response of real structures, and how these limits might vary with the level of ground motion, the type/use of structure (building, bridge, tank, etc.), the structural material, the structural system, the height, and so on. The realism desired should account for approximations in design, analysis, and hazard definition, as well as some measure of costs.

- Examination of the consequences of lifting restrictions on particular structural systems in high hazard areas, particularly in light of modern interpretations of favored systems that are at some odds with archaic interpretations. For example, tall structures are required to have a moment-resisting frame, which today means at least a bay of a beam-column plane frame in at least two positions in each of two directions, but which used to mean a “complete” space frame in which every column participated in each direction.

- A rational method of accounting for geometric instability in a linear static analysis where the real behavior is dynamic and nonlinear. (The “P-delta” problem.)

- Methods to identify circumstances in which the torsional response of structures is significant, and how best to account for such response in linear analyses.

- Methods to approximate nonlinear response when designing by a linear analysis. (The “R factor” problem.)

- The increasing standardization of performance based earthquake engineering will require many quantitative measures to characterize performance, all of which will require substantiation. Many will be available from existing sources, but others will require new problem focused research.

- Predicting the nonlinear dynamic response of components supported by structures using simple methods. (The current provisions for nonstructural components are the outgrowth of one such problem-focused study conducted about ten years ago, which was very enlightening; however, the current provision implemented an allowance for nonlinear response in the component attachment that has not received proper study.)

- Identifying in a simple fashion the likely maximum internal forces in real structures designed to yield in strong ground motion. (The Omega factor problem.)
- Validation of the factors (C_d) used in linear analysis to estimate the maximum displacement of yielding structures during strong ground shaking.
- The need for and utility of quantitative design provisions to account for the redundancy in a structural system, specifically focusing on the effect of such provisions on the reliability of performance. (The rho factor problem.)
- A systematic review of existing methods for analysis and related criteria for design, nonlinear and linear methods, both static and dynamic, with an objective of rationalizing the limitations upon each method.
- The reliability implications of the present methods for linear analysis and design that incorporate load and resistance factors calibrated for gravity and wind loads. An evaluation of the transition to other factors for explicit nonlinear analysis.
- Evaluation of the concept that detailing rules are coupled exclusively to the R factor; are there characteristics of ground motions in low hazard areas or high hazard areas that justify any change in this principle?
- A study of the relative costs and benefits of strength and ductility in low to moderate hazard areas.
- Response characterization of jointed precast concrete systems. Evaluation of the present practice whereby some such systems (such as “tilt-up” concrete wall buildings) are designed with rules tailored for cast-in-place concrete walls.
- Definition of connection properties that significantly affect the performance of jointed precast concrete systems, with an emphasis on practice in low to moderate hazard areas.
- Extrapolation of the findings of the SAC program to define concerns and research needs for braced frames of steel.
- Evaluation of the state of knowledge of prestressed masonry with respect to seismic performance; present building code provisions are a guess at best.
- Evaluation of the significance of rigid and flexible diaphragm assumptions for the design of wood framed buildings.
- Evaluation of the significance of glued diaphragms on the performance of wood buildings.

The solicitation of needs from participants should make use of as many methods of communication as necessary, and it should extend to the user community. Direct survey, network bulletin boards on specific topics, review of ballot issues, and many more are feasible. Beyond soliciting needs from the participants, there should be occasional efforts to systematically observe the process and to evaluate standards and codes as they exist. Given proper sensitivities to federal government action and control, many of these types of studies might best be commissioned from the academic and industry communities.

The scope should include essentially all types of structures, not simply buildings. There are a plethora of standards for specialized structures (various types of tanks, towers, transmission lines, etc.) that have included adaptations of the equivalent static force method contained in the previous generations of the *Uniform Building Code*. These standards are facing some difficulty in becoming coordinated with the newer generation of seismic design standards for buildings, which are based upon new expressions of the ground shaking hazard, new design limit states, new site amplification factors, and new expectations on performance. Furthermore, the scope should be limited to new structures, but should be stretched to include standards and guides for evaluation and rehabilitation of existing structures.

2.4 HOW SHOULD IT BE DONE?

Before paring down any list of potential support studies, the available resources that could be brought to bear must be identified. The resources include the research staff at NIST, the participants in the various committees, trade associations in the construction industry, and the academic research community. NIST will need to establish an outreach through participation in committees and professional societies. In addition, advisory boards such as those formed by ATC on its projects will be very helpful in determining available expertise, facility, and interest.

It is intended that these code-development studies will be performed by both NIST personnel and by independent individuals and/or groups selected to address specific issues based upon their knowledge, expertise, and experience. In some cases the efforts will be cooperative with personnel from NIST and from other organizations. In others NIST will perform only a management function. In either case, the relevant code committee is to be considered the client for the effort.

Schedules will be set recognizing the relative importance of the issues, the capabilities for the necessary studies, and the schedules of the various committees in the development process. The prioritization will require external advisory boards with real power. These priorities and schedules must account for the somewhat absolute deadlines for code actions. Model building codes have operated for decades on a three-year cycle. Standards that are integral to the code process have mostly conformed to this cycle, but there is a real tension. The technical activities of interest to standards committees, and to this initiative, do not necessarily lend themselves as well to absolute schedules. Many such committees actually plan in six-year cycles, but issue new editions of their standards each three years. The longer term planning is necessary because many technical issues require a longer term to be refined to the point that consensus can be achieved. This initiative must support both the short- and long-term objectives of the various committees.

The cycles of the various important players overlap significantly. For example, consider the following as a likely schedule for the 2006 edition of the *International Building Code* (IBC):

- Mid 2001: Establishment of agenda at BSSC for changes to the 2000 *NEHRP Recommended Provisions for New Buildings*
- Mid 2002: Establishment of agenda for changes in many key structural engineering standards (ASCE 7, ACI 318, AISC, TMS, etc.)
- End of 2003: Publication of *NEHRP Recommended Provisions for New Buildings* (which will likely change the agenda of several standards committees)
- Fall 2004: Last date for completing substantial technical work in standards committees
- Fall 2004: Last date for submitting proposals for change from the prior edition of the code

- Spring 2005: Code committee meetings offering last chance for substantial action regarding planned changes
- Summer 2005: Last date for publishing referenced standards
- Fall 2005: Final ratification of 2006 edition of IBC

Clearly, the work for one code cycle extends over at least five years, even though the cycle is three years. The above list is ideally simple; the real workings of each individual committee are considerably more complex, as are the interactions. This interdependent and overlapping nature must be recognized in planning the support activities in this program.

It will be important to avoid the appearance of federal government mandate in this support program. The essential objectives should be kept in the forefront: first safety, measured for individuals and for society; second economy, measured primarily for society. The manner of planning, executing, and reporting the work shall be oriented as a service in providing the technical basis for the seismic code development process.

The product of individual studies will be subject to a careful review, both within NIST and in the technical community at large. However, unlike other NIST products that might be published as independent, authoritative reports, the timing of publication of study results must be coordinated with the schedules of committee activities. Some reports will be needed in the archival literature to enable appropriate citation in commentaries that accompany most standards. In most cases, publication should await the final actions of standards committees. The program will do little good if published reports make recommendations at serious odds with the actions of a consensus standards committee. In many cases the results of studies will be useful for developing the *TechBriefs* described as another aspect of the overall program of earthquake engineering research and development at NIST.

At the beginning, a budget can be tentatively set by simply assigning an average of two (plus or minus) study items for each of the dozen BSSC technical subcommittees that work on updating the *NEHRP Recommended Provisions for New Buildings*, plus about four more for each of the major structural standards, plus an allowance for the roughly dozen other standards for limited types of structures. This would result in about 60 study items for the first three-year cycle, or 20 per year. Most of these could probably be accomplished for about $25,000, but there will be a few that are much larger. When coupled with an allowance for interface with the participants in the process, advisory committees, and so on, an initial budget of about $1,000,000 annually appears to be appropriate.

2.5 Feasibility

Coherence of the overall NEHRP program is one of the keys to feasibility for this program. The other NEHRP agencies must be in full support. Careful coordination with existing entities that develop seismic standards and building codes will also be crucial to success. Existing authority must not be usurped. Given the apparent appetite of participants in the process for technical support for the many decisions, there is every reason to anticipate success. Such vision should not be interpreted to mean that all the current thorny problems will automatically be successfully resolved. The program will be viewed as a success if a significant minority of the expressed needs are resolved with the aid of studies conducted under this program.

2.6 Benefits

The fundamental benefits will be more consistent safety, which will achieve goals of NEHRP, and better use of resources. The resources in question are broadly defined and include physical and human resources used to design and construct the nation's infrastructure, as well as the resources consumed in the code development process.

APPENDIX 3
Issue Paper 3:
Problem-focused Study in Performance-Based Seismic Engineering
by
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3.1 INTRODUCTION

Performance-based seismic engineering (PBSE) is a rapidly developing area of practice that may have wide application to the evaluation and upgrade of existing structures as well as the design and construction of new structures. Although there are many potential definitions as to what, precisely, performance-based seismic engineering is, this paper broadly envisions it as a related series of technologies, that together permit the performance of structures in future earthquakes to be reliably predicted and as well as enabling the development of structures which will provide predictable and desirable performance in future earthquakes. From this perspective, performance-based seismic engineering may be thought of as closely related to performance-based engineering and design technologies for other hazards including, for example, fire and blast. While many of the technologies developed to facilitate performance-based seismic engineering may be applicable to performance-based engineering for these other hazards, this paper focuses on technology specifically developed for seismic engineering application.

PBSE may be thought to have initiated in the 1970s, following the collapse of several hospitals in the 1971 San Fernando earthquake. Following this event, it was recognized that some classes of facilities, for example, hospitals and other facilities important to emergency response should be designed and constructed to remain in service following strong earthquakes, so that they could be available for use in disaster recovery operations. The building codes of that era made rudimentary attempts to provide for such performance, by requiring that such structures be designed with greater lateral strength than other structures and by requiring more stringent quality assurance measures during their construction. As seen in more recent earthquakes, notably the 1989 Loma Prieta and 1994 Northridge events, while these measures have improved the performance of these facilities, relative to the performance of other structures, they have not completely provided the level of performance desired.

In part, the failure of the post-San Fernando design procedures for performance-based design of emergency response facilities may be attributed to the fact that these procedures were not specifically performance-based. Rather than providing a means of predicting the performance of the structure in future events, and designing so that the predicted performance was achieved, these early procedures merely adjusted the level of conservatism inherent in the empirically-based prescriptive design procedures that had been in place for many years.

The modern era of PBSE initiated in the mid-1980s with a series of projects initiated by the National Science Foundation (NSF) and Federal Emergency Management Agency (FEMA) under the National Earthquake Hazards Reduction Program (NEHRP) and which were intended to reduce earthquake hazards related to existing seismically-vulnerable buildings. The first of these projects lead to publication of a methodology, *ATC-14*[3] to permit the identification of buildings with significant potential to experience life-threatening damage. Over a period of approximately 10 years, this methodology evolved and was expanded until in its most recent published form,

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[2] Professor, School of Civil and Environmental Engineering, Georgia Tech, Atlanta, GA
[3] Applied Technology Council. 1985 *Evaluating the Seismic Resistance of Buildings*, Report No. ATC-14, Redwood City, California.

FEMA-310[4]; it includes methodologies to identify others level of earthquake-induced damage and consequences, such as loss of availability for safe occupancy. The development of these publications occurred in parallel with the development of the *FEMA-273/274*[5] and *FEMA-356*[6] methodologies for performance-based seismic rehabilitation of buildings. These methodologies were extended in application to the design of new moment-resisting steel frame buildings with the publication of *FEMA-350*[7].

While each of the aforementioned efforts resulted in considerable advancement in the development and practices of PBSE, each addressed only a portion of the problem. In 1997, at the request of FEMA, the Earthquake Engineering Research Institute (EERI) developed an action-plan for the development of comprehensive PBSE guidelines. This action plan, published in 1999 as *FEMA-349*[8] is currently being used by FEMA as the roadmap for development of comprehensive PBSE guidelines. While much of this work is anticipated to be performed by the Applied Technology Council, under project ATC-58, there is substantial room for participation in this effort by other organizations including the National Institute of Standards and Technology (NIST), National Science Foundation (NSF), United States Geologic Survey (USGS), individual universities and private organizations.

This paper explores several areas of technology, essential to the development and implementation of PBSE that may be advantageously pursued by NIST. These include development of standard measures of performance, systems for qualifying the performance capability of construction components, tools for predicting performance, performance translation tools for experimental data, construction systems capable of providing desired performance, sensor development and calibration, systems for monitoring performance, and multi-hazard simulation and experimentation. Each of these technologies is discussed in the following sections.

3.2 PERFORMANCE MEASURES

One of the most important challenges facing the development of PBSE is the definition of standards means of measuring earthquake-performance of structures. The existing FEMA publications relating to PBSE generally measure earthquake performance relative to a series of four quasi-standard levels of performance typically described as Operational, Immediate Occupancy, Life Safety, and Collapse Prevention. In the implementation of current PBSE methodologies, stakeholders are expected to select which of these levels the building should be capable of providing, given that it experiences earthquake hazards of specified intensity. Designers are then expected to predict the ability of a building to meet the selected performance level and to adjust the building design in a manner that permits the performance level to be attained.

Although the methodologies provide procedures by which the ability of a building to meet these performance levels may be judged, the levels themselves are quite arbitrary, do not really

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[4] American Society of Civil Engineers. 1998 *Handbook for the Seismic Evaluation of Buildings – A Prestandard, Report No. FEMA-310*, Federal Emergency Management Agency, Washington, D.C.

[5] Building Seismic Safety Council. 1997. *Guidelines and Commentary for the Seismic Rehabilitation of Buildings, Report No. FEMA-273/274*. Federal Emergency Management Agency, Washington, D.C.

[6] American Society of Civil Engineers. 2000. *Prestandard and Commentary for Seismic Rehabilitation of Buildings, Report No. FEMA-356*. Federal Emergency Management Agency, Washington, D.C.

[7] SAC Joint Venture. *Recommended Guidelines for the Design of New Moment-Resisting Steel Frame Buildings, Report No. FEMA-350*. Federal Emergency Management Agency, Washington, D.C.

[8] Earthquake Engineering Research Institute. 2000. *Action Plan for the Development of Performance-Based Earthquake Engineering, Report No. FEMA-349.* Federal Emergency Management Agency, Washington, D.C.

represent discrete behavioral states, and therefore are quite difficult to predict reliably. Consider for example, the Collapse Prevention level. At this level of performance, a structure is anticipated to be damaged so severely, that incremental loading would be likely to produce collapse. Collapse occurs in structures when the deformations induced in the structure or damage sustained by the structures' elements reach a point that either locally, or globally, the structure becomes incapable of supporting gravity loads. Yet current methodologies for predicting this performance level, rather than being related to prediction of the gravity load carrying capacity of the structure, are tied to the loss, by individual structural elements, of the ability to sustain deformations and stresses induced by lateral loading. While this inconsistency may be more a result of inadequacy of the performance-prediction techniques contained in current methodologies, it may also be the result of an unpredictable performance state, itself.

The other standard performance levels entail similar problems. The Immediate Occupancy level for example represents a performance state in which the structure has sustained so little damage that it remains approximately as safe for occupancy after the damaging event as it was before. Yet often, the acceptance criteria used by current methodologies for predicting the Immediate Occupancy state are based on the appearance of psychologically disturbing damage as opposed to damage that actually compromises safety. While there are reasons for this inconsistency, it suggests that some improvement in our standard measures of performance could occur.

Perhaps most important, the performance levels used by current methodologies may not adequately address the concerns of the stakeholders who must chose between alternative performance levels. Many stakeholders considering the performance of facilities in future disasters, in addition to concern for potential life safety impacts, express considerable concern for the likely repair costs associated with earthquake damage and the potential loss of use of facilities, while they are closed for inspection and repair. The current standard performance levels do not directly address these issues.

Just as the National Bureau of Standards (NBS), once was the custodian for standard physical measures of weight and length, NIST could play a role in determining and maintaining the standards for definitions of building and structure performance. These measures could be specific to individual classes of construction, or could be broader reaching, but like other measures once maintained by NBS would provide a common means for defining performance.

As an initial step in this process, it is proposed that a series of workshops be held to obtain feedback from the technical and stakeholder communities as to the important attributes of performance measures. This effort could be performed in a period of one to two years at an estimated cost of $250k. Based on feedback obtained at the workshops, a task team comprised of earthquake/structural engineering practitioners and researchers would develop and propose a series of standard performance measures. It is estimated that this would entail a 2-year effort and an expenditure of approximately $500k. Finally, an ongoing effort of collecting earthquake data, following the occurrence of earthquakes, and using this data to validate the sufficiency of the performance measures is recommended. It is recommended that this effort be budgeted as a recurring annual expense of $200k. Since earthquakes do not occur annually, but rather, on an occasional basis, in most years these funds would not be expended. Realistically, this task could be performed only upon the occurrence of a significant earthquake, which in the past has occurred once every 10 years or so. The estimated cost to perform this task is approximately $2,000,000. It is recommended that annuity fund of $200k per year be allocated to cover these costs when they are incurred.

The damage state, or performance level, achieved by a structure, is only one part of the performance definition used by PBSE methodologies. The second part is definition of the hazard intensity, or severity, at which the desired performance is to be attained. Current measures of hazard intensity used in PBSE are relatively crude and typically consist of elastic response spectra, or parameters derived from such spectra that are used to characterize severity of shaking at given probabilities of exceedance. While elastic response spectra are a useful tool for characterizing the probable response of a structure that remains undamaged by the ground motion, they do not adequately capture many aspects of the behavior of structures that are damaged by the ground motion, a state more common to structural behavior in severe earthquakes. To more accurately predict behavior of structures in advanced damage states, it is necessary to use more sophisticated analysis tools, such as nonlinear response history analysis.

Unfortunately, the response of a damageable structure to ground shaking is highly dependent on the individual record of motion that the structure is subjected to. Because current state of knowledge does not permit the exact ground motion record that a structure will experience in the future to be predicted instead, when using response history analysis techniques, it is necessary to use a representative suite of motions that are anticipated to capture, or envelope, the likely ground motion characteristics of earthquakes that may affect the structure in the future. There are no current standards for the selection of appropriate suites of time histories or methods to scale them to represent the desired hazard levels. For a given project today, the ground motion records selected for the purpose of PBSE are likely to depend more on the capabilities of the project geotechnical engineer, than on an understanding of the characteristics of ground shaking records that are meaningful to the performance of structures.

There is a tremendous need for the definition of standard series of ground motion records, applicable to sites with different geologic and seismologic characteristics and representing different levels of hazard, that are suitable for use in performance prediction. Working with USGS, NIST could play a valuable role in performing studies that support the development of such standard ground motion suites and in maintaining them in standard format for use by PBSE practitioners. As with the development of performance measures, it is recommended that this task initiate with a series of workshops, to collect user input on the important parameters for developing standard ground motions. This takes two separate forms, first collection of data on the characteristics of ground motions that are important to structural performance and second collection of data on the important geologic and seismologic characteristics of earthquakes that affect the character of ground shaking. It is estimated that each of these data collection efforts will span over 2 years at a cost of $250k. Once this data is obtained, it is estimated that an additional 2-year effort at a cost of $500k, working with USGS will be required to develop a suite of standardized ground motions together with electronic publication of these ground motions for widespread access and use. Finally, it is recommended that a continuing maintenance effort of $100k per year be budgeted for updating and improving these standard ground motion records.

3.3 PERFORMANCE QUALIFICATION

Buildings and structures are comprised of a myriad of components, ranging from structural elements such as beams, columns and walls, to nonstructural components such as ceilings, computer systems and windows. The performance of a building or structure comprised of such components is directly dependent on the performance of the individual components. Design professionals, designing structures to provide specified performance, must have data available on the likely performance of the various components that comprise the structure, under the conditions of loading they are anticipated to experience.

Today, there are limited data available on the hysteretic performance of common structural elements and assemblies. Often these data have been accumulated using incompatible testing protocols and have been reported in ways that are not completely compatible with the concerns of PBSE practitioners. Although the existing PBSE methodologies have utilized these data to develop acceptance criteria for use in judging probable performance of structures, PBSE could benefit substantially from the compilation of these data into a consistent database, as well as the expansion of this database to include the full range of structural components encountered in construction and to ensure that it includes data on components tested and reported in a consistent useful manner.

In order to assemble the data required to populate this database, it is suggested that a series of research fellowships be funded, each in several dedicated areas of structural systems, for example, masonry wall structure, concrete wall structures, concrete frame structures, etc. Each research fellow would be charged with performing literature searches to determine the existing hysteretic testing and performance data available in the public domain, and to the extent possible, assemble the data in a common format, consistent with use for performance-based engineering. A total of 8 fellowships, at a funding level of $300k each, operating over a period of 2 years are envisaged. At the completion of this compilation effort, a 1-year effort to compile the data into electronic, web-accessible format at a cost of $500k is recommended.

In the area of nonstructural components the need is even greater as there is a dearth of performance data on the behavior of various nonstructural components when subjected to earthquake-induced accelerations and displacements. Particularly for performance levels entailing relatively little damage, and rapid post-earthquake restoration of normal occupancy and function, data on permissible levels of earthquake acceleration, displacement and energy input to these nonstructural components are badly needed. NIST could play a lead role in the establishment of an accessible database on the performance capability of various nonstructural components. This role could include establishment of standard qualification protocols, to providing an electronic repository for storage of data information developed by various suppliers and researchers, to physically performing qualification testing to acting as a ratings agency, much as do the Underwriters Laboratory and Factory Mutual laboratories for electrical and fire performance qualification of components.

Development of standardized performance qualification protocols for nonstructural components will first require nonlinear response history analyses of a series of prototype structures, for different ranges of ground motions, in order to provide better data on the nature of accelerations and displacements induced by structures, responding in a nonlinear manner, to different types of ground shaking on nonstructural components. A two-year study, in an amount of $500k is suggested for this initial effort. Once the range of motion imparted by structures responding in a nonlinear manner to supported components is understood, a series of standard motion records should be developed to represent these important characteristics. It is estimated that this effort could be accomplished in one year, with approximately $250k of funding. Establishment of an evaluation and qualification service would largely be able to use existing NIST facility and laboratory. However, it would be necessary to staff the laboratory at an estimated cost of $500k per year. Actual costs of assembling test specimens, testing them, and publishing qualification reports would be borne by the manufacturers of components requesting such qualification. After some 5 years, it may be possible that sufficient requests for this service will be made to allow funding of the entire overhead associated with this effort.

3.4 PERFORMANCE PREDICTION TOOLS

The performance-based design process requires that the designer demonstrate that a design is capable of providing desired performance when subjected to a design hazard level event. Three approaches are generally available for demonstration that a design is capable of such performance: 1) adherence to prescriptive standards, 2) testing and 3) simulation/calculation. In the first of these approaches, the ability of a design to deliver the desired performance is not actually evaluated. Rather, an approving authority determines before hand that designs fulfilling certain characteristics will be deemed capable of providing the desired performance, based on historical performance of similar designs, or through the use of testing or simulation of prototypes having these characteristics. This method is the simplest for the designer to implement although it is limiting with regard to the freedom permitted the designer in customizing various aspects of the design. The second approach, testing, consists of the construction of a design prototype, simulating it to the design loading, and observing its performance. To the extent that the prototype is constructed in the same manner as production models, and that testing truly simulates the design event, this method is the most reliable of the performance prediction methodologies. However, it is also the most expensive and largely impractical for use with buildings, where each individual design is typically constructed only one time. The third approach, simulation is therefore the most applicable approach to PBSE. In this approach, a mathematical model of the building or structure is constructed and a mathematical simulation of its behavior and performance in one or more design events is predicted.

Currently, simulation is limited to rather crude modeling of a portion of the structural system. Elements that are believed not to significantly contribute either to global strength or stiffness of the structure are generally not modeled and nonstructural elements, which are a very important factor in building performance, are almost never modeled. Structural elements that are modeled are typically represented well in the elastic (undamaged) range of response, but rather poorly in the highly nonlinear range of response, which unfortunately, is quite important to predicting performance for many real structures. The result is that the most widely used approach to predicting performance of structures as part of PBSE neglects many of the elements that are important to and effect performance while using inaccurate models for those elements that are directly considered. At their best, these simulation techniques are able to only directly estimate the amount of response of the structure including structural displacements, accelerations and velocities, and the resulting forces and deformations in structural elements. These simulations are not able to directly predict the extent of physical damage sustained either by the structural or nonstructural components and can not predict important parameters that may affect the performance delivered by the structure, such as the number of lives lost, the cost of conducting repairs, or the period of time that a building is out of service.

Since simulation is likely to remain the primary means of verifying a structure’s performance capability, substantial improvement in current simulation techniques is clearly needed. NIST could participate in the development and improvement of individual element models that better represent the behavior of real structural and nonstructural elements when subjected to severe cyclic demands, however, this work is probably most effectively conducted by university researchers. Perhaps a more important and significant role would be the development and maintenance of a standard electronic library of structural modeling elements that could be utilized by practitioners in modeling individual structures.

To this point in time, primary development of structural simulation software has occurred at universities. Following the primary development, individual researchers or students worked with commercial software developers to convert these research-oriented software packages into user-friendly, commercially marketable packages that could be used by the design professional community. The commercial enhancements placed on the research software as included providing necessary documentation and support necessary to make wide-scale implementation of the simulation software available and viable, as well as development of user-friendly input-output modules. Typically, each such package has been a self-contained package including input/output modules, element libraries, and solution algorithms. As structural simulation becomes more complex, requiring greater computing power and more comprehensive solution systems this current model of software development may evolve into an alternate form. In this evolving model, individual commercial packages may be limited to input/output processors and solution algorithm/number crunching engines, while standardized element libraries, maintained at a central electronic site are used as the basis for modeling structures and their nonstructural components, on a license basis. NIST could feasibly be a developer and maintainer of such a standardized element model library, drawing on the development efforts of university researchers to support the building of the library.

In order to develop such an element library, it will first be necessary to conduct a survey to identify the various element models that are currently available and their capabilities. This could be accomplished in an 18-month effort at a cost of $300k. A similar level of effort is suggested to develop a series of prototype, or "test bed" structures that could be used to judge the accuracy and stability of these element models, under different response analysis conditions. Once the element models have been identified, and test bed structures developed, it will be necessary to verify the fitness of these element models in analyses of the test bed structures. A two-year, $1,000k effort is envisaged for this. Following this effort, it is recommended that one or more workshops be held, at which the results of the test bed models would be presented and consensus reached as to appropriate "standard" models. This effort would be performed over a one-year period at a cost of $200k. A similar level of effort would be required to implement the element models on an accessible electronic database. Finally, a budget of $200k per year is recommended to maintain this database and to expand it with additional element models, as they become available.

There is also a need to expand current structural simulation software so that it directly predicts damage, as well as structural response, and provides estimates of such quantities as probable repair cost, residual stability against collapse, remaining cyclic energy dissipation capacity, etc. NIST could become a primary developer of such enhanced PBSE simulation modules. It is estimated that the cost of such development could be on the order of $10,000k.

3.5 Performance Translation Tools

Another area that requires extensive work is the development of standard methods of translation and interpretation of experimental data for uniform use in analytical models and procedures as well as methods of interpreting analytical results to predict performance. Improvements in our ability to predict performance requires that the behavior observed in tests of structural elements and subassemblies be incorporated (or translated) correctly into analytical models. For example, if crack widths in a concrete shear wall are to be used as a design criterion for an "Operational" performance level, careful analytical modeling of tests on single-story walls will be required to gage the effect of the idealized boundary conditions in the test on the crack widths and potential localized high strains in the steel reinforcement, so that the correlation between behavior of a simple test specimen and a similar element within a real structure can be properly understood. This will imply, for example, a careful evaluation of whether the anchorage conditions for the wall reinforcement in the top and bottom of the test specimen influence the crack widths and crack patterns significantly. As PBSE requires an understanding of the behavior of the structure throughout a wide range of displacements, very robust models for material and element behavior under reversed cyclic loads will be needed for this task. These models are not currently available except in limited forms in advanced commercial codes (DIANA or ABAQUS, for example) and are seldom if ever used in design practice. Thus advanced simulation tools that incorporate neural networks and advanced visualization tools will be needed in order to properly extract the behavior of complex two- and three-dimensional structural elements and translate this behavior into simplified robust models that can be used in practice. NIST can help harness the computational power required to do these studies, provide benchmark calibration problems, and develop the neural and mesh adaptation algorithms that will be required to address these issues.

The inverse problem, i.e. translating analytical results into predictions of actual performance, also arises. Consider the very simple case of a flexible moment-resisting frame. Current PBSE methods permit the use of relatively simple simulation techniques, such as a pushover analysis to assess the behavior of the structure. Such analysis may tend to over-predict the P-Δ effects and under-predict the influence of higher modes of deformation on base shear. In either case, the predicted performance may be unreliable. Similar problems in analytical veracity exist for braced systems, where current analytical methods predict only marginal improvements in structural deformation capacity for a wide range of strengthening strategies. In both of these cases, as well as for other structural types, extensive simulations should be run and some simplified "translations" developed to translate analytically predicted damage to actual likely damage in the real structure.

In order to develop this performance translation capability, a series of large-scale physical tests replicated by electronic simulations would be performed. It is estimated that the physical tests would be conducted under the NEES effort and would not be directly budgeted by NIST. However, NIST could play a significant role in the electronic simulation of the tests and in developing the necessary calibration and performance translations based on evaluation of the comparable test and simulation data. A large multi-year effort of at lest 10-year duration and $20,000k budget would be required to make any significant progress in this area.

3.6 Construction Systems

PBSE made major advances in recent years with the development of damage-tolerant structural element technologies including base isolation systems, energy dissipation systems, buckling-restrained braces and hybrid precast concrete frames. These damage tolerant systems can provide structures with the ability to modify structural response, dissipate energy and reduce earthquake-induced accelerations and displacements experienced by structures, with relatively little structural damage, as compared to more conventional structural systems. These systems make possible economical development of structures capable of resisting strong ground shaking with minimal damage. Despite the great benefits offered by these technologies, popularizing their use in the routine design and construction of structures has proven difficult. Reasons for the slow adoption of these technologies have included a reluctance of the design professions, building regulators and building developers to utilize unproven technologies, as well as restrictive quality control criteria that have been imposed on these technologies. For example, when base isolation devices or energy dissipation devices are employed in a structure, building codes typically require that project-specific prototype testing of the devices be performed to confirm the adequacy of the response properties of the device, assumed in design analyses and to demonstrate that the technology is reliable. These requirements for project-specific prototype testing are both costly and time consuming and as a result serve as impediments to rapid deployment of these systems in building construction.

Similar quality assurance measures are not imposed on the use of traditional structural systems and elements. In the authors' opinion, this is largely because through repeated use, design professionals and regulators have come to "trust" the reliability of so-called conventional systems, not because the conventional systems are inherently more capable of reliable performance than these newer technologies. Consider for example, moment-resisting steel frame construction, a so-called conventional technology. For many years, design codes permitted these frames to be detailed according to prescriptive criteria without any need to perform project-specific qualification testing. However, following the 1994 Northridge earthquake, in which it was seen that this "conventional technology" did not behave as anticipated, criteria for project specific-testing, similar to that required by the codes for base isolation systems and energy dissipation systems, were introduced into the code as the industry lost confidence in the reliability of this once conventional technology. Following this discovery, a large research and development program was implemented by the SAC Joint Venture, with funding from FEMA, to determine the causes of the unreliable performance and to demonstrate through programs of laboratory testing and analytical investigation that when properly designed and constructed, the moment-resisting steel frame technology could perform reliably. Following this program of research, the codes were once again changed to treat this structural type as a conventional technology, not requiring project-specific qualification testing, except under unique circumstances.

NIST, with its laboratory facilities and analytical capabilities, is ideally suited to assist in prequalifying the use of new developmental technologies, in order to speed their acceptance. NIST has already played such a role with regard to their participation in the Precast Seismic Structural Systems (PRESS) program, with the development of precast hybrid concrete frames. A similar role could be fulfilled for other systems to provide the building development community with adequate confidence that new technologies are suitable for use in construction projects without extraordinary project-specific testing and justification. A number of such new technologies are currently under development including shape-memory alloys, rheo-sensitive materials, active damping systems, and composites. Many of these technologies may have potential application to the development of high performance structures and to the implementation of PBSE. Participation by NIST in prequalification programs would greatly speed their adoption and implementation.

To implement this program, an effort similar to that described for establishment of a nonstructural component performance evaluation and qualification laboratory would is suggested. NIST's existing laboratory and facility would be utilized for this purpose. A basic team of personnel to perform the work would need to be established at an estimated cost of $500k per year. An initial one-time start-up cost of $1,000k, expended over a period of 2 years would be required to develop initial protocols and procedures by which qualifications would be evaluated. Actual costs associated with testing would be borne by private parties, such as materials industry associations, interested in obtaining system qualification.

3.7 Sensor Development and Calibration

Another important area in which NIST has excelled in the past is in sensor development and calibration. Improvements in PBSE will require verification of performance-prediction methodologies through benchmarking to predictions of performance of real structures that experience damage, either in earthquakes or in the laboratory setting. This will require input both from the instrumentation of some actual large-scale structures in high seismic areas and considerable expansion in the instrumentation of laboratory tests. It would appear that these applications would require very different types of instrumentation. Instrumentation installed in actual buildings, and which must await the occurrence of an earthquake before they can actually provide meaningful data should be robust, low-maintenance sensors with local amplification, data acquisition and storage and wireless transmission capability. Laboratory instrumentation would more properly require either dense arrays of small sensors (wireless micro-electro mechanical (MEM) sensors, for example) or fast non-contact multi-point measurement systems to characterize crack formation and growth in concrete specimens. One can postulate that advances in material science (ceramics, in particular), communications and IT technologies will lead in a very short time to a revolution in sensor technology. NIST has the expertise and facilities to lead in this area. As the keeper of calibration standards, NIST is in the best position to assess the potential of new technologies as well as to dramatically decrease their implementation time. It is envisaged that this work would be conducted in parallel with ongoing work under the NSF-sponsored Network for Earthquake Engineering Simulation (NEES) program, at an annual cost of $1,000k per year, to participate in individual NEES projects, including obtaining and mounting test sensors, collecting, evaluating and reporting data.

3.8 PERFORMANCE-MONITORING SYSTEMS

In recent years, with the advent, or pending advent of economical wireless instrumentation technologies that can detect straining, cracking and other degradation of structural elements, as well as variations in global response characteristics such as natural period of vibration and effective damping, considerable interest has been expressed in the use of such technologies to perform health-monitoring of structures. In theory, following an earthquake event, rather than having to rely on time consuming and costly visual observation of damaged structures, together with destructive inspection and other invasive techniques, it should be possible to use such instrumentation to monitor the health of structures and reliably determine whether significant damage has been sustained by a structure, within minutes of the occurrence of an earthquake event.

Given that even in zones of very high seismicity, such as coastal California, the likely return period for potentially damaging earthquakes at any specific site is on the order of tens of years, it seems unlikely that owners could anticipate net economic benefit for installing such systems. In areas of lower seismicity, the potential return on investment for installation of such systems seems even less attractive. Therefore, the authors are not strong proponents for the installation of health monitoring systems in structures, except perhaps for a select set of very important, monumental structures, such as long span bridges, major gravity arch damns or super tall buildings.

The above notwithstanding, installation of such systems in a small set of buildings, to provide improved understanding of the actual response of buildings in earthquakes could be quite helpful. Because buildings tend to be quite large and are costly to construct, prototype shake table testing of actual buildings, as opposed to simplified, scaled structural models is almost never done. Therefore, there are limited data on the actual response of real buildings in earthquakes. Through limited installation of performance-monitoring systems in a few carefully selected buildings, representative of broad classes of construction and placed in regions that are relatively likely to experience damaging ground shaking, it should be possible to learn much about the actual response of structures. Currently, such instrumentation of structures is primarily done by the USGS and its sister organizations. NIST could supplement these efforts by deploying more comprehensive performance-monitoring systems in selected buildings. In the event that such systems capture building response to strong ground shaking, the resulting data could be used to calibrate and verify the adequacy of performance-prediction, simulation software and approaches. It is recommended that such work be performed under the umbrella of the ANSS program. The primary cost to NIST is in the form of liaison personnel, estimated at $300k per year.

3.9 MULTIHAZARD TESTING AND SIMULATION

To date, PBSE development has focused primarily on the effects of ground shaking on structures, and to a somewhat lesser extent, on the effects of ground failure such as liquefaction and lateral spreading. Historically, however, significant earthquake losses have occurred as a result of earthquake-induced fire. Fire was a significant cause of loss in the 1906 San Francisco, 1923 Kanto, 1989 Loma Prieta and 1995 Kobe earthquakes, yet PBSE has essentially neglected this facet of earthquake performance. NIST, with its extensive capabilities in fire engineering is ideally suited to extend PBSE into consideration of post-earthquake fire related performance. Further, this area of study will relate directly to the post-Sept 11, 2001 studies NIST is planning to perform in the area of fire and blast-related structural behavior.

From the standpoint of PBSE, there are currently no ties between the prediction of structural performance and the performance of non-structural components that may lead either to the development of fires or to a decrease in the fire-fighting and fire-resistance capabilities of a

structure. NIST is in the enviable position of having unique structural and fire testing facilities and capabilities. These facilities can be coupled with the new NEES test sites to develop new testing and simulation techniques to address this multi-hazard mitigation.
Since only limited research has been conducted in this area, a very large level of effort would be required to develop effective performance-based engineering capability in this area. Initial estimates of probable costs for such a program are on the order of $5,000k over a 5-year period.

3.10 Workshop Discussion

Following presentation of these potential work areas at the ATC-57 Workshop, a breakout session was held to discuss these recommendations, and to attempt to prioritize the recommendations. As part of this process a straw poll was taken in which each of the breakout session participants was requested to select those three activity areas that each participant felt were both most important to accomplish and also most compatible with NIST's capability and organizational mission. Participants were not asked to rank the three items each selected, but rather, to identify those three items they deemed most important and relevant. Not all participants selected a full set of three recommended areas. Table 1-1 presents a prioritized summary of this straw voting.

Table 1-1. Summary of Straw Vote Prioritization

Recommended Work Area	**Votes**
Develop Standardized Performance Levels and Measures	9
Develop Performance Standards for Nonstructural Components	7
Provide Performance Qualification for Nonstructural Components	7
Develop Databases of Standard Element Models	5
Develop Post-earthquake Fire PBE Capability	5
Develop Standardized Ground Motion Suites	4
Maintain Databases of Structural Element Hysteretic Performance	4
Develop Damage-simulation Capability	3
Sensor Development and Calibration	0
Qualification of New Materials and Systems	0

As review of the table indicates nearly all attendees indicated strong support for work involving the development of standardized performance levels and measures. Session discussion indicated that this support extends from the common belief that current performance measures are inadequate, the belief that standardized performance measures are essential to the implementation of PBSE and the belief that this work is highly compatible with NIST's capabilities and basic mission. While no attendee specifically included as their top items of interest the development and calibration of sensor capability, development of this capability could be an essential ingredient in any overall program of developing and ensuring the usefulness of meaningful performance measures and should be considered an integral part of this strongly recommended area of work.

The breakout session also indicated strong support for work related to the development of standard performance evaluation protocols for nonstructural components and also the establishment of a national nonstructural component performance qualification laboratory. Each of the proponents for these work areas indicated that they felt development of performance data for nonstructural components had lagged far behind that for structural components, that these data were essential to the implementation of performance-based engineering, that this work was highly compatible with NIST's capabilities and mission, and that no other identified party was likely to perform this work if NIST did not.

3.11 SUMMARY

PBSE is a rapidly developing field that requires the development of methods of performance measurement, systems and methodologies to reliably predict performance in future events, standardized libraries of structural analysis elements and ground motions that may be used to simulate the performance of structures, calibration of these tools to the actual behavior experienced by real structures, the development of new damage-control and damage tolerant technologies, and the extension of PBSE concepts to include consideration of post-earthquake fire effects. Working together with the other NEHRP agencies, as well as private industry and universities, NIST can play a key role in the development, dissemination and implementation of these PBSE technologies. Based on discussions held at the ATC-57 Workshop, it appears that NIST could be most productive and supportive of overall NEHRP efforts in this area by assisting in the development and maintenance of standardized performance measures, and by providing a standard national performance qualification capability for nonstructural components.

APPENDIX 4
Issue Paper 4:
Development of Technical Resources and Associated Problem-Focused Research for Improved Seismic Engineering Practice

by
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4.1 INTRODUCTION

Within the typical seismic design office, which may range in size from as few as one person to several hundred or more persons, the pressures of economic competitiveness drastically reduce, if not eliminate, the time and funds available to develop new technologies and information to improve seismic engineering practices. Officials having the responsibility to regulate design and construction to protect the public safety have similar time and budget constraints. To obtain new knowledge to advance the way they practice and regulate seismic design, design practitioners (industry) and regulators depend on research and professional organizations to develop new technologies and prepare associated practice guidelines, manuals of design, and other technical resources for implementation.

This issue paper seeks to establish the rationale and basis for a successful and ongoing industry-driven program for the development of technical resources to advance seismic engineering practices and for the conduct of associated problem-focused research. High on the priority list of needed technical resources are tutorials, primers, code commentaries, guidelines, and manuals of design for a wide variety of building and lifeline structure types, structural and nonstructural components, loading conditions and hazard mitigation topics, including seismic design, seismic rehabilitation, earthquake damage prediction, and the repair of earthquake damaged structures. When written by professional organizations to incorporate an appropriately broad consensus of engineering opinion and state-of-the-art research and practice information, technical resource documents provide a consistent and acceptable means for practicing engineers and regulators to reduce earthquake hazards and to stay abreast of and use current information and technology, including applicable research results. Such documents can also serve as resources to code development bodies and provide an essential means for transferring research results into practice. The proposed program element considers and recognizes the roles of the other National Earthquake Hazard Reduction Program (NEHRP) agencies to support the development of technical resources for the improvement of seismic engineering practices: (1) the NSF role to fund studies to advance fundamental knowledge in earthquake engineering, earth sciences processes, and societal preparedness and response to earthquakes, which is carried out in large part by the three NSF-funded earthquake engineering research centers (MAE, the Mid-American Earthquake Engineering Research Center; MCEER, the Multidisciplinary Center for Earthquake Engineering Research; and PEER, the Pacific Earthquake Engineering Research Center); (2) FEMA's role to develop tools to improve seismic engineering practices, including model code provisions for the seismic design of new buildings and guidelines and standards of practice for the seismic evaluation and rehabilitation of existing buildings; (3) NIST's limited program of problem-focused research and development in earthquake engineering aimed at improving building codes and standards for both new and existing construction, and advancing seismic practices for structures and lifelines; and (4) the USGS program to monitor earthquakes, assess seismic hazards for the Nation, and conduct research on the basic earth science processes controlling earthquake occurrence and effects. Of special relevance to the NIST program of

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technical resources development and associated problem-focused research is the highly successful FEMA program to develop guidelines, model code provisions, code commentaries, practice handbooks, and other technical resources.

FEMA's Program to Develop Improved Seismic Engineering Practices for Buildings and Lifeline Structures. Since the mid 1980s the Federal Emergency Management Agency has carried out a highly successful program in guidelines and manuals development aimed at improving seismic codes for new buildings and creating a family of seismic evaluation and rehabilitation guidelines and standards of practice for use on existing buildings. Products from the FEMA program, known as the "yellow-book series", have been broadly accepted by the seismic engineering profession and model code development bodies because of the extensive involvement in their development by leading design professions, researchers, and regulators. FEMA-funded publications in the yellow-book series include: (1) the *NEHRP Recommended Provisions for the Seismic Design of New Buildings and Other Structures* (FEMA 368 and FEMA 369), which have been updated every three years since their initial publication in 1985, (2) a manual for *Reducing the Risks of Nonstructural Earthquake Damage* (FEMA 74), (3) the first and second editions of FEMA 154, *Rapid Screening of Buildings for Potential Seismic Hazards: A Handbook*; (4) the *NEHRP Handbook for the Seismic Evaluation of Buildings* (FEMA 178), and its successor document, *Pre-standard for the Seismic Evaluation of Buildings* (FEMA 310), (5) the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273), and its successor document, the *Pre-standard and Commentary for the Seismic Rehabilitation of Buildings* (FEMA 356); (6) procedures for the *Evaluation and Repair of Earthquake Damaged Concrete-Wall and Masonry-Wall Buildings* (FEMA 306, FEMA 307 and FEMA 308), (7) *An Action Plan for Performance Based Seismic Design* (FEMA 349), which defines a major, multi-year effort to produce the next generation of performance based seismic design guidelines for new and existing buildings; and (8) *Recommended Seismic Design Criteria for Steel Moment Frame Buildings* (FEMA 350, FEMA 351, FEMA 352, and FEMA 353), which are the culmination products of a $12 million FEMA-funded research and development effort carried out by the SAC Joint Venture[3] after the discovery of fractures in beam-column joints of steel moment frame buildings shaken by the 1994 Northridge, California, earthquake. Other ongoing or recently completed FEMA-funded projects to improve seismic engineering practices include (1) an ongoing project to resolve discrepancies between the two primary inelastic analysis procedures currently recommended for use in seismic rehabilitation of buildings (ATC-55 project); (2) the development of a Commentary for the seismic provisions of the *International Building Code*; and (3) a compendium of design examples using the 1997 *Uniform Building Code*, the 2000 *International Building Code*, and the 2000 *NEHRP Recommended Provisions for the Seismic Design of New Buildings and Other Structures*.

FEMA has also sponsored the American Lifelines Alliance, whose current partners include the Federal Highway Administration and Pacific Gas and Electric Company, to conduct a limited program of guidelines and standards development projects for lifeline structures and systems.

4.2 PROPOSED PROGRAM TO DEVELOP TECHNICAL RESOURCES AND CONDUCT ASSOCIATED PROBLEM-FOCUSED RESEARCH FOR IMPROVED SEISMIC ENGINEERING PRACTICES

The proposed program element is intended to (1) build NIST's current responsibilities for the conduct of problem-focused research and development in earthquake engineering, and (2) complement the existing highly successful FEMA effort to develop guidelines, handbooks, standards of practice, and other technical resources for reducing the seismic hazards of new and

[3] SAC Joint Venture is a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering.

existing buildings. The program element encompasses the broad range of buildings and lifelines needed by today's society, including existing structures and newly designed structures. The sub-elements include:

1. The systematic identification of needed technical resources,
2. Problem-focused research to advance the state of knowledge relating to needed seismic engineering technical resources, and
3. Systematic development of needed guidelines, manuals, and other technical resources for advancing seismic engineering practices.

A systematic and broadly based program is required in order to encompass the wide diversity in building and lifeline types and components possible in today's built environment. A large portion of the existing stock of buildings nationwide, for example, has been characterized as comprising at least 15 different types of lateral-force resisting systems, and within these types there is wide variation in the number of stories, in plan dimensions and shape, and in the strength and stiffness of key building elements (e.g., floor and roof diaphragms). There are also a vast number of buildings with mixed construction. In addition, most buildings contain nonstructural components, including heating, ventilation, and air conditioning equipment, cladding, suspended ceilings, and wall partitions, which have their own response characteristics, and in some cases, may affect the overall response of the building to earthquake-induced ground shaking. Lifeline structures are even more varied, consisting of transportation structures (e.g., overpass bridges, long-span bridges, highways, railroads, ports and harbors), water storage, treatment, and distribution systems (e.g., dams, pipelines, treatment equipment, tanks), power-generation systems (plants, pipelines, tanks, transmission towers, substations), and communication systems (towers, substations, distribution lines). While many of these structural systems have common earthquake resisting attributes, the wide variation in systems and structural properties requires research and development efforts that are focused on specific structure types, and in some cases, families of structure types with common attributes.

Sub-Element 1: Identification of Needed Technical Resources. It is envisioned that research and development topics undertaken as part of this program element would be selected in one of three ways: (1) by a process involving input and prioritization of potential topics by representatives of the design and construction industry, gathered in a workshop setting, perhaps on an annual basis, (2) by NIST staff based on programmatic decisions; or (3) from unsolicited proposals submitted to the program by external private-sector organizations. Criteria for funding would include:

- Demonstrated need and feasibility, including the identification of the specific technical resource (e.g., guideline or manual) that will ultimately be produced by NIST or FEMA;
- Project technical approach, including laboratory equipment to be used (in the case of a research proposal) and approach for obtaining broadly based engineering input (in the case of technical resource development proposals);
- Overall project management;
- Quality control procedures; and
- Relevant expertise of the project development team.

Sub-Element 2: Problem-Focused Research. Problem-focused research conducted under this sub-element will support the development of guidelines, manuals, and other technical resources to advance seismic engineering practices for buildings and lifeline systems. A model for the problem-focused research is the research portion of the FEMA-funded SAC Steel Project to develop seismic design guidelines for the evaluation, repair, or upgrade of existing steel moment-frame buildings and the design of new steel moment-frame buildings (FEMA 350, 351, 352, and 353 reports). Research conducted under this program may be motivated by observations of the performance of building and lifeline structures during severe earthquake-induced ground shaking, as was the case for the SAC Steel Project, or otherwise recommended by researchers or practitioners with a specific technical resource in mind (e.g., specific guideline or manual). The intent is not to duplicate the NSF research program, but rather to develop specific problem-focused research information for those who develop guidelines, manuals and other technical resources for advancing seismic engineering practices. Given NIST's current mission, staff expertise, and facilities, a portion of the research conducted under this sub-element will likely include, but is not limited to, the following technologies:

1. Advanced construction technologies, including high performance materials, structural control and smart systems, and innovative connections and systems.
2. Remote sensing and non-destructive evaluation technologies for damage and facility-condition assessments and intelligent health monitoring, including smart sensors, sensor arrays, field sensor data integration, and wireless communications.

Other research topics will likely be identified by representatives of the design and construction industry in priority-setting workshops and by those who submit unsolicited suggestions or proposals (see discussion above on process for project identification). It is envisioned that the problem-focused research would be conducted internally by NIST staff, or externally by other organizations funded by NIST support.

Sub-Element 3: Development of Technical Resources. The technical resources development process will necessarily include the review of current standards of practice; and the synthesis and reformatting of available research information from NIST-funded investigations as well as other sources (e.g., NSF, or international efforts). The NIST program for this sub-element will focus largely on lifelines and will compliment the similar effort already being carried out by FEMA to reduce the seismic hazards of new and existing buildings and certain lifelines. Constant communication between NIST and FEMA will be needed to eliminate any duplication of effort. The associated problem-focused research to support technical resources development of both FEMA and NIST will be conducted under Sub-Element 2, as described above.
Examples of needed technical resources include: tutorials; primers; design guidelines for different structure types and different audiences (ranging from engineers to construction inspectors); manuals of design (for existing as well as new codes and standards); code commentaries; technical guidance for contractors and the building trades; synthesis efforts involving the review of research results and the state of practice; and critiques and reviews of existing hazard mitigation approaches and information, including construction details, to uncover the positive and negative implications of their use in seismic hazard mitigation. Care must be taken not to conduct projects that are already being carried out by private-sector associations, but important evaluations of such efforts may be necessary in order to reduce the impact of commercial interests intended to elevate the economic viability of one product over that of a competitor.
Following is a proposed delineation of technical resources to be developed by NIST and by FEMA. The list of needed technical resources to be developed by FEMA recognizes the ongoing efforts by FEMA to address lifelines through the American Lifeline Alliance (ALA), including projects in the short-range plan of ALA. Needed problem-focused research to provide the technical basis for information included in FEMA-funded technical resources would be carried out under the NIST program.

<u>Examples of Technical Resources to be Developed/Supported by NIST</u>: (1) guidelines and manuals for seismic design of new municipal landfills; (2) updating of existing guidelines for the

seismic design of new and the upgrade of existing petrochemical facilities, including guidance on collateral hazards; (3) updating of existing guidelines for the seismic design of oil and natural gas pipeline systems; (4) guidelines for the seismic design of fossil fuel power plants; (5) updating of existing guidelines for the seismic design and upgrade of port and harbor facilities; (6) development of a post-earthquake damage database for lifeline components and systems (ongoing activity); and (7) synthesis efforts to review existing research and practice relating to the seismic design and seismic rehabilitation of lifelines.

Examples of Technical Resources to be Developed/Supported by FEMA: (1) a technical resource defining the seismic capacities of existing nonductile concrete frame buildings and the prevalence of this construction type nationwide; (2) guidelines and manuals for the seismic design of pre-cast concrete buildings; (3) guidelines for consideration of inter-story drift in the design and assessment of equipment and nonstructural component anchorage; (4) seismic reliability guidelines for wastewater, electric power, natural gas pipelines, telecommunication, highways, commuter rail, and ports and harbors (planned ALA projects); (5) seismic design guidelines for water and wastewater pipelines (ongoing ALA project); (6) seismic vulnerability assessment guidelines for oil and gas pipeline systems (planned ALA project); (7) seismic load and design guidelines for electric power transmission towers and poles and distribution poles (planned ALA project); and (8) seismic load and design guidelines for telecommunication poles and towers (planned ALA project).

4.3 Resources Needed

It is envisioned that the proposed program for development of technical resources and the conduct of associated problem-focused research for improved seismic engineering practices would be carried out by NIST technical staff as well as other organizations supported by NIST. The resources needed to prepare comprehensive technical resources and to conduct needed associated problem-focused research are dependent upon a variety of factors, including: (1) the complexity of the topic being addressed; and (2) the level of research and development required to resolve key issues for which research or practice information is not otherwise available. The needed resources include:

- Personnel
- Information
- Funding

Table 4-1 identifies resources needed for a 5-year effort to develop technical resources and associated problem-focused research to improve seismic engineering practices.

4.4 Feasibility of Developing Technical Resources and Conducting Associated Problem-Focused Research for Improved Seismic Engineering Practices

The feasibility of developing needed technical resources and conducting associated problem-focused research for improved seismic engineering practices is deemed to be very high. This conclusion is based on precedence, as exemplified by several recently completed projects, including the FEMA-funded SAC Steel Project described above and the recent development of nationally applicable *Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273), an $8 million FEMA-funded effort completed in 1997 by a broadly based development team organized by the Applied Technology Council, the Building Seismic Safety Council, and the American Society of Civil Engineers. While no new research was carried out in support of FEMA 273, the

Table 4-1. Five-Year Effort to Develop Technical Resources and Associated Problem-Focused Research Projects

Topic	Level of Complexity	Requirements			
		Personnel	Information	Cost	Time
Problem-Focused Research Projects					
Identification of the seismic capacities of existing nonductile concrete frame buildings and the number and distribution of such buildings nationwide*	High	Practicing and research engineers; building officials; technical support personnel; project manager	Building inventory data on a regional basis; seismic design criteria; research data on seismic capacity;	$500,000	2 years
Testing and evaluation of use of carbon fiber for rehabilitation of buildings* and lifelines	High	Research engineers, technical support personnel; project manager	Justification and description of needed technical resource; existing research information	$300,000	2 years
Research on innovative connections and systems for buildings*	High	Research engineers, technical support personnel; project manager	Justification and description of needed technical resource; existing research information	$1,000,000	3 years
Research on advanced technologies (e.g., remote sensing, ground penetrating radar) for damage assessment of buried lifelines	High	Research engineers, technical support personnel; pipeline operators; pipeline regulators; project managers	Justification and description of needed technical resource; existing research information	$500,000	3 years
Development of postearthquake damage database for lifeline components and systems	High	Research engineers; performance evaluation and modeling specialists; data archiver; project manager	Resource for research community developing damage and fragility models for lifeline systems	$250,000 initially; $25,000 each year afterwards	Ongoing

*Technical resource defining needed actions or engineering guidance to be developed later by FEMA.

Table 4-1. Proposed 5-Year Program of NIST-Funded Technical Resource Development and Associated Problem-Focused Research Projects (Continued)

Topic	Level of Complexity	Requirements			
		Personnel	Information	Cost	Time
Technical Resource Development Projects					
Guidelines for the seismic design of fossil fuel power plants	High	Practicing and research engineers; fossil fuel power plant operators; power plant regulators; project manager	Past studies on fossil fuel power plant performance, evaluation criteria; current standards or criteria for seismic performance	$2,000,000	3 years
Guidelines for the seismic design of oil and gas pipeline systems	High	Practicing and research engineers; pipeline operators; pipeline manufacturers; pipeline regulators; project manager	Characterization of seismic hazards, service criteria, seismic response of piping, equipment, tanks, post-earthquake emergency planning	$400,000	2 years
Guidelines for the seismic design and upgrade of port and harbor facilities	High	Practicing and research engineers; port facility operators; port regulators; project manager	Characterization of seismic and geotechnical hazards; performance criteria; seismic response of water-front structures and cargo handling and storage facilities, post-earthquake emergency planning	$500,000	2 years
Guidelines for the seismic design of new municipal landfills	Moderate	Geotechnical and environmental engineers; project manager	Geotechnical information	$300,000	2 years

overall developmental effort included a focused task to summarize for the guidelines development team all available pertinent research data.

The existing personnel pool of U. S. practicing engineers, research engineers, regulatory personnel, and other required personnel, including earth science and public policy specialists, is more than sufficient for a broad program to develop technical resources and to conduct associated problem-focused research for improving seismic engineering practices. Similarly, the existing archive of NEHRP-funded research data generated during the last 25 years can be expected to serve as a major resource of information. Equally important is the potential for useful research information expected from the existing NSF-funded centers for earthquake engineering research (MAE, MCEER, and PEER) and other major new advanced technology research programs in earthquake engineering, including the USGS-funded Advanced National Seismic System and the NSF-funded George E. Brown National Earthquake Engineering Simulation Collaboratory.

Critical to the success of the proposed program for development of technical resources is the concurrent execution of as-needed problem-focused research to resolve key issues pertinent to the technical resource (e.g., guideline or manual) under consideration. Because the NEHRP agency functions do not currently include an established mechanism to carry out problem-focused research and while there is considerable programmatically focused research in the NSF-funded centers, a strong needs-driven problem-focused research program is seen as one of the major achievements to be gained from the successful establishment of the overall proposed industry roadmap described in this and other related issue papers.

Another feasibility issue relates to the need for state-of-practice reviews as an integral part of the technical resource development process. Numerous prior efforts to conduct state-of-practice reviews have demonstrated the profession's clear willingness to provide open, comprehensive information about current methods and procedures used in their daily practices. No barriers are foreseen on this aspect of the developmental process.

4.5 Benefits of the Proposed Program Element

The benefits from the proposed program for "Development of Technical Resources and the Conduct of Associated Problem-Focused Research to Improve Seismic Engineering Practices" are varied and significant. The benefits include:

1. The proposed program and the complimentary FEMA implementation program would serve collectively as high-visibility NEHRP efforts for comprehensive, systematic research utilization. This is a benefit that will be favorably received by the U. S. Congress, which has consistently advocated the implementation of research results.
2. Seismic engineering practices would be improved through the continued development and use of state-of-the-art technical resources (e.g., guidelines and manuals), which would provide consistency, standardization, new technology, and new methods for use in mitigating the effects of earthquakes.
3. New high-level knowledge would be made available to the larger community of practicing seismic engineers, increasing their capabilities and broadening the nation's overall capability for reducing seismic hazards.
4. Technical resources would be made available to make the nation's inventory of buildings and infrastructure more resilient to the effects of earthquakes, saving lives and property for generations to come.

APPENDIX 5
Issue Paper 5:
Technology Transfer Mechanisms and Programs

by

Edwin T. Dean, S.E.[1] and James M. Delahay, P.E.[2]

5.1 INTRODUCTION

Advances in seismic engineering have occurred through lessons learned after every damaging earthquake and through the dedication of individuals and institutions to develop technology to advance the state of knowledge and reduce the damaging affects of earthquakes on the built environment. Ever continuing losses after significant earthquakes demonstrate that there is still much to learn and many engineering advancements yet to achieve. Seismic engineering, as a defined practice, has had a relatively short history. Technical innovation in seismic engineering is driven by the ingenuity of individual practitioners, creative research by members of academia, and through the support and technical guidance of government.

A key strategy in advancing the state of the art in seismic engineering is effective technology transfer. In order to truly change the way structures are built to withstand earthquakes, the knowledge gained during seismic events and through research must be placed in the hands of the practitioners who are actually designing them. In this way, future losses of life and property can be avoided through the improvement of the design process. The mechanisms of this technology transfer must consider the participants in the process and be structured in a way that best fits that group and also takes into consideration the industry's needs.

In the past, the National Institute of Standards and Technology (NIST) has not been focused on putting seismic engineering research into practice. In order to be effective in implementing technology transfer, NIST must create a technology transfer program to accomplish this missing program element. A research plan that is driven by a problem-focused program is required to promote a technology transfer agenda. Research for the sake of knowledge will not necessarily translate into meaningful technology that can be directly utilized in general practice. To this end, a technology transfer master plan needs to be established to enable the strategic implementation of needed technology to the general practice of seismic engineering.

Four groups in our society play key roles in shaping, promoting, and implementing the use and development of technology in our profession. These groups are:

- Private sector
- Academia
- Government
- Collaborative organizations

Individually each group fosters different incentives for advancing seismic engineering technology. Collectively all of these groups, as does society at large, benefit through technological advancements.

The private sector is comprised of the owners, designers, consultants, builders and occupants/users. The underlying fabric of the private sector is economic and the private sector garners many economic benefits through the implementation of new technologies.

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Academia is the universities, colleges and individual researchers who educate and develop new knowledge through science and applied research. Academic research is fundamental to shaping new technology and fulfilling their roles as educators and a depository of knowledge.

Government, primarily at the state and federal levels, plays both a regulatory role in standardizing and codifying technology as well as promoting technology to protect the public welfare. Government has the financial resources and mandate to fund basic research, mitigate the hazards posed by earthquakes and provide emergency response after earthquakes. Local governments also take on the role of regulators, but in the form of the local community building officials who must enforce the building code requirements that often develop from the new technology.

Collaborative organizations are the professional and technical societies, trade groups and not-for-profit organizations that work as objective, consensus networks advancing technological development. Collaborative organizations provide the vehicle for the effective synthesis and distribution of technology from research into practice –- *technology transfer*.

Each group plays a role and shares in their responsibility in advancing the progress of technical innovation. The challenge of moving technical innovation in seismic engineering into the mainstream professional practice where its implementation can be brought to the betterment of design and construction of buildings and lifelines requires a focused effort of all of these groups. From this coordinated, goal oriented, cooperative effort, even greater progress in seismic engineering design can be achieved in the future. This is the aim of technology transfer. Technological innovation that is shaped by research, promoted by government and implemented by the private sector is synthesized through the collaborative organizations. This paper explores the mechanisms that allow for the transfer of technology from research to practice and the programs necessary to turn ideas into reality.

5.2 OBJECTIVE

The objective of technology transfer is the continual implementation of innovative or improved technologies into the practice of seismic engineering design and construction. Technology in this light is the practical application of knowledge to reduce the damaging effects of earthquakes on the built environment. The presentation of this knowledge can take various forms; publication of guidelines, codes and standards; forums, workshops and seminars; college coursework; case studies and easily accessible databases or other repositories of information. The reduction in the damaging effects of earthquakes though the implementation of advanced technology results in direct and indirect social and economic benefits.

Moderate earthquakes in the United States in 1989 in San Francisco[3] and 1994 in Los Angeles[4], California and less damaging but more recent event in 2001 in Seattle[5], Washington illustrate the damaging risks that are present in areas threatened by earthquake ground motions. These areas are by no means limited to the western United States. Great historic earthquakes have occurred in the central U.S. in the New Madrid[6] region near St. Louis, Missouri and Memphis, Tennessee and on the East Coast in Charleston[7], South Carolina, while a small event was recorded recently on April 20, 2002 near Buffalo[8], New York. Direct economic damage from these events is measured

[3] Loma Prieta, October 17, 1989 Magnitude (M) 6.9, Modified Mercalli Intensity (MMI) IX
[4] Northridge, January 7, 1994, M6.8, MMI VII
[5] Nisqually, February 28, 2001, M6.8
[6] New Madrid tri-events, MMI XI: December 16, 1811, , M_r 7.5; January 23, 1812, M_r 7.3; and February 7, 1812, M_r 7.8;
[7] Charleston, August 31, 1886, MMI X
[8] Plattsburgh, April 20, 2002, M5.1

in the billions of dollars. Estimates for the San Francisco, Los Angeles and Seattle events are over $6, $20 and $3.5 billion, respectively. Actual costs far exceed these values since losses due to business interruption or business failures, lost wages, lost economic opportunities such as retail sales, tourism and the cost to families seeking temporary shelter, not to mention the loss of lives, are not included in these dollar estimates. The value in implementing innovative or improved technologies into the practice of seismic engineering design and construction is measured against a reduction in the staggering losses that will result from the damaging effects of earthquakes in many parts of the United States in the future. Better design, construction or greater financial investment in the implementation of these technologies is the best, most practical means to protect and mitigate future losses.

Effective technology transfer mechanisms draw upon the strongest industry resources to create applications that readily fulfill broadly recognized design and construction needs. These applications are synthesized through a consensus process that reviews their applicability, economic and technical viability and promotes their acceptance and use.

5.3 RESOURCES

Technology transfer is accomplished where specific needs or limitations in current technology are identified and the best resources are targeted to be brought to the challenge of bringing applicable research into practice to address these needs. The process is continuous and dynamic, adjusting to ongoing changes in priorities, earthquake events and funding availability. Resources are drawn from the four groups that play the most significant roles in shaping the development of technology. From these resources, the researchers and practitioners are drawn together to meld the latest research guided by the practical application of this knowledge in a consensus process under a collaborative organization promoted and funded by government.

It is paramount that the participants are drawn from the best available experts in the particular field or aspect being explored. Because often times there are great demands on the most qualified experts, one means of securing their sage input, provide guidance and overview to the project, and recognize the limited time they have available to participate is to formulate a process that has two levels. The highest level is comprised of the senior advisors who have roles ranging from steering or guiding the selection and development of the process to one that provides critical oversight and comprehensive reviews at critical milestones. Experienced researchers and practitioners who have greater availability to provide focused time and effort to the project and its development then carry out the production and day-to-day development of the technology resources. An organization or individual who has responsibility and accountability for the control of the funds, the quality execution of the work and the timely delivery of work product at the scheduled milestones conducts the program's management. This arrangement allows for a process that balances experience and oversight with availability and responsiveness in a well-organized consensus process. There also needs to be an inherent objective separation between the group responsible for oversight and the group producing the application, fostering a healthy environment for critical objectivity. Folded into this mix is a direct and deliberate effort to promote diversity. The participants are drawn from broad base of professional experience levels and backgrounds, regions of the United States and areas of expertise. Technology transfer is best accomplished where clear objectives have been defined and the best available, complementary, resources are secured and promoted through funding in a collaborative consensus process.

Collaborative organizations provide the means to secure consensus and input from a diverse section of the stakeholder community and provide a forum to transmit the technological applications into practice. The many professional, technical, trade and not-for-profit organizations hold this role as a major part of their mandates and commit significant resources to fulfilling this effort.

Technology transfer is best accomplished by drawing together the broad groups and individuals who can identify the community needs and define clear objectives and priorities to achieve the timely development of applications. Integrating into this process the many stakeholders through collaborative organizations builds consensus, acceptance and a means to introduce and implement the technologies into common practice.

5.4 PROGRAM MODEL

A clear recognition of the technological needs and a focused resolve to develop problem-solving applications is the over-arching engine driving technical innovation and improvement. Critical areas demanding new technological innovation or improvement must be developed and defined through an inclusive strategic planning process that defines clear needs, goals and priorities. The final product should be defined at the start, and should be framed around the technology transfer plan. The end user should be defined, as that will influence the form of the final product. For example, the product will be different if the end user is the code development community versus practicing engineers. The stakeholders, the key groups shaping, promoting and implementing the use of seismic engineering technology will use this strategically focused agenda to guide their efforts to define technology transfer programs. The project organizational model for technology transfer must be defined to establish the process through which the effort will operate.

Financial support fuels the ability to obtain the most qualified individuals to participate and focus on the development of technical resources and secure its timely completion. Volunteer efforts play a great role in our industry; however, they are sometimes limited by the number of individuals that can be drawn into that arrangement as well as by the timeframe in which documents are developed. A wonderful blending of the funded and volunteer effort occurs when the participants in the process leverage their time. This leverage occurs when the participants work at lower rates than are usual and customary in their day-to-day practice, reaping the benefits of the involvement that they have in the development of these documents as a resource in furthering the value of their own research and practice.

While support can come from many sources, the government institutions are the primary organizations that maintain funding levels adequate for meaningful technological development. It is essential that government provide this support, since technological progress will likely receive little investment if left to private sector incentives alone. Government initiative and funding matched by individual contributions of time and effort underwritten by the longstanding culture in the professional and academic communities of promoting public welfare all coalesce to create an environment that readily promotes and leverages the advancement of engineering technologies.

A structured organizational model (Figure 3-1) must promote the effective transfer of technology yet is accountable to both the fiscal and technology objectives. It must be emphasized that this is a project organizational model. Applied Technology Council and other organizations in the past have used such project-specific models.

This model organizes the project participants to define both technical and fiscal accountability. Some key attributes of this organizational model are:

- Overall project responsibility lies with the Project Executive.
- The Project Manager ensures technical quality and budget fidelity.
- The Senior Review Committee provides general guidance on the technical direction and monitors and approves the technical content of the project.

- The Project Team is comprised of the best available experienced Practitioners and Researchers resources in the field that a project encompasses.

This model has proven to be successful. The SAC Steel Project and the development of FEMA 273 have both operated under a similar arrangement and have been tremendously successful.

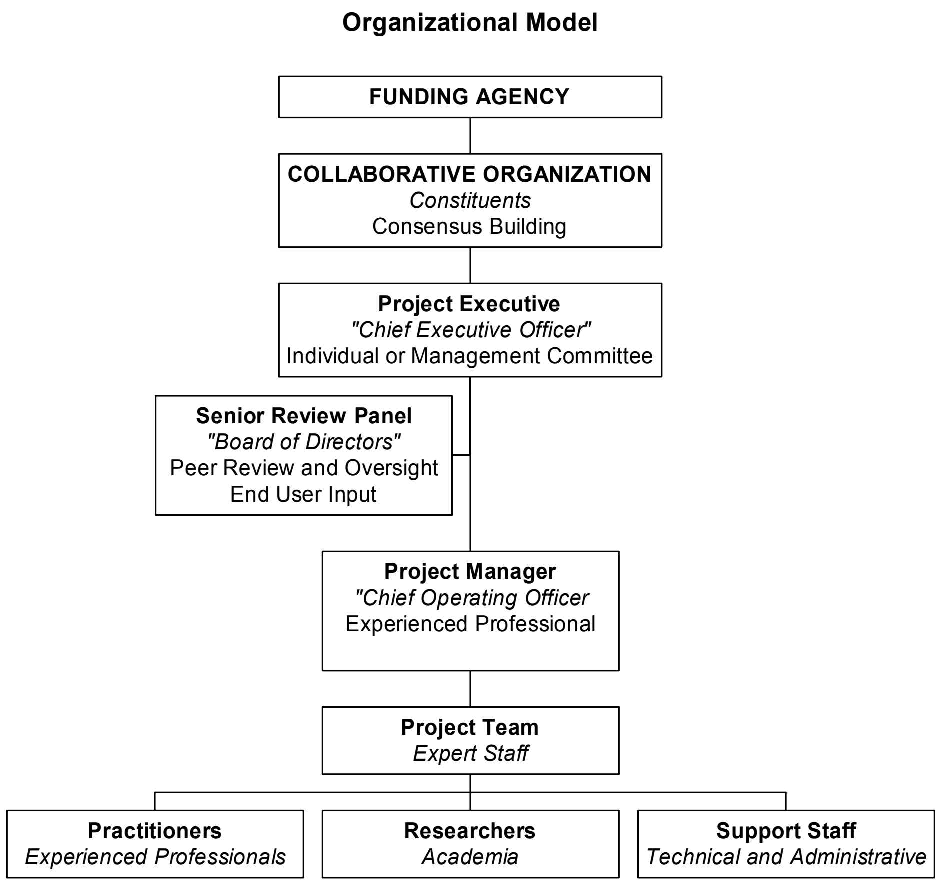

Figure 3-1. Project Organizational Model; flexible, will vary with project goals and organizational structure of the Collaborative Organization

5.5 BENEFITS

There are many incentives to the development and promotion of technical innovation. The benefits to aggressive promotion of technology transfer are many and the resulting technical innovation to reduce the damaging effects of earthquakes on the built environment has even broader socio-economic benefits. The devastation that results after a major earthquake and the loss of buildings and other infrastructures, businesses and the jobs they support, are much more costly than the investment in technical innovation to mitigate these potential losses.

Fortunately, history has shown that frequency of major earthquake events has been low. This however, manifests itself in a false sense of complacency. The continual progress of technology transfer in seismic engineering has the benefit of continuously educating professionals and other members of the affected community. It is only a matter of time until a major seismic event occurs in a highly populated metropolitan area causing extreme damage. Vigilance on the part of the professionals involved in seismic engineering is the first line of defense against an ever-increasing risk.

While much of the technology transfer resources are directed at design professionals, there are a great number of opportunities to transfer technology directly to the construction industry, building officials and their inspectors, and to the general public at large. There is no inherent limit to the benefits that may be realized as technical innovations are transferred. Technical innovations take many forms, from design guide resources, to guidelines used in construction, to improvements in building code provisions.

The greatest benefit will be the most difficult to measure -- unrealized losses resulting from improvements in construction arising from improved seismic design and construction practices. The process is slow and not uniformly applied, with much of current seismic design practice occurring in the western United States where there is the greatest perceived risk. The existing building inventory does not benefit unless the buildings and other structures are strengthened. The amount of existing construction that is rehabilitated each year is small compared to the amount of new construction. Some of the greatest technological advantages are lost when design professionals fail to integrate sound seismic engineering technologies into new construction. Technology transfer programs need to be flexible enough to reach out to the broad community of design professionals and their clients and demonstrate the value of the economic investment in the application of seismic resistant construction throughout all areas at risk in the United States.

5.6 CONCLUSION

Our understanding of earthquakes and their effects on the built environment continues to grow and evolve. The practice of seismic engineering advances as applied research and engineering practice embrace improved technologies. The process of moving technology from research into practice in any comprehensive way requires the influence of government and cooperation of the many individuals and organizations that make up the seismic design community working in concert.

The private sector, academia, government and collaborative organizations are groups that all play a role in shaping, promoting and implementing the use and development of technology in our profession. The best individuals from these groups are drawn together to synthesize quality technical resources used to advance the state of practice. These technical resources are integrated into professional practice through an inclusive consensus process that eventually improves the quality of construction and reduces its vulnerability to catastrophic earthquake damage. A sound organizational model will promote the effective transfer of technology in a fiscally and technically accountable arrangement.

All benefit from implementation of innovative or improved technologies into professional practice and into construction.

APPENDIX 6
Issue Paper 6:
Program Management
by
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6.1 INTRODUCTION

The development of an industry roadmap for a NEHRP[3]-funded problem-focused research and development program in earthquake engineering provides the opportunity to chart potentially highly useful programs and products. It will be important to utilize the earthquake community for the continuing evolution of these program topics and in prioritizing them. The National Institute of Standards and Technology (NIST) has indicated that both non-NIST participants (through an external grants program) and NIST personnel will perform these activities. Because the external and internal portions of this program need to be fully coordinated and focused, a management plan that provides strong public/private leadership and accommodates governmental and non-governmental guidance needs to be established.

The following is intended to provide a starting point for the discussion leading to recommendations for an effective managements structure. Nevertheless, regardless of the structure, it must be remembered that individuals in management positions will hold the key to success or failure. We will not be able to select these individuals. For consistency of format this paper is organized in the identical manner as the other issue papers.

6.2 WHAT NEEDS TO BE DONE?

A special NIST management team for this program needs to be established because this will be a coupled external and internal NIST program. Although makeup of this team may be constrained by Federal agency policies and procedures, it must have a strong leader and team members with recognized technical skills and management expertise. This team also needs to actively interact with all external and internal participants and others active in the earthquake community.

An independent external review committee for this program needs to be established. The size of the committee and attributes of its members needs to cover the breadth of its responsibilities. The authority and responsibilities of this review committee will depend upon the management structure selected.

A mechanism must be established to provide exchange of information and ideas among all project participants throughout the execution of each project task. To assure quality reporting and evaluation, systems need to be established to assess successful and timely project completions. Participation by the project task investigators, the special NIST management team, external review committee, and the project task sponsors is needed. Authority to terminate unsuccessful tasks must be used.

A mechanism must be established to encourage the contribution of innovative new ideas and concepts for the creation of new goals and or projects from the earthquake community.

6.3 HOW SHOULD IT BE DONE?

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[3] NEHRP is the National Earthquake Hazards Reduction Program

NIST management team - Several management structures should be studied to ascertain the best structure for this program consistent with NIST operations. Four examples are identified below:

1. Consider the FEMA/SAC[4] Steel Moment Frame project. Like NSF[5], FEMA does not have an internal research and development activity and has a limited number of program management personnel. Therefore, they elected to have the SAC Joint Venture create a management team for this problem-focused program. The Joint Venture had a six member Project Management Committee with one representative from each of the joint venture organizations plus the Program Manager, the Project Director for Topical Investigations, and the Project Director for Product Development. This committee identified and prioritized the individual project tasks, selected the task participants, decided on task funding, facilitated inter-task communication, and enforced task deadlines and funding caps. An external Project Oversight Committee of thirteen members from the concerned user community provided input to the overall direction of the project, but not to the management decisions. The additional management substructure may be worthy of further evaluation for use in establishing an effective structure for NIST.
2. Consider the NSF earthquake engineering research center approach. The Center has a Director who is responsible to NSF, the Dean and university administration. Typically there is a Deputy Director and a Management Board with representatives from either technical focus areas or representative institutional members of the Center. They also have an external review committee with members selected from the non-participating earthquake community. They establish topical focus areas and have leaders identified in these areas.
3. Consider the NEES[6] Consortium Management structure. This form has not been established yet, but a major effort is being expended to create an effective structure. By the time this program gets funding the NEES management structure should be available for evaluation.
4. Consider the U.S. Geological Survey (USGS) external grants program. The USGS has had an external grants program for a number of years. The USGS solicits proposals from researchers on an annual basis. For FY 2003 $6 million is available for external grants to be divided among five regions of the United States. USGS publishes a goals document that identifies the research emphasis and priorities for the current proposal solicitation. The program is managed within the USGS and projects are selected using internal and external reviewers.

Independent Review Committee – The responsibilities and necessary authority of this committee are highly dependent upon the selected program management structure. It is important to assure that over zealous management or excessive meddling by the review committee will not subvert the needs and potential contributions of the program. It will be beneficial to spend sufficient time to address these potential problems and devise strategies to mitigate potential problems. The key

[4] FEMA is the Federal Emergency Management Agency and SAC is a joint venture of the Structural Engineers Association of California, the Applied Technology Council, and the California Universities for Research in Earthquake Engineering [now the Consortium of Universities for Research in Earthquake Engineering]

[5] NSF is the National Science Foundation

[6] NEES is the George E. Brown, Jr. Network for Earthquake Engineering Simulation

will be to have knowledgeable, cooperative membership on the management team and the review committee. Without successful cooperation the program will have limited chance of success. After initial appointments, service on the review committee should be staggered to assure necessary historic perspective and continuity of programs.

Some of these responsibilities and their authority could include

1. Recommend the short and long-term goals of the program and relative funding levels,
2. Recommend topical goals, prioritization of these topical goals, and allocation of funds to achieve these goals,
3. Work with NIST management to achieve an equitable distribution of funds to external and internal NIST activities,
4. Recommend projects to be funded, and recommend funding levels for these projects,
5. Review project timeliness and quality of work product

<u>Commitment to Cooperative Efforts</u> – Problem-focused research and development benefits from the synergistic interchange of ideas and information through the project task execution. The FEMA/SAC project, the NSF earthquake centers programs, and the proposed NEES consortium all place emphasis upon multimember and multidisciplinary cooperation. This proved to be vital to the success of the FEMA/SAC program, and those participants became believers in the mutual benefits of this type of cooperation. Although it took a commitment of time and travel by each participant, and a commitment to deliver results on schedule, the benefit was substantial. Teams of participants focused on a common goal should be formed and a respected leader named. Members of the External Review Committee with appropriate expertise should be included on these teams.

<u>Willing Acceptance of Innovative Ideas and Concepts</u> – These are difficult times for individuals willing to share innovative ideas. The US patent Office seems willing to grant patents without doing an independent search of the prior knowledge and use, limiting their search to the referenced sources in the patent application. This results in patents being granted that unnecessarily restrict application of unique concepts in construction. A mechanism needs to be established whereby the originator of an innovative concept can be given credit for the idea, and the concept can be developed through this program to practical application without going through the patent route.

6.4 WHAT MAKES IT POSSIBLE?

NIST is experiencing the same pressure as the other Federal agencies to shrink its technical staff. Although the NIST Building and Fire Research Laboratory has over 15 open positions at the present time, it is not feasible to assign many of these full-time positions to administer this program. By establishing this program management in a structure similar to those discussed above, NIST can provide key leadership and direction without full-time commitment of a large number of key personnel. The use of unique NIST facilities, equipment and personnel as part of the overall research and development program and their active participation in the task teams will enhance their ability to provide the services mandated by Congress to them. The distribution of funding between external and internal NIST activities must depend upon expertise of the personnel and the capabilities of the available facilities.

6.5 WHY SHOULD IT BE DONE?

Because this program is expected to be developed from new funding of problem-focused research and development it is reasonable, and necessary, to utilize the community members to identify appropriate goals and projects. To achieve full community involvement in the identification of problem-focused research and development needs, and participation in tasks to meet these needs, it is necessary for the community to have significant positions in the leadership and management team. Without this strong external participation NIST may not be able to assure the success of this program or garner the needed support from the community.

The proposed management structure will provide credibility to the community that the selected program project tasks are appropriate, that the allocation of the limited financial resources to both external and internal NIST project tasks are appropriate, and that performance criteria and review of all funded project tasks to assure timely, quality research and development results are carried out fairly.

6.6 WORKSHOP RECOMMENDATIONS

It was recognized that current NEHRP funding places emphasis on the basic research programs of the National Science Foundation and the U.S. Geological Survey. New funds for problem-focused and applications research are necessary. It was agreed that this problem-focused research program needs to be user and needs driven. Further, it must include appropriate project and task evaluations and a willingness to terminate projects not achieving the desired goals and individuals not meeting agreed deadlines. That is, it should be run like a business enterprise rather than as an academic program. To achieve community support for and advocacy of this problem-focused research initiative, it is important that the needs of the design and construction community be addressed. On this basis the following recommendations were made:

1. An external review committee be established to assist NIST in identifying long and short-term goals. This includes the identification of problem-focused topical areas and potential projects. This committee should meet at least yearly to provide review of project accomplishments and provide recommendations for future activities and projects. This committee would be funded separately from the funds provided to individual projects. An annual budget estimate of $50,000 is proposed.
2. For each significant multi-year problem-focused research topic, the management structure for that project be similar to the FEMA/SAC Steel Moment Frame project. If more than one topic is active at a given time, more than one project management committee needs to be established. These project management committees should be funded from the project funds.
3. For projects of short duration or of limited complexity, NIST staff should be assigned to provide the necessary project management.
4. The allocation of new problem-focused research funding between internal NIST and external projects was discussed thoroughly. It was concluded that a rigid formula would not be productive and that the External Review Committee should work with NIST to see that the best, and most efficient utilization of the funds be implemented. An initial allocation distribution of 40% internal and 60% external seemed to have consensus support from the Working Group attendees.

APPENDIX 7

PROJECT PARTICIPANTS AND RESUMES

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James E. Beavers, Ph.D., P.E. Dr. James E. Beavers is currently the Visiting Associate Director, External Affairs, College of Engineering, University of Illinois. He served as Deputy Director of the Mid-America Earthquake headquartered at the University of Illinois from 1998 to 2003 and has over 25 years of experience in the earthquake-engineering field. In addition, he has his own company, James E. Beavers Consultants, specializing in structural engineering and natural and technological hazards. Before joining the Mid-America Earthquake Center, he spent 25 years at Oak Ridge, Tennessee, where he held positions of Research Professor, University of Tennessee and Corporate Fellow, Lockheed Martin Energy Systems, Inc. At Oak Ridge he was involved in design, evaluation and research for earthquake and wind effects on buildings and structures, including chemical and nuclear facilities. These latter facilities included the Clinch River Breeder Reactor, High Flux Isotope Research Reactor, Gas Centrifuge Uranium Enrichment Plant, and the Y-12 Weapons Plant. He has testified before the United States Congress on earthquake issues numerous times and has chaired three national/international symposia. He has also chaired more than 10 national committees, served on an additional 40 more and has author/co-author more than 100 papers. He is a founding co-editor-in-chief of the American Society of Civil Engineers' journal *Natural Hazards Review* and was editor-in-chief of the Earthquake Engineering Research Institute's journal *Earthquake Spectra* from 1987 to 1993. Dr. Beavers received his M.S. and Ph.D. degrees in Civil Engineering from Vanderbilt University and his B.S. degree in Civil Engineering from University of Missouri at Rolla. His professional associations include American Concrete Institute, American Society of Civil Engineers, Earthquake Engineering Research Institute, International Society of Explosives Engineers, National Society of Professional Engineers, and Seismological Society of America.

Edwin T. Dean, P.E., S.E. Mr. Dean is a Principal and manager of Nishkian Dean Consulting Structural Engineers in Portland, Oregon. A registered structural engineer, Mr. Dean has been actively practicing in the design of commercial, institutional and residential buildings throughout the western United States for more than 18-years. He is currently a member of the Building Seismic Safety Council Board of Directors, of the National Institute of Building Sciences in Washington, DC, and a past President and Board Member of the Applied Technology Council, Redwood City, California. He has served on the ASCE Project Advisory Committee for the Standardization of the FEMA 273 *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, the FEMA 310 *Handbook for the Seismic Evaluation of Buildings*, as well as a Vice Chair of the ASCE Standards Committee on Seismic Rehabilitation of Buildings. Mr. Dean was appointed by the Governor to serve on the Oregon Seismic Safety Policy Advisory Commission for 4 years. He was born in Sydney, New York. He graduated from University of Washington in 1985 with a Bachelor of Science Degree in Civil Engineering.

James M. Delahay, P.E. As President/CEO of LBYD, Inc., a 40-person consulting structural and civil engineering firm in Birmingham, Alabama, Mr. Delahay has been the structural engineer of record for hundreds of commercial and industrial building projects. He has 22 years of experience in the structural engineering field, holding the position of principal with LBYD for the last 16 years. His design experience includes the engineering of numerous building structures for many commercial and industrial projects throughout the United States, utilizing material types varying from steel, concrete and masonry, to wood and aluminum. Mr. Delahay has been involved in building code development since 1991, representing the Structural Engineer's Association of Alabama (SEAOAL) on the Southern Building Code Congress International's (SBCCI) Wind Load Committee. He has been a member of the American Society of Civil Engineers (ASCE) Committee 7 on Minimum Design Loads For Buildings and Other Structures since 1995, a member of the ASCE 7 Task

Committee on Wind Loads since 1996, and is currently serving as the vice-chairman of that group. From 1999 to the present, Mr. Delahay has served on the Structural Committee of the International Building Code, as one of three practicing engineers representing the National Council of Structural Engineer's Associations (NCSEA). In 2002, he was elected chairman of that committee, the first practicing engineer to hold the position. He is also the chair of the NCSEA Code Advisory Committee, which represents the interests of structural engineers to the Building Code development community. He served on the Board of Assessment of the National Institute of Standards and Technology, Building and Fire Research Laboratory, Structures Division from 1998 to 2001 for the National Research Council of the National Academy of Sciences.

Ronald T. Eguchi. Mr. Eguchi is President and CEO of ImageCat, Inc., a risk management company specializing in the development and use of advanced technologies for risk assessment and reduction. Mr. Eguchi has over 20 years of experience in risk analysis and risk management studies. He has directed major research and application studies in these areas for government agencies and private industry. He currently serves on several Editorial Boards including the *Natural Hazards Review* published by the American Society of Civil Engineers and the Natural Hazards Research and Applications Information Center, University of Colorado, and the *Journal on Uncertainties in Engineering Mechanics* published by Resonance Publications, Inc. He is also a past member of the Editorial Board of the Earthquake Engineering Research Institute's Journal *SPECTRA.* He was recently appointed to a National Research Council panel that prepared a report on "Assessing the Costs of Natural Disasters." In 1997, he was awarded the ASCE C. Martin Duke Award for his contributions to the area of lifeline earthquake engineering. He still remains active in the ASCE Technical Council on Lifeline Earthquake Engineering serving on several committees and having chaired the Council's Executive Committee in 1991. In 1992, Mr. Eguchi was asked to chair a panel, established jointly by the Federal Emergency Management Agency and the National Institute of Standards and Technology, to develop a plan for assembling and adopting seismic design standards for public and private lifelines in the United States. This effort has led to the formation of the American Lifeline Alliance, currently managed by the Multihazard Mitigation Council of the National Institute of Building Sciences. Mr. Eguchi currently serves on MCEER's (Multidisciplinary Center for Earthquake Engineering Research) two Research Committees (one guiding research projects sponsored by the National Science Foundation and one guiding the Federal Highway Administration Project). He is also a charter member of the Mayor's Blue Ribbon Panel for the City of Los Angeles. He has authored over 100 publications, many of them dealing with the seismic risk of utility lifeline systems.

Ronald O. Hamburger, S.E. Mr. Hamburger has nearly 30 years of experience in design, construction, research, evaluation, investigation and repair of commercial, institutional, and industrial facilities. He is an internationally recognized expert in performance-based structural, earthquake and blast engineering, and has played a lead role in the development of national structural engineering standards and building code provisions. He chairs the Building Seismic Safety Council's Provisions Update Committee and a as a member of the Council's Code Resources Support Committee, was active in the formulation of seismic provisions contained in both the International Building Code and the NFPA (National Fire Protection Association) 5000 Construction and Safety Code. Following the September 11, 2001 terrorist attacks in New York, Mr. Hamburger served as the lead investigator into the collapse of New York's twin World Trade Center towers on behalf of the Structural Engineering Institute of the American Society of Civil Engineers and the Federal Emergency Management Agency. Mr. Hamburger has lectured in earthquake engineering at the University of California at Berkley, the University of California at Los Angeles, Stanford University, and numerous other academic institutions and has published nearly 100 papers on structural and earthquake engineering. He is a past President and Fellow of the Structural Engineers Association of California, a past Director and Vice President of the Earthquake Engineering Research Institute, and is currently Vice-President elect of the National Council of Structural Engineers Associations. He is managing Principal of Simpson Gumpertz & Heger's structural engineering operations in San Francisco.

Robert D. Hanson, Ph.D. Dr. Hanson is Professor Emeritus of Civil Engineering, University of Michigan and serves as a consultant for the Federal Emergency Management Agency. He holds a Ph.D. in Civil Engineering from California Institute of Technology, is a registered professional engineer in North Dakota (inactive) and Michigan (current), and is a member of the National Academy of Engineering. His teaching career at the University of Michigan began in 1966 and he served as Chairman of the Department of Civil Engineering from 1976 to 1984. He is a past president of the Earthquake Engineering Research Institute, and served on several National Academy of Engineering research panels. His research interests in earthquake engineering include evaluation of existing buildings for seismic vulnerabilities, design of seismic upgrades to minimize vulnerabilities, evaluation of earthquake damaged buildings, design of repair and seismic upgrade schemes for earthquake damaged buildings, use of supplemental damping systems to enhance the seismic performance, development of new supplemental energy dissipation systems, and development of active control devices for vibration control of buildings using electro-rheological materials. He has participated in over ten post-earthquake field investigations, has over 100 publications, and has received numerous awards, including the ASCE Reece Research Prize, and being made an Honorary Member of the Earthquake Engineering Research Institute (2001) and a Fellow of the American Society of Civil Engineers (1999). In 1996 he received the "Meritorious Service Award" from FEMA.

James R. Harris, P.E., Ph.D. Dr. Harris is a Principal and founder of J.R. Harris & Company, a structural engineering firm in Denver, Colorado. He is a registered engineer in four states (Colorado, California, Missouri, and Ohio) and has designed or evaluated hundreds of structures ranging from dwellings to high-rise buildings, including industrial facilities, long span structures, buildings in the highest seismic zones, excavation bracing, pile and pier foundations, and renovations of historic buildings. His experience includes six years of full-time research, with a focus on the loading and response of structures, particularly earthquake and snow loadings, and on improving the formulation and use of engineering standards. Dr. Harris has written over 25 reports and journal articles on the results of his research and is an active member of several committees in organizations that produce national standards for structural engineering practice, including the American Concrete Institute, the American Institute of Steel Construction, the American Society of Civil Engineers, the Building Seismic Safety Council, and the International Standards Organization. Dr. Harris received his Ph.D. degree in Structures and Foundations from the University of Illinois in 1980, and a Master of Science Degree in Civil Engineering (Structures) and a Bachelor of Science Degree in Civil Engineer (Structures) from the University of Illinois in 1975 and 1968, respectively.

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ACRONYMS

ACI, American Concrete Institute

AF&PA, American Forest and Paper Association

AGC, Associated General Contractors

AIA, American Institute of Architects

AISC, American Institute of Steel Construction

ALA, American Lifeline Alliance

ANSS, Advanced National Seismic System

ASCE, American Society of Civil Engineers

ATC, Applied Technology Council

BSSC, Building Seismic Safety Council

CAD, computer aided design

CAE, computer aided engineering

CALBO, California Building Officials

CAM, computer aided manufacturing

CPM, computerized project management

CSI, Construction Specifications Institute

CUREE, Consortium of Universities for Research in Earthquake Engineering (formerly California Universities for Research in Earthquake Engineering)

DBIA, Design-Build Institute of America

EERI, Earthquake Engineering Research Institute

FEMA, Federal Emergency Management Agency

IABSE, International Association for Bridge and Structural Engineering

IAI, International Alliance for Interoperability

ICBO, International Conference of Building Officials

IFC, industry foundation class

IOP, Institute of Physics

IT, information technology

KWH, kilowatt hour

MAE, Mid-American Earthquake Engineering Research Center

MCEER, Multidisciplinary Center for Earthquake Engineering Research

MEM, micro-electro mechanical

NBS, National Bureau of Standards

NEES, National Earthquake Engineering Simulation

NEHRP, National Earthquake Hazards Reduction Program

NFPA, National Fire Protection Association

NIST, National Institute of Standards and Technology

NSF, National Science Foundation

PBSE, performance-based seismic engineering

PEER, Pacific Earthquake Engineering Research Center

PRESS, Precast Seismic Structural Systems, a federally funded program

SAC, a joint venture partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering

SEAOC, Structural Engineers Association of California

SSRC, Structural Stability Research Council

TMS, The Masonry Society

URM, unreinforced masonry

USGS, United States Geological Survey

WCSEA, Western Council of Structural Engineers Associations

APPLIED TECHNOLOGY COUNCIL PROJECTS AND REPORT INFORMATION

One of the primary purposes of Applied Technology Council is to develop resource documents that translate and summarize useful information to practicing engineers. This includes the development of guidelines and manuals, as well as the development of research recommendations for specific areas determined by the profession. ATC is not a code development organization, although several of the ATC project reports serve as resource documents for the development of codes, standards and specifications.

Applied Technology Council conducts projects that meet the following criteria:

1. The primary audience or benefactor is the design practitioner in structural engineering.
2. A cross section or consensus of engineering opinion is required to be obtained and presented by a neutral source.
3. The project fosters the advancement of structural engineering practice.

Brief descriptions of completed ATC projects and reports are provided below. Funding for projects is obtained from government agencies and tax-deductible contributions from the private sector.

ATC-1: This project resulted in five papers that were published as part of *Building Practices for Disaster Mitigation, Building Science Series 46*, proceedings of a workshop sponsored by the National Science Foundation (NSF) and the National Bureau of Standards (NBS). Available through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22151, as NTIS report No. COM-73-50188.

ATC-2: The report, *An Evaluation of a Response Spectrum Approach to Seismic Design of Buildings*, was funded by NSF and NBS and was conducted as part of the Cooperative Federal Program in Building Practices for Disaster Mitigation. Available through the ATC office. (Published 1974, 270 Pages)

> ABSTRACT: This study evaluated the applicability and cost of the response spectrum approach to seismic analysis and design that was proposed by various segments of the engineering profession. Specific building designs, design procedures and parameter values were evaluated for future application. Eleven existing buildings of varying dimensions were redesigned according to the procedures.

ATC-3: The report, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (ATC-3-06), was funded by NSF and NBS. The second printing of this report, which includes proposed amendments, is available through the ATC office. (Published 1978, amended 1982, 505 pages plus proposed amendments)

> ABSTRACT: The tentative provisions in this document represent the results of a concerted effort by a multi-disciplinary team of 85 nationally recognized experts in earthquake engineering. The provisions serve as the basis for the seismic provisions of the 1988 and subsequent issues of the *Uniform Building Code* and the *NEHRP Recommended Provisions for the Development of Seismic Regulation for New Buildings*. The second printing of this document contains proposed amendments prepared by a joint committee of the Building Seismic Safety Council (BSSC) and the NBS.

ATC-3-2: The project, "Comparative Test Designs of Buildings Using ATC-3-06 Tentative Provisions", was funded by NSF. The project consisted of a study to develop and plan a program for making comparative test designs of the ATC-3-06 Tentative Provisions. The project report was written to be used by the Building Seismic Safety Council in its refinement of the ATC-3-06 Tentative Provisions.

ATC-3-4: The report, *Redesign of Three Multistory Buildings: A Comparison Using ATC-3-06 and 1982 Uniform Building Code Design Provisions*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 112 pages)

> ABSTRACT: This report evaluates the cost and technical impact of using the 1978 ATC-3-06 report, *Tentative Provisions for the Development of Seismic Regulations for Buildings*, as amended by a joint committee of the Building Seismic Safety Council and the National Bureau of Standards in 1982. The evaluations are based on studies of three existing California buildings redesigned in accordance with the ATC-3-06 Tentative Provisions and the 1982 *Uniform Building*

Code. Included in the report are recommendations to code implementing bodies.

ATC-3-5: This project, "Assistance for First Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council", was funded by the Building Seismic Safety Council to provide the services of the ATC Senior Consultant and other ATC personnel to assist the BSSC in the conduct of the first phase of its Trial Design Program. The first phase provided for trial designs conducted for buildings in Los Angeles, Seattle, Phoenix, and Memphis.

ATC-3-6: This project, "Assistance for Second Phase of ATC-3-06 Trial Design Program Being Conducted by the Building Seismic Safety Council", was funded by the Building Seismic Safety Council to provide the services of the ATC Senior Consultant and other ATC personnel to assist the BSSC in the conduct of the second phase of its Trial Design Program. The second phase provided for trial designs conducted for buildings in New York, Chicago, St. Louis, Charleston, and Fort Worth.

ATC-4: The report, *A Methodology for Seismic Design and Construction of Single-Family Dwellings*, was published under a contract with the Department of Housing and Urban Development (HUD). Available through the ATC office. (Published 1976, 576 pages)

ABSTRACT: This report presents the results of an in-depth effort to develop design and construction details for single-family residences that minimize the potential economic loss and life-loss risk associated with earthquakes. The report: (1) discusses the ways structures behave when subjected to seismic forces, (2) sets forth suggested design criteria for conventional layouts of dwellings constructed with conventional materials, (3) presents construction details that do not require the designer to perform analytical calculations, (4) suggests procedures for efficient plan-checking, and (5) presents recommendations including details and schedules for use in the field by construction personnel and building inspectors.

ATC-4-1: The report, *The Home Builders Guide for Earthquake Design*, was published under a contract with HUD. Available through the ATC office. (Published 1980, 57 pages)

ABSTRACT: This report is an abridged version of the ATC-4 report. The concise, easily understood text of the Guide is supplemented with illustrations and 46 construction details. The details are provided to ensure that houses contain structural features that are properly positioned, dimensioned and constructed to resist earthquake forces. A brief description is included on how earthquake forces impact on houses and some precautionary constraints are given with respect to site selection and architectural designs.

ATC-5: The report, *Guidelines for Seismic Design and Construction of Single-Story Masonry Dwellings in Seismic Zone 2*, was developed under a contract with HUD. Available through the ATC office. (Published 1986, 38 pages)

ABSTRACT: The report offers a concise methodology for the earthquake design and construction of single-story masonry dwellings in Seismic Zone 2 of the United States, as defined by the 1973 *Uniform Building Code*. The Guidelines are based in part on shaking table tests of masonry construction conducted at the University of California at Berkeley Earthquake Engineering Research Center. The report is written in simple language and includes basic house plans, wall evaluations, detail drawings, and material specifications.

ATC-6: The report, *Seismic Design Guidelines for Highway Bridges*, was published under a contract with the Federal Highway Administration (FHWA). Available through the ATC office. (Published 1981, 210 pages)

ABSTRACT: The Guidelines are the recommendations of a team of sixteen nationally recognized experts that included consulting engineers, academics, state and federal agency representatives from throughout the United States. The Guidelines embody several new concepts that were significant departures from then existing design provisions. Included in the Guidelines are an extensive commentary, an example demonstrating the use of the Guidelines, and summary reports on 21 bridges redesigned in accordance with the Guidelines. In 1991 the guidelines were adopted by the American Association of Highway and Transportation Officials as a standard specification.

ATC-6-1: The report, *Proceedings of a Workshop on Earthquake Resistance of Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1979, 625 pages)

ABSTRACT: The report includes 23 state-of-the-art and state-of-practice papers on earthquake resistance of highway bridges. Seven of the twenty-three papers were authored by participants from Japan, New Zealand and Portugal. The Proceedings also contain recommendations for future research that were developed by the 45 workshop participants.

ATC-6-2: The report, *Seismic Retrofitting Guidelines for Highway Bridges*, was published under a contract with FHWA. Available through the ATC office. (Published 1983, 220 pages)

ABSTRACT: The Guidelines are the recommendations of a team of thirteen nationally recognized experts that included consulting engineers, academics, state highway engineers, and federal agency representatives. The Guidelines, applicable for use in all parts of the United States, include a preliminary screening procedure, methods for evaluating an existing bridge in detail, and potential retrofitting measures for the most common seismic deficiencies. Also included are special design requirements for various retrofitting measures.

ATC-7: The report, *Guidelines for the Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through the ATC office. (Published 1981, 190 pages)

ABSTRACT: Guidelines are presented for designing roof and floor systems so these can function as horizontal diaphragms in a lateral force resisting system. Analytical procedures, connection details and design examples are included in the Guidelines.

ATC-7-1: The report, *Proceedings of a Workshop on Design of Horizontal Wood Diaphragms*, was published under a grant from NSF. Available through the ATC office. (Published 1980, 302 pages)

ABSTRACT: The report includes seven papers on state-of-the-practice and two papers on recent research. Also included are recommendations for future research that were developed by the 35 workshop participants.

ATC-8: This report, *Proceedings of a Workshop on the Design of Prefabricated Concrete Buildings for Earthquake Loads*, was funded by NSF. Available through the ATC office. (Published 1981, 400 pages)

ABSTRACT: The report includes eighteen state-of-the-art papers and six summary papers. Also included are recommendations for future research that were developed by the 43 workshop participants.

ATC-9: The report, *An Evaluation of the Imperial County Services Building Earthquake Response and Associated Damage*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 231 pages)

ABSTRACT: The report presents the results of an in-depth evaluation of the Imperial County Services Building, a 6-story reinforced concrete frame and shear wall building severely damaged by the October 15, 1979 Imperial Valley, California, earthquake. The report contains a review and evaluation of earthquake damage to the building; a review and evaluation of the seismic design; a comparison of the requirements of various building codes as they relate to the building; and conclusions and recommendations pertaining to future building code provisions and future research needs.

ATC-10: This report, *An Investigation of the Correlation Between Earthquake Ground Motion and Building Performance*, was funded by the U.S. Geological Survey (USGS). Available through the ATC office. (Published 1982, 114 pages)

ABSTRACT: The report contains an in-depth analytical evaluation of the ultimate or limit capacity of selected representative building framing types, a discussion of the factors affecting the seismic performance of buildings, and a summary and comparison of seismic design and seismic risk parameters currently in widespread use.

ATC-10-1: This report, *Critical Aspects of Earthquake Ground Motion and Building Damage Potential*, was co-funded by the USGS and the NSF. Available through the ATC office. (Published 1984, 259 pages)

ABSTRACT: This document contains 19 state-of-the-art papers on ground motion, structural response, and structural design issues presented by prominent engineers and earth scientists in an ATC seminar. The main theme of the papers is to identify the critical aspects of ground motion and building performance that currently are not being considered in building design. The report also contains conclusions and recommendations of working groups convened after the Seminar.

ATC-11: The report, *Seismic Resistance of Reinforced Concrete Shear Walls and Frame Joints: Implications of Recent Research for Design Engineers*, was published under a grant from NSF. Available through the ATC office. (Published 1983, 184 pages)

ABSTRACT: This document presents the results of an in-depth review and synthesis of research reports pertaining to cyclic loading of reinforced concrete shear walls and cyclic loading of joints in reinforced concrete frames. More than 125 research reports published since 1971 are reviewed and evaluated in this report. The preparation of the report included a consensus process involving numerous experienced design professionals from throughout the United States. The report contains reviews of current and past design practices, summaries of research developments, and in-depth discussions of design implications of recent research results.

ATC-12: This report, *Comparison of United States and New Zealand Seismic Design Practices for Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1982, 270 pages)

ABSTRACT: The report contains summaries of all aspects and innovative design procedures used in New Zealand as well as comparison of United States and New Zealand design practice. Also included are research recommendations developed at a 3-day workshop in New Zealand attended by 16 U.S. and 35 New Zealand bridge design engineers and researchers.

ATC-12-1: This report, *Proceedings of Second Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges*, was published under a grant from NSF. Available through the ATC office. (Published 1986, 272 pages)

ABSTRACT: This report contains written versions of the papers presented at this 1985 workshop as well as a list and prioritization of workshop recommendations. Included are summaries of research projects being conducted in both countries as well as state-of-the-practice papers on various aspects of design practice. Topics discussed include bridge design philosophy and loadings; design of columns, footings, piles, abutments and retaining structures; geotechnical aspects of foundation design; seismic analysis techniques; seismic retrofitting; case studies using base isolation; strong-motion data acquisition and interpretation; and testing of bridge components and bridge systems.

ATC-13: The report, *Earthquake Damage Evaluation Data for California*, was developed under a contract with the Federal Emergency Management Agency (FEMA). Available through the ATC office. (Published 1985, 492 pages)

ABSTRACT: This report presents expert-opinion earthquake damage and loss estimates for industrial, commercial, residential, utility and transportation facilities in California. Included are damage probability matrices for 78 classes of structures and estimates of time required to restore damaged facilities to pre-earthquake usability. The report also describes the inventory information essential for estimating economic losses and the methodology used to develop loss estimates on a regional basis.

ATC-13-1: The report, *Commentary on the Use of ATC-13 Earthquake Damage Evaluation Data for Probable Maximum Loss Studies of California Buildings*, was developed with funding from ATC. Available through the ATC office. (Published 2002, 72 pages)

ABSTRACT: The intent of this *Commentary* is to explain the development of the earthquake building evaluation data originally published in the ATC-13 report, *Earthquake Damage Evaluation Data for California*, prepared for FEMA in 1985. The *Commentary* includes a discussion of the scope and results of the ATC-13 project, a description of the most common type of Probably Maximum Loss (PML) study, a discussion and some examples of how ATC-13 is typically used as a basis for a PML study, and recommended improvements to the ATC-13 data. Appendices contain additional data and clarifying descriptions for parameters and definitions included in the ATC-13 report.

ATC-14: The report, *Evaluating the Seismic Resistance of Existing Buildings*, was developed under a grant from the NSF. Available through the ATC office. (Published 1987, 370 pages)

ABSTRACT: This report, written for practicing structural engineers, describes a methodology for performing preliminary and detailed building seismic evaluations. The report contains a state-of-practice review; seismic loading criteria; data collection procedures; a detailed description of the building classification system; preliminary and detailed analysis procedures; and example case studies, including nonstructural considerations.

ATC-15: The report, *Comparison of Seismic Design Practices in the United States and Japan*, was published under a grant from NSF. Available through the ATC office. (Published 1984, 317 pages)

ABSTRACT: The report contains detailed technical papers describing design practices in the United States and Japan as well as recommendations emanating from a joint U.S.-Japan workshop held in Hawaii in March, 1984. Included are detailed descriptions of new seismic design methods for buildings in Japan and case studies of the design of specific buildings (in both countries). The report also contains an overview of the history and objectives of the Japan Structural Consultants Association.

ATC-15-1: The report, *Proceedings of Second U.S.-Japan Workshop on Improvement of Building Seismic Design and Construction Practices*, was published under a grant from NSF. Available through the ATC office. (Published 1987, 412 pages)

ABSTRACT: This report contains 23 technical papers presented at this San Francisco workshop in August, 1986, by practitioners and researchers from the U.S. and Japan. Included are state-of-the-practice papers and case studies of actual building designs and information on regulatory, contractual, and licensing issues.

ATC-15-2: The report, *Proceedings of Third U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1989, 358 pages)

ABSTRACT: This report contains 21 technical papers presented at this Tokyo, Japan, workshop in July, 1988, by practitioners and researchers from the U.S., Japan, China, and New Zealand. Included are state-of-the-practice papers on various topics, including braced steel frame buildings, beam-column joints in reinforced concrete buildings, summaries of comparative U. S. and Japanese design, and base isolation and passive energy dissipation devices.

ATC-15-3: The report, *Proceedings of Fourth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1992, 484 pages)

ABSTRACT: This report contains 22 technical papers presented at this Kailua-Kona, Hawaii, workshop in August, 1990, by practitioners and researchers from the United States, Japan, and Peru. Included are papers on postearthquake building damage assessment; acceptable earth-quake damage; repair and retrofit of earthquake damaged buildings; base-isolated buildings, including Architectural Institute of Japan recommendations for design; active damping systems; wind-resistant design; and summaries of working group conclusions and recommendations.

ATC-15-4: The report, *Proceedings of Fifth U.S.-Japan Workshop on Improvement of Building Structural Design and Construction Practices*, was published jointly by ATC and the Japan Structural Consultants Association. Available through the ATC office. (Published 1994, 360 pages)

ABSTRACT: This report contains 20 technical papers presented at this San Diego, California workshop in September, 1992. Included are papers on performance goals/acceptable damage in seismic design; seismic design procedures and case studies; construction influences on design; seismic isolation and passive energy dissipation; design of irregular structures; seismic evaluation, repair and upgrading; quality control for design and construction; and summaries of working group discussions and recommendations.

ATC-16: This project, "Development of a 5-Year Plan for Reducing the Earthquake Hazards Posed by Existing Nonfederal Buildings", was funded by

FEMA and was conducted by a joint venture of ATC, the Building Seismic Safety Council and the Earthquake Engineering Research Institute. The project involved a workshop in Phoenix, Arizona, where approximately 50 earthquake specialists met to identify the major tasks and goals for reducing the earthquake hazards posed by existing nonfederal buildings nationwide. The plan was developed on the basis of nine issue papers presented at the workshop and workshop working group discussions. The Workshop Proceedings and Five-Year Plan are available through the Federal Emergency Management Agency, 500 "C" Street, S.W., Washington, DC 20472.

ATC-17: This report, *Proceedings of a Seminar and Workshop on Base Isolation and Passive Energy Dissipation*, was published under a grant from NSF. Available through the ATC office. (Published 1986, 478 pages)

> ABSTRACT: The report contains 42 papers describing the state-of-the-art and state-of-the-practice in base-isolation and passive energy-dissipation technology. Included are papers describing case studies in the United States, applications and developments worldwide, recent innovations in technology development, and structural and ground motion issues. Also included is a proposed 5-year research agenda that addresses the following specific issues: (1) strong ground motion; (2) design criteria; (3) materials, quality control, and long-term reliability; (4) life cycle cost methodology; and (5) system response.

ATC-17-1: This report, *Proceedings of a Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control,* was published under a grant from NCEER and NSF. Available through the ATC office. (Published 1993, 841 pages)

> ABSTRACT: The 2-volume report documents 70 technical papers presented during a two-day seminar in San Francisco in early 1993. Included are invited theme papers and competitively selected papers on issues related to seismic isolation systems, passive energy dissipation systems, active control systems and hybrid systems.

ATC-18: The report, *Seismic Design Criteria for Bridges and Other Highway Structures: Current and Future***,** was developed under a grant from NCEER and FHWA. Available through the ATC office. (Published, 1997, 151 pages)

> ABSTRACT: Prepared as part of NCEER Project 112 on new highway construction, this report reviews current domestic and foreign design practice, philosophy and criteria, and recommends future directions for code development. The project considered bridges, tunnels, abutments, retaining wall structures, and foundations.

ATC-18-1: The report, *Impact Assessment of Selected MCEER Highway Project Research on the Seismic Design of Highway Structures***,** was developed under a contract from the Multidisciplinary Center for Earthquake Engineering Research (MCEER, formerly NCEER) and FHWA. Available through the ATC office. (Published, 1999, 136 pages)

> ABSTRACT: The report provides an in-depth review and assessment of 32 research reports emanating from the MCEER Project 112 on new highway construction, as well as recommendations for future bridge seismic design guidelines. Topics covered include: ground motion issues; determining structural importance; foundations and soils; liquefaction mitigation methodologies; modeling of pile footings and drilled shafts; damage-avoidance design of bridge piers, column design, modeling, and analysis; structural steel and steel-concrete interface details; abutment design, modeling, and analysis; and detailing for structural movements in tunnels.

ATC-19: The report, *Structural Response Modification Factors* was funded by NSF and NCEER. Available through the ATC office. (Published 1995, 70 pages)

> ABSTRACT: This report addresses structural response modification factors (R factors), which are used to reduce the seismic forces associated with elastic response to obtain design forces. The report documents the basis for current R values, how R factors are used for seismic design in other countries, a rational means for decomposing R into key components, a framework (and methods) for evaluating the key components of R, and the research necessary to improve the reliability of engineered construction designed using R factors.

ATC-20: The report, *Procedures for Postearthquake Safety Evaluation of Buildings*, was developed under a contract from the

California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA. Available through the ATC office (Published 1989, 152 pages)

> ABSTRACT: Introduced two weeks prior to the 1989 Loma Prieta, California, earthquake, the ATC-20 report provides procedures and guidelines for making on-the-spot evaluations and decisions regarding continued use and occupancy of earthquake damaged buildings. Written specifically for volunteer structural engineers and building inspectors, the report has become the *de-facto* national standard for safety evaluation of earthquake-damaged buildings. The report includes rapid and detailed evaluation procedures for inspecting buildings and posting them as INSPECTED (apparently safe, green placard), LIMITED ENTRY (yellow placard) or UNSAFE (red placard). Also included are special procedures for evaluation of essential buildings (e.g., hospitals), evaluation procedures for nonstructural elements and geotechnical hazards, and guidance on human behavior following earthquakes.

ATC-20-1: The report, *Field Manual: Postearthquake Safety Evaluation of Buildings*, was developed under a contract from OES and OSHPD. Available through the ATC office (Published 1989, 114 pages)

> ABSTRACT: This report, a companion Field Manual for the ATC-20 report, summarizes the postearthquake safety evaluation procedures in a brief concise format designed for ease of use in the field.

ATC-20-2: The report, *Addendum to the ATC-20 Postearthquake Building Safety Procedures*, was published under a grant from the NSF and funded by the USGS. Available through the ATC office. (Published 1995, 94 pages)

> ABSTRACT: This *Addendum* to the ATC-20 report provides updated assessment forms, placards, and procedures that are based on an in-depth review and evaluation of the widespread application of the ATC-20 procedures following five earthquakes occurring after the initial release of the ATC-20 report in 1989. One of the principal recommendations is the replacement of the yellow LIMITED ENTRY posting placard with a revised yellow placard entitled, RESTRICTED USE. Also included are procedures for conducting initial wind-shield surveys of damaged areas, guidance on estimating the cost to repair earthquake damage, and updated guidance on human behavior following natural disasters, including a concise handout for owners and occupants of damaged buildings.

ATC-20-3: The report, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings,* was funded by ATC and R. P. Gallagher Associates. Available through the ATC office. (Published 1996, 295 pages)

> ABSTRACT: This report contains 53 case studies using the ATC-20 Rapid Evaluation procedure, including updates described in the ATC-20-2 *Addendum*. Each case study is illustrated with photos and describes how a building was inspected and evaluated for life safety, and includes a completed safety assessment form and placard (INSPECTED, RESTRICTED USE, OR UNSAFE). The report is intended to be used as a training and reference manual for building officials, building inspectors, civil and structural engineers, architects, disaster workers, and others who may be asked to perform safety evaluations after an earthquake.

ATC-20 Training Slide Set: This training slide set for the ATC-20 *Procedures for Postearthquake Safety Evaluation of Buildings* was developed jointly by ATC and FEMA. Available through the ATC office. (Released in 2003, 230 slides in PowerPoint Format)

> ABSTRACT: The ATC-20 Training Slide Set contains slides of photographs, schematic drawings and textual information, with speaker notes, describing the ATC-20 procedures and their implementation. The slide set is intended as a tool for training volunteer engineers and building inspectors on the application of the ATC-20 procedures, including revisions in the ATC-20-2 *Addendum*. The slide set replaces the ATC-20-T report, *Postearthquake Safety Evaluation of Buildings Training Manual*, which was published in 1993 and contained 160 slides, with speaker notes. Topics covered include: posting system; evaluation procedures; structural basics; wood frame, masonry, concrete, and steel frame structures; nonstructural elements; geotechnical hazards; hazardous materials; and field safety.

ATC-21 Update: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook (FEMA 154, Second Edition)*, was developed under a contract from FEMA. Available through the ATC office and FEMA (Published 2002, 140 pages)

> ABSTRACT: The FEMA 154 report (second edition) describes a rapid visual screening procedure for identifying those buildings that might pose serious risk of loss of life and injury, or of severe curtailment of community services, in case of a damaging earthquake. The screening procedure utilizes a methodology based on a "sidewalk survey" approach that involves identification of the primary structural load resisting system and building materials, and assignment of a basic structural hazards score and modification factors based on observed building characteristics. Application of the methodology identifies those buildings that are potentially hazardous and should be analyzed in more detail by a professional engineer experienced in seismic design. The report contains three Data Collection Forms, one each for regions of low, moderate, and high seismicity. The forms are also available on ATC's web site, www.ATCouncil.org. (The *Second Edition* of this report replaces the *First Edition*, which was published in 1988.)

ATC-21-1 Update: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation (FEMA 155, Second Edition)*, was developed under a contract from FEMA. Available through the ATC office and FEMA. (Published 2002, 104 pages)

> ABSTRACT: The FEMA 155 report (second edition) contains the technical basis for the updated (second edition) rapid visual screening procedure, including (1) a summary of results from the efforts to solicit user feedback, and (2) a detailed description of the Basic Structural Hazard Score and the Score Modifier developmental effort. The minutes of the Users Workshop, which was convened to obtain feedback on needed improvements to the first edition of the rapid visual screening procedure, are also provided as an appendix. (The *Second Edition* of this report replaces the *First Edition*, which was published in 1988.)

ATC-21-2: The report, *Earthquake Damaged Buildings: An Overview of Heavy Debris and Victim Extrication*, was developed under a contract from FEMA. (Published 1988, 95 pages)

> ABSTRACT: Included in this report, a companion volume to the first edition of the FEMA 154 and FEMA 155 reports, is then state-of-the-art information on (1) the identification of those buildings that might collapse and trap victims in debris or generate debris of such a size that its handling would require special or heavy lifting equipment; (2) guidance in identifying these types of buildings, on the basis of their major exterior features, and (3) the types and life capacities of equipment required to remove the heavy portion of the debris that might result from the collapse of such buildings.

ATC-21-T: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards Training Manual* was developed under a contract with FEMA. Available through the ATC office. (Published 1996, 135 pages; 120 slides)

> ABSTRACT: This training manual is intended to facilitate the presentation of the contents of the first edition of the FEMA 154 report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*. The training materials consist of 120 slides and a companion training presentation narrative coordinated with the slides. Topics covered include: description of procedure, building behavior, building types, building scores, occupancy and falling hazards, and implementation.

ATC-22: The report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*, was developed under a contract from FEMA. Available through the ATC office. (Originally published in 1989; revised by BSSC and published as the *FEMA 178 NEHRP Handbook for Seismic Evaluation of Existing Buildings* in 1992; subsequently revised by the American Society of Civil Engineers (ASCE) and published as the FEMA 310 *Handbook for the Seismic Evaluation of Buildings – A Prestandard* in 1998, 211 pages)

> ABSTRACT: This handbook provides a methodology for seismic evaluation of existing buildings of different types and occupancies in areas of different seismicity throughout the United States. The methodology, which has been field tested in several programs nationwide, utilizes the information and procedures developed for and

documented in the ATC-14 report. The handbook includes checklists, diagrams, and sketches designed to assist the user.

ATC-22-1: The report, *Seismic Evaluation of Existing Buildings: Supporting Documentation*, was developed under a contract from FEMA. (Published 1989, 160 pages)

ABSTRACT: Included in this report, a companion volume to the ATC-22 report, are (1) a review and evaluation of existing buildings seismic evaluation methodologies; (2) results from field tests of the ATC-14 methodology; and (3) summaries of evaluations of ATC-14 conducted by the National Center for Earthquake Engineering Research (State University of New York at Buffalo) and the City of San Francisco.

ATC-23A: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part A: Survey Description, Summary of Results, Data Analysis and Interpretation*, was developed under a contract from the Office of Statewide Health Planning and Development (OSHPD), State of California. Available through the ATC office. (Published 1991, 58 pages)

ABSTRACT: This report summarizes results from a seismic survey of 490 California acute care hospitals. Included are a description of the survey procedures and data collected, a summary of the data, and an illustrative discussion of data analysis and interpretation that has been provided to demonstrate potential applications of the ATC-23 database.

ATC-23B: The report, *General Acute Care Hospital Earthquake Survivability Inventory for California, Part B: Raw Data*, is a companion document to the ATC-23A Report and was developed under the above-mentioned contract from OSHPD. Available through the ATC office. (Published 1991, 377 pages)

ABSTRACT: Included in this report are tabulations of raw general site and building data for 490 acute care hospitals in California.

ATC-24: The report, *Guidelines for Seismic Testing of Components of Steel Structures*, was jointly funded by the American Iron and Steel Institute (AISI), American Institute of Steel Construction (AISC), National Center for Earthquake Engineering Research (NCEER), and NSF. Available through the ATC office. (Published 1992, 57 pages)

ABSTRACT: This report provides guidance for most cyclic experiments on components of steel structures for the purpose of consistency in experimental procedures. The report contains recommendations and companion commentary pertaining to loading histories, presentation of test results, and other aspects of experimentation. The recommendations are written specifically for experiments with slow cyclic load application.

ATC-25: The report, *Seismic Vulnerability and Impact of Disruption of Lifelines in the Conterminous State*s, was developed under a contract from FEMA. Available through the ATC office. (Published 1991, 440 pages)

ABSTRACT: Documented in this report is a national overview of lifeline seismic vulnerability and impact of disruption. Lifelines considered include electric systems, water systems, transportation systems, gas and liquid fuel supply systems, and emergency service facilities (hospitals, fire and police stations). Vulnerability estimates and impacts developed are presented in terms of estimated first approximation direct damage losses and indirect economic losses.

ATC-25-1: The report, *A Model Methodology for Assessment of Seismic Vulnerability and Impact of Disruption of Water Supply Systems*, was developed under a contract from FEMA. Available through the ATC office. (Published 1992, 147 pages)

ABSTRACT: This report contains a practical methodology for the detailed assessment of seismic vulnerability and impact of disruption of water supply systems. The methodology has been designed for use by water system operators. Application of the methodology enables the user to develop estimates of direct damage to system components and the time required to restore damaged facilities to pre-earthquake usability. Suggested measures for mitigation of seismic hazards are also provided.

ATC-26: This project, U.S. Postal Service National Seismic Program, was funded under a contract with the U.S. Postal Service (USPS). Under this project, ATC developed and submitted to the USPS the following interim documents, most of which pertain to the seismic evaluation and rehabilitation of USPS facilities:

ATC-26 Report, *Cost Projections for the U. S. Postal Service Seismic Program* (completed 1990)

ATC-26-1 Report, *United States Postal Service Procedures for Seismic Evaluation of Existing Buildings (Interim)* (Completed 1991)

ATC-26-2 Report, *Procedures for Post-disaster Safety Evaluation of Postal Service Facilities (Interim)* (Published 1991, 221 pages, available through the ATC office)

ATC-26-3 Report, *Field Manual: Post-earthquake Safety Evaluation of Postal Buildings (Interim)* (Published 1992, 133 pages, available through the ATC office)

ATC-26-3A Report, *Field Manual: Post Flood and Wind Storm Safety Evaluation of Postal Buildings (Interim)* (Published 1992, 114 pages, available through the ATC office)

ATC-26-4 Report, *United States Postal Service Procedures for Building Seismic Rehabilitation (Interim)* (Completed 1992)

ATC-26-5 Report, *United States Postal Service Guidelines for Building and Site Selection in Seismic Areas (Interim)* (Completed 1992)

ATC-28: The report, *Development of Recommended Guidelines for Seismic Strengthening of Existing Buildings, Phase I: Issues Identification and Resolution*, was developed under a contract with FEMA. Available through the ATC office. (Published 1992, 150 pages)

ABSTRACT: This report identifies and provides resolutions for issues that will affect the development of guidelines for the seismic strengthening of existing buildings. Issues addressed include: implementation and format, coordination with other efforts, legal and political, social, economic, historic buildings, research and technology, seismicity and mapping, engineering philosophy and goals, issues related to the development of specific provisions, and nonstructural element issues.

ATC-29: The report, *Proceedings of a Seminar and Workshop on Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*, was developed under a grant from NCEER and NSF. Available through the ATC office. (Published 1992, 470 pages)

ABSTRACT: These Proceedings contain 35 papers describing state-of-the-art technical information pertaining to the seismic design and performance of equipment and nonstructural elements in buildings and industrial structures. The papers were presented at a seminar in Irvine, California in 1990. Included are papers describing current practice, codes and regulations; earthquake performance; analytical and experimental investigations; development of new seismic qualification methods; and research, practice, and code development needs for specific elements and systems. The report also includes a summary of a proposed 5-year research agenda for NCEER.

ATC-29-1: The report, *Proceedings of a Seminar on Seismic Design, Retrofit, and Performance of Nonstructural Components*, was developed under a grant from NCEER and NSF. Available through the ATC office. (Published 1998, 518 pages)

ABSTRACT: These Proceedings contain 38 technical papers presented at a seminar in San Francisco, California in 1998. The paper topics include: observed performance in recent earthquakes; seismic design codes, standards, and procedures for commercial and institutional buildings; seismic design issues relating to industrial and hazardous material facilities; design analysis, and testing; and seismic evaluation and rehabilitation of conventional and essential facilities, including hospitals.

ATC-30: The report, *Proceedings of Workshop for Utilization of Research on Engineering and Socioeconomic Aspects of 1985 Chile and Mexico Earthquakes*, was developed under a grant from the NSF. Available through the ATC office. (Published 1991, 113 pages)

ABSTRACT: This report documents the findings of a 1990 technology transfer workshop in San Diego, California, co-sponsored by ATC and the Earthquake Engineering Research Institute. Included in the report are invited papers and working group recommendations on geotechnical issues, structural response issues, architectural and urban design considerations, emergency response planning, search and rescue, and reconstruction policy issues.

ATC-31: The report, *Evaluation of the Performance of Seismically Retrofitted Buildings*, was developed under a contract from the National Institute of Standards and Technology (NIST, formerly NBS) and funded by the USGS. Available through the ATC office. (Published 1992, 75 pages)

ABSTRACT: This report summarizes the results from an investigation of the effectiveness of 229 seismically retrofitted buildings, primarily unreinforced masonry and concrete tilt-up buildings. All buildings were located in the areas affected by the 1987 Whittier Narrows, California, and 1989 Loma Prieta, California, earthquakes.

ATC-32: The report, *Improved Seismic Design Criteria for California Bridges: Provisional Recommendations,* was funded by the California Department of Transportation (Caltrans). Available through the ATC office. (Published 1996, 215 pages)

ABSTRACT: This report provides recommended revisions to the current *Caltrans Bridge Design Specifications* (BDS) pertaining to seismic loading, structural response analysis, and component design. Special attention is given to design issues related to reinforced concrete components, steel components, foundations, and conventional bearings. The recommendations are based on recent research in the field of bridge seismic design and the performance of Caltrans-designed bridges in the 1989 Loma Prieta and other recent California earthquakes.

ATC-32-1: The report, *Improved Seismic Design Criteria for California Bridges: Resource Document,* was funded by Caltrans. Available through the ATC office. (Published 1996, 365 pages; also available on CD-ROM)

ABSTRACT: This report, a companion to the ATC-32 Report, documents pertinent background material and the technical basis for the recommendations provided in ATC-32, including potential recommendations that showed some promise but were not adopted. Topics include: design concepts; seismic loading, including ARS design spectra; dynamic analysis; foundation design; ductile component design; capacity protected design; reinforcing details; and steel bridges.

ATC-33: The reports, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273), *NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 274), and *Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 276), were developed under a contract with the Building Seismic Safety Council for FEMA. Available through the ATC office. (Published 1997, *Guidelines*, 440 pages; *Commentary*, 492 pages, *Example Applications*, 295 pages). In 2000 the FEMA 273 report was revised by ASCE and published as the FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, which is available from FEMA.

FEMA 273 ABSTRACT: Developed over a 5-year period through the efforts of more than 60 paid consultants and several hundred volunteer reviewers, the FEMA 273 *Guidelines* provide nationally applicable, state-of-the-art guidance for the seismic rehabilitation of buildings. The *Guidelines* contain several new features that depart significantly from previous seismic design procedures used to design new buildings: seismic performance levels and rehabilitation objectives; simplified and systematic rehabilitation methods; varying methods of analysis, including new linear static and nonlinear static analysis procedures; quantitative specifications of component behavior; and procedures for incorporating new information and technologies, such as seismic isolation and energy dissipation systems, into rehabilitation.

FEMA 274 ABSTRACT: A companion document to the *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (FEMA 273) and the *Prestandard and Commentary for the Seismic Evaluation of Buildings* (FEMA 356), the FEMA 274 *Commentary* contains explanatory background information and the technical basis for the guidance provided in Chapters 2 through 11 of the FEEMA 273 *Guidelines*. Topics covered include:

- general requirements for Simplified and Systematic Rehabilitation;
- modeling and analysis, foundations and geotechnical hazards, steel and cast iron, concrete, masonry, wood and light metal framing, and seismic isolation and energy dissipation (applicable to Systematic Rehabilitation);

- Simplified Rehabilitation; and
- Architectural, mechanical, and electrical components (applicable to Simplified and Systematic Rehabilitation)

FEMA 276 ABSTRACT: The *Example Applications* document, organized to guide the engineer through the rehabilitation process, contains (1) a description of the general steps in the seismic rehabilitation process, (2) background information relating to the development of typical rehabilitation costs; and (3) seismic rehabilitation examples organized by model building type. The examples include a description of the model building type and its common structural characteristics, loads, and load paths; an explanation of the typical analysis procedures commonly used to the determine the response behavior of the existing building and proposed rehabilitation; a list of measures that may be employed to rehabilitate typical deficiencies commonly found in the model building type; and typical costs for seismic rehabilitation based on the FEMA *Typical Costs of Seismic Rehabilitation* documents, second edition (FEMA 156 and 157).

ATC-34: The report, *A Critical Review of Current Approaches to Earthquake Resistant Design***,** was developed under a grant from NCEER and NSF. Available through the ATC office. (Published, 1995, 94 pages)

ABSTRACT: This report documents the history of U. S. codes and standards of practice, focusing primarily on the strengths and deficiencies of current code approaches. Issues addressed include: seismic hazard analysis, earthquake collateral hazards, performance objectives, redundancy and configuration, response modification factors (*R* factors), simplified analysis procedures, modeling of structural components, foundation design, nonstructural component design, and risk and reliability. The report also identifies goals that a new seismic code should achieve.

ATC-35: This report, *Enhancing the Transfer of U.S. Geological Survey Research Results into Engineering Practice* was developed under a cooperative agreement with the USGS. Available through the ATC office. (Published 1994, 120 pages)

ABSTRACT: The report provides a program of recommended "technology transfer" activities for the USGS; included are recommendations pertaining to management actions, communications with practicing engineers, and research activities to enhance development and transfer of information that is vital to engineering practice.

ATC-35-1: The report, *Proceedings of Seminar on New Developments in Earthquake Ground Motion Estimation and Implications for Engineering Design Practice*, was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1994, 478 pages)

ABSTRACT: These Proceedings contain 22 technical papers describing state-of-the-art information on regional earthquake risk (focused on five specific regions—Northern and Southern California, Pacific Northwest, Central United States, and northeastern North America); new techniques for estimating strong ground motions as a function of earthquake source, travel path, and site parameters; and new developments specifically applicable to geotechnical engineering and the seismic design of buildings and bridges.

ATC-35-2: The report, *Proceedings: National Earthquake Ground Motion Mapping Workshop*, was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1997, 154 pages)

ABSTRACT: These Proceedings document the technical presentations and findings of a workshop in Los Angeles in 1995 on several key issues that affect the preparation and use of national earthquake ground motion maps for design. The following four key issues were the focus of the workshop: ground motion parameters; reference site conditions; probabilistic versus deterministic basis, and the treatment of uncertainty in seismic source characterization and ground motion attenuation.

ATC-35-3: The report, *Proceedings: Workshop on Improved Characterization of Strong Ground Shaking for Seismic Design,* was developed under a cooperative agreement with USGS. Available through the ATC office. (Published 1999, 75 pages)

ABSTRACT: These Proceedings document the technical presentations and findings of a workshop in Rancho Bernardo, California in 1997 on the Ground Motion Initiative (GMI) component of the ATC-35 Project. The workshop focused on identifying needs and developing improved representations of earthquake ground motion for use in seismic design practice, including codes.

ATC-37: The report, *Review of Seismic Research Results on Existing Buildings*, was developed in conjunction with the Structural Engineers Association of California and California Universities for Research in Earthquake Engineering under a contract from the California Seismic Safety Commission (SSC). Available through the Seismic Safety Commission as Report SSC 94-03. (Published, 1994, 492 pages)

ABSTRACT: This report describes the state of knowledge of the earthquake performance of nonductile concrete frame, shear wall, and infilled buildings. Included are summaries of 90 recent research efforts with key results and conclusions in a simple, easy-to-access format written for practicing design professionals.

ATC-38: This report, *Database on the Performance of Structures near Strong-Motion Recordings: 1994 Northridge, California, Earthquake*, was developed with funding from the USGS, the Southern California Earthquake Center (SCEC), OES, and the Institute for Business and Home Safety (IBHS). Available through the ATC office. (Published 2000, 260 pages, with CD-ROM containing complete database).

ABSTRACT: The report documents the earthquake performance of 530 buildings within 1000 feet of sites where strong ground motion was recorded during the 1994 Northridge, California, earthquake (31 recording sites in total). The project required the development of a suitable survey form, the training of licensed engineers for the survey, the selection of the surveyed areas, and the entry of the survey data into an electronic relational database. The full database is contained in the ATC-38 CD-ROM. The ATC-38 database includes information on the structure size, age and location; the structural framing system and other important structural characteristics; nonstructural characteristics; geotechnical effects, such as liquefaction; performance characteristics (damage); fatalities and injuries; and estimated time to restore the facility to its pre-earthquake usability. The report and CD also contain strong-motion data, including acceleration, velocity, and displacement time histories, and acceleration response spectra.

ATC-40: The report, *Seismic Evaluation and Retrofit of Concrete Buildings*, was developed under a contract from the California Seismic Safety Commission. Available through the ATC office. (Published, 1996, 612 pages)

ABSTRACT: This 2-volume report provides a state-of-the-art methodology for the seismic evaluation and retrofit of concrete buildings. Specific guidance is provided on the following topics: performance objectives; seismic hazard; determination of deficiencies; retrofit strategies; quality assurance procedures; nonlinear static analysis procedures; modeling rules; foundation effects; response limits; and nonstructural components. In 1997 this report received the Western States Seismic Policy Council "Overall Excellence and New Technology Award."

ATC-41 (SAC Joint Venture, Phase 1): This project, Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 1, was funded by FEMA and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREE. Under this Phase 1 program SAC prepared the following documents:

SAC-94-01, *Proceedings of the Invitational Workshop on Steel Seismic Issues, Los Angeles, September 1994* (Published 1994, 155 pages, available through the ATC office)

SAC-95-01, *Steel Moment-Frame Connection Advisory No. 3* (Published 1995, 310 pages, available through the ATC office)

SAC-95-02, *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment-Frame Structures* (FEMA 267 report) (Published 1995, 215 pages, available through ATC and FEMA)

SAC-95-03, *Characterization of Ground Motions During the Northridge Earthquake of January 17, 1994* (Published 1995, 179 pages, available through the ATC office)

SAC-95-04, *Analytical and Field Investigations of Buildings Affected by the Northridge Earthquake of January 17, 1994* (Published 1995, 2 volumes, 900 pages, available through the ATC office)

SAC-95-05, *Parametric Analytical Investigations of Ground Motion and Structural Response, Northridge Earthquake of January 17, 1994* (Published 1995, 274 pages, available through the ATC office)

SAC-95-06, *Surveys and Assessment of Damage to Buildings Affected by the Northridge Earthquake of January 17, 1994* (Published 1995, 315 pages, available through the ATC office)

SAC-95-07, *Case Studies of Steel Moment Frame Building Performance in the Northridge Earthquake of January 17, 1994* (Published 1995, 260 pages, available through the ATC office)

SAC-95-08, *Experimental Investigations of Materials, Weldments and Nondestructive Examination Techniques* (Published 1995, 144 pages, available through the ATC office)

SAC-95-09, *Background Reports: Metallurgy, Fracture Mechanics, Welding, Moment Connections and Frame systems, Behavior* (FEMA 288 report) (Published 1995, 361 pages, available through the ATC office and FEMA)

SAC-96-01, *Experimental Investigations of Beam-Column Subassemblages, Part 1 and 2* (Published 1996, 2 volumes, 924 pages, available through the ATC office)

SAC-96-02, *Connection Test Summaries* (FEMA 289 report) (Published 1996, available through the ATC Office and FEMA)

ATC-41-1 (SAC Joint Venture, Phase 2): This project, Program to Reduce the Earthquake Hazards of Steel Moment-Resisting Frame Structures, Phase 2, was funded by FEMA and conducted by a Joint Venture partnership of SEAOC, ATC, and CUREE. Under this Phase 2 program SAC has prepared the following documents:

SAC-96-03, *Interim Guidelines Advisory No. 1 Supplement to FEMA 267 Interim Guidelines* (FEMA 267A Report) (Published 1997, 100 pages) superseded by FEMA-350 to 353.

SAC-99-01, *Interim Guidelines Advisory No. 2 Supplement to FEMA-267 Interim Guidelines* (FEMA 267B Report, superseding FEMA-267A). (Published 1999, 150 pages) superseded by FEMA-350 to 353.

FEMA-350, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*. (Published 2000, 190 pages, available through the ATC Office and FEMA)

FEMA-351, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*. (Published 2000, 210 pages, available through ATC Office and FEMA)

FEMA-352, *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings*. (Published 2000, 180 pages, available through the ATC Office and FEMA)

FEMA-353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications*. (Published 2000, 180 pages, available through the ATC Office and FEMA)

FEMA-354, *A Policy Guide to Steel Moment-Frame Construction*. (Published 2000, 27 pages, available through the ATC Office and FEMA)

FEMA-355A, *State of the Art Report on Base Materials and Fracture*. (Published 2000, 107 pages, available through the ATC Office and FEMA)

FEMA-355B, *State of the Art Report on Welding and Inspection*. (Published 2000, 185 pages, available through the ATC Office and FEMA)

FEMA-355C, *State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking*. (Published 2000, 322 pages, available through the ATC Office and FEMA)

FEMA-355D, *State of the Art Report on Connection Performance*. (Published 2000, 292 pages, available through the ATC Office and FEMA)

FEMA-355E, *State of the Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes*. (Published 2000, 190 pages, available through the ATC Office and FEMA)

FEMA-355F, *State of the Art Report on Performance Prediction and Evaluation of Steel Moment-Frame Structures*. (Published 2000, 347 pages, available through the ATC Office and FEMA)

SAC Phase 2 Background Documents, 66 volumes in total (informal background technical reports by SAC researchers describing details of SAC investigations; published 1996 through 2000; available through the ATC Office).

ATC-43: The reports, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual* (FEMA 306), *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Technical Resources* (FEMA 307), and *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA 308)**,** were developed for FEMA under a contract with the Partnership for Response and Recovery, a Joint Venture of Dewberry & Davis and Woodward-Clyde. Available through the ATC Office and FEMA (Published, 1998, *Evaluation Procedures Manual*, 270 pages; *Technical Resources*, 271 pages, *Repair Document*, 81 pages)

ABSTRACT: Developed by 26 nationally recognized specialists in earthquake engineering, these documents provide field investigation techniques, damage evaluation procedures, methods for performance loss determination, repair guides and recommended repair techniques, and an in-depth discussion of policy issues pertaining to the repair and upgrade of earthquake damaged buildings. The documents have been developed specifically for buildings with primary lateral-force-resisting systems consisting of concrete bearing walls or masonry bearing walls, and vertical-load-bearing concrete frames or steel frames with concrete or masonry infill panels. The intended audience includes design engineers, building owners, building regulatory officials, and government agencies.

ATC-44: The report, *Hurricane Fran, North Carolina, September 5, 1996: Reconnaissance Report***,** was funded by the Applied Technology Council. Available through the ATC office. (Published 1997, 36 pages)

ABSTRACT: Written for an intended audience of design professionals and regulators, this report contains information on hurricane size, path, and rainfall amounts; coastal impacts, including storm surges and waves, forces on structures, and the role of erosion; the role of beach nourishment in reducing wave energy and crest height; building code requirements; observations and interpretations of damage to buildings, including the effect of debris acting as missiles; and lifeline performance.

ATC-48 (ATC/SEAOC Joint Venture Training Curriculum): The training curriculum, *Built to Resist Earthquakes, The Path to Quality Seismic Design and Construction for Architects, Engineers, and Inspectors*, was developed under a contract with the California Seismic Safety Commission and prepared by a Joint Venture partnership of ATC and SEAOC. Available through the ATC office (Published 1999, 314 pages)

ABSTRACT: Bound in a three-ring notebook, the curriculum contains training materials pertaining to the seismic design and retrofit of wood-frame buildings, concrete and masonry construction, and nonstructural components. Included are detailed, illustrated, instructional material (lessons) and a series of multi-part Briefing Papers and Job Aids to facilitate improvement in the quality of seismic design, inspection, and construction.

ATC-51: The report, *U.S.-Italy Collaborative Recommendations for Improved Seismic Safety of Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian Nation Seismic Survey). Available through the ATC office. (Published 2000, 154 pages)

ABSTRACT: Developed by a 14-person team of hospital seismic safety specialists and regulators from the United States and Italy, the report provides an overview of hospital seismic risk in Italy; six recommended short-term actions and four recommended long-term actions for improving hospital seismic safety in Italy; and supplemental information on (a) hospital seismic safety regulation in California, (b) requirements for nonstructural components in California and for buildings regulated by the Office of U. S. Foreign Buildings, and (c) current seismic evaluation standards in the United States.

ATC-51-1: The report, *Recommended U.S.-Italy Collaborative Procedures for Earthquake Emergency Response Planning for Hospitals in Italy*, was developed under a contract with Servizio Sismico Nazionale of Italy (Italian Nation Seismic Survey). Available through the ATC office. (Published 2002, 120 pages)

ABSTRACT: Developed by a 14-person team of hospital seismic safety specialists and regulators from the United States and Italy, the report contains : (1) descriptions of current procedures and concepts for emergency response planning in the United States and Italy, (2) an overview of relevant procedures for both countries for evaluating and predicting the seismic vulnerability of buildings, including procedures for postearthquake inspection, (3) recommended procedures for earthquake emergency response planning and postearthquake assessment of hospitals, to be implemented through the use of a Postearthquake Inspection Notebook and demonstrated through the application on two representative hospital facilities; and (4) other recommendations, including emergency response training, postearthquake inspection training, and mitigation of seismic hazards.

ATC-52: The project, "Development of a Community Action Plan for Seismic Safety (CAPSS), City and County of San Francisco", was conducted under a contract with the San Francisco Department of Building Inspection. Under Phase I, completed in 2000, ATC defined the tasks to be conducted under Phase II, a multi-year ATC effort scheduled to commence in 2001. The Phase II tasks include: (1) development of a reliable estimate of the size and nature of the impacts a large earthquake will have on San Francisco; (2) development of technically sound consensus-based guidelines for the evaluation and repair of San Francisco's most vulnerable building types; and (3) identification, definition, and ranking of other activities to reduce the seismic risks in the City and County of San Francisco.

ATC-53: The report, *Assessment of the NIST 12-Million-Pound (53 MN) Large-Scale Testing Facility*, was developed under a contract with NIST. Available through the ATC office. (Published 2000, 44 pages)

ABSTRACT: This report documents the findings of an ATC Technical Panel engaged to assess the utility and viability of a 30-year-old, 12-million pound (53 MN) Universal Testing Machine located at NIST headquarters in Gaithersburg, Maryland. Issues addressed include: (a) the merits of continuing operation of the facility; (b) possible improvements or modifications that would render it more useful to the earthquake engineering community and other potential large-scale structural research communities; and (c) identification of specific research (seismic and non-seismic) that might require the use of this facility in the future.

ATC-R-1: The report, *Cyclic Testing of Narrow Plywood Shear Walls,* was developed with funding from the Henry J. Degenkolb Memorial Endowment Fund of the Applied Technology Council. Available through the ATC office (Published 1995, 64 pages)

ABSTRACT: This report documents ATC's first self-directed research program: a series of static and dynamic tests of narrow plywood wall panels having the standard 3.5-to-1 height-to-width ratio and anchored to the sill plate using typical bolted, 9-inch, 5000-lb. capacity hold-down devices. The report provides a description of the testing program and a summary of results, including comparisons of drift ratios found during testing with those specified in the seismic provisions of the 1991 *Uniform Building Code*.

ATC Design Guide 1: The report, *Minimizing Floor Vibration***,** was developed with funding from ATC's Henry J. Degenkolb Memorial Endowment Fund. Available through the ATC office. (Published, 1999, 64 pages)

ABSTRACT: Design Guide 1 provides guidance on design and retrofit of floor structures to limit transient vibrations to acceptable levels. The document includes guidance for estimating floor vibration properties and example calculations for a variety of currently used floor types and designs. The criteria for acceptable levels of floor vibration are based on human sensitivity to the vibration, whether it is caused by human behavior or machinery in the structure.

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