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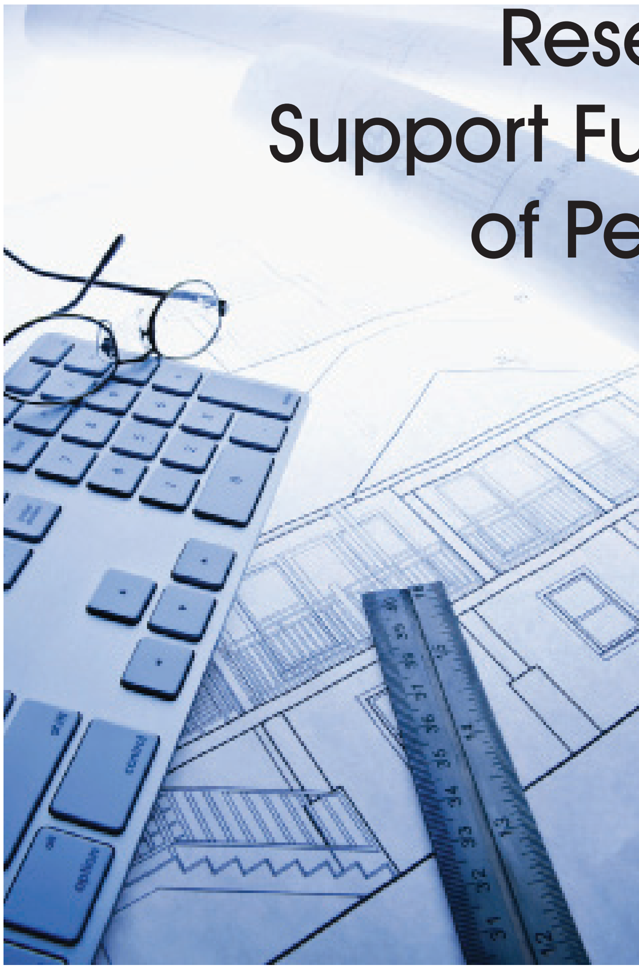

Research Required to Support Full Implementation of Performance-Based Seismic Design

National Institute of Standards and Technology
U.S. Department of Commerce

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Research Required to Support Full Implementation of Performance-Based Seismic Design

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Table of Contents

EXECUTIVE SUMMARY

The performance of modern buildings with respect to protecting life safety in recent earthquakes (e.g., 1989 Loma Prieta, 1994 Northridge, and 2001 Nisqually) generally has been adequate. However, economic losses reflecting damage-repair costs and temporary loss of use of buildings exceeded public expectations. Older buildings constructed with little or no consideration of seismic demands often performed poorly and, in some cases, created unacceptable risks to life safety; retrofit of such buildings is possible but often expensive and disruptive to building operations.

The building performance issues highlighted by these earthquakes have stimulated considerable interest in performance-based seismic design (PBSD). Fully developed PBSD should enable:

- Design of individual new buildings to better suit an owner's performance needs when a code-complying prescriptive design is judged to be inadequate or excessively uncertain.

- Determination of the performance resulting from application of current prescriptive code provisions for various systems in order to identify adjustments needed to provide more consistent performance as well as to refine the overall code objectives, if warranted.

- Refinement of current prescriptive code provisions for critical and/or high-risk buildings to more reliably provide the performance expected for these special occupancies.

- Efficient retrofit designs that target the specific performance desired by owners or building jurisdictions.

The first generation of performance-based design tools was contained in the 1997 Federal Emergency Management (FEMA) publication, *NEHRP (National Earthquake Hazards Reduction) Guidelines for the Rehabilitation of Buildings*, FEMA 273. This document applied only to the retrofit of existing buildings and utilized deterministic performance levels that would not meet the needs of the full range of stakeholders. To encourage further development of PBSD, FEMA commissioned several action plans that included work plans and budgets, and these efforts culminated in 2002 when FEMA provided the Applied Technology Council (ATC) with funding to develop next-generation performance-based seismic design (ATC 58).

However, it is now recognized by the technical community that the development of a PBSD system that will realize the full potential of the concept requires robust data on the expected seismic performance of most, if not all, structural systems, nonstructural components and systems, foundations, and supporting soil types as well as improved ability to predict the specific characteristics of ground motions at any site. The ATC 58 project team has concluded that sufficient technology exists to create a performance-based design procedure but that a lack of research and performance data will limit its scope and, potentially, its accuracy and usefulness.

This report identifies the research required for the nation to take full advantage of PBSD by describing 37 research topics in some detail. The bulk of this research is aimed at generating in-depth data about the performance, over a full range of seismic loadings, of building materials, systems, and components found in both new and older buildings. These data will serve as the basis for a library of fragilities -- mathematical relationships between seismic loading and damage – that is sufficient to model most buildings in this country. A second highly critical task is to determine the performance expected from use of prescriptive code or standards requirements in designing new buildings and retrofitting existing buildings. The results of this task will not only improve the codes and standards but also will facilitate an orderly transition to wide use of PBSD in the next decade.

CHAPTER 1

INTRODUCTION TO PERFORMANCE-BASED SEISMIC DESIGN

Performance-based design of buildings, or at least certain subsystems of buildings, has been practiced since early in the twentieth century, and England, New Zealand, and Australia have had performance-based building codes in place for decades. The International Code Council (ICC) in the United States has had a performance code available for voluntary adoption since 2001 (ICC, 2001). The Inter-Jurisdictional Regulatory Collaboration Committee (IRCC) is an international group representing the lead building regulatory organizations of 10 countries formed to facilitate international discussion of performance-based regulatory systems with a focus on identifying public policies, regulatory infrastructure, education, and technology issues related to implementing and managing these systems. The common interest is to provide a means for design and construction of individual buildings that will satisfy owners' and tenants' needs more efficiently than overarching building code requirements intended for general use. In addition, designing directly for desired performance rather than following prescriptive rules facilitates international transfer of building design and technology.

> The common interest is to provide a means for design and construction of individual buildings that can satisfy the owners' and tenants' needs more efficiently than overarching building code requirements intended for general use.

Most U.S. buildings are designed to comply with prescriptive building code regulations. The prescriptive design rules are based primarily on experience with past performance of buildings although theoretical and/or experimental research are having an increasing impact. Since it is impractical to have rules that individually apply to each combination of occupancy, building configuration, and building material used in this country, building code requirements generally are written to apply to wide ranges of buildings; therefore, the applicability and appropriateness of any such rule to any single building varies significantly.

The use of prescriptive code requirements can be demonstrated by considering the need to provide life safety with respect to structural fire. Building code provisions include specification of minimum fire protection for structural elements to ensure structural stability for a given time period, minimum number and location of exits, and certain controls on the exit path from anywhere in the building. These design requirements may vary for different occupancies, building sizes and heights, and structural systems creating, in many cases, a complex, overlapping set of rules. Using performance-based design, a performance objective is defined, most often to be equivalent to the performance intended by the building code, and a design developed to meet that objective. Often, interpretations are needed to bridge the gap from the general objective to a more specific set of requirements. For example, in application of performance-based design to this issue, adequate life safety with respect to fire may be defined as providing an exit path for all occupants that will remain fire- and smoke-free for a given time period. In addition, the structure could be required to remain stable for a period of time expected to be adequate for firefighters to gain control of the fire. Given the set of specific requirements, the acceptability of a performance-based design will be verified by calculations or tests. Performance-based building regulations typically consist of a definition of the performance objectives and associated requirements as well as administrative controls on the process, particularly verification procedures.

Design of buildings to withstand earthquake shaking can be traced to eighteenth century earthquakes in Lisbon, Portugal, and Calambria, Italy, after which simple building systems were developed to prevent overall collapse. Modern regulations, incorporating various levels of engineering calculations, began after seismic events in Messina, Italy, in 1911 and Kanto, Japan, in 1923. The first engineering design requirements in the United States were codified after the 1925 Santa Barbara earthquake.

Early seismic code requirements were intended to prevent catastrophic building collapse and/or the collapse of heavy building components into streets and sidewalks. These initial and rather crude performance objectives fit well into the traditional building regulatory goal of providing for life safety and, although refined over the years, it remains the primary goal of prescriptive seismic code provisions. Individual code requirements also have been updated many times based on observations of building performance in earthquakes. Over the past 40 years, a scientific basis has been overlain on what originated as a purely heuristic code development process, allowing the results of research to be incorporated. It also has been recognized that buildings with higher perceived risk or importance (e.g., emergency facilities, hospitals, and schools) should perform better than normal buildings.

Code design requirements for such buildings are more stringent in order to provide higher reliability for the life safety of occupants or, for critical buildings, to provide for building functionality after an earthquake. However, the adequacy of current prescriptive provisions for these purposes is generally unproven.

> Early seismic code requirements were intended to prevent catastrophic building collapse and/or the collapse of heavy building components into the streets and sidewalks. These initial rather crude performance objectives fit well into the traditional building regulatory goal of providing for life safety in buildings and, although refined over the years, it remains the primary goal of prescriptive seismic code provisions.

Beginning in the 1960s, engineers and regulators, especially in high seismic zones, recognized the risk represented by older buildings and the need to retrofit them in certain circumstances. However, it was clear that it was difficult and expensive to make an old building comply literally with all code rules for new buildings and certain compromises were made to encourage risk reduction. It was generally recognized that these compromises essentially created a second, lower performance level for retrofitted existing buildings. When the FEMA-funded project to develop formal engineering guidelines for retrofit of existing buildings began in 1989 (ATC, 1989), it was recommended that the rules and guidelines be sufficiently flexible to accommodate a much wider variety of local or even building-specific seismic risk reduction policies than has been traditional for new building construction. The initial design document, NEHRP *Guidelines for the Seismic Rehabilitation of Existing Buildings*, FEMA 273, therefore contained a range of formal performance objectives that corresponded to specified levels of seismic shaking. The performance levels were generalized descriptions of overall damage states with titles of Operational, Immediate Occupancy, Life Safety, and Collapse Prevention. These levels were intended to identify limiting performance states important to a broad range of stakeholders by measuring: the ability to use the building after the event; the traditional protection of life safety provided by building codes; and, in the worst case, the avoidance of collapse. The ground motion intensity to be used for retrofit design was also variable and could be defined as rare very strong shaking or more frequently expected moderate shaking determined either probabilistically or from consideration of a specific event at a known fault location.

In the same period during which FEMA 273 was developed, building performance during the 1989 Loma Prieta and 1994 Northridge earthquakes generated additional interest in a more formal system of performance-based seismic design (PBSD). Although neither earthquake resulted in large life loss, concerns were raised about damage resulting in economic losses from repair and loss of use on the local economies and potential effects on regional economic dependencies. These economic concerns stimulated a broad dialogue concerning building code seismic performance objectives resulting in recognition of the facts that stakeholders had a poor understanding of code performance expectations and that actual building performance could vary widely due to the complicated matrix of prescriptive code rules for various occupancies, structural types, and site locations. Recognition of these issues fostered even more interest in developing improved procedures for estimating performance for specific buildings under various levels of shaking that would, in turn, encourage better building practices. Following the Northridge event, the Structural Engineers Association of California (SEAoC, 1995) developed a PBSD process, known as Vision 2000, that was more generalized than that contained in FEMA 273 but used similarly defined performance objectives.

Over the 10-year period after publication of FEMA 273, its procedures were reviewed and refined and eventually published in 2006 as an American Society of Civil Engineers (ASCE) national standard -- *Seismic Rehabilitation of Existing Buildings*, ASCE 41. Although intended for rehabilitation of existing buildings, the performance objectives and accompanying technical data in ASCE 41 responded to the general interest in PBSD and have been used for the design of new buildings to achieve higher or more reliable performance objectives than perceived available from prescriptive code provisions. Procedures similar to those in ASCE 41 also have been used to show equivalence to code performance for designs not meeting all prescriptive rules, a course of action that may be desirable for an individual building if an economical structural system has been identified that does not meet all prescriptive code rules. ASCE 41 is considered to represent the first generation of performance-based seismic design procedures.

ONGOING PROGRAM TO DEVELOP PERFORMANCE-BASED SEISMIC DESIGN

Responding to the earthquake community's growing interest in more generally applicable PBSD procedures, FEMA funded development of an action plan by the Earthquake Engineering Research Center (EERC) at the University of California at Berkeley that was published in 1996 as *Performance-Based Seismic Design of Buildings, An Action Plan for Future Studies*, FEMA 283. The total cost of the 10-year development effort called for in the plan was estimated at $32 million, much of it targeted at resolving technical issues. Concerned about the high cost, particularly for tasks that required research, FEMA provided the Earthquake Engineering Research Institute (EERI) with funding to develop a second plan that was published in 2000 as *Action Plan for Performance-Based Seismic Design*, FEMA 349. FEMA 349 described a list of "essential" tasks costing an estimated $20 million and a list of "optimal" tasks costing an estimated $27 million. At the lower "essential" spending level, FEMA 349 became the primary scoping document for the ensuing ATC project, Development of Next Generation Performance-Based Seismic Design Procedures, that is commonly referred to as the ATC 58 project.

Discussions during development of FEMA 283 and 349 served to heighten interest in PBSD and clarified the vision and advantages of such a design methodology. The primary technical advancement needed to anchor the technology was an ability to reliably predict specific damage to structural and nonstructural systems in a given building for a given level of ground shaking. The development of such a procedure would establish the United States as the world leader in earthquake engineering, would provide a focus for ongoing research and post-earthquake data collection efforts, and would facilitate the development of highly efficient building codes and other design standards. The full range of potential uses of this procedure includes:

- Design of individual new buildings to better suit an owner's performance needs when a code prescriptive design is judged inadequate or excessively uncertain.

- Determination of the performance provided by current prescriptive code provisions for various systems with the subsequent development of adjustments that will provide more consistent performance and, if warranted, refine the overall code objectives.

- Refinement of current prescriptive provisions for critical and/or high risk buildings to more reliably provide the performance expected for the given occupancy.

- Provision of a consistent consensus-backed method to show equivalence to code-provided performance and thereby enable increased use of economical structural systems and new materials that do not meet all prescriptive code requirements.

- Provision of efficient retrofit design procedures to target specific levels of performance desired by owners or jurisdictions.

- Encouragement for more efficient use of U.S. materials and technology in other countries due to the ability to utilize reliable PBSD goals rather than attempting to conform to a myriad of prescriptive requirements.

> The development of such a procedure would establish the United States as the world leader in earthquake engineering, would provide a focus for ongoing research and post-earthquake data collection efforts, and would facilitate the development of highly efficient building codes and other design standards.

A PBSD system will realize its full potential only if robust data on the expected seismic performance of most, if not all, structural systems, nonstructural components and systems, foundations, and supporting soil types are available and if it is possible to better predict the specific characteristics of ground motions at any site. Currently, the ATC 58 project team has concluded that sufficient technology exists to create a performance-based design procedure but that a lack of research and performance data will limit its scope and, potentially, its accuracy and usefulness.

> Currently, the ATC 58 project development team has concluded that sufficient technology exists to create a performance-based design procedure but that a lack of research and performance data will limit its scope and, potentially, its accuracy and usefulness.

The current plan for the ATC 58 project is described in FEMA 445, *Next-Generation Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings*. This plan reflects several reductions in both funding and scope from that envisioned in either FEMA 283 or FEMA 349. FEMA 349 was formulated with the expectation of eventual FEMA sponsorship and several important aspects of the overall program, such as post-earthquake data collection and laboratory component and system testing, were not considered to be part of FEMA's mission and were deleted from the program (FEMA 349, page 11). Also, the initial ATC 58 scope was based on the lower level of funding recommended by FEMA 349. Finally, the FEMA 445 plan budgets reflect further reductions in levels of effort due to a current lack of available funding. These reductions were accomplished by eliminating certain tasks (e.g., outreach to stakeholders/decision makers) and making across-the-board decreases in most other task budgets, suggesting implicitly, if not explicitly, a more conceptual product that could be made more robust over time.

The expectation of limitations on the ATC 58 product stems from clarification and expansion of the PBSD vision as much as from lack of full funding. When the project was initiated, it was assumed that the next generation performance-based design procedure would be a refinement of the procedures for existing buildings developed in FEMA 273. It was intended that the performance levels (Immediate Occupancy, Life Safety, etc.) would be refined to make them more understandable to stakeholders and that the uncertainties inherent in the calculations would be identified so that the reliability of reaching the intended performance could be explicitly stated. However, PBSD research performed at the Pacific Earthquake Engineering Research Center (PEER) and the recommendations from a stakeholders' workshop indicate that, in order to fulfill its promise, a performance-based procedure must estimate expected losses from earthquake shaking and not be limited to predefined performance states.

Losses from damage in an earthquake fall into three categories:

- The direct cost of damage repair,
- The cost of lost use of a building, and
- The risk of death and serious injury to occupants and passers-by.

A procedure that estimates these losses for any building for any ground shaking with a known reliability enables formulation of the results of evaluation and design in a way that will satisfy the needs of all stakeholders. However, the amount of data needed for such a procedure is extensive and must include not only the relationship between ground motion intensity and damage states, known as fragilities, but also the relationship between damage states and losses, known as consequence functions. The potential variation in damage state given a certain ground motion intensity and the variation in losses given a certain damage state represents the uncertainty of the calculation and these potential variations also must be known. Similarly, large variations in the intensity of ground motion at a site given a certain earthquake must be taken into account in the procedure.

Based on current funding, the current ATC 58 project work plan and the current pace of publicly and privately funded PBSD research, potential limitations of the ATC 58 individual building performance prediction procedure scheduled for release in 2010 have been identified by the authors of this report with input from members of the ATC 58 project team and the participants in a 2008 workshop convened by the Building Seismic Safety Council (BSSC) of the National Institute of Building Sciences (NIBS). These limitations are described in Table 1. As the ATC 58 project proceeds, it is intended that seismic design methods will be developed based on the 2010 prediction procedures.

Table 1 Potential Limitations of the ATC 58 Performance-Based Design Procedure

Potential Limitations	Reasons
Predicted damage for many structural systems and nonstructural systems or components may be inaccurate and/or uncertainties may be large.	• Lack of laboratory or field data to establish reliable fragilities for all structural systems. • Fragilities based primarily on drift or floor acceleration from structural analysis; fragilities based on other response characteristics that are sometimes more appropriate will have to be developed by future users.
Losses in many structural and nonstructural systems and components may be inaccurate and/or uncertainties may be large.	• Lack of laboratory or field data to establish reliable consequence functions for one or more of the important loss categories. • Consequence functions for conditions out of the ordinary will have to developed by user.
The site seismic hazard may not be accurately represented either by the mean or by the distribution of potential responses.	• Inadequacy of procedures to select and scale ground motions to represent the distribution of responses. • The seismic hazard in the central and eastern United States is not well understood. • Time histories appropriate to the central and eastern states are not well defined. • Response spectra shapes for rare ground motions are not adequately defined, particularly in the near field.
Structural response near collapse or incorporating nonstandard failure modes may be inaccurate.	• Current simulation methods do not model complete failure of certain structural components adequately or predict the potential effect of such failures on the remaining structure. • Modeling of three-dimensional effects may be inadequate, particularly for nonstructural components.
Losses due to ground deformation will not be considered.	• The ability to predict locations and amplitudes of ground deformation is inadequate. • Simulation of structural response to ground deformation is inadequate.
Estimates of losses due to breakage of pressurized pipe and damage from pipe contents may be inadequate.	• Poor ability to predict pipe breakage. • Poor ability to predict losses from pipe contents.
Estimates of losses due to fire following earthquake will not be considered.	• Poor ability to predict ignition. • Complex nature of analysis for fire spread.
PBSD will not immediately be capable of providing a design meeting the "Alternative Means and Methods" section of the code that can be used for new lateral systems or for economical systems that do not meet all prescriptive code requirements.	• The identification of losses implied by current code designs will not be known until studies of typical code-compliant buildings are made. • Such losses currently are not defined (except for the FEMA P695 effort) and may be variable between systems. • The results of such studies will permit appropriate code goals to be established and use of PBSD to show equivalence of a non-code system.
The methodology will not be linked to BIM-like technologies although much of the data needed for PBSD probably eventually will be contained in BIM models.	• Incorporation of BIM technology has not been considered in formulating the PBSD action plans.

CHAPTER 2

PROCESS USED TO IDENTIFY AND SET RESEARCH PRIORITIES

Each of the members of the BSSC team that authored this report is thoroughly familiar with performance-based seismic design having either participated in one or both of the previous action plan development projects (FEMA 283 or FEMA 349) or currently serving on the ATC 58 project team. A one-day workshop, attended by approximately 30 additional experts including members of the ATC 58 project team, was convened to confirm important research topics and set priorities (see the Acknowledgements section for names and affiliations of the BSSC team and workshop participants.

To focus participants and maximize input at the workshop, the BSSC team reviewed documents listing research topics previously identified as important to the entire earthquake engineering community and then selected those topics most directly applicable to furthering performance-based seismic design. Documents reviewed included:

- *Securing Society Against Catastrophic Earthquake Losses,* 2003, prepared by the Earthquake Engineering Research Institute primarily to provide background for the preparation for the 2004 reauthorization of the National Earthquake Hazards Reduction Program.

- *Preventing Earthquake Disasters: The Grand Challenge in Earthquake Engineering*, 2003, prepared by the National Research Council of the National Academies to set the research agenda for the Network for Earthquake Engineering Simulation (NEES).

- *The Missing Piece: Improving Seismic Design and Construction Practice, ATC 57*, 2003, prepared by the Applied Technology Council for FEMA as a result of the strategic planning process for NEHRP in the period 1998 to 2001.

- *Prioritized Research for Reducing the Seismic Hazards of Existing Buildings, ATC 73*, 2007, prepared by the Applied Technology Council for the National Science Foundation to set an agenda for NEES research related to existing buildings as well as for research sponsored or carried out by other federal agencies.

The initial version of the list compiled by the BSSC team included 85 research topics, many of which were incompletely defined or overly general and, not unexpectedly, many of which were overlapping. From this initial list, the team selected and described 33 research topics to serve as a focus for discussion at the project workshop. To additionally focus discussions, the topics were placed into the following five categories:

- Fragility Category (F) -- research related to generating the many structural and nonstructural fragilities and consequence functions needed for a robust performance-based seismic design procedure.

- Modeling and Analysis Category (MA) -- research related to analysis and computer modeling of structures, foundations, and soils to predict the full range of response (from elastic to failure) to ground motions.

- Geotechnical and Ground Motion Category (G) -- research related to better prediction and characterization of ground motion at any site or to geotechnical issues.

- Losses Not Considered Category (NC) -- research related to several important secondary damage types (e.g., water damage, soil movement, and fire-following earthquake) that are not being considered in the ATC 58 development project due to complexity, lack of data, and budget limitations.

- Short Term Category (ST) -- research needed immediately to improve ongoing performance-based design in current practice, primarily related to use of performance-level type performance-based design as described in ASCE 41.

Workshop participants also were invited to suggest additional topics prior to the meeting and four more were added through this process.

At the workshop, the topics in each category were discussed in detail by groups of specialists in breakout sessions and the recommended priorities reported back to all participants. At the end of the workshop, all workshop participants placed all topics into priority groups by written ballot irrespective of category. Appendix A contains the lists of research topics by category, additional details about the organization of the workshop, and the raw results of the voting used to determine priorities.

RECOMMENDED RESEARCH

The categories described in the previous section were useful for discussion purposes at the workshop; however, they do not necessarily relate well to research priorities. Thus, the research topics recommended in this report are not divided into these categories and the short-form prefix labels (F, MA, G, NC, and ST) used at the workshop have been dropped. For identification purposes, however, short form labels are convenient and labels relating primarily to priority have been assigned to each research topic recommended in this section. The process used to transform workshop results into research topics presented in this section is described in detail in Appendix A.

Research required to encourage expanded use of the current practice of PBSD and to build a strong constituency for next-generation PBSD is treated as a single group. This research is judged to be needed immediately. The short form label for this group is CP (Current Practice).

Research required to take full advantage of the potential of next generation PBSD over the longer term (as visualized by the ATC 58 project; see page 4) is broken into two groups, one is rated as critical and the second, as essential. A short form label of FPA (Future Practice A) is used for the critical group and FPB (Future Practice B) is used for the essential group.

In the remainder of this report, each research topic is described on a single page that also includes an explanation of its importance to PBSD and the kinds of research that might be necessary. (The identifier used at the workshop is noted in paretheses to allow the topic to be traced to the workshop discussions and voting.)

RESEARCH REQUIRED TO IMPROVE AND ENCOURAGE CURRENT PRACTICE (CP) OF PBSD (primarily ASCE 41 procedures)

The following research topics are listed in approximate priority order, but all topics in this group (CP-xx) are judged to be in need of immediate attention.

Research Topic CP-1 (Workshop Topic ST7)

Benchmark current performance-based design methodologies

Description

Current performance-based seismic design methodologies are intended to achieve desired limited levels of damage, defined in terms of standardized structural and nonstructural performance levels, at different design intensities. These procedures are widely used and have been standardized as ASCE 41-06 (ASCE, 2006). The basis for these procedures was developed in the mid-1990s through the collaborative efforts of researchers and practitioners using a synthesis of available research data. During development, the results from the procedures were compared with documented building performance and with code procedures for design of new buildings in selected case studies; however, these studies were not comprehensive and contradictions were not reconciled. Results of the ASCE 41 procedures are currently perceived to be conservative, but there has been no systematic effort to critically examine the performance predicted by the procedures, compare them with other evaluation and design methodologies, or thoroughly investigate inconsistencies. Such an effort is needed to gain confidence in current performance-based design methodologies.

Importance

Current PBSD methodologies sometimes yield results that appear inconsistent with expected performance. The expressed concerns have not been addressed in a systematic manner, eroding the support and limiting the use of the procedures, particularly for some building systems and materials. Since the current generation of tools is not expected to be replaced for several years, there is a need to critically examine the existing procedures and provide guidance for their use.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
					✓	✓	✓

Research Topic CP-2 (Workshop Topic MA2, ST6)

Improve analytical models and demand assessment capabilities for buildings in near-collapse seismic loading

Description

In current performance-based assessment approaches, a prevalent performance objective is collapse prevention for maximum considered earthquake shaking. Collapse assessment is usually accomplished by dynamic analysis that does not directly simulate collapse but rather assesses collapse indirectly based on the calculated demands. The current methods are necessarily approximate and usually conservative. Development of reliability-based methods to assess appropriate levels of demand, given the inherent dispersion, would result in more consistent and reliable assessment of the collapse prevention performance objective. Some initial work has been done on this topic during the past decade (i.e., work done by the Pacific Earthquake Engineering Research Center and work done as part of the FEMA 695/ATC 63 project to quantify building system performance). Additional work is being done as part of the NEES program, but the level of effort is far below that which is needed for collapse assessment of actual structures.

Importance

Current approaches to assessing collapse by comparing demands with estimated component collapse capacities is inherently conservative. Therefore, improvement of analytical models to directly simulate the initiation of collapse is critically important to improving performance assessments at the collapse limit state.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large-to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
	✓	✓	✓	✓	✓	✓	

Research Topic CP-3 (Workshop Topic ST5)

Improve procedures for the selection and scaling of earthquake ground motions and the interpretation of results from response history analyses

Description

Errors in ground motion assumptions can overshadow the accuracy of analytical performance predictions. In addition to the lack of recorded ground motions to represent the wide variety of actual conditions, it has recently been recognized that large linear scaling of recorded ground motions to match a site-specific response spectrum can be overly conservative in many situations. Proper and consistent rules for the selection and scaling of ground motions are needed. Guidance on proper techniques for conducting nonlinear response history analysis also is lacking.

Importance

Unlike past prescriptive building design procedures, performance-based seismic design procedures require the use of ground motion representations that accurately reflect expected demands. PBSD depends on the availability of reasonably representative ground motion demands with uncertainties sufficiently small as to not dominate results. Although this research topic is listed under Current Practice, it is also a significant issue for Next Generation Practice.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
				✓	✓	✓	✓

Research Topic CP-4 (Workshop Topic ST2)

Clarify and coordinate translation of test results to currently used performance levels

Description

The ability to predict performance depends on accurate correlation of damage states and engineering demand parameters. Performance levels and acceptance criteria embedded in current evaluation methodologies generally are based on research conducted over a decade ago. That limited research data required considerable interpretation to create acceptance criteria. The process of extracting acceptance criteria from test data is not well documented and is not consistent among materials and systems. Consistent rules are needed to guide future researchers in designing tests and to achieve parity among materials. In addition, recent research should be used to validate or update published acceptance criteria.

Importance

Test results form the foundation for performance-based seismic design parameters. Inaccurate translation of the test results to performance criteria can waste resources, prevent rehabilitation measures from being undertaken, and/or prevent desired performance from being achieved. Technically sound, consistent, and well-documented sets of acceptance criteria are needed to corroborate or replace those in current use.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
					✓		✓

RESEARCH REQUIRED TO IMPROVE AND ENCOURAGE FUTURE PRACTICE (FPA) OF PBSD

The following research topics are listed in approximate priority order, but all topics in this group (FPA-xx) are judged to be critical and in need of immediate attention.

Research Topic FPA-1 (Workshop Topic F2)

Generate data through testing for developing structural fragilities (critical level priority, but see also FPB-1 for essential level priority item)

Description

This effort is called for in both FEMA 283 and FEMA 349 and is generally recognized as a high priority. This testing must be sufficiently complete and documented to allow the development of consequence functions, possibly by others. The following are the highest priority structural systems:

Lateral-Force-Resisting Systems

- Steel braced frames
- Steel or concrete frames with masonry infill
- Concrete shear walls
- Lateral force

Other lateral force components

- Diaphragm chords and collectors

Gravity systems

- Precast concrete

Importance

The development of robust fragility functions for structural systems is a key component of PBSD. Laboratory testing of lateral-force-resisting components and systems can be used to develop experimentally based fragility functions or to validate numerical models that can be used to develop analytically based fragility functions.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesiz-ing, Processing Existing Data
	✓	✓	✓	✓			

Research Topic FPA-2 (Workshop Topic F3)

Generate data through testing for developing nonstructural fragilities (critical level priority but see also FPB-2 for essential level priority item)

Description

This effort is called for in both FEMA 283 and FEMA 349 and is generally recognized as a high priority. This testing must be sufficiently complete and documented to allow the development of consequence functions, possibly by others. The highest priority subsystems listed in approximate priority order are:

- Building emergency and life safety systems
- Sprinkler systems other than drops through ceilings
- Pressure piping systems
- Precast concrete cladding
- Heating, ventilating, and air conditioning systems
- Fixed windows
- Skylights over large atria
- Glass fiber reinforced concrete cladding
- Suspended lighting systems
- Factory built curtain wall systems
- Computer floor, raised floor, cooling systems, and computing equipment
- Exterior insulation and finish systems (EIFS) such as synthetic stucco.

Importance

The development of robust fragility functions for building nonstructural systems is a key component of performance-based seismic design. Laboratory testing of building nonstructural components and systems can be used to develop experimentally based fragility functions or to validate numerical models that can be used to develop analytically based fragility functions. This effort is particularly important considering the lack of data on the seismic performance of nonstructural components and systems compared to structural systems.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
	✓		✓	✓			

Research Topic FPA-3 (Workshop Topic MA8)

Develop representative losses for primary categories of code-designed buildings to enable selection of appropriate performance goals for the building code and to test consistency of current procedures

Description

Ongoing studies related to FEMA P695/ATC 63 are, for the first time, developing data that will permit the probable performance of various building types to be compared in relation to collapse. Other losses implied by code design are unknown and only tangentially mentioned in published code "intents." An important use of PBSD will be to make code performance more consistent and better targeted at desirable goals. In addition, such studies will provide owners with the information needed to make decisions about requesting designs to provide better than "code performance." Although this topic could include calibration of the performance of code-conforming buildings, calibration with existing codes should not serve as the sole basis for selecting performance objectives in future performance procedures.

Importance

The intent of building codes has been discussed qualitatively over the years, but the actual performance expected from code-conforming buildings has never been analytically assessed. Understanding how buildings designed to current codes actually perform is critical to rational assessment of code changes required to achieve consistent and appropriate performance.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
				✓		✓	

Research Topic FPA-4 (Workshop Topic F8)

Develop a plan (data and funding) for collecting and storing data on losses from future earthquakes

Description

This issue has been discussed in most earthquake-related meetings and workshops held since the 1994 Northridge earthquake, but there is still no plan to systematically collect damage data after future earthquakes or to store these data for future use. Recently, the Building Seismic Safety Council, with encouragement from the NEHRP agencies, conducted a project to produce a conceptual design for a national post-earthquake information management system (PIMS). This system would provide for the collection and archiving of post-earthquake damage data. Support for the continuing development of this system is judged to be a critical priority.

Importance

The collection of damage and performance data following earthquakes is important to PBSD so that the predictions from numerical models and the results of laboratory experiments can be assessed in light of data gathered after real seismic events. Larger damage databases on structural and nonstructural system performance can be used to create and refine fragilities for PBSD.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
					✓		✓

Research Topic FPA-5 (Workshop Topic F7)

Create a curated database related to PBSD that can include raw data, fragilities, and loss functions related to structural, nonstructural, and soils and foundation systems

Description

It is likely that new fragility and loss data will be generated for decades to come. A central storage location should be established for both established fragilities and the data from which fragilities can be developed. These new fragility data could be part of the PIMS system described in Research Topic FPA-4.

Importance

The collection of new fragility and loss data is important to PBSD in order to maintain up-to-date knowledge regarding the seismic performance of structural and nonstructural systems during earthquakes and to avoid duplicate research in the future.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
					✓		✓

Research Topic FPA-6 (Workshop Topic MA6)

Improve modeling and analysis procedures for soil-foundation-structure interaction so that they better consider determination of dynamic base, input of earthquake ground motions, damping, and soil-foundation stiffness/strength

Description

Nonlinear dynamic analysis requires input of earthquake ground motions to an analytical model of a building. Current practice varies widely but generally is based on simplified models. Improved procedures are needed for more accurate performance assessments. It has been suggested for some time that the relatively large inelastic displacements predicted for short-period buildings are not often observed in the field due to soil-structure interaction. This topic would include:

- Study of effects of applying ground motions in different ways using fixed bases, soil-springs, and other models
- Study of ground motion modification effects (e.g., slab averaging, etc.)
- Study of different damping models including material nonlinearity and radiation damping;
- Study of soil-foundation stiffness and strength models
- Comparison of results with recorded responses of actual buildings
- Comparison of the relative degree of effort and corresponding benefits of the improved models (many enhanced approaches may require a level of modeling or analysis work that is excessive compared with the resulting improvements in response estimation)

Importance

Modern assessment approaches involve application of earthquake time history series to analytical models. It therefore is vitally important that correct procedures be developed.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
			✓	✓		✓	✓

Research Topic FPA-7 (Workshop Topic F4)

Develop protocol for testing and documentation of results to enable development of consequence functions for both structural and nonstructural systems and components

Description

Some testing that may be adequate for development of fragilities is not sufficiently robust or documented to support development of consequence functions. Development of consequence functions requires documentation of damage during testing in sufficient detail to estimate cost of repairs, potential resulting building downtime, and risks to life safety. Guidance is needed concerning how to incorporate in fragility experiments the collection of the data required for development of robust consequence functions.

Importance

Robust consequence functions for structural and nonstructural systems are a key component of PBSD. Although little extra effort is required to provide sufficient documentation for the development of experimentally based consequence functions, very few past experiments have provided sufficient documentation to make this possible.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
							✓

Research Topic FPA-8 (Workshop Topic MA1)

Develop improved models and simulation procedures to include more realistic damage simulation

Description

The current generation of performance-assessment typically involves linear and nonlinear dynamic analyses with performance based primarily on peak values of computed interstory drift and floor accelerations. Use of other engineering demand parameters (EDP) sometimes would be more appropriate, but this seldom occurs because data are lacking. Improved understanding of modeling parameters and dynamic simulation are needed to improve accuracy of results. More advanced damage measures including use of cumulative damage parameters should be developed. In addition to developing improved models, the use of analytical models to simulate structural and nonstructural response needs to be calibrated against dynamic response of structures tested on shaking tables and in actual earthquakes. Damping models require reconsideration for use in PBSD, and new models are needed, especially for structural components, to represent damage accumulation through cyclic loading.

Importance

Because any performance-assessment is directly related to the computed dynamic response of the structure, it is critically important that response simulations represent as accurately as possible the actual response during earthquake loading.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
		✓	✓	✓	✓	✓	

Research Topic FPA-9 (Workshop Topic F5)

Develop consequence functions for structural and nonstructural systems if not available

Description

Although future testing for development of fragilities may include the necessary data for consequence functions, it is unclear if the cost estimating and other considerations needed for consequence functions will be completed by the same researchers. This task, however, is essential to PBSD. In addition, many systems for which fragilities have been developed or deduced do not have adequate consequence functions.

Importance

The development of robust consequence functions for structural and nonstructural systems is a key component of PBSD. Although little extra effort is required to provide sufficient documentation for the development of experimentally based consequence functions, very few past experiments have provided sufficient documentation to make this possible.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
							✓

Research Topic FPA-10 (Workshop Topic F1)

Obtain historical testing data (much may be proprietary) from testing laboratories for development of fragilities

Description

Many components have been tested for seismic performance over the years, but it is unclear what data exist and to what extent they may be applicable to current systems and components and whether the data are available for PBSD use. Given the current lack of hard fragility data, a concerted and organized effort should be made to collect all information that might be available.

Importance

This effort is important to avoid costly duplication of experiments that may have been conducted in the past but whose results are not available in the public domain. Considering the relatively low level effort that would be required to conduct this effort, the potential for payback is large.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
							✓

Research Topic FPA-11 (Workshop Topic G6)

Improve understanding of all aspects of ground motion and time histories with increased instrumentation

Description

Through instrumentation (e.g., by the National Strong Motion Program and the Advanced National Seismic System), the earthquake engineering and science communities have learned much about ground motion and its time histories during loss-inducing earthquakes like the 1994 Northridge event. However, the current quantity of instrumentation has resulted in lost opportunities to increase the understanding of all aspects of ground motion and its time histories that affect structures during not only the Northridge earthquake but also other large events like the 2002 Denali earthquake. Increased instrumentation is required in order to improve the understanding of such aspects of ground motion as near-surface ground motion amplification, soil-foundation-structure interaction, and structural response and performance directly.

Importance

All aspects of ground motion and its time histories that affect structures are critical to PBSD in that they constitute the seismic demand to which structures must be designed in order to supply sufficient capacity. Improved prediction of the performance of structures requires improved understanding of these demands. While analytical modeling of ground motion and its time histories (e.g., see research topic FPB-7) also can improve this understanding, such models ultimately rely on data from instrumentation for calibration and/or validation.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesiz-ing, Processing Existing Data
			✓	✓			✓

Research Topic FPA-12 (Workshop Topic G5)

Improve ability to predict soil movement including liquefaction, lateral spread, landslide, and soil failure at foundations

Description

Permanent movement of soil masses associated with earthquake-induced liquefaction, lateral spread, landslide, or soil failure generally is caused by transient or long-term exceedance of the shearing resistance of the soil. Such soil movement at foundations of structures, in turn, can contribute significantly to damage to the structures and their contents and the consequent losses. Although the general cause of soil movement is understood, it is not now possible to adequately predict locations and amplitudes of soil movement during an earthquake. Further geotechnical engineering research is required.

Importance

Losses due to soil movement currently are not considered in the ATC 58 performance-based design procedures. Improving the ability to predict soil movement is primary to improving the ability to predict damage to structures and contents from soil movement (FPA-13) and to developing the capability to consider losses to an individual building from soil movement (FPA-14). The importance of the two cited research topics also is judged to be critical for PBSD.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesiz-ing, Processing Existing Data
	✓	✓	✓	✓	✓	✓	✓

Research Topic FPA-13 (Workshop Topic MA7)

Improve ability to predict damage to structures and contents from soil movements including liquefaction, lateral spread, landslide, and soil failure at foundations

Description

Soil movements can contribute to building damage and these effects should be included in comprehensive performance assessments. This is especially needed for existing construction where preconstruction mitigation to preclude certain modes of soil failure is not possible.

Importance

Losses due to soil movement currently are not considered in the ATC 58 performance-based design procedures. Where present, soil failure is an important consideration in performance assessment of buildings, particularly for assessing repair costs.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
✓		✓	✓	✓	✓		✓

Research Topic FPA-14 (Workshop Topic NC6)

Develop capability to consider losses to an individual building from soil movements

Description
This issue is related to topic FPA-13. Liquefaction and lateral spreading often are not considered to be life safety issues, but they clearly can result in damage and possibly downtime. Landsliding from the site downward or from above the site also is a potential life safety risk. Methods to estimate these risks in the performance-based format need to be developed.

Importance
Although information currently exists for estimating the potential for liquefaction and lateral spreading, methods are needed for estimating losses due to these soil movements to completely account for repair costs and downtime losses for an individual building's structure, foundation, and immediately adjacent infrastructure (e.g., water, sewer, power, fiber-optics, sidewalks, driveways). For moderate earthquake ground motions on Site Class F soils (those susceptible to liquefaction and lateral spreading), the costs associated with liquefaction and lateral spreading are likely to dominate the losses associated with repair and downtime. Where landslides are likely, the life safety risk has been clearly demonstrated. For truly catastrophic landslides (e.g., Chi-Chi earthquake), the resulting impact on repair costs, downtime, and casualties will overwhelm the effects of ground shaking on the individual building. Estimating the landslide potential and the resulting effects is critical to developing a complete estimate of losses for an individual building.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
✓	✓	✓	✓	✓	✓	✓	

RESEARCH REQUIRED TO IMPROVE AND ENCOURAGE FUTURE PRACTICE (FPB) OF PBSD

The following research topics are listed in approximate priority order, but all topics in this group (FPB-xx) are judged to be essential and in need of immediate attention.

Research Topic FPB-1 (Workshop Topic F2)

Generate data through testing for developing structural fragilities. (essential level priority but see also FPA-1 for critical priority level items)

Description

This research is called for in both FEMA 283 and FEMA 349 and is generally recognized as a high priority. Testing must be sufficiently complete and documented to allow the development of consequence functions, possibly by others. After those listed in FPA-1, the following structural systems are considered the next priorities:

Lateral-Force-Resisting Systems
- Reinforced masonry
- Light steel stick framing systems
- Light wood stick framing systems
- Limited ductility steel moment frames

Other Lateral Force Components
- Wood diaphragms
- Precast concrete with and without concrete topping
- Steel deck with concrete topping
- Steel ribbed deck roof

Gravity Systems
- Concrete gravity frames

Importance

The development of robust fragility functions for structural systems is a key component of PBSD. Laboratory testing of lateral-force-resisting components and systems can be used to develop experimentally based fragility functions or to validate numerical models that can be used to develop analytically based fragility functions.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
	✓	✓	✓	✓			

Research Topic FPB-2 (Workshop Topic F3)

Generate data through testing for developing nonstructural fragilities (essential level priority, but see also FPA-2 for critical priority level item)

Description

This effort has been called for in both FEMA 283 and FEMA 349 and is generally recognized as a high priority. This testing must be sufficiently complete and documented to support the development of consequence functions, possibly by others. After those systems listed in FPA-2, the following subsystems are considered the next priority:

- Escalators
- Interior wall finishes other than paint
- Sliding windows
- Roof/flashing/joints
- Screens and louvers
- Metal panel cladding
- AAC cladding

Importance

The development of robust fragility functions for building nonstructural systems is a key component of PBSD. Laboratory testing of building nonstructural components and systems can be used to develop experimentally based fragility functions or to validate numerical models that can be used to develop analytically based fragility functions. This effort is particularly important considering the lack of data on the seismic performance of nonstructural components and systems compared to structural systems.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
✓		✓	✓				

Research Topic FPB-3 (Workshop Topic MA3)

Expand sensitivity analyses to determine where the greatest uncertainties and needs are in the seismic performance assessment process

Description

Performance assessment involves seismic hazard analysis, structural response simulation, damage assessment, and determination of performance in terms of capital losses, downtime, and casualties. Studies are needed to determine the sensitivity of final results to the quality of the information in each step of the process, to guide both future research and how information is gathered and processed in performance assessments.

Importance

This research is important to efficient and accurate performance assessment.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesiz-ing, Processing Existing Data
						✓	

Research Topic FPB-4 (Workshop Topic F9)

Enter existing related loss data into database

Description

Although not extensive, damage and loss data sets from past earthquakes should be entered into a permanent, curated database similar to that described in FPA-4. Although some of these data sets are electronic, they are still friable and must be saved. Fragilities from past damage data cannot be appropriately deduced without the availability of all the data.

Importance

The long-term maintenance of a central repository of damage and performance data following earthquakes is important to PBSD in order to maintain an up-to-date knowledge base regarding the seismic performance of structural and nonstructural systems during earthquakes.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
							✓

Research Topic FPB-5 (Workshop Topic G4)

Improve understanding/modeling of how local soil conditions modify ground shaking

Description

Local near-surface soil conditions can significantly amplify, de-amplify, or otherwise modify the earthquake ground shaking affecting a structure in interaction with its foundation. Models capable of characterizing the change in ground shaking caused by local soil conditions exist, but their accuracy is complicated by the fact that natural soil deposits can exhibit strong spatial variability over even relatively short horizontal and vertical distances. This spatial variability can significantly increase the uncertainty of the characterization of the soil and its influence on structural performance. Improving the understanding and modeling of this phenomenon requires additional geotechnical engineering research.

Importance

The impact of local soil conditions on ground shaking and consequent losses can rival that of the selection and scaling and/or generation of input "bedrock" ground motion time histories (CP-3 and FPB-7) or the modeling and analysis of structures and foundations (e.g., FPA-8) and their interactions with soils (e.g., FPA-6). The cited research topics also have been judged to be essential to take full advantage of PBSD.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
		✓	✓	✓	✓	✓	✓

Research Topic FPB-6 (Workshop Topic G3)

Identify new ground motion characteristics or parameters that will improve correlation with nonlinear structural response and damage

Description

In predicting seismic performance of structures, the nonlinear structural response to ground motion and associated damage typically are correlated with simple ground motion characteristics or parameters such as peak ground acceleration or spectral response acceleration at the fundamental elastic vibration period of the structure. These measures of ground motion intensity are chosen mainly because they correspond to existing seismic hazard models. Other ground motion characteristics or parameters need to be identified that correlate better with seismic performance, particularly for cases when the structural system becomes nonlinear and its dynamic properties change with ground motion intensity or when its response is driven by multiple modes of vibration.

Importance

The characterization or parameterization of ground motion intensity in a way that correlates well with nonlinear structural response and damage is key to the efficiency and sufficiency of next generation seismic performance prediction. The identification of new ground motion characteristics or parameters will drive the development of corresponding seismic hazard data and models (FPB-12) that can be combined with structural response/damage data and models, serving to coordinate earthquake science and earthquake engineering research and practice.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesiz-ing, Processing Existing Data
			✓	✓	✓	✓	✓

Research Topic FPB-7 (Workshop Topic G2)

Improve the generation, selection, and scaling of simulated ground motions

Description

Geophysics-based and/or stochastic simulations of earthquake ground motions are sometimes, but not yet broadly, relied upon for the characterization of seismic hazard and/or the nonlinear dynamic time-history analyses of structures conducted as part of PBSD procedures. Like recorded ground motions, simulated motions must be selected appropriately and may need to be scaled (or otherwise modified) to a specified level of seismic intensity as described further under CP-3.

Importance

Recorded ground motions for relatively infrequent large-magnitude and close-distance earthquakes, which are often the scenarios of interest or the events that contribute most to predicted losses, are very limited in number. Simulated ground motions can fill this gap and also can be tailored to both the geology between a specific site and earthquake fault and the local soil conditions, thereby reducing the uncertainty in predicted ground shaking. Currently, however, the generation of simulated ground motions is not well-vetted by earthquake engineers who could use them for improving seismic hazard data and models (FPB-12) and/or select them for input to structural analyses, perhaps with some scaling. Improving their generation, selection, and scaling requires, and thereby promotes, collaboration between the earthquake engineers who will use the simulated ground motions and the earthquake scientists who develop them.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
				✓	✓	✓	✓

Research Topic FPB-8 (Workshop Topic NC3)

Develop capability to consider losses from water damage from broken pipes or tanks

Description
Losses from water damage, particularly downtime, are well known, but few data are available from which loss functions can be developed. However, such a capability will be important to encourage restraint of piping systems and to improve restraint requirements.

Importance
Although low-to-moderate earthquake shaking may not have a pronounced detrimental effect on the overall structure, the water associated with broken water pipes (both supply and discharge) or tanks can cause severe nonstructural damage (e.g., Sylmar Hospital during the 1994 Northridge earthquake). It is essential that the impact of water damage be considered if accurate estimates of overall building repair costs and downtime are to be developed.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
	✓	✓	✓		✓	✓	✓

Research Topic FPB-9 (Workshop Topic F6)

Conduct in-situ testing of the behavior of existing buildings, including those slated for demolition

Description

It is widely recognized that there is a lack of fragility and loss data on full-scale buildings. Whenever possible, real buildings should be used to generate these data. This is particularly true of buildings scheduled for demolition.

Importance

Testing full-scale buildings over their entire range of performance represents the most realistic way to gather fragility data and to evaluate the various components included in PBSD. Although relatively expensive, such landmark experiments, if conducted with care, can provide large payback in terms of new knowledge.

Types of Research Potentially Required

Experimental Research					**Analytical Research**		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
				✓			

Research Topic FPB-10 (Workshop Topic F10)

Beyond test data, develop analytical fragilities to extend fragility databases

Description
Not all fragilities can be experimentally based. Validated analytical models and simulation capabilities need to be utilized to generate fragilities for structural and nonstructural components and systems.

Importance
The capability to generate analytical fragility functions using numerical models that are validated based on a limited number of experiments is critical in order to develop PBSD at a reasonable cost.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
					✓	✓	

Research Topic FPB-11 (Workshop Topic MA4)

Develop procedures to enable use of engineering demand parameters (EDPs) in addition to drift and floor accelerations

Description

The performance-assessment approach currently emerging in the ATC 58 project primarily uses interstory drift and floor acceleration as the two engineering demand parameters (EDPs) for damage assessment. For some structural and nonstructural components, these EDPs do not relate well to performance. For example, shear might be a better EDP for a low-rise shear wall, and vector EDPs may be needed for some components (e.g., combined shear and deformation demand for slab-column connections). An expanded set of EDPs should be developed considering the most common construction conditions, those that are most critical to building performance, and those that are not well represented by the current ATC 58 EDPs. For important components, appropriate new EDPs should be developed. Procedures/software should be developed for implementing these new EDPs, or vectors of EDPs, in performance assessment software such as PACT (the software used to demonstrate ATC 58 procedures). A systematic study should be carried out to identify the structural and nonstructural systems for which EDPs other than drift and acceleration are appropriate and to determine implementation strategies with respect to analysis and fragilities.

Importance

Circumstances have already been identified within the ATC 58 project where neither drift nor floor acceleration can serve as an adequate EDP. The overall importance to the accuracy and usability of PBSD is unknown without a systematic study of the issue.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
					✓		✓

Research Topic FPB-12 (Workshop Topic G1)

Improve seismic hazard data and models including attenuation models

Description

Seismic hazard data include probabilistic ground motion maps and corresponding site hazard curves, deterministic ground motion scenarios, and associated response spectra. The models developed to derive these data incorporate information on seismic sources, earthquake magnitudes and frequencies, and attenuation models (a.k.a., ground motion prediction equations) that consider probabilistic characterizations of source, path, and site effects. While important progress on the latter was made recently by the PEER's Next Generation Attenuation (NGA) Project, which was incorporated in the recent update of the U.S. Geological Survey (USGS) National Seismic Hazard Maps, the project findings are applicable only to certain seismic sources (shallow crustal earthquakes), ground motion characteristics (spectral response accelerations), and a limited geographic region (western United States).

Importance

Proper seismic hazard data and models are required to properly evaluate the seismic performance of structures. While seismic hazard has been researched in the United States mainly by earthquake scientists, collaborative and/or coordinated research by earthquake engineers is important to the accuracy of PBSD. The concern that current seismic hazard data and models may not lead to accurate representations of potential structural responses is a potential limitation of the ATC 58 PBSD procedures (e.g., see Table 1 in Chapter 1 of this report).

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
				✓	✓	✓	✓

Research Topic FPB-13 (Workshop Topic MA5)

Develop methods to consider dynamic soil pressure on buildings

Description
Dynamic soil pressure on buildings commonly is assessed using long-established methods that current research suggests are inaccurate for building foundation walls. New procedures should be studied to determine their applicability to common building conditions and new methods should be developed as needed.

Importance
Basement pressures are an important consideration in many buildings with subterranean levels. This research topic should focus on investigations for typical conditions.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
		✓			✓	✓	

Research Topic FPB-14 (Workshop Topic NC1)

Develop capability to consider post-earthquake fire damage from sources internal to the building

Description

In any one building, losses from earthquake-caused fire may be more significant than shaking damage. In addition, if known, the risks from within the building probably can be mitigated. The fire risk will vary significantly among different building types or occupancies, but a complete performance-based assessment methodology should include this capability.

Importance

To accurately estimate overall building repair costs and downtime, consideration of the impacts of fire damage is essential.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
	✓	✓	✓		✓	✓	✓

Research Topic FPB-15 (Workshop Topic NC4)

Develop capability to consider losses from internal releases of hazardous materials

Description
Hazardous materials are becoming more common in certain building occupancies (e.g., laboratory, healthcare, and industrial facilities). The internal release of these materials will likely have an adverse effect on the building occupants and, in the worst case scenario, may lead to casualties. This risk may apply only to a small number of buildings but, for those buildings, the resulting losses may be more significant than shaking losses. The importance of containment systems can be demonstrated only by estimating the potential effects on the building and its occupants.

Importance
Quantification of the hazardous materials that are likely to be housed in a building, their susceptibility to release, and their potential effect on the building and its occupants is critical to properly estimating the overall repair costs, downtime, and casualties.

Types of Research Potentially Required

Experimental Research					Analytical Research		
Material Testing	Component Testing	Small-scale System Testing	Large- to Full-scale Testing or Instrumentation	In-situ Testing or Instrumentation	Development of New Theory, Concepts, Procedures, or Models	Parametric Studies Using Current Models or Software	Gathering, Synthesizing, Processing Existing Data
	✓				✓	✓	✓

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ACKNOWLEDGEMENTS

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APPENDIX A

Workshop Materials

- Preworkshop information package
- Summary of workshop (includes added topics)
- Summary results of priorities from voting
- Clarification, combination, and reduction of Research Topic list for presentation in this report

Workshop for the Identification of Missing Elements in Current Plans for the Development and Implementation of Performance-Based Seismic Design

PRE-WORKSHOP INFORMATION PACKAGE
Pre-workshop Instructions

Dear Workshop Participant:

Thanks again for participating in this important workshop. The Project Management Committee is charged with developing a report on this subject for use by the NEHRP Directorate. We will base research priorities largely on the result of this workshop.

Enclosed (attached-if emailed) are the following:

- A Pre-workshop Preparation Agenda
  - Please glance at the right hand column of the agenda to get a brief overview of how the workshop will be conducted.
- A Pre-workshop Research Topics List
  - This list consists of 31 topics pertinent to performance-based design in five categories which have been mined by the PMC from several recent reports on research needs.
- How the various topics relate to improving the viability of performance-based design in the future will become clearer at the workshop.

AS NOTED IN THE PRE-WORKSHOP PREPARATION AGENDA, IF YOU FEEL that a crucial research need is missing from the Pre-workshop Research Topics List, YOU MUST SUBMIT A REQUEST TO BSSC TO PRESENT A PROPOSAL BY MAY 27, 2008. If approved, you will have approximately 5 minutes to present the proposed topic at the workshop and then the workshop participants will decide if the topic will be added to the Research Topics List.

Some familiarity with ATC 58 is important for meaningful participation in the Workshop. A 3 page overview of the project and a complete 35% draft is available for download on the ATC website (www.atcouncil.org/atc-58.shtml). You will be pre-assigned to break-out sessions in accordance with your experience and expertise as well as on the need for balanced representation in each session.

If you have pre-workshop questions, feel free to discuss them with any of the members of the PMC as noted below.

Again, thanks for participating,

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Time	Item	Leader	Notes for Participants
7:30 am	Continental Breakfast		
8:30 am	Introduction and Purpose of Project	Holmes Hayes Mahoney	The purpose of the project is to develop a prioritized research ("research" for this workshop to be clarified by Jack Hayes) agenda designed to fill the gaps in currently funded PBSD research.
8:45 am	History of development of performance based seismic design (FEMA 273-FEMA 283-FEMA 349-ATC 58), including scope reductions and budget constraints.	Hamburger	This section will briefly review various reductions in the development plans originally envisioned by the community, primarily focusing on the current ATC 58 action plan funded by FEMA. Other NEHRP agencies may have activities that overlap performance-based design needs, but are not following any overarching plan.
9:00 am	Potential limitations and implementation issues with PBD using products within the current ATC 58 program and with research knowledge currently existing or under development.	Holmes	How will the final products of the current program be affected by the change to a probabilistic format, the parsing of research and development responsibilities, and reductions in budget and scope that have occurred?
9:30 am	Introduction to Research Topics prepared for this project	Holmes	The PMC of this Workshop Project have studied comprehensive lists of earthquake engineering research needs published in the last five years and have selected and refined a subset specifically or generally related to performance-based engineering. The research topics are in five somewhat arbitrary categories and are included in this pre-workshop information package. The primary purpose of this workshop is to review, adjust and prioritize these lists.
9:45 am	Introduction and discussion of research topics not on our pre-workshop list nominated by the workshop participants	Pre-approved Participants	It is not judged beneficial to spend a large amount of time at the workshop re-plowing the ground of developing lists of research. The PMC has attempted to do that. However, if important and potentially influential research is not represented on the list, we invite workshop participants to present their case for addition of topics in this section. Participants will be recognized to propose new topics only if pre-approved by the PMC. Proposed topics must be submitted to BSSC for approval by the PMC by May 27, 2008.
10:15 am	Instructions for Breakout 1	Holmes	
10:30 am	Breakout 1A: Identification and prioritization of structural systems requiring testing or research to enable development of adequate fragilities and/or consequence functions for PBD.	Moehle Whittaker	It is well understood that one of the most significant deficiencies in current PBD calculations is the lack of fragilities based on lab or field data. Development of such data is not within the scope of FEMA funded efforts. Priorities for developing such data for the many structural systems used in the US will be the subject of this breakout.
	Breakout 1B Identification and prioritization of nonstructural components and systems requiring testing or research to enable development of adequate fragilities and/or consequence functions for PBD.	Filiatrault Miranda	This breakout is similar to !A but will focus on setting priorities for development of nonstructural data.
11:30 am	Reports from Breakouts	Luco Moehle Filiatrault	
Noon	Lunch		

Time	Item	Leader	Notes for Participants
1:00 pm	Instructions for Breakout 2		
1:15 pm	Breakout 2A Discussion and prioritization of Short Term Category of Research Topic.	Phipps Hooper	As can be seen by reviewing the Short Term Category of Research Topics, this research is intended to have a more immediate impact on practice by providing data to improve performance-based engineering as currently practiced in the US—primarily ASCE 41.
	Breakout 2B Discussion of "Conditions not Covered" category of Research Topics • Identification of additional effects • Prioritize list (high, moderate, not needed).	Holmes Hamburger	As can be seen by reviewing the Conditions Not Covered Category of Research Topics, this research is intended to enable estimation of losses from complex effects such as fire-following or water damage. Losses from these effects (and others) are only marginally covered or not included at all in the current ATC 58 scope.
2:15 pm	Summarize Breakouts	Phipps Holmes	
3:00 pm	Plenary session for discussion of importance of various Research Topics to establish priorities. Instructions for voting.	Holmes Participants	Reflecting on the discussion of the day and their own interests, participants will be allowed to speak for five minutes on the importance of their favorite research as it relates to PBD. There is insufficient time to discuss every Research Topic identified.
4:00 pm	Ballot voting for priorities of Research Topics—Topics will be placed into one of three priority classes.	Participants	Each participant will place each Research Topic (original and those added in the morning) into one of three priority categories: 9 being the highest, 8, and 7. If a voter feels a research topic is not needed for PBD at all, a lower rating than 7 can be given. The results (priorities) of Breakout Session 1 will not be integrated into the overall list. The results of Breakout 2 will inform but not bind participants. Suggestions for determining priorities will be given at the workshop. The Voting will be done the old fashioned way, paper ballot. The results will be used by the PMC to help formulate the report for the project, but it is unlikely the specific voting results will be included in the report. The results will be sent to participants.
4:15 pm	Adjourn		

Table 2, Research Topics

Note: Items marked with * added since Preworkshop Package.

FRAGILITY CATEGORY		
No.	**Task**	**Priority**
FI	**Obtain historical testing data (much may be proprietary) from testing labs for development of fragilities.**	
	It is known that many components have been tested for seismic performance over the years. It is unclear what data exist and to what extent it may be applied to current systems and components and whether the data are available for PBD use. However, given the lack of hard fragility data, a concerted and organized effort should be made to collect all information that might be available.	
F2	**Generate data through testing for developing structural fragilities.**	
	This effort has been called for in both FEMA 283 and FEMA 349 and is generally recognized as a high priority. This testing must be sufficiently complete and documented to allow the development of consequence functions, possibly by others. Workshop breakout session 1A will focus on identification and prioritization of specific related testing and research needs.	
F3	**Generate data through testing for developing nonstructural fragilities.**	
	This effort has been called for in both FEMA 283 and FEMA 349 and is generally recognized as a high priority. This testing must be sufficiently complete and documented to allow the development of consequence functions, possibly by others. Workshop breakout session 1B will focus on identification and prioritization of specific related testing and research needs.	
F4*	**Develop protocol for testing and documentation of results to enable development of consequence functions for both structural and nonstructural systems and components.**	
	Currently some testing that may be adequate for development of fragilities is not sufficiently robust or documented to enable development of consequence functions. Guidance is needed.	
F5*	**Develop consequence functions for structural and nonstructural systems where not available.**	
	Although future testing for development of fragilities may include the necessary data for consequence functions, it is unclear if the cost estimating and other considerations needed for consequence functions will be completed by the same researchers. However, this task is essential to PBD. In addition, many systems for which fragilities have currently been developed or deduced do not have adequate consequence functions.	
F6	**Conduct in-situ testing of the behavior of existing buildings, including those slated for demolition.**	
	It is widely recognized that there is a lack of fragility or loss data from full scale buildings. Whenever possible, real buildings should be used to generate fragilities and loss data. This is particularly true of buildings scheduled for demolition.	

FRAGILITY CATEGORY		
No.	**Task**	**Priority**
F7	**Create curated database related to Performance-based engineering that could include raw data, fragilities and loss functions related to structural, nonstructural, and soils and foundation systems.**	
	It is likely that new fragility and loss data will be generated for decades to come. A central storage location should be established for not only established fragilities but also data that from which fragilities could be developed.	
F8	**Develop plan (data and funding) to collect and store loss data from future earthquakes.**	
	This issue has been discussed in many meetings and workshops. However, there is still currently no plan to systematically collect damage data in a future earthquake, or to store it for future use.	
F9	**Enter existing related loss data into database.**	
	Although not extensive, there are damage and loss data sets from past earthquakes that should be entered into a permanent, curated database similar to F 5 for use in the future. Although some of these data sets are already electronic, they are still friable and must be saved.	
F10	**Beyond test data, develop analytical fragilities to extend fragility databases.**	
	Not all fragilities can be experimentally based. Validated analytical models and simulation capabilities need to be utilized to generate fragilities for structural and nonstructural components and systems.	

MODELING AND ANALYSIS CATEGORY		
No.	**Task**	**Priority**
MA1	**Develop improved models and simulation procedures to include more realistic damage simulation.**	
	The current generation of performance assessment typically involves linear and nonlinear dynamic analysis, with performance based on peak values of computed response. Improved understanding of modeling parameters and dynamic simulation is needed to improve accuracy of results, and more advanced damage measures, including cumulative damage measures, should be developed.	
MA2	**Improve analytical models and simulation capabilities for buildings in near-collapse seismic loading.**	
	In current performance-based assessment approaches, a prevalent performance objective is the avoidance of collapse for some maximum considered seismic loading. In the performance assessment methodology being developed in the ATC 58 project, collapse modeling is important to assessing casualty rates. Collapse assessment today is usually accomplished by dynamic analysis that does not directly simulate collapse, with collapse assessed indirectly based on the calculated demands. These methods are necessarily approximate and usually conservative. Collapse simulation capabilities should be developed to directly simulate the initiation and progression of collapse.	
MA3	**Expand sensitivity analyses to determine where the greatest uncertainties and needs are in the seismic performance assessment process.**	
	Performance assessment involves seismic hazard analysis, structural response simulation, damage assessment, and determination of performance in terms of capital losses, downtime, and casualties. Studies are needed to determine sensitivity of final results to the quality of the information in each step of the process, both to guide future research and to guide how information is gathered and processed in performance assessments.	
MA4	**Develop procedures to enable to use EDPs in addition to drift and floor accelerations.**	
	The performance-assessment approach emerging in the current generation of the ATC 58 uses interstory drift and floor acceleration as the two engineering demand parameters for damage assessment. For some components, these EDPs do not relate well to performance. For example, shear might be a better EDP for a low-rise shear wall. An expanded set of EDPs should be developed, along with procedures for their use.	
MA5	**Develop methods to consider dynamic soil pressure in buildings.**	
	Dynamic soil pressure on buildings commonly is assessed using long-established methods that current research suggests are inaccurate for building foundation walls. Improved methods should be developed.	
MA6	**Improve modeling and analysis procedures for soil-foundation-structure interaction, including determination of dynamic base, input of earthquake ground motions, damping, and soil-foundation stiffness/strength.**	
	Nonlinear dynamic analysis requires input of earthquake ground motions to an analytical model of the building. Current practice varies widely, but generally is based on simplified models. Improved procedures are needed for more accurate performance assessment.	

MODELING AND ANALYSIS CATEGORY		
No.	**Task**	**Priority**
MA7	**Improve ability to predict damage to structures and contents from soil movements including liquefaction, lateral spread, landslide, and soil failure at foundations.**	
	Soil movements can contribute to building damage and these effects should be included in comprehensive performance assessments.	
MA8	**Develop representative losses for primary categories of code-designed buildings to enable selection of appropriate performance goals for the building code and to test consistency of current procedures.**	
	Ongoing studies related to ATC 63 are, for the first time, developing data enabling comparison of probable performance of various buildings types, at least related to collapse. Other losses implied by code design are unknown and only tangentially mentioned in published code “intents.” An important use of PBD will be to make code performance more consistent and better targeted at desirable goals. In addition, such studies will enable owners to make better decisions about requesting designs to provide better than “code performance.”	

GEOTECHNICAL AND GROUND MOTION CATEGORY		
No.	**Task**	**Priority**
G1	**Improve seismic hazard data and models including attenuation models.**	
	Proper seismic hazard data and models are required to properly evaluate the seismic performance of structures. This includes information on seismic sources, earthquake magnitudes and frequencies, as well as attenuation models that consider the probabilistic characterizations of source, path, and site effects. While important progress was made recently in NGA program, its findings are applicable only to certain ground motion characteristics and to a limited geographic region.	
G2	**Improve the generation, selection, and scaling of simulated ground motions**	
	Non-linear dynamic time-history analyses conducted as part of the performance-based seismic design procedure may, in some instances, rely on the generation of simulated ground motions. Like recorded ground motions, simulated motions may need to be scaled (or otherwise modified) to a specified level of seismic intensity. In order to avoid bias in demand estimates that can be induced by improper generation, selection and/or scaling of simulated ground motions, improved procedures are required, particularly for small ensembles of ground motions.	
G3	**Identify new ground motion characteristics or parameters that will improve correlation with nonlinear structural response and damage**	
	Currently, the performance of structural systems is typically correlated with simple ground motion characteristics or parameters such as peak ground acceleration or spectral acceleration at the fundamental elastic structural period. Other ground motion characteristics or parameters need to be identified that correlate better with performance, particularly when the structural system becomes nonlinear and its dynamic characteristics are changing with ground motion intensity, or when its response is driven by multiple modes of vibration.	
G4	**Improve understanding/modeling of how local soil conditions modify ground shaking**	
	Models capable of characterizing the change in surface shaking due to various local soil conditions are required for performance-based seismic design. Complicating the issue is the fact that natural soil deposits can exhibit strong spatial variability even over relatively short horizontal and vertical distances. This spatial variability can significantly increase the uncertainty of the characterization of the soil and its influence on the performance evaluation.	
G5	**Improve ability to predict soil movement including liquefaction, lateral spread, landslide and soil failure at foundations**	
	Soil failure problems involve permanent deformations of soil masses, generally through transient or long-term exceedance of the shearing resistance of the soil. Predictions of the geotechnical performance and interaction of geo-materials with structures is critical to the development of performance-based earthquake engineering.	

GEOTECHNICAL AND GROUND MOTION CATEGORY		
No.	**Task**	**Priority**
G6	**Improve understanding of all aspects of ground motion and time histories with increased instrumentation**	
	Despite the recent information on the evaluation of the relation between ground response/failure and structural performance, developed recently within the hazard assessment research program of the Pacific Earthquake Engineering Research Center, many elements related to ground motion characterization, evaluation of free-field ground response and evaluation of soil-foundation-structure interaction are missing for the complete development and implementation of performance-based seismic design. Increasing instrumentation will allow the collection of information necessary for an improved understanding of the relevant aspects of ground motion and time histories.	

LOSSES NOT CONSIDERED CATEGORY		
No.	**Task**	**Priority**
NC1	**Develop capability to consider post earthquake fire damage from sources internal to the building.**	
	In any one building, losses from earthquake-caused fire may be more significant than shaking damage. In addition, if known, the risks from within the building can probably be mitigated. This risk may only be applicable in certain regions, neighborhoods, or for certain building types or occupancies, but a complete performance-based assessment methodology should include this capability.	
NC2	**Develop capability to consider post earthquake fire damage from sources external to the building.**	
	In any one building, losses from earthquake-caused fire may be more significant than shaking damage. In neighborhoods of densely built wood frame housing or in urban-forest interface areas, the risk of multiple building conflagrations may be greater than the risk from shaking, even probabilistically. These risks can only be marginally controlled by an owner, but a complete performance-based assessment methodology should include this capability.	
NC3	**Develop capability to consider losses from water damage from broken pipes or tanks.**	
	Losses from water damage, particularly downtime, are well known. However, little data are available from which loss functions can be developed. However, such a capability will be important to encourage restraint of piping systems and to improve restraint requirements.	
NC4	**Develop capability to consider losses from internal releases of hazardous materials**	
	This risk may only apply to a small number of buildings, but for those buildings, the losses may be more significant than shaking losses. The importance of containment systems can only be demonstrated by estimating potential effects on the building and its occupants.	
NC5	**Develop capability to consider losses associated with an individual building from loss of utilities.**	
	Buildings are, in fact, often shut down for these reasons. An owner making decisions about downtime may need this information to make informed decisions. It is not clear how this information would be generated for various regions, but similar to risks from external fire, a complete performance-based assessment methodology should include this capability.	
NC6	**Develop capability to consider losses to an individual building from soil movement**	
	This issue is related to Topic MA 7, calling for improved methods to predict these damages. Liquefaction and lateral spreading is often considered to be not a life safety risk, but clearly will create repair costs and possibly downtime. Landsliding from the site downward, or above the site is also a potential life safety risk. Methods to estimate these risks in the performance-based format need to be developed.	

SHORT TERM CATEGORY		
No.	**Task**	**Priority**
ST1	**Improve usefulness of existing performance levels by relating them more to owner concerns.**	
	Discrete performance levels in common use often fall short of providing meaningful information to owners and engineers. For example, “life safety” addresses the potential for life loss, but does not provide quantitative data regarding expected damage or repairs. “Collapse Prevention” is based on component assessment rather than explicit evaluation of collapse. Refinements and advancements are needed to improve the usefulness of current procedures.	
ST2	**Clarify and coordinate translation of test results to performance levels.**	
	Performance levels and acceptance criteria embedded in current evaluation methodologies (e.g. ASCE 41) are generally based on research conducted over a decade ago. That limited research data required considerable interpretation to create acceptance criteria. The process of extracting acceptance criteria from test data is not well documented, and is not consistent among materials and systems. Consistent rules are needed to guide future researchers in designing tests, and to achieve parity among materials. In addition, recent research should be used to validate or update published acceptance criteria.	
ST3	**Develop benefit cost relationships among various discrete performance levels.**	
	The value of performance-based engineering is the improved ability to successfully communicate risk and define options for mitigation. At present there are no tools consistently applied for this purpose. Tools are needed to enable engineers to convey the implications of designing or retrofitting to achieve different levels of performance.	
ST4	**Add probabilistic concepts to current PBSD.**	
	Current procedures in widespread use enable engineers to determine whether acceptable performance can be expected for a given level of seismic excitation. The procedures do not account for the inherent uncertainties in the prediction of losses due to earthquakes. Unrealistic expectations can result.	
ST5	**Improve procedures for the selection and scaling of earthquake ground motions and the interpretation of results from response history analyses.**	
	Errors in ground motion assumptions can overshadow the accuracy of analytical performance predictions. Proper and consistent rules for the section of ground motions are needed. In addition, guidance on proper techniques for conducting response history analyses is lacking.	
ST6	**Improve analytical models and demand assessment capabilities for buildings in near-collapse seismic loading.**	
	In current performance-based assessment approaches, a prevalent performance objective is collapse prevention for maximum considered earthquake shaking. Collapse assessment is usually accomplished by dynamic analysis that does not directly simulate collapse, with collapse assessed indirectly based on the calculated demands. The current methods are necessarily approximate and usually conservative. Development of reliability-based methods to assess appropriate levels of demands, given the inherent dispersion, would result in more consistent and reliable assessment of the Collapse Prevention performance objective.	

ST7	**Benchmark current performance-based design methodologies.**	
	Current performance-based seismic design methodologies are intended to achieve desired limited levels of damage, def ned in terms of standardized structural and nonstructural performance levels, at different design intensities. These procedures are widely used and have been standardized as ASCE 41-06 (ASCE, 2006). The basis for these procedures was developed in the mid-1990s through the collaborative efforts of researchers and practitioners using a synthesis of available research data. During development, the results from the procedures were compared with documented building performance and with code procedures for design of new buildings in selected case studies; however, these studies were not comprehensive and contradictions were not reconciled. Results of the ASCE 41 procedures are currently perceived to be conservative, but there has been no systematic effort to critically examine the performance predicted by the procedures, compare them with other evaluation and design methodologies, or thoroughly investigate inconsistencies. Such an effort is needed to gain conf dence in current performance-based design methodologies.	

Table 3, RESEARCH TOPICS WORKSHOP BALLOT SUMMARY

RESEARCH TOPICS		VOTING RESULTS					
No.	Task	9s	8s	7s	<7s	Average	Rank
MA 8	Develop representative losses for primary categories of code-designed buildings to enable selection of appropriate performance goals for the building code and to test consistency of current procedures.	20	8	1		8.7	1
F 2	Generate data through testing for developing structural fragilities.	20	6	2		8.6	2
ST7	Benchmark current performance-based design methodologies.	18	5	2		8.6	3
MA 2	Improve analytical models and simulation capabilities for buildings in near-collapse seismic loading.	18	9	3		8.5	4
ST6	Improve analytical models and demand assessment capabilities for buildings in near-collapse seismic loading.	18	9	1	1	8.5	5
F 8	Develop plan (data and funding) to collect and store loss data from future earthquakes.	18	6	6		8.4	6
F 3	Generate data through testing for developing nonstructural fragilities.	15	9	4		8.4	7
F 7	Create curated database related to performance-based engineering that could include raw data, fragilities, and loss functions related to structural, nonstructural, and soils and foundation systems.	15	10	5		8.3	8
MA 6	Improve modeling and analysis procedures for soil-foundation-structure interaction including determination of dynamic base, input of earthquake ground motions, damping, and soil-foundation stiffness/strength.	13	12	5		8.3	9
F4	Develop protocol for testing and documentation of results to enable development of consequence functions for both structural and nonstructural systems and components.	12	13	5		8.2	10
MA 1	Develop improved models and simulation procedures to include more realistic damage simulation.	13	11	6		8.2	11
F 5	Develop consequence functions for structural and nonstructural systems where not available.	14	8	8		8.2	12
ST 5	Improve procedures for the selection and scaling of earthquake ground motions and the interpretation of results from response history analyses.	9	16	4		8.2	13
F 1	Obtain historical testing data (much may be proprietary) from testing labs for development of fragilities.	11	13	6		8.2	14
G 6	Improve understanding of all aspects of ground motion and time histories with increased instrumentation.	11	11	8		8.1	15
ST 2	Clarify and coordinate translation of test results to performance levels.	13	9	5	2	8.1	16
MA 7	Improve ability to predict damage to structures and contents from soil movements including liquefaction, lateral spread, landslide, and soil failure at foundations.	10	10	9		8.0	17
G 5	Improve ability to predict soil movement including liquefaction, lateral spread, landslide, and soil failure at foundations.	8	14	8		8.0	18

RESEARCH TOPICS		VOTING RESULTS					
No.	Task	9s	8s	7s	<7s	Average	Rank
NC 6	Develop capability to consider losses to an individual building from soil movement	10	9	11		8.0	19
MA 3	Expand sensitivity analyses to determine where the greatest uncertainties and needs are in the seismic performance assessment process.	7	14	9		7.9	20
F 9	Enter existing related loss data into database.	7	13	9		7.9	21
G 4	Improve understanding/modeling of how local soil conditions modify ground shaking.	9	9	12		7.9	22
G 3	Identify new ground motion characteristics or parameters that will improve correlation with nonlinear structural response and damage.	5	16	9		7.9	23
G 2	Improve the generation, selection, and scaling of simulated ground motions.	7	11	12		7.8	24
NC 3	Develop capability to consider losses from water damage from broken pipes or tanks.	6	13	11		7.8	25
ST 4	Add probabilistic concepts to current PBSD.	10	8	9	2	7.8	26
F 6	Conduct in-situ testing of the behavior of existing buildings, including those slated for demolition.	8	10	10	1	7.8	27
F 10	Beyond test data, develop analytical fragilities to extend fragility databases.	6	9	14		7.7	28
NC 2	Develop capability to consider post-earthquake fire damage from sources external to the building.	3	9	17	1	7.4	29
MA 4	Develop procedures to enable to use EDPs in addition to drift and floor accelerations.	3	8	17	1	7.4	30
G 1	Improve seismic hazard data and models including attenuation models.	1	9	19		7.4	31
ST 1	Improve usefulness of existing performance levels by relating them more to owners' concerns.	1	11	16	1	7.4	32
NC 5	Develop capability to consider losses associated with an individual building from loss of utilities.	0	10	20		7.3	33
MA 5	Develop methods to consider dynamic soil pressure in buildings.	3	3	23		7.3	34
ST 3	Develop benefit cost relationships among various discrete performance levels.	2	6	19	2	7.2	35
NC 1	Develop capability to consider post-earthquake fire damage from sources internal to the building.	1	4	24	1	7.1	36
NC 4	Develop capability to consider losses from internal releases of hazardous materials.	0	5	21	3	7.0	37

Clarification and Consolidation of Research Topic List

- ST separated into “ASCE 41” category”
- Low scoring ST (1, 3, and 4) dropped because short term topics determined to be lower priority are unlikely to have an impact.
- MA2 and ST6 were combined into ST6
- Certain NC items of “not considered” were voted as not important to consider and will be dropped (NC1, NC4, and NC5)
- MA8 and ST7 are very similar but are both kept as high priority
- Fragilities are separated into one group of highest priority and one group of high priority.

This leaves four ASCE 41 topics (one priority group of highest priority) and twenty-six ATC 58 topics (broken into two groups, one also labeled highest priority and one high priority).

MA7 and G5 and NC6 are all related to soil movement and should be connected somehow.