Next-Generation Performance-Based Seismic Design Guidelines

Program Plan for New and Existing Buildings

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Foreword

One of the primary goals of the Department of Homeland Security's Federal Emergency Management Agency (FEMA) is prevention or mitigation of this country's losses from hazards that affect the built environment. To achieve this goal, we as a nation must determine what level of performance is expected from our buildings during a severe event, such as an earthquake, blast, or hurricane. To do this, FEMA contracted with the Applied Technology Council (ATC) to develop next-generation performance-based seismic design procedures and guidelines, which would allow engineers and designers to better work with stakeholders in identifying the probable seismic performance of new and existing buildings. These procedures could be voluntarily used to: (1) assess and improve the performance of buildings designed to a building code "life safety" level, which would, in all likelihood, still suffer significant structural and nonstructural damage in a severe event; and (2) more effectively meet the performance targets of current building codes by providing verifiable alternatives to current prescriptive code requirements for new buildings.

This FEMA 445 Program Plan builds on earlier plans developed for FEMA by the Earthquake Engineering Research Institute, and the Earthquake Engineering Research Center. As a basis for this plan, FEMA 349 (EERI, 2000) provided a description of the key activities necessary for developing performance-based seismic design criteria, and FEMA 283 (EERC, 1996) emphasized the research that would be required.

This Program Plan is based on the results of a workshop soliciting the input of the nation's leading seismic professionals in preparing a long-term plan to develop new performance-based seismic design procedures. It does an excellent job of capturing the recommendations from that workshop and describing the necessary requirements. Execution of the plan, however, is contingent upon funding, and FEMA had concerns regarding the availability of funding at the levels necessary to achieve the ambitious goals outlined in the plan. As a result, FEMA and ATC developed a reduced scope and extended schedule under which the program could proceed with less than full funding. This Program Plan includes the projected costs for both the original and modified-scope programs.

Publication of this Program Plan does not obligate FEMA or any other federal agency to any portion of the plan contained herein. The information and opinions contained in this Program Plan are solely those of the project participants, and do not necessarily represent the views of FEMA.

FEMA wishes to express its sincere gratitude to all who were involved in this project and in the development of this Program Plan. The result of their hard work and dedication will play an important role in helping the nation move towards performance-based seismic design and reducing losses suffered by the citizenry in future earthquakes.

—Federal Emergency Management Agency

Preface

Advancement of present-generation performance-based seismic design procedures is widely recognized in the earthquake engineering community as an essential next step in the nation's drive to develop resilient, loss-resistant communities. This Program Plan offers a step-by-step, task-oriented program that will develop next-generation performance-based seismic design procedures and guidelines for structural and nonstructural components in new and existing buildings.

This FEMA 445 Program Plan is a refinement and extension of two earlier FEMA plans: FEMA 283 *Performance-Based Seismic Design of Buildings – an Action Plan*, which was prepared by the Earthquake Engineering Research Center, University of California at Berkeley in 1996, and FEMA 349 *Action Plan for Performance Based Seismic Design*, which was prepared by the Earthquake Engineering Research Institute in 2000. The state of practice for performance-based assessment, performance-based design of new buildings, and performance-based upgrades of existing buildings will all be significantly advanced under this Program Plan.

The preparation of this Program Plan, and developmental work completed to date, has been performed by the Applied Technology Council (ATC) under the ATC-58 project entitled *Development of Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings*. The technological framework developed under this program is transferable and can be adapted for use in performance-based design for other extreme hazards including fire, wind, flood, and terrorist attack. The decision-making tools and guidelines developed under this Program Plan will greatly improve our ability to develop cost-effective and efficient earthquake loss reduction programs nationwide.

Christopher Rojahn, ATC Executive Director

Acknowledgments

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The Project Management Committee consisted of Christopher Rojahn (Chair), Ronald O. Hamburger (Co-Chair), Peter J. May, Jack P. Moehle, Maryann T. Phipps (ATC Board Representative), and Jon Traw. The Structural Products Development Team consisted of Andrew Whittaker (Team Leader), Gregory Deierlein, Andre Filiatrault, John Hooper, and Andrew T. Merovich. The Nonstructural Performance Products Team consisted of Robert E. Bachman (Team Leader), David Bonowitz, Philip J. Caldwell, Andre Filiatrault, Robert P. Kennedy, Gary McGavin, Eduardo Miranda, and Keith Porter. The Risk Management Products Team consisted of Craig D. Comartin (Team Leader), Brian J. Meacham (Associate Team Leader), C. Allin Cornell, and Charles Kircher. Project Steering Committee members consisted of William T. Holmes (Chair), Daniel P. Abrams, Deborah B. Beck, Randall Berdine, Roger D. Borcherdt, Jimmy Brothers, Michel Bruneau, Terry Dooley, Mohammed Ettouney, John Gillengerten, William J. Petak, Randy Schreitmueller, and James W. Sealy. Jon A. Heintz served as Report Editor, and Peter N. Mork produced the camera-ready document. The affiliations of these individuals are provided in the list of project participants at the end of this report.

Input to this Program Plan was provided by a broad range of earthquake engineering specialists during a FEMA-sponsored workshop conducted by ATC in February 2003. Participants included researchers and practicing structural engineers as well policy makers and regulators. The sage advice provided by these individuals substantially influenced the direction and scope of this Program Plan.

The vision, insight, and patience provided by the FEMA Project Officer, Michael Mahoney, and the FEMA Technical Monitor, Robert D. Hanson, are also gratefully acknowledged.

Executive Summary

The Applied Technology Council (ATC), under the sponsorship of the Department of Homeland Security's Federal Emergency Management Agency (FEMA), is currently engaged in a project to advance the state of practice in performance-based seismic design. This report, FEMA 445 Program Plan, offers a step-by-step, task-oriented program that will develop next-generation performance-based seismic design procedures and guidelines for structural and nonstructural components in new and existing buildings. The preparation of this Program Plan, and developmental work completed to date, has been performed under the ATC-58 project entitled *Development of Next-Generation Performance-Based Seismic Design Guidelines for New and Existing Buildings*.

This Program Plan offers background on current code design procedures, introduces performance-based seismic design concepts, identifies improvements needed in current seismic design practice, and outlines the tasks and projected costs for a two-phase program to develop next-generation performance-based seismic design procedures and guidelines. This plan is a refinement and extension of two earlier FEMA plans: FEMA 283 *Performance-Based Seismic Design of Buildings – an Action Plan*, which was prepared by the Earthquake Engineering Research Center, University of California at Berkeley in 1996, and FEMA 349 *Action Plan for Performance Based Seismic Design*, which was prepared by the Earthquake Engineering Research Institute in 2000.

Building Code Procedures for Seismic Design

Building codes establish minimum requirements for safety through the specification of prescriptive criteria that regulate acceptable materials of construction, identify approved structural and nonstructural systems, specify required minimum levels of strength and stiffness, and control the details of how a building is to be put together. Although these prescriptive criteria are intended to result in buildings capable of providing certain levels of performance, the actual performance of individual building designs is not assessed as part of the traditional code design process. As a result, the performance capability of buildings designed to these prescriptive criteria can be better than the minimum standards anticipated by the code, while the performance of others could be worse.

Performance-based Design

Performance-based seismic design explicitly evaluates how a building is likely to perform, given the potential hazard it is likely to experience, considering uncertainties inherent in the quantification of potential hazard and uncertainties in assessment of the actual building response. It permits design of new buildings or upgrade of existing buildings with a realistic understanding of the risk of casualties, occupancy interruption, and economic loss that may occur as a result of future earthquakes.

It also establishes a vocabulary that facilitates meaningful discussion between stakeholders and design professionals on the development and selection of design options. It provides a framework for determining what level of safety and what level of property protection, at what cost, are acceptable to building owners, tenants, lenders, insurers, regulators and other decision makers based upon the specific needs of a project.

In contrast to prescriptive design approaches, performance-based design provides a systematic methodology for assessing the performance capability of a building, system or component. It can be used to verify the equivalent performance of alternatives, deliver standard performance at a reduced cost, or confirm higher performance needed for critical facilities.

First-generation procedures introduced the concept of performance in terms of discretely defined performance levels with names intended to connote the expected level of damage: Collapse, Collapse Prevention, Life Safety, Immediate Occupancy, and Operational Performance. They also introduced the concept of performance related to damage of both structural and nonstructural components. Performance Objectives were developed by linking one of these performance levels to a specific level of earthquake hazard. Although intended for existing buildings, these procedures are being extrapolated for use in the performance-based design of new buildings.

The Need for Next-Generation Procedures

As the state of knowledge and experience base advances, limitations in present-generation procedures are being identified by researchers and practitioners. These include questions regarding the accuracy of analytical procedures in predicting actual building response, questions regarding the level of conservatism present in acceptance criteria, the inability to reliably and economically apply performance-based procedures to the design of new buildings, and the need for alternative ways of communicating performance to stakeholders that is more meaningful and useful for decision-making purposes. Next-generation performance-based design procedures are needed to:

- Revise the discrete performance levels defined in first-generation procedures to create new performance measures (e.g. repair costs, casualties, and time of occupancy interruption) that better relate to the decision-making needs of stakeholders, and that communicate these losses in a way that is more meaningful to stakeholders.
- Create procedures for estimating probable repair costs, casualties, and time of occupancy interruption, for both new and existing buildings.
- Develop a framework for performance assessment that properly accounts for, and adequately communicates to stakeholders, limitations in our ability to accurately predict response, and uncertainty in the level of earthquake hazard.

Framework for Next-Generation Procedures

The next-generation performance-based seismic design procedures developed under this Program Plan will express performance directly in terms of quantified risks that a building owner or decision maker will

be able to understand. Stakeholders prefer to define these risks in terms of the potential for casualties, repair costs, and occupancy interruption. Stakeholder guidance will be developed to assist decision makers in selecting appropriate levels of risk as the basis of design and upgrade projects. Engineering guidelines will be prepared to assist design professionals in developing building designs that are reliable and capable of meeting the selected risk criteria.

Program Plan

Work under this Program Plan is divided into two phases:

- *Phase 1: Developing a Methodology for Assessing the Seismic Performance of Buildings.* In this phase, a methodology will be developed for assessing the probable seismic performance of individual buildings in future earthquakes.
- *Phase 2: Developing Performance-Based Seismic Design Procedures and Guidelines.* In this phase, seismic design procedures and guidelines will be developed to assist engineers in designing buildings to meet desired performance goals, and to assist stakeholders in taking advantage of the benefits of performance-based design.

Work in each phase is organized around six broad categories of work: Planning and Management Program; Structural Performance Products; Nonstructural Performance Products; Risk Management Products; Guidelines Products; and Stakeholders Guide Products. Work in each technical area will be performed by one of three Product Development Teams, consisting of the Structural Performance Products Team, the Nonstructural Performance Products Team, and the Risk Management Products Team.

Planning and Management Program tasks will be carried out within a project management structure consisting of three committees: Project Management Committee, Project Technical Committee, and Project Steering Committee. Collectively, these committees provide management, technical oversight, and control of the work performed by the three Product Development Teams.

Projected Costs and Schedule

As originally planned, the total projected project costs of Phase 1 and 2 of this Program Plan are estimated to be approximately $21 million in 2004 dollars. Estimates of personnel and other costs were developed using prevailing labor costs common to projects of this type at the time this plan was prepared, and do not include escalation due to changes in the value of money, labor rates, internal government costs, or inflation. Phase 1 has a projected cost of approximately $11 million, and Phase 2 has a projected cost of approximately $10 million. At this funding level, each phase will last approximately five years, and the work of Phase 1 will be substantially complete before Phase 2 begins.

Since available funding was not adequate to support the full Program Plan, a reduced scope and extended schedule was developed under which the program could proceed with less than full funding. Projected costs for the modified-scope program are approximately 50% of those for the original program. Each phase is planned to be accomplished in approximately five to seven years, and Phase 1 has been underway for four years. Phase 2 is planned to begin upon completion of Phase 1.

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