ATC 73

Prioritized research for reducing the seismic hazards of existing buildings

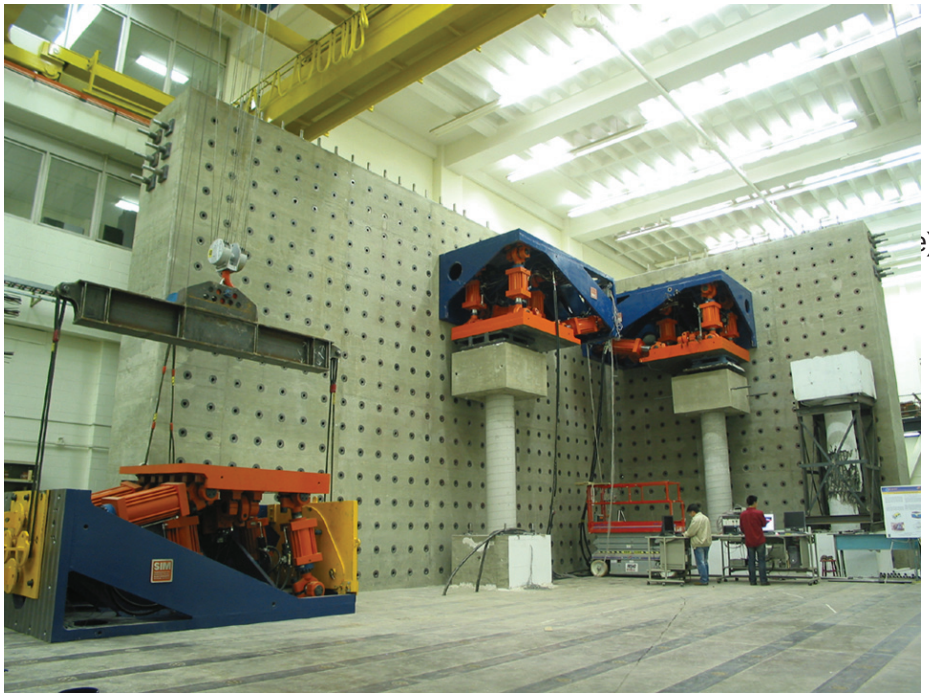

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Photo: Multi-Axial Full-scale Sub-Structuring Testing & Simulation Facility, University of Illinois at Urbana-Champaign, one of 15 geographically-distributed, shared-use, next-generation experimental research equipment sites in the National Science Foundation-funded Network for Earthquake Engineering Simulation (NEES). Courtesy of Amr Elnashai, Director, Mid-America Earthquake Center.

ATC-73

Prioritized Research for Reducing the Seismic Hazards of Existing Buildings

A Consensus Perspective of Practicing Design Professionals and Other Stakeholders Developed for the NSF-Funded Network for Earthquake Engineering Simulation--NEES

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A. Introduction

Reducing property damage, casualties and business interruption caused by the failure of seismically hazardous buildings is one of the major challenges of our time. The solution lies in the identification and rehabilitation of existing vulnerable buildings. The problem is exacerbated by widely varying seismic conditions, the use of different construction materials and physical configurations, and widely varying building seismic design and construction requirements, ranging from no requirements to relatively strict requirements for critical new facilities. Coordinated research to investigate the most pressing problems and to develop new knowledge and new solutions will provide the basis for reducing the number and impacts of seismically hazardous buildings.

This report on prioritized research needs for reducing the seismic hazards of existing buildings was developed specifically for individuals and institutions planning to submit proposals in response to the National Science Foundation (NSF) program solicitation for research using the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). NEES provides 15 geographically-distributed, shared-use, next-generation experimental research equipment sites built and operated specifically to advance earthquake engineering research and education through collaborative and integrated experimentation, theory, data archiving, and model-based simulation (source: NEES Consortium, Inc. web site, www.nees.org). Funding for research to be conducted using NEES facilities is solicited annually by NSF for three categories of research projects: *Individual Investigator, Small Group,* and *Grand Challenge* projects, with each category having specified requirements, periods of performance, and funding levels.

The prioritized list of research needs is based on consensus developed during a National Earthquake Hazards Reduction Program (NEHRP) Workshop on Meeting the Challenges of Existing Buildings, conducted in San Francisco in September 2007 by the Applied Technology Council (ATC) and the Earthquake Engineering Research Institute (EERI), with funding from the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), NSF, and the U. S. Geological Survey (USGS). The goal of the workshop was twofold:

- Identify and prioritize existing research needs, from the perspective of practicing seismic design professionals and in support of the recently established NEES program, to foster development of more effective existing building evaluation and rehabilitation techniques; and
- Identify the barriers to the mitigation of earthquake risk to existing buildings and develop action plans to improve seismic rehabilitation guidance and its implementation.

Attendees included 85 invited participants representing a multi-disciplinary and geographically diverse stakeholder group, including researchers, practitioners, regulators, public policy interests, and product and materials representatives. Details of workshop activities and workshop findings will be available in the ATC-71 Project report, *Proceedings of NEHRP Workshop on Meeting the Challenges of Existing Buildings*, to be published in 2008 (in preparation).

While specifically developed for the NEES Research (NEESR) program, the research needs identified and prioritized in this report are also intended to support the earthquake hazard reduction programs of the other NEHRP agencies (FEMA, NIST, and USGS) as well as other Federal

agencies. The activities of the NEHRP agencies[1] form a complementary program that has the ultimate aim of reducing earthquake losses across the Nation. At its foundation is research, which underpins nearly all of NEHRP's activities. The basic research supported and conducted by NSF and USGS extends across a number of earthquake-related disciplines including structural engineering, mechanics and materials, geotechnical engineering, sensing and control, seismology, geology, and the social sciences. 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 systems, materials, and technologies, and developing measurement and prediction tools underpinning performance standards for buildings and lifelines. FEMA activities include the synthesis of NIST, NSF, and USGS basic and applied research results into useable loss reduction tools and methods, including technical guidance aimed at improving the seismic safety of new and existing buildings (adapted from the NEHRP Strategic Plan of 2003).

A key premise in the planning and execution of the September 2007 NEHRP Workshop on Meeting the Challenges of Existing Buildings was that a broad, integrated and coordinated research, development, and implementation program was needed, considering the related missions of the NEHRP agencies, limited available resources, and the difficulties associated with reducing the seismic hazards of existing buildings. It was also recognized that a coordinated integrated program offers opportunities for broad support from more than one agency and enables concentrated focus on the most pressing problems.

This report has been organized to provide a Strategic Plan for implementing the overall NEES Prioritized Research Program for Reducing the Seismic Hazards of Existing Buildings. The plan begins with a Vision for the research program, following by goals that support the Vision, and research needs that support the goals. Both the goals and related research needs have been prioritized by participants in the 2007 NEHRP Workshop on Meeting the Challenges of Existing Buildings (a brief description of the process followed, and the workshop participants involved is provided in Appendix A).

B. Vision for the NEES Research Program for Reducing the Seismic Hazards of Existing Buildings

Vision statements are often used to convey a mental picture of the ultimate consequences of a strategic plan. For this proposed NEES Prioritized Research Program for Reducing the Seismic Hazards of Existing Buildings, the Vision is:

Substantial Reduction of Casualties and Other Losses from Existing Buildings in Earthquakes.

This vision speaks to understanding what causes damage and collapse so that buildings can be evaluated to determine their potential for collapse, casualties, and other losses (including property losses, losses resulting from time out of service, and socio-economic impact in regional communities and the nation), determining actions to be taken to reduce potential losses, and executing those actions. Supporting this vision is the notion that collapse-hazard buildings may only be a small

[1]Source. FEMA, 2003, *Expanding and Using Knowledge to Reduce Earthquake Losses: The National Earthquake Hazards Reduction Program Strategic Plan 2001-2005*, FEMA 383 Report, Federal Emergency Management Agency, Washington, DC, available at www.nehrp.gov/pdf/strategic_plan_2003.pdf.

subset of the existing building stock, that reliable engineering tools can be developed that accurately predict damage and loss, including the effects on nonstructural components and contents, that new materials and systems can be developed to reduce losses, and that convincing information and mechanisms can be formulated and made available to the public to foster loss reduction.

C. Highest Priority Goals and Research Needs

The overarching recommendation from the Research Needs breakout group was to develop a coordinated research agenda for existing buildings that could be used to establish a program in which individual research projects serve a series of goals advancing the state of knowledge toward a common vision. Based on this recommendation, individual research needs were grouped into one or more goals that were deemed crucial to meeting the challenges of existing buildings. Research needs were grouped such that the successful accomplishment of any one of the needs within a goal would serve to advance the profession towards achieving that goal. In turn, successful accomplishment of any one goal would advance the profession towards meeting the vision of *Substantial Reduction of Casualties and Other Losses from Existing Buildings in Earthquakes*.

Recommended goals, and needs within each goal, are listed in order of priority ranking based on the opinions of workshop participants. It was recognized that individual needs could serve more than one goal. Highest priority needs within each goal are listed below. Needs that arose in workshop discussions, but did not resonate with some level of consensus among participants, are recorded for future reference in the complete list of research needs (Appendix B).

Goal 1: Establishment of a Coordinated Research Program

There was general agreement that a coordinated research program related to existing buildings was needed as part of the NEES program. A wide range of issues that go beyond research supported by NSF was identified by the broad based user community represented at the workshop. Support from NSF, other federal agencies, from city and state agencies, and from the industrial community will be essential to success. In order to make progress on reducing the risks posed by existing buildings, a different mechanism for stimulating, selecting and coordinating research in this area is needed. Such a mechanism is envisioned to include the following:

1.1 Establishment of a list of goals and related high-priority research needs that accomplish the profession's needs in a timely fashion. This report is intended to fulfill this function, but the process should be repeated from time to time as new knowledge or opportunity is created.

1.2 Distribution of goals and high-priority research needs at the time that proposals are requested. Posting of this report on a website listed in the NSF solicitation as a source for user-community-identified critical research topics would facilitate this process.

1.3 Streamlining of the proposal writing phase. A pre-proposal could be solicited in which research teams identify the problem(s) they wish to address, establish their expertise in the area selected, and indicate the NEES sites to be utilized as well as tentative budgets. The objective of the pre-proposal phase is to eliminate the time wasted by researchers in preparing proposals that have low probabilities of receiving support, to maximize the advantages of the NEES sites, and to produce results that can be readily implemented. The

successful pre-proposals offering the greatest potential to address critical issues in mitigating the risk of existing buildings could be invited to a meeting where general focus would be given for preparation of final proposals.

Prior to each funding cycle, it would be beneficial for researchers planning to submit proposals to understand how the program will be administered, the topics that are likely to receive high priority, and updates on projects underway or completed. A meeting could be organized as part of the NEES Annual meeting to accomplish this.

1.4 Establishment of knowledgeable review panels. The NEHRP agencies could take the lead in organizing review and oversight panels that include expertise and vision regarding the nature of existing building problems. Researchers should understand, at the time of proposal preparation, that they will be part of a coordinated effort in which the details of a specific project may be adjusted to complement other research awards and to address overlapping objectives. A review panel that includes a cross-section of researchers, practitioners, and government and industry representatives should review both the pre-proposals as well as the subsequent full proposals.

1.5 Establishment of research advisory committees. Once projects are awarded advisory committees should be established to provide guidance to individual, group, or grand challenge projects.

1.6 Coordination of research projects to achieve goals. The coordination activity could be carried out during the NEES Annual meeting, or could be assigned to qualified individuals or organizations.

Goal 2: Mitigation of Building Collapse Risks

Understanding what causes collapse is key to identifying buildings for which the risk of casualties is high, and focusing mitigation efforts to most effectively protect life and property. Highest priority research needs in support of this goal are:

2.1 Full- or large-scale shake table testing of complete building structural and/or nonstructural systems. Full- or large-scale testing is needed to capture redundancies, system overstrengths, or interactions between components that might not be accounted for in the testing of scale models or subassemblies. Testing at large deformations and to collapse is needed to calibrate developing evaluation tools.

2.2 In-situ testing of the behavior of existing buildings. Test specimens constructed in the laboratory may or may not recreate actual situations encountered in the field. Testing of actual buildings in place will provide more reliable data for calibration of analytical procedures.

2.3 Identification and inventory of buildings that are collapse risks, by type and region. Not all buildings of a certain construction type are collapse risks, and regional variations in construction can influence performance. The ability to identify which subset of the existing building stock is at risk, and determining which buildings in what areas are at risk within this subset, is key to effective prioritization of mitigation activities.

2.4 Improved ability to reliably simulate collapse. Existing analysis methods are limited in their ability to accurately simulate collapse due to the lack of data on structural components

and systems at large deformations, and limitations in analysis formulations and implementations. Physical testing and complementary development of more robust analysis formulations is needed to simulate collapse of complex collapse behavior, including the effects of large deformations and three-dimensional response.

Goal 3: Advancement of Guidelines and Standards for Existing Buildings

Nationally applicable guidelines and standards form the engineering backbone that supports evaluation and mitigation of earthquake risk. Guidelines and standards are, by nature, evolutionary, requiring sustained attention to keep them current. Highest priority research needs in support of this goal are:

3.1 Fragility data for structural and nonstructural components and systems, and a consistent framework for developing and establishing such data. Next-generation performance-based procedures for seismic assessment and design of buildings are currently under development as part of the FEMA-funded ATC-58 project. The backbone of procedures for quantifying risk in terms of casualties, direct economic losses, and downtime is the collection of fragility data on the damageability of structural and nonstructural components. Recommended protocols for laboratory testing of structural and nonstructural components and systems found in buildings are documented in the FEMA 461 report, *Interim Protocols for Determining Seismic Performance Characteristics of Structural and Nonstructural Components through Laboratory Testing*.

3.2 Risk-based approaches to selection of ground motions for evaluation of buildings. Current seismic hazard maps are described in terms of spectral response intensities (ground displacements, velocities, and accelerations), which provide a good first-order estimate of the damaging effects of earthquakes. However, other characteristics of ground motions (frequency content, duration, pulse effects) can significantly affect risk of building damage and collapse. A more consistent approach to seismic hazard mapping would be to provide more consistent correlation to risks of building damage and collapse. Further research is needed to understand and quantify the damaging features of earthquake ground motions on buildings and seismological studies to characterize the probabilities of these hazards.

3.3 Uniform method for development of acceptance criteria in guidelines and standards for seismic evaluation and rehabilitation of buildings. Existing consensus standards for seismic evaluation and rehabilitation have been developed, in part, based on the judgment and experience of those contributing to their development. In some instances, biases and additional conservatism has been incorporated in the acceptance criteria to provide increased factors of safety. Objective specifications for development of acceptance criteria are needed to provide consistent criteria that are aligned with the stated performance intent of the documents.

3.4 Improved analytical platforms for next-generation nonlinear analysis and quantification of risk. Next-generation procedures for the seismic evaluation and rehabilitation of existing buildings require more refined analytical simulations and interface with more robust and diverse data sets. New software and analytical tools are needed to improve our capability to implement these procedures.

3.5 Information on soil-foundation-structure interaction effects on input ground motion. Differences between analytical studies of damaged buildings and observed building damage suggest that there are significant soil-foundation-structure interaction effects that are not well understood. Improved understanding of these effects and accurate ways to characterize them in analysis are particularly important for evaluation of existing buildings, since these effects may reduce the earthquake demands (or apparent demands), thus resulting in more reliable and cost-effective mitigation measures.

Goal 4: Communication of Earthquake Risks

Assessment, identification, and quantification of earthquake risks are pointless activities if the methods do not provide information in meaningful ways, or if the information is not usable or understandable by stakeholders and decision-makers. Effective means of communication, along with consistent and understandable messages, are needed to influence policy and initiate seismic rehabilitation activities. Highest priority research needs in support of this goal are:

4.1 Development of a nonproprietary building rating system. Several methods for rating the seismic performance of buildings currently exist. They vary in complexity, and in their ability to communicate information that is meaningful to decision-makers. Some of these systems are proprietary, or can be manipulated to achieve a desired result. Identification and quantification of seismic risks in a succinct way that is meaningful, technically defensible, and universally known and accepted is key to effective communication between stakeholders.

4.2 Information on most effective ways to communicate risk and mitigation alternatives. Traditionally, engineers have not had effective tools to assess earthquake risks and convey them in meaningful ways to key stakeholders (building owners, financial and insurance organizations, government officials, and the public). Socio-economic metrics that characterize casualty, financial loss, and downtime risks of performance-based approaches provide a framework to quantify performance and risk in ways that relate to effective decision making. However, challenges remain in communicating the probabilistic aspects of risk and mitigation in ways that are well understood and meaningful to the variety of stakeholders affected by building performance and safety.

4.3 Definition of acceptable (or tolerable) risk. Until recently, the methods and tools to enable engineers to accurately assess risks have not been available, so decisions on minimum performance standards have tended to evolve over time (often triggered by earthquake disasters) and have not been established through a rigorous and consistent process. The effectiveness of new tools and procedures to assess and mitigate risk will be limited by the absence of approaches to examine and make decisions about the minimum performance and safety standards that are deemed appropriate by the relevant stakeholders. Such methods must recognize the context of earthquake risks relative to other risks and the relative costs to mitigate risks to various levels.

Goal 5: Calibration of Engineering Tools with Realistic Data

Data from full- and large-scale tests are needed to support the development of engineering tools used for seismic evaluation and rehabilitation of existing buildings. Advanced procedures and techniques are promising, but require validation to enable their full potential to be realized. Both full- and large-

scale simulations and post-earthquake data collection and analysis are needed to accomplish this. Highest priority research needs in support of this goal are:

5.1 Full-/large-scale or in-situ testing of complete building systems. This recommended research need combines high-priority research needs 2.1 and 2.2. Testing of complete or components of building systems on shake tables or in-situ provide reliable data that can be used to calibrate analytical procedures.

5.2 Collection and archiving of detailed information on earthquake damage to nonstructural building components and systems. Some of the most valuable data and understanding of earthquake effects on buildings are gained from observations following earthquakes. Considerably more could be learned if there were more consistent and detailed efforts to collect and archive information on the behavior of nonstructural components and systems during earthquakes. This will require the development of protocols and enabling technologies to collect, archive and manage the data. The data should include sufficient specificity so as to accurately distinguish variations in damage and explain, through accurate science, these variations.

5.3 Expansion of building instrumentation in the strong-motion instrumentation program, including instrumentation of potentially hazardous buildings. Accurate measurements of ground motions and building response during earthquakes are essential to improve scientific understanding of the behavior of building systems. Improved low-cost (wireless) sensors and data collection and management systems would reduce costs and thereby enable wider deployment of strong-motion instrumentation. Additionally, methods are needed to identify optimal sensor configurations and signal processing to accurately quantify behavior of both overall and localized damage to structural and nonstructural systems.

Goal 6: Development of New Materials and New Building Systems

Innovative materials and creative applications in existing building systems can lead to new, cost-effective, less-disruptive, and better-performing seismic rehabilitation solutions. Highest priority research needs in support of this goal are:

6.1 Behavior and performance data on innovative structural materials and systems for use in seismic analysis and design. Effective mitigation ultimately relies on developing solutions that are economical to construct and least disruptive to building occupants, aesthetics, and function. Innovative new solutions are best developed through close collaboration of practicing engineers and researchers who bring complementary expertise in creative design, testing, and analysis.

6.2 Approaches for mitigating risk of non-engineered buildings. Non-engineered buildings constitute a large portion of the building inventory and their performance in an earthquake may have significant socio-economic ramifications. Engineering studies could provide some cost-effective rehabilitation techniques to reduce risks associated with such buildings.

6.3 Assessment of synergistic benefits of multi-hazard rehabilitation. Seismic rehabilitation has been documented to improve performance under other hazards (e.g., wind hazards or man-made [blast] hazards). Quantifying these benefits, or understanding and quantifying how design for other hazards can improve seismic performance, especially

in regions of moderate seismicity, will help foster acceptance of seismic mitigation activities across the nation.

Goal 7: Development of Building Investigative Technologies

One of the biggest challenges related to assessment of existing buildings is knowing, with some degree of certainty, the condition of the building, how it was constructed, and what materials were used in the construction. Development of new technologies and strategies for investigating the condition of existing buildings would significantly improve our ability to reliably assess seismic risk. Highest priority research needs in support of this goal are:

7.1 New tools for non-destructive investigation of building components. More effective technologies are needed to assess the configuration and condition of existing buildings, where the structure is often difficult to access (e.g., enclosed behind architectural walls or facades) or otherwise inspect. Common needs including characterizing the in-situ properties of materials in structural members and foundations and identifying the locations and properties of encased reinforcement and anchors.

7.2 New building information and data collection and archiving systems when drawings are unavailable or building components are concealed. In addition to improved nondestructive evaluation of in-situ conditions, improved information systems are needed to collect, archive and manage information on existing conditions that are relevant to seismic performance assessment and mitigation. Ideally, information can be archived in a systematic way to be maintained for future use and shared (in appropriate ways) with the research community.

D. Ranked Order of Highest Priority Research Needs

More than 50 specific research needs were identified, grouped into categories, ranked in terms of relative importance, and assigned to one or more coordinated goals. Highest priority individual research needs across all goals are listed in Table 1. Lower priority needs, identified in workshop deliberations but not assigned the highest priority rankings by workshop participants, are provided in the complete list of research needs in Appendix B.

E. Summary

This report on prioritized research needs for reducing the seismic hazards of existing buildings was developed specifically for individuals and institutions planning to submit proposals in response to the NSF program solicitation for research using the George E. Brown, Jr. Network for Earthquake Engineering Simulation. The vision for the overall research program is *Substantial Reduction of Casualties and Other Losses from Existing Buildings in Earthquakes.* Goals that support the Vision, and research needs that support the goals have been identified and prioritized by participants in the 2007 NEHRP Workshop on Meeting the Challenges of Existing Buildings, which was held in San Francisco in September 2007 under the sponsorship of the Applied Technology Council and the Earthquake Engineering Research Institute, with funding from the four NEHRP agencies: FEMA, NIST, NSF, and USGS.

Table 1 Highest Priority Research Needs

Overall Priority Ranking	Research Need	Goal
1	Fragility data for structural and nonstructural components and systems, and a consistent framework for developing and establishing such data	Goal 3: Advancement of Guidelines and Standards for Existing Buildings
2	Development of a nonproprietary building rating system	Goal 4: Communication of Earthquake Risks
3	Risk-based approaches to selection of ground motions for evaluation of buildings	Goal 3: Advancement of Guidelines and Standards for Existing Buildings
4	Full- or large-scale shake table testing of complete building systems	Goal 2: Mitigation of Building Collapse Risks Goal 5: Calibration of Engineering Tools with Realistic Data
5	In-situ testing of the behavior of existing buildings	Goal 2: Mitigation of Building Collapse Risks Goal 5: Calibration of Engineering Tools with Realistic Data
6	Uniform method for development of acceptance criteria in guidelines and standards	Goal 3: Advancement of Guidelines and Standards for Existing Buildings
7	Behavior and performance data on innovative structural materials and systems for use in seismic analysis and design	Goal 6: Development of New Materials and New Building Systems
8	Improved analytical platforms for next-generation nonlinear analysis and quantification of risk	Goal 3: Advancement of Guidelines and Standards for Existing Buildings
9	Information on soil-foundation-structure interaction effects on input ground motion	Goal 3: Advancement of Guidelines and Standards for Existing Buildings
10	New tools for non-destructive investigation of building components	Goal 7: Development of Building Investigative Technologies
11	Identification and inventory of buildings that are collapse risks, by type and region	Goal 2: Mitigation of Building Collapse Risks
12	Soil-foundation-structure interaction (deformations, capacity, and behavior under extreme loading)	Goal 3: Advancement of Guidelines and Standards for Existing Buildings

More than 50 specific research needs were identified (see Appendix B), grouped into categories, ranked in terms of relative importance, and assigned to one or more of the following coordinated goals, listed in order of importance:

Goal 1: Establishment of a Coordinated Research Program

Goal 2: Mitigation of Building Collapse Risks

Goal 3: Advancement of Guidelines and Standards for Existing Buildings

Goal 4: Communication of Earthquake Risks

Goal 5: Calibration of Engineering Tools with Realistic Data

Goal 6: Development of New Materials and New Building Systems

Goal 7: Development of Building Investigative Technologies

Of the more than 50 research needs identified, 12 were categorized as highest priority (see Table 1).

Of critical importance to workshop participants was the need to establish a coordinated research program (Goal 1), which would involve the announcement of the highest priority research needs, as identified by the profession; solicitation of pre-proposals to address the highest priority research needs; evaluation of the pre-proposals and selection of those offering the greatest potential to address critical issues; submission of full proposals for the successful pre-proposals; awarding of grants; creation of advisory panels consisting of a cross-section of researchers, practitioners, and government and industry representatives to review work on the awarded projects; and coordination of research carried out on the awarded projects.

Appendix A Workshop Research Needs Development Process and Participants

Twenty-six NEHRP Workshop attendees participated in one or more of three Research Needs breakout sessions conducted as part of the workshop. Breakout participants are listed below. Breakout sessions consisted of seeded brainstorming discussions and prioritization activities aimed at identifying the highest priority research needs from a practitioner's point of view. Ideas for research needs developed in concurrent breakout sessions on other topics/issues were transferred to and considered in the breakout session on research needs. Details of workshop breakout activities are reported in the ATC-71 Project report, *Proceedings of NEHRP Workshop on Meeting the Challenges of Existing Buildings*, to be published in 2008 (in preparation).

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Appendix B Complete List of Research Needs

More than 50 specific research needs were identified, grouped into categories, ranked in terms of relative importance, and assigned to one or more coordinated goals. All issues identified during workshop discussions, including lower priority needs, are recorded in this appendix for future reference.

Goal 1: Establishment of a Coordinated Research Program

Recommended steps:

1.1: Establishment of a list of goals and related high-priority research needs that accomplish the profession's needs in a timely fashion.

1.2: Distribution of goals and high-priority research needs at the time that proposals are requested.

1.3: Streamlining of the proposal writing phase.

1.4: Establishment of knowledgeable review panels.

1.5: Establishment of research advisory committees.

1.6: Coordination of research projects to achieve goals.

Goal 2: Mitigation of Building Collapse Risks

Highest priority research needs:

2.1: Full- or large-scale shake table testing of complete building systems.

2.2: In-situ testing of the behavior of existing buildings.

2.3: Identification and inventory of buildings that are collapse risks, by type and region.

2.4: Improved ability to reliably simulate collapse.

Other research needs:

- Information on the collapse risk associated with infill wall and old braced frame systems
- Quantitative information on the relationship between casualties and collapse
- Information on the effects of redundancy in preventing collapse

Goal 3: Advancement of Guidelines and Standards for Existing Buildings

Highest priority research needs:

3.1: Fragility data for structural and nonstructural components and systems, and a consistent framework for developing and establishing such data.

3.2: Risk-based approaches to selection of ground motions for evaluation of buildings.

3.3: Uniform method for development of acceptance criteria in guidelines and standards for seismic evaluation and rehabilitation of buildings.

3.4: Improved analytical platforms for next-generation nonlinear analysis and quantification of risk.

3.5: Information on soil-foundation-structure interaction effects on input ground motion.

Other research needs:

- Soil-foundation-structure interaction (deformations, capacity, and behavior under extreme loading)
- Modeling of shear and other failure modes to capture performance of existing buildings
- Practical guidance on nonlinear response-history analysis, with specific reference to diaphragms and torsion
- Information on performance of low-ductility buildings in regions of low and moderate seismicity
- Information on the effects of different ground motion characteristics on structural response in the inelastic range
- Investigation of safety factors provided when tested material properties are available
- Identification of environmental/energy costs to replace versus re-use a building (i.e., evaluation based on equivalent carbon footprint)
- Generation, selection, and scaling of simulated ground motions
- Guidance on modeling of soil failure
- Sensitivity analysis using the Pacific Earthquake Engineering Research (PEER) Center/ATC-58 assessment framework to identify where the greatest uncertainties and needs are in the seismic performance assessment process
- Guidance on ground motion selection and scaling procedures
- Validation and clarification of what the ASCE 31 (*Seismic Evaluation of Existing Buildings*) and ASCE 41 (*Seismic Rehabilitation of Existing Buildings*) standards provide in terms of actual earthquake safety
- Procedures to evaluate effects of liquefaction (e.g., lateral spreading, differential settlement) on structural performance, and guidance on protection of foundations from such effects
- Guidance on appropriate quality control measures to ensure that bracing and anchorage of nonstructural components are properly designed and constructed
- Guidance on proper consideration of foundation uplift and sliding

Goal 4: Communication of Earthquake Risks

Highest priority research needs:

4.1: Development of a nonproprietary building rating system.

4.2: Information on most effective ways to communicate risk and mitigation alternatives.

4.3: Definition of acceptable (or tolerable) risk.

Other research needs:

- Generation of scenario loss studies, and dissemination of information from such studies
- Investigation and identification of the biggest impediments to post-earthquake recovery efforts related to buildings (e.g., wood-frame residential construction, unreinforced masonry buildings, non-ductile concrete systems) or infrastructure (e.g., transportation network, utility distribution systems)
- Identification of the "most bang for the buck" rehabilitation measures in terms of rehabilitation costs versus benefit

Goal 5: Calibration of Engineering Tools with Realistic Data

High priority research needs:

5.1: Full-/large-scale or in-situ testing of complete building systems.

5.2: Collection and archiving of detailed information on earthquake damage to nonstructural building components and systems.

5.3: Expansion of the strong-motion instrumentation program to include more building instrumentation, including instrumentation of potentially hazardous buildings.

Other research needs:

- Establishment of an online database of information from large-scale tests and post-earthquake damage investigations
- Investigation of the impact of fire ignitions following earthquakes
- Collection and archiving of detailed information on structural building components and systems
- Collection and archiving of financial loss data from past and future earthquakes
- Test data for evaluation of soil-foundation-structure interaction effects
- Improved post-earthquake inspection and tagging procedures to avoid the potential for progressive collapse

Goal 6: Development of New Materials and New Building Systems

Highest priority research needs:

6.1: Behavior and performance data on innovative structural materials and systems for use in seismic analysis and design

6.2: Approaches for mitigating risk of non-engineered buildings

6.3: Assessment of synergistic benefits of multi-hazard rehabilitation

Other research needs:

- Identification of new innovative systems for minimizing residual building deformation
- Investigation of the effects of finish materials on the performance of wood-frame residential construction
- Development of systems for the protection of foundations from effects of liquefaction

Goal 7: Development of Building Investigative Technologies

Highest priority research needs:

7.1 New tools for non-destructive investigation of building components

7.2 New building information and data collection and archiving systems when drawings are unavailable or building components are concealed