ATC **58-2**

Preliminary evaluation of methods for defining performance

Continued Operations and Continued Occupancy	The Building can continue its operation "almost" immediately Minimal to no damage (Green Emergency Tagging).
Interrupted Operations and Continued Occupancy	Reoccupation of the building is almost immediate and the cost of repair is modest. Limited Damage (Green Emergency Tagging).
Interrupted Operations and Interrupted Occupancy	Reuse of the building is delayed and repair may be costly. Significant damage (Yellow Emergency Tagging).
Life Safety	Reuse of the building is unlikely and it will need to be replaced. Collapse prevention (Red Emergency Tagging).

ATC Applied Technology Council

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Applied Technology Council

The Applied Technology Council (ATC) is a nonprofit, tax-exempt corporation established in 1971 through the efforts of the Structural Engineers Association of California. ATC's mission is to develop state-of-the-art, user-friendly engineering resources and applications for use in mitigating the effects of natural and other hazards on the built environment. ATC also identifies and encourages needed research and develops consensus opinions on structural engineering issues in a non-proprietary format. ATC thereby fulfills a unique role in funded information transfer.

ATC is guided by a Board of Directors consisting of representatives appointed by the American Society of Civil Engineers, the National Council of Structural Engineers Associations, the Structural Engineers Association of California, the Western Council of Structural Engineers Associations, and four at-large representatives concerned with the practice of structural engineering. Each director serves a three-year term.

Project management and administration are carried out by a full-time Executive Director and support staff. Project work is conducted by a wide range of highly qualified consulting professionals, thus incorporating the experience of many individuals from academia, research, and professional practice who would not be available from any single organization. Funding for ATC projects is obtained from government agencies and from the private sector in the form of tax-deductible contributions.

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ATC-58-2

Preliminary Evaluation of Methods for Defining Performance

by

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Preface

In September 2001 the Applied Technology Council (ATC) was awarded a contract by the Federal Emergency Management Agency (FEMA) to conduct a long-term project to prepare next-generation Performance-Based Seismic Design Guidelines for new and existing buildings (ATC-58 Project). The project is to consider and build on the FEMA-349 report, *Action Plan for Performance-Based Seismic Design* (EERI, 2000), which provides an action plan of research and development activities to produce and implement design guidelines that specify how to design buildings having a predictable performance for specified levels of seismic hazard. Ultimately FEMA envisions that the end product from this overall project will be design criteria for performance-based seismic design that could be incorporated into existing established seismic design resource documents, such as the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (BSSC, 2001), the FEMA 273 *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997), and its successor document, the FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE, 2000).

The ATC-58 Project is being conducted in several phases, as resources become available. To date in Phase 1, which commenced in late 2001, ATC developed a management process for the project, identified and engaged key project management and oversight personnel, developed a project Work Plan, developed a report on performance characterization, and conducted two workshops to obtain input on project needs and goals.

This report documents the results of an initial effort on the ATC-58 project to develop recommendations for the characterization of performance. The recommendations are based on findings emanating from an ATC-58 Workshop on Communicating Earthquake Risk, which was held in Chicago, Illinois, on June 18, 2002, and on discussions amongst the ATC-58 project participants.

The Applied Technology Council gratefully acknowledges the ATC-58 Product One Development, who authored this report, and the ATC-58 Project Management Committee and ATC-58 Steering Committee, who guided its development. The ATC-58 Product One Development Team consisted of Ronald Mayes (Team Leader), Daniel Alesch, Bruce Ellingwood, and James Malley. Membership on the ATC-58 Project Management Committee consists of Christopher Rojahn (Project Executive Director), Ronald Hamburger (Project Technical Director), Peter May, Jack Moehle, Maryann Phipps (ATC Board Representative), and Jon Traw. The ATC-58 Steering Committee is chaired by William Holmes and its membership consists of Daniel Abrams, Randall Berdine, Roger D. Borcherdt , Michel Bruneau, Mohammed Ettouney, John Gillengerten, William Petak, Joe Sanders, Randy Schreitmueller, and James Sealy. The affiliations of these individuals are provided in the List of Project Participants.

ATC also gratefully acknowledges the financial support provided by the Federal Emergency Management Agency and the guidance and oversight provided by Michael Mahoney (FEMA Project Officer) and Robert Hanson (FEMA Technical Consultant).

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Executive Director

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Chapter 1

Introduction

1.1 Background

Presently, seismic code requirements are based on “life safety”, meaning their goal is to prevent the loss of life or life-threatening injury to building occupants or pedestrians, primarily by preventing building collapse. During a design-level earthquake, buildings designed to such codes could suffer significant structural and nonstructural damage, possibly to the point of having to be demolished. However, as long as a building does not collapse during an earthquake or generate large quantities of heavy falling debris, it meets the intent of current code design requirements. While this may be an acceptable minimum design level for many types of buildings, it is not adequate for certain occupancies, such as critical facilities or buildings where the owner wants to have damage limited to either a repairable level or have the facility functional immediately after an earthquake. As has been vividly demonstrated during recent earthquakes, even well designed buildings conforming to contemporary codes can perform as specified and still be unfit for normal occupancy and use for an extended period of time following an earthquake, as a result of both structural and nonstructural damage and the necessary repair operations.

Recognizing the need to advance the technology of performance-based design, the Federal Emergency Management Agency (FEMA) provided funding in 1993 to the Earthquake Engineering Research Center (EERC) at the University of California at Berkeley to conduct a project on FEMA’s behalf to suggest the requirements for a program to develop performance-based seismic design guidelines for buildings. With the input of a panel of leading earthquake engineers and structural researchers, EERC recommended a six-year program of research and development with an estimated implementation cost of $32 million (1995 dollars). These recommendations were published in the FEMA 283 report, *Performance Based Seismic Design of Buildings* (EERC, 1996). Prior to funding such a major initiative, FEMA turned to the Earthquake Engineering Research Institute (EERI) for confirmation that the proposed program was appropriate. EERI followed a process very similar to that undertaken by EERC, though somewhat broader community participation was obtained. The EERI project also culminated in the development of an action plan published in April 2000 as the FEMA 349 report, *Action Plan for Performance-Based Seismic Design*. The FEMA-349 plan extended over an implementation period of ten years and required funding in amounts ranging from $20 to $27 million (1998 dollars).

The FEMA 349 *Action Plan* calls for the establishment of a mechanism for characterizing different levels of seismic performance for different seismic hazard conditions and building characteristics as well as quantification of more reliable building performance characteristics. The *Action Plan* also notes that the primary goal of performance-based seismic design is the development of building design criteria that would give a building owner or regulator the ability to select a building's expected performance for a specific earthquake hazard. A secondary goal is to develop the most reliable method of predicting a given building’s response to a given ground motion.

In 2001 FEMA contracted with the Applied Technology Council to use the FEMA 349 *Action Plan* as the basis for carrying out a long-term effort to develop next-generation seismic design guidelines and criteria for new and existing buildings. The project undertaken by the Applied Technology Council to carry out this effort is known as the ATC-58 project.

Ultimately, FEMA envisions that the end product from the ATC-58 project will be design criteria for performance-based seismic design that could then be incorporated into existing established seismic design resource documents, such as the FEMA 368 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (BSSC, 2001), the FEMA 273 *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997), and its successor document, the FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings* (ASCE, 2000). These resource documents could be implemented on a voluntary basis by individual development teams or could be adopted into the provisions of the building codes and become either an alternative or basic minimum standard for the design and upgrade of buildings. Furthermore, when updated to include results from the ATC-58 project, the resulting performance-based design procedures could also be used to improve the reliability/acceptability of prescriptive code procedures.

1.2 Product One Report Development Effort

This Product One Report, which describes the results from one of the initial ATC-58 project activities, is based, in part, on the findings from the ATC-58 Workshop on Communicating Earthquake Risk, which was held in June 2002. This workshop brought together a group of building owners, building users, regulators, underwriters, and financiers with a stake and interest in the successful development and implementation of performance-based seismic design, as well as broader applications of performance-based design technologies. These stakeholders were involved to assist the project team in understanding aspects of seismic risk that are important to this stakeholder community, and that should be directly addressed by performance-based design procedures. The workshop was considered to be the initial effort in the performance of Task 1.2 of the FEMA-349 *Action Plan*.

Based on the input obtained at the workshop, the next task, which corresponds to Task 2.2.1 of the FEMA-349 *Action Plan*, was to develop recommendations for the characterization of performance. This report summarizes initial project activities pertaining to that task.

In addition to considering the performance parameters of significance to stakeholders and users, as expressed by the results of the workshop, the Product One Development Team also considered the need to quantify performance objectively if it is to be predicted, and the establishment of a vocabulary that is useful both to designers and stakeholders. The team met through teleconferences held bi-weekly for 4 months following the workshop and reviewed the performance levels developed in the FEMA 273 *Guidelines for the Seismic Rehabilitation of Existing Buildings*, and its successor document, the FEMA 356 *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, the Vision 2000 Report on *Performance Based Design of New Buildings* (SEAOC, 1995), and the FEMA 350 *Recommended Seismic Design Criteria for New Steel Moment Frame Buildings* (SAC, 2000a).

1.3 Report Contents and Organization

This report has been written to describe existing methods for characterizing performance (for purposes of performance-based seismic design) as well as to provide recommendations for improved performance characterization in the documents that will be forthcoming from the ATC-58 project. Following this introduction is Chapter 2, which describes past efforts to characterize performance for purposes of performance-based seismic design. Chapter 3 focuses on the ATC-58 Workshop on Communicating Earthquake Risk, which was held on June 18, 2002 in Chicago, Illinois. This chapter includes a brief description of the workshop and summaries and assessments of the workshop discussions. Chapter 4 contains the Product One Development Team's recommendations for the development of performance-based seismic design criteria. The recommendations are presented in four subject areas: (1) primary performance metrics; (2) discrete or continuous performance levels; (3) levels of analysis; and (4) risk communication concepts. A report summary and conclusions are provided in Chapter 5.

In addition, the report contains three appendices that provide supplemental information. Appendix A describes performance levels and ranges contained in the FEMA 273 Report, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997). Appendix B discusses performance characterization, as described in the Vision 2000 Report, *Performance Based Design of New Buildings* (SEAOC, 1995). Appendix C describes the performance levels used in the FEMA 350 Report, *Recommended Seismic Design Criteria for New Steel Moment Frame Buildings* (SAC, 2000a), as well as procedures to assign confidence to the probability that damage will exceed that defined for the desired performance level, given a specified level of ground shaking. The report also includes a list of references, a list of project participants, and Applied Technology Council projects and report information.

Chapter 2

Characterization of Performance in Past Performance-Based Seismic Design Efforts

Interest in performance-based seismic design first developed under initiatives to mitigate seismic hazards in the existing stock of buildings. Since few existing buildings meet current code criteria, yet many existing buildings have demonstrated an ability to survive earthquakes with acceptable levels of damage, lack of compliance with codes for new building construction, by itself, has not been considered a compelling reason to upgrade. Rather, decision makers are more likely to commit to upgrade buildings when a projection (evaluation) of future earthquake performance has been made that the decision maker deems unacceptable. Such decision makers naturally request that buildings be upgraded to provide acceptable performance, which, by nature, will vary from decision maker to decision maker. In recognition of this, the ATC project team that developed the FEMA-273 Report, *NEHRP Guidelines for Seismic Rehabilitation of Buildings*, developed rudimentary performance-based evaluation and upgrade design procedures that provided the decision maker and design team with a menu-approach to selection of appropriate performance objectives for individual projects.

As published in the FEMA-273 Report (ATC/BSSC, 1997) and the FEMA-356 report (ASCE, 2000), a series of standard performance outcomes, termed performance levels, were established; these are summarized in Appendix A. These performance outcomes related to outcomes such as earthquake-induced building collapse (or collapse prevention), onset of earthquake-induced building damage that could pose a hazard, and postearthquake building operability. The decision maker is asked to select one or more of these performance outcomes, and a ground-motion event or hazard level for which this performance is to be achieved. The designer is provided with a procedure that is intended to allow determination as to whether these various performance levels are exceeded for the selected design hazard. Although the FEMA 273/356 procedures are rational and clearly performance-based, they do have shortcomings. First, the procedures do not directly address control of economic losses, one of the most significant decision maker concerns. Also, the procedures are focused on assessing the performance of the individual structural and nonstructural components that comprise a building, as opposed to the global performance of the building as a whole. Perhaps most significantly, the reliability of the procedures in delivering the design performance has not been characterized. Many engineers who have applied the procedures believe that they are excessively conservative and result in unwarranted rehabilitation measures. On the other hand, because the reliability of the procedures has never been quantitatively and rationally evaluated, it is possible that instead of being too conservative, the procedures do not adequately provide the performance capability expected by the decision makers. It is likely that both outcomes are true for different types of buildings.

Concurrent with the development of performance-based design procedures for seismic rehabilitation, the structural engineering community also became interested in the development of performance-based procedures for design of new construction. This was spurred in part by the large economic losses experienced in the 1989 Loma Prieta, California, earthquake. Although that event caused few life threatening hazards in modern buildings, it resulted in an estimated $7 billion of economic loss. Many judged that these losses were excessively high for a relatively moderate and distant event, and that design procedures should be developed that would both permit and encourage the construction of facilities that were less vulnerable to economic loss. These interests were intensified by the $30 billion economic loss that occurred in the 1994 Northridge, California, earthquake. Many observed that although building codes appeared to protect life safety, they did not provide sufficient protection of the public's economic welfare.

In 1994, using funds provided by FEMA in response to the 1994 Northridge earthquake, the Structural Engineers Association of California (SEAOC) undertook a project to develop a framework for performance-based design procedures for new construction. Known as the Vision 2000 Project, this SEAOC effort extended some of the FEMA 273 concepts to new building design and also popularized the concept of performance-based design within the design community. This effort was spurred on by a series of international workshops, as well as efforts in other countries to explore the development of performance-based design approaches. The performance objectives recommended by SEAOC (1995) in the Vision 2000 report, *Performance Based Seismic Engineering of Buildings,* were eventually adopted into the Commentary to the 1997 Edition of the *NEHRP Recommended Provisions for Seismic Regulation for New Buildings and Other Structures* (BSSC, 1998), as a means of quantifying the performance intent of the building codes. The performance objectives described in the Vision 2000 Report are summarized in Appendix B. The Japanese revised their *Building Standards Law* to encompass many of the recommendations contained in the Vision 2000 Report and some corporations began to request designs using the Vision 2000 approach to performance definitions. Unfortunately, the Vision 2000 Report, which was largely based on the technology contained in FEMA 273, is subject to the same limitations as that document (and the successor FEMA 356 Report).

In response to unanticipated damage sustained by moment-resisting steel frames in the Northridge earthquake, FEMA sponsored the SAC Program to Reduce Seismic Hazards in Steel Moment Frame Buildings, which was carried out by the SAC Joint Venture, a partnership of the Structural Engineers Association of California, the Applied Technology Council, and California Universities for Research in Earthquake Engineering (now known as the Consortium of Universities for Research in Earthquake Engineering). This project developed specific design and rehabilitation criteria for steel moment-frame structures that extended the performance-based design techniques contained in FEMA 273/356. The design recommendations from this six-year, $12 million project were published as the FEMA 350 report, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*, and the FEMA 351 report, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*. These recommended design criteria specifically quantified performance in terms of the global behavior of buildings, as well as the behavior of individual components, and also incorporated a formal structural reliability framework to characterize the confidence associated with meeting intended performance goals. Although the FEMA/SAC criteria represent significant technical improvements to the performance-based design approach established in FEMA 273/356, many engineers have stated a belief that these new procedures are excessively complex for routine implementation on projects. Furthermore, the effort required to extend the FEMA/SAC approach to the broader class of structural systems used in modern construction would significantly exceed that proposed in either the FEMA 283 report, *Performance-Based Seismic Design of Buildings – An Action Plan for Future Studies* (FEMA, 1996), or the FEMA-349 report, *Action Plan for Performance Based Seismic Design* (EERI, 2000). The SAC performance objectives and the steps to achieve them are summarized in Appendix C.

Chapter 3
Summary of Findings from Workshop on Communicating Earthquake Risk

3.1 Introduction

The ATC-58 Workshop on Communicating Earthquake Risk was held in Rosemont, Illinois on June 18, 2002 and the results are reported in the ATC-58-1 Report, *Proceedings of FEMA-Sponsored Workshop on Communicating Earthquake Risk* (ATC, 2002). The purpose of the workshop was to obtain preliminary feedback from a cross section of building stakeholders, including real estate developers, building owners, corporate tenants, lenders, insurers and other interested parties as to how performance-based seismic design guidelines can most usefully deal with issues of earthquake risk. In particular, the workshop dealt with three important issues:

- identification of those aspects of earthquake-related risk that are of most concern to the stakeholders;
- appropriate means to communicate the low-probability but potentially significant consequences of earthquakes; and
- appropriate means to communicate the considerable uncertainties associated with prediction of the effects of earthquakes and the performance of individual affected structures.

The Workshop was attended by members of the ATC-58 Project Management Committee, the Project Steering Committee, and the Product One Development Team, whose members served as recorders for the several breakout sessions, and representatives of the Federal Emergency Management Agency. In addition, the workshop was attended by a select group of invited participants selected to represent specific stakeholder communities. A complete list of attendees is contained in Appendix A of the ATC 58-1 Report. Together, the workshop attendees included representatives of the following stakeholder communities:

- attorneys;
- building design professionals including architects and engineers;
- building regulators;
- corporate facilities managers;
- commercial real estate developers;
- commercial lenders;
- university facility managers;
- development planning consultants;
- earthquake engineering researchers;
- federal government facility managers;
- healthcare providers;
- property underwriters; and
- social scientists.

While a number of important stakeholder groups were represented at the workshop, generally, each stakeholder group was represented by only one or two individuals. Several important stakeholder groups, notably residential and institutional building owners and retailers were not represented at all. Nevertheless, it is felt that the results of the workshop provide insight into the needs and preferences of the general stakeholders of performance-based engineering.

3.2 Workshop Focus

The workshop was organized around two key activities. The first involved each participant answering a series of prepared questions on earthquake risk issues. In the second, the participants were divided into three groups and each group discussed the answers they had to given to each of the questions. Following the group discussions the participants could change their answer to any question. The Product One Development Team members acted as recorders to each of the discussion groups and kept detailed notes on the discussions that occurred. The statistical summaries of the participants' answers to each of the questions are included herein and the Product One Development Team's assessment of the group discussions follow the statistical summary.

One of the global issues arising from the workshop was the extent to which the stakeholder group in attendance at the workshop in Chicago represented the broader community. Because workshop attendees did not include representation from all building owner groups, it is recommended that the actual statistical results be taken as indicative of trends that would be likely to result from a larger group of stakeholders. The notes taken during the group discussion proved to be helpful in differentiating the opinions of design professionals and other stakeholders and these differences are noted in the Product One Development Team's assessments described below.

Another global issue that arose was related to the confidence level used in many of the questions. It was clear from the stakeholders' input during the discussion groups that, wherever possible, only one confidence level should be used in a performance based design criteria. It is not clear when that decision should be made but there are good arguments for the use of either a 90% confidence level or an 85% confidence level. The arguments for the 90% level are that it is used in current Probable Maximum Loss (PML) studies and it was used in the FEMA/SAC recommendations. The argument for the 85% level is that it represents (approximately) the mean standard deviation. The Product One Development Team recommends that 90% be the highest confidence level considered for communication with non-technical stakeholders; this could be synonymous and interchangeable with "We are very confident that……".

There were three other global issues that arose from the group discussion that were not necessarily reflected in the response statistics. The first was a strong preference for expressing uncertainty in terms of ranges rather than confidence intervals. These are not necessarily mutually exclusive, especially if stakeholders understand up front that the "range" corresponds to a "90% (or 85%) confidence interval." Second, there was a significant difference in the response between non-engineers and engineers with regard to the definition of events. The non-engineering stakeholders had a strong preference for "scenarios" rather than "hazard curves" or "event probabilities." The feeling was that with a "scenario," one knows what one has to deal with in decision making, whereas "probabilities" gave wiggle room. Finally, it was the Product One Development Team's assessment that there was no one method of communicating the results of a performance-based design (PBD) study that was better than others. The preferred method would be strongly dependent on the stakeholder group, as the perceptions of building owners, facility managers, corporate risk managers, and government agencies appear to be quite different. These are elaborated below.

3.3 Workshop Questions and Responses

In the sections that follow, each question that was asked at the workshop is presented along with the statistical results from all the workshop participants. In all questions except that listed in Section 3.3.1 the attendees were asked to check their choice of several options that was most important to them. The results are expressed as a percentage of the total response, followed by the Product One Development Team's assessment of the group discussion that resulted on each question.

3.3.1 Potential Impacts

In this question each attendee was asked to rank the importance of seven potential earthquake impacts, with 1 being the most important and 7 the least important. The results are presented in Table 3-1, where the mean ranking is presented in the first column and the number in ( ) provides the inferred order of ranking.

Product One Development Team Assessment. Life safety is a fundamental issue and must be the basis of the lowest performance level in PBD. The Product One Development Team was prepared to accept this premise and focus on other issues. The team was surprised, however, at how little attention was paid to life safety in

Table 3-1 Ranking of Potential Earthquake Impacts

Mean rank	Inferred order of rank	Potential Impacts
2.0	(1)	Avoiding loss of life
3.0	(2)	Avoiding serious injuries
3.7	(4)	Minimizing the potential for financial ruin due to combined effects of business interruption, lost capital, repair costs, and employee costs.
4.0	(4)	Avoiding long-term interruption of facility functions or occupancy
4.3	(4)	Avoiding the total physical loss of a building or facility
5.0	(5)	Assuring continuous facility normal-use function or occupancy
6.0	(6)	Minimizing repair costs

the working group discussions and hypothesized that this was because recent US earthquakes had very few deaths and the attendees accepted that present codes and standards were already achieving this performance goal. There seemed to be a distinct difference between the views of engineers and other stakeholders. Engineers were more focused on life safety and liability issues whereas economic viability was much more important to the stakeholders. The cost of interrupted service and the prospects of financial ruin were recurring themes, especially among the representatives of the business community. A distinction between individual risk and community risk was also identified.

3.3.2 Life Safety Performance Choices

In this question, attendees were asked to select the preferred life-safety performance choices. Their responses are presented in Table 3-2.

Product One Development Team's Assessment. This was a poorly worded question and nothing useful came out of the group discussion. The answer to this question depends on the number of occupants and the building size.

Table 3-2 Life Safety Performance Choices

Percentage of Participants Choosing the Response	Response Choices
22%	Reducing the probability of the loss of any life by 5 percent
74%	Reducing the number of serious, life-threatening injuries by 20 individuals
4%	Reducing the number of less serious, non-life-threatening injuries by 150 individuals

3.3.3 Functionality Performance Choices

This question focused on functionality performance choices. Attendee responses are presented in Table 3-3.

Table 3-3 Functionality Performance Choices

Percentage of Participants Choosing the Response	Response Choices
52%	Reduce the time basic utility services (power, water) are not available (hindering critical operations) by 24 hours
17%	Reduce the time required to secure the facility for safe access to retrieve contents and begin repairs by 36 hours
30%	Reduce the time that it takes to restore full functions by 5 days

Product One Development Team's Assessment. The highest priority here is clearly more regional than building specific, but it would be important for utility companies to know if a number of businesses have opted for higher performance in their buildings. The Product One Development Team was not sure how this issue should be addressed, but it is an important issue if an owner chooses the operational performance option. Should one of the criteria for the operational performance level be on-site back-up power and water? Although it did not receive a high rating the group discussions revealed that the ability to retrieve contents from a building was important. The choices are occupant-dependent; business interruptions in certain key industries would impact the entire community and lead to wide-spread financial insolvency.

3.3.4 Repair Performance Choices

This question focused on repair performance choices. The results are presented in Table 3-4.

Table 3-4 Repair Performance Choices

Percentage of Participants Choosing the Response	*Response Choices*
35%	Reduce the costs of repairing the structure by 25 percent
35%	Reduce the odds that the earthquake will result in financial insolvency (ruin) by 5 percent
26%	Reduce the losses due to business interruption resulting from earthquake damage and repair operations by 10 percent
4%	Reduce the probability that the facility cannot be repaired by 20 percent

Product One Development Team's Assessment. There is some consistency in the responses to this question and the views expressed in Tables 3-2 and 3-3. Collectively these three questions seem to be related to the interpretation of a performance-based design being a continuous function (if one were available) rather than being part of performance-based design criteria. Stakeholders want as much information as possible for decision making. This discussion reinforced the notion that performance-based design should produce as much information as possible with regard to alternate methods of expressing performance

3.3.5 Loss of Life

This question solicited loss-of-life information presentation choices. The response results are presented in Table 3-5.

Table 3-5 Loss of Life: Information Presentation Choices

Percentage of Participants Choosing the Response	*Response Choices*
22%	Expected number of lives that will be lost
43%	The probability of any loss of life
22%	The probability that the number of lives lost will exceed X (where you specify the threshold level X in advance)
13%	The average number of lives expected to be lost per year

Product One Development Team's Assessment. This question initiated the Product One Development Team's first discussion on the very poor reception that annualized losses of any kind received. It is recommended that annualized losses not be used in communicating with the majority of the stakeholders. It may be appropriate for those stakeholders familiar with the concept (e.g. insurance companies) but for others it conveyed the wrong impression of the risk, which they believe is a significant but relatively infrequent event. Participants also wanted to be aware of their full exposure, should a scenario-type event occur. Furthermore, it is the team's judgment that a target statement including "the expected loss of lives" or "number of lives lost" is politically unacceptable and thus the Product One Development Team recommends that only the 2nd and 3rd choices be considered for use in the performance-based design criteria.

3.3.6 Potential Damage to Facilities

This question solicited information presentation choices regarding potential damage to facilities. The results are presented in Table 3-6.

Product One Development Team's Assessment. The group discussion revealed that the third response choice received the highest rating because it was the most comprehensive with regard to the overall cost impact. The design engineer can provide the information for the first and second response choices but only an owner can develop the information required in the third

Table 3-6 Potential Damage to Facilities: Information Presentation Choices

Percentage of Participants Choosing the Response	*Response Choices*
22%	Probable facility repair cost, expressed as a percentage of the building replacement value
13%	Number of hours or days before full functions can be resumed in the facility
52%	Dollar value of lost business and other costs associated with business interruption
13%	The average annual economic losses per year, expected to occur as a result of earthquakes

response choice. It is recommended that the fourth response choice not be considered for future use for the majority of the stakeholders for the reasons cited in Section 3.3.5.

3.3.7 Potential Repair Costs

This question solicited preferences pertaining to potential repair costs. The results are presented in Table 3-7.

Product One Development Team's Assessment. The use of an absolute cost expressed in terms of a range of repair costs and a probability based expression of repair costs are not mutually exclusive and both should be considered for use. This will avoid the need to differentiate between stakeholders since the first and third response choices were ranked 1 and 2 with the absolute concept being the higher of the two.

3.3.8 Likelihood of Seismic Events

In this question, attendees were asked to provide choices pertaining to the likelihood of seismic events. The results are presented in Table 3-8.

Product One Development Team's Assessment. It is recommended that the first and fourth response choices be eliminated from further consideration. The vast majority of participants expressed a preference that risk be stated with regard to a time frame, and a 20-to-50 year time frame seemed to be reasonable from a

Table 3-7 Potential Repair Costs: Information Presentation Choices

Percentage of Participants Choosing the Response	*Response Choices*
39%	Absolute cost, expressed in present dollars, of repairing the facility to bring it back to full functions
17%	Percentage of replacement costs that repair costs will constitute
26%	The probability that the cost of repairs will exceed Y dollars (where you specify the threshold level Y in advance)
4%	"Risk of ruin" – The likelihood that the costs of repair (and other earthquake costs) will lead to financial insolvency
13%	The average annual expected cost of repair and other earthquake-related losses

Table 3-8 Ways of Presenting Information about the Likelihood of Seismic Events

Percentage of Participants Choosing the Response	*Response Choices*
0%	There is a 2 percent chance in any year of a very damaging earthquake
45%	The probability of a very damaging earthquake over the next 20 years is 33 percent
36%	A very damaging earthquake can be expected, on average, once every 50 years
18%	Although the probability in any year of a very damaging earthquake is low, there is a moderately high probability that such an event will occur within the next 20 years

stakeholders' perspective. The term "very damaging" needs to be more quantitative. It is also recommended that consideration be given to using two time frames in the performance-based design criteria. Life safety considerations could be based on a 50-year period (or longer for structures such as government and University buildings) whereas 20 to 30 years might be used for business interruption considerations. The responses to this question also demonstrate the importance of clear risk communication; note that the first and third response choices are identical from a risk point of view, and yet the first choice was preferred by 0% of participants, while the third choice received 36% support.

3.3.9 Time Frame for Facility Investment Decisions

This question solicited preferences for presenting information regarding the number of years most appropriate to the "planning horizon" for making investments in facilities. The results are provided in Table 3-9.

Table 3-9 The Timeframe (Number of Years) Most Appropriate to "Planning Horizon" for Making Investments in Facilities

Percentage of Participants Choosing the Response	*Response Choices*
0%	5 years
9%	10 years
9%	20 years
18%	30 years
23%	50 years
41%	A different "horizon" for each decision, depending on the expected term of commitment

Product One Development Team's Assessment. See the discussion in Section 3.3.8 regarding different time frames for life safety and business interruption related issues. The time frame should be consistent with "historical experience and recollection."

3.3.10 Potential Loss of Life

In this question, attendees were asked to provide preferences pertaining to ways of presenting potential loss of life for a hypothetical structure when fully occupied. Attendee responses are provided in Table 3-10.

Table 3-10 Ways of Presenting Information about Potential Loss of Life for a Hypothetical Structure When Fully Occupied

Percentage of Participants Choosing the Response	*Response Choices*
5%	Over a period of many years, the average expected number of fatalities per year is 1.3.
0%	In any given year there is a 5 percent probability of experiencing one or more earthquake-related fatalities associated with this facility.
36%	In the next 20 years, there is a 25 percent probability of 10 or more earthquake-related fatalities associated with this structure.
50%	If a magnitude 7 earthquake occurs, the expected number of fatalities for this structure is 20.
9%	Given the most severe earthquake likely to occur in the next 100 years, a maximum of fifty lives are expected to be lost in this structure.

Product One Development Team's Assessment. This was one of several issues on which there was a differentiation between the views of engineers and non-engineer stakeholders. The non-engineer stakeholders had quite a strong preference for scenario-type events (fourth response choice) whereas engineers preferred the probability based statement (third response choice). The Product One Development Team believes that these two choices need not be mutually exclusive. The annualized expressions are not recommended for further consideration for the majority of the stakeholders.

3.3.11 Potential Earthquake Losses

This question solicited choices for presenting information about potential earthquake losses (i.e., dollar value of lost business, repair costs, employee costs). The results are presented in Table 3-11.

Table 3-11 Ways of Presenting Information about Potential Earthquake Losses

Percentage of Participants Choosing the Response	*Response Choices*
18%	The annualized expected earthquake-related loss for this facility is $10,000.
55%	The probability of a single earthquake loss exceeding $500,000 in the next 20 years is 33 percent.
27%	The probable maximum loss associated with a major earthquake (expected one time every 500 years) is $6,000,000.

Product One Development Team's Assessment. There seemed to be a preference for the second response choice over the third response choice because of the 20-year time frame. The financial representative liked the PML concept, as this is something with which they are familiar. It is recommended that, if it is possible to develop a continuous loss curve, this would be the most beneficial method of communicating this issue, as it would cover all time horizons. This was the one set of choices where an annualized loss estimation may make some sense for some companies. The annualized number is one that insurance companies and those with large real estate portfolios find of some value. On the other hand, it was noted that annualized losses tend to be relatively small, and because of this may not impact decision making significantly. However, large nonrecurring losses are difficult to make provision for in an extended time frame.

3.3.12 Prediction of Seismic Events

This question solicited preferences for communicating uncertainties about predictions of seismic occurrences. The results are provided in Table 3-12.

Table 3-12 Ways of Communicating Uncertainties about Predictions of Seismic Occurrences

Percentage of Participants Choosing the Response	*Response Choices*
36%	We are 95 percent confident that there is a 30 percent chance of a magnitude 7.0 or greater earthquake in the next 20 years.
50%	The probability of a magnitude 7.0 or greater earthquake occurring in the next 20 years is between 20 percent and 35 percent.
14%	We are very confident that an earthquake of magnitude 7.0 or greater is at least somewhat likely in the next 20 years.

Product One Development Team's Assessment. The discussion groups revealed that the use of two probabilities in one sentence is very difficult to interpret and should not be considered for use. One of the groups was unanimously in favor of the second response choice because of its simplicity. Phrases like "very confident" and "at least somewhat likely" did not appeal to the stakeholder groups and should not be used.

3.3.13 Uncertainties in Economic Losses

In this question, attendees were asked to provide preferences for ways of communicating uncertainties about the potential value of non-life related earthquake losses. The results are provided in Table 3-13.

Product One Development Team's Assessment. It is recommended that both the first and third response choices be considered for use in the performance-based design procedure. One of the discussion groups indicated a strong preference for "ranges" rather than "confidence intervals" as a means for risk communication. The Product One Development Team believes that these two concepts might be combined, with appropriate education and communication.

Table 3-13 Ways of Communicating Uncertainties about the Potential Value of Non-Life Related Earthquake Losses

Percentage of Participants Choosing the Response	*Response Choices*
41%	We are 90 percent confident that losses from an earthquake for this structure will not exceed $800,000.
14%	We are very confident that losses from an earthquake associated with this structure will not exceed $800,000.
45%	The dollar value of potential losses for this structure are expected to be between $400,000 and $900,000.

3.3.14 Confidence Level in Repair Costs

The final question solicited choices pertaining to the desired minimum "level of confidence" in predictions for making decisions about seismic improvements for a hypothetical $2 million dollar investment. The results are presented in Table 3-14.

Product One Development Team's Assessment. One of the discussion groups focused their discussion on the confidence levels and had a difficult time distinguishing the 95 and 99% confidence levels for risk communication purposes. The second and third groups focused on the relative issues and found that the second response choice gave the biggest bang for the buck. However, this was also associated with the perception or desirability of using the 90% confidence level.

Table 3-14 Minimum "Level of Confidence" in Predictions for Making Decisions about Seismic Improvements for a Hypothetical $2 Million Dollar Investment

Percentage of Participants Choosing the Response	*Response Choices*
0%	50 percent confidence in the results for an analysis cost of $25,000, and a possible variation of +/- $500,000 in the value of earthquake related losses.
86%	90 percent confidence in the results for an analysis cost of $50,000 and a possible variation of +/- $200,000 in the value of earthquake related losses.
9%	95 percent confidence in the results for an analysis cost of $75,000, and a possible variation of +/-$100,000 in the value of earthquake related losses.
5%	99 percent confidence in the results for an analysis cost of $200,000, and a possible variation of +/- $50,000 in the value of earthquake related losses.

Chapter 4

Recommendations for Performance-Based Design Criteria

The Product One Development Team provides the following recommendations for the development of performance-based design criteria. The recommendations are presented in four subject areas as follows:

- primary performance metrics;
- discrete or continuous performance levels;
- levels of analysis; and
- risk communication concepts.

It is also recommended that at periodic intervals during the ATC-58 project, these recommendations and others that are developed be revisited with stakeholders to ensure that the end product satisfies the ultimate goal of communicating with them in understandable terms. The recommendations that follow are believed to be representative of the feedback received from the broad based but limited stakeholder group at the June, 2002, Chicago workshop. It should also be noted that the Product One Development Team believes there is no one method of communicating the results of a performance based design study that is better than the others. The preferred method is strongly dependent on the stakeholder group and the desired application.

4.1 Primary Performance Metrics

The four most important issues from a stakeholders' perspective are the direct losses due to the damage to the building and its contents, the downtime and indirect losses associated with the loss of use of a facility, and the associated life loss and injuries to the occupants. Accordingly the Product One Development Team believes that the following four performance metrics are the key elements for effective communication with stakeholders:

- direct losses, including both the cost of damage and cost of repair;
- downtime associated with the loss of use of a building;
- indirect losses associated with the loss of use of a building; and
- life loss and injuries to the occupants and those in the immediate vicinity of a building.

The goal will be for the design engineer to be able to determine the direct losses, which include the cost of damage to the building and its contents, plus the repair costs associated with returning the facility to full use. With the completion of the procedure, the design engineer also will be able to develop an estimate of the downtime associated with the loss of use of a facility. The downtime will have an impact on the indirect economic losses that an owner needs to develop to determine the full economic impact of an earthquake.

As noted in Chapter 2 and Appendices A, B, and C, neither the direct or indirect losses nor the downtime are explicitly addressed in the three performance based design criteria that have been developed to date in the FEMA 273 Report, the Vision 2000 Report, and the FEMA 350 Report. The downtime associated with the loss of use of a building is implicitly included in some of the descriptive performance levels (e.g. immediate occupancy) but does not appear in others (e.g. life safety). Loss of life has been an important goal of all design codes developed over the past 50 years and this has generally been interpreted to mean the prevention of collapse of a structure. In attempting to quantify life loss and injuries in future performance-based design projects, it is recommended that injuries and loss of life include those resulting from falling internal and external hazards, such as parapets and glass cladding.

4.2 Continuous or Discrete Performance Levels

The FEMA 273 and Vision 2000 performance levels are summarized in Appendices A and B, respectively, and, as noted, they have discrete performance levels with explicit structural and non-structural design requirements associated with them. The alternate to the discrete levels of performance is to envision a continuum between the discrete levels as indicated in Figure 4-1. The continuum option will identify a greater range of cost/benefit design options for the owner, and it may produce design alternatives with modest cost increases that produce significant improvements in performance but not achieve everything that is embodied in all elements of a discrete performance level. The Project One Development Team recommends that future performance-based design criteria attempt to reflect the most reliable estimates of direct losses and associated downtime, and that this be done over a full range of performance expectations rather than a set of discrete performance levels.

One of the benefits of the current discrete levels of performance is that it provides the design engineer with reasonably explicit descriptions of performance for both structural and non-structural components, which is a plus when communicating with stakeholders lacking technical backgrounds. If the continuum concept of performance levels proves to be too difficult to implement in the future, the Product One Development Team recommends that the four discrete levels of performance presented in Figure 4-1 and Table 4-1 be considered for adoption.

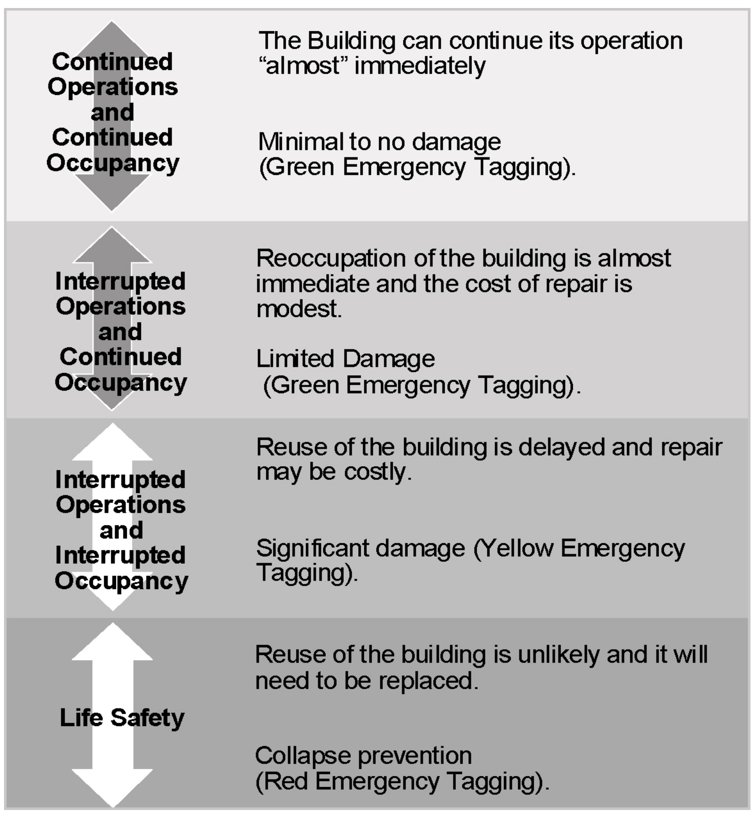

Figure 4-1 Recommended implied continuum of performance levels with discrete levels overlaid

Table 4-1 Recommended Discrete Levels of Performance, if Required

Performance Level	*Building Usability*	*Damage Description*
Life safety	Reuse of the building is unlikely and it will need to be replaced	Collapse Prevention
Interrupted Occupancy and Operations	Reuse of the building is delayed and repair maybe costly	Significant or Substantial Damage
Continued Occupancy and Interrupted Operations	Reoccupation of the building is almost immediate and the cost of repair is modest	Limited Damage
Continued Occupancy and Operations	The building can continue its operations "almost" immediately.	Minimal/ Little or No Damage

It is recommended that the performance of structural and non-structural elements should be coupled if explicit performance levels are used. Coupling was part of the Vision 2000 performance levels in that the damage level (e.g. little or no damage) applies to both structural and non-structural elements. This is different from the philosophy of the FEMA 273 approach, in which it was permissible to select different performance levels for the structural and nonstructural components. In addition, a footnote will be required for the continuous operation performance level that states: "To achieve continuous operation for certain types of occupancies, on-site emergency power and water may be required."

Achievement of performance goals, such as life safety or collapse prevention, in performance-based design is measured through some statement of "likelihood" or "relative frequency." This concept can (and has been) communicated in two ways: (1) *probability* of failure to meet the performance objective, and (2) *confidence* in the ability to make that assertion. Because both statements involve the concept of probability and can easily be misconstrued (and were by the stakeholders at the workshop) when they are coupled in one statement of a performance objective, it is essential that efforts be made to distinguish the two concepts and to communicate them clearly during the course of the project. Moreover, the manner in which probability goals and confidence statements are addressed in performance-based design for different categories of buildings and occupancies should be addressed. For example, in the SAC Project, the performance objective for all building categories was to limit the failure probability to below 2% in 50 years. The epistemic uncertainties in the analysis led to a confidence parameter that enables the analyst to assert that this performance objective is met with, say, 90% confidence. However, the issue of how to deal with different performance objectives for different occupancies (e.g., those in Table 1-1 of *ASCE Standard 7-02*, ASCE, 2002) was not addressed. In that standard, different occupancy categories are addressed through an importance factor, which effectively increases the design load and lowers the failure probability. Alternatively, one might hold the failure probability the same, and require an increase in the confidence that the objective is met. Both approaches lead to additional conservatism in design. In any event, it is recommended that the number of probability goals or levels of confidence be limited to facilitate communication with stakeholders and decision makers. There is evidence that more than two or three levels will be found to be unworkable.

4.3 Levels of Analysis

It was clear from the discussion during the workshop that the stakeholders had a strong preference to receive their communication in deterministic language. That is, they would like to know the consequences resulting from a specific magnitude event (e.g., magnitude 7) that is representative of the largest event that could impact their facility. This need of the stakeholders could be met with improved communication language, while utilizing a probabilistic design approach. Of major importance during the implementation of a probabilistic or deterministic design approach are the factors that impact design and their uncertainties.

In evaluating the alternate deterministic and probabilistic approaches, five different possible global approaches were identified that could be considered for the development of the performance-based design criteria for this project. These approaches progress from the relatively straightforward approach of Level 1 to the most sophisticated and not yet developed Level 5. These five levels, and the Product One Development Team's perception of required additional data needs, are summarized below. It is recommended that Level 5, the most sophisticated level of analysis, be the goal of the new performance-based design criteria and if this proves to be too difficult to achieve, then Level 4 should become the default option.

4.3.1 Level 1 Analysis

This lowest level of analysis includes uncertainties in both demand and capacities but not in consequences. It can be applied to both a deterministic and probabilistic event. In summary, this level has the following attributes:

- 1(a) is a deterministic event (e.g., a magnitude-7 earthquake occurring 25 km from the site) and 1(b) is a probabilistic event;
- uncertainties in demand;
- uncertainties in capacity; and
- no uncertainties in consequences.

This approach is similar to the approach taken in Load and Resistance Factor Design (LRFD), in which the uncertainties in demand are encapsulated in load factors, which are applied to a design-basis event that is specified probabilistically (e.g., 50-yr mean recurrence interval for wind, rain and snow; 2,475-yr mean recurrence interval for earthquake). Many in the structural engineering profession probably would be most comfortable with this or the Level 3 approach, since it most closely resembles current professional practice.

4.3.2 Level 2 Analysis

The next level of analysis is the same as Level 1 but with the inclusion of uncertainties in the consequences (direct and indirect costs, downtime and life loss and injuries). In summary, this level has the following attributes:

- 2(a) is a deterministic postulated event (e.g., a magnitude-7 earthquake occurring 25 km from the site), and 2(b) is a probabilistic event;
- uncertainties in demand;
- uncertaintiesy in capacities; and
- uncertainties in consequences (direct and indirect losses, morbidity/mortality).

Level 2(a) is the level of analysis that a broad spectrum of the stakeholders would prefer in the short term. It makes the risk communication part of the task relatively simple. Structural performance with regard to uncertainties in demand and capacity can be evaluated from technology that is basically available now and is comparable to that utilized in the FEMA-funded SAC project to investigate the seismic hazards of steel moment-frame buildings. However the consequences and their related uncertainties will need to be developed.

4.3.3 Level 3 Analysis

The third level of analysis is similar to that used in the SAC design procedures and includes an integration over the full range of seismicity impacting the site and the uncertainties in the demand and the capacity of a structure. Unlike Level 2, it does not include uncertainties in consequences. The attributes of this level are as follows:

- fully coupled analysis, that is, integration of a system fragility and hazard;
- uncertainties in demand;
- uncertainties in capacity; and
- no uncertainties in consequences.

This approach focuses on the decision process in the structural engineering aspects of risk assessment. Uncertainties in consequences are not considered, and thus variation in socioeconomic impacts (the data for which will require much work to develop) are not explicitly addressed.

4.3.4 Level 4 Analysis

The fourth level of analysis is the same as Level 3 but with the inclusion of the consequences (direct and indirect losses, downtime and loss of life and injuries). This is one level higher than that used in the SAC design procedures and is the recommended option if the project is not able to achieve the highest and most difficult Level 5. The attributes of this level are as follows:

- fully coupled analysis, that is, integration of a system fragility and hazard;
- uncertainties in demand;
- uncertainties in capacity; and
- uncertainties in consequences (direct and indirect losses, morbidity/mortality).

This is comparable to the SAC approach in its structural engineering aspects, but it also includes the consequences and their uncertainties. The technology to perform such structural engineering analyses is available, at least for steel moment frames. How it would work for other types of construction, especially masonry or light-frame construction in the Eastern United States, is problematic since it is unlikely that there will be the same level of investment in these different technologies to answer this question definitively, as there was for the SAC Project.

4.3.5 Level 5 Analysis

This is the most rigorous level, as it includes a fully coupled analysis as well the uncertainties in all aspects that impact the results of the analysis. It is the only level of analysis that attempts to include the uncertainties in the seismic input. The attributes of this level are:

- fully coupled analysis, that is, integration of system fragility and hazard;
- uncertainties in demand;
- uncertainties in capacity;
- uncertainties in modeling hazard; and
- uncertainties in consequences (opportunity losses, repair costs, morbidity/mortality).

At this level, most factors known to impact the decision process are explicitly modeled, or at least recognized. This is the level of analysis that the Product One Development Team recommends should be pursued in the development of the performance-based design criteria. It will be used in practice only by the most sophisticated structural engineers or decision makers, or for monumental or very important buildings, where the investment in performing such an assessment is judged as being beneficial on a cost/benefit basis. It may also be used selectively by code and standard development committees to check the accuracy of simpler or more prescriptive provisions.

The most significant factor that distinguishes Level 5 from Level 4 assessment is the inclusion of the epistemic uncertainty in the earthquake ground motion. In the Western United States, where (it is believed that) most of the causative sources have been identified, this source of uncertainty may be relatively small. In the Eastern United States, where hazard analysis is based on postulated seismotectonic provinces rather than causative sources, the epistemic uncertainty is enormous. (For example, at the Zion Nuclear Power Plant in Zion, Illinois, where a comprehensive seismic risk assessment was performed, the median return period for a PGA of 0.4g was 6 x 10^{-6}/yr, with a range of 1.3 x 10^{-6} to 4.3 x 10^{-5}. Assuming a 95% confidence interval, the logarithmic standard deviation, β_U, which is a measure of this uncertainty, is approximately 0.90.)

4.3.6 Additional Data Requirements for the Various Levels of Analysis

There is a significant amount of data that are required to be able to implement each of the above recommended levels of analysis. The needs are presented below for each of the 5 levels of analysis.

Levels 1 and 2

These needs include:

- identification of design-basis event (or events);
- appropriate ensembles of earthquake ground motion;
- portfolio of fragilities for common building structural systems;
- portfolio of fragilities for nonstructural components, cladding, and other items;
- databases that map structural and nonstructural performance levels to repair/replacement cost; and
- costs associated with direct and indirect losses. Note that downtime estimates are additional requirements for a Level 2 analysis.

Level 3

Data needed for this level include:

- appropriate ensembles of ground motion;
- portfolio of fragilities for common building structural systems;
- portfolio of fragilities for nonstructural components, cladding, and other items; and
- a protocol for identifying specific probability levels associated with specific performance objectives.

Level 4

Data needed for this level include:

- median seismic hazard curves for the continental United States (these are already available from the U.S. Geological Survey (USGS));
- ensemble of ground motions;
- portfolio of fragilities for common building structural systems;
- portfolio of fragilities for nonstructural components, cladding, and other items;
- databases that map specific structural and nonstructural responses to heuristically stated performance levels;
- databases that map structural and nonstructural performance levels to repair/replacement cost; and
- target probabilities of failure to meet performance objectives.

Level 5

Data needed for this level include:

- all information listed for Level 4 above; and
- epistemic uncertainty in earthquake ground motion.

It is likely that, in the multi-year ATC-58 project, which is targeted toward a broad constituency of stakeholders, several elements of each level will be developed. It is important that the methodologies in each level be internally consistent. If and when these levels of analysis are implemented, the Product One Development Team encourages the decision maker to use as high a level as circumstances warrant. Providing incentives to use the more sophisticated levels of analysis would be desirable.

4.4 Risk Communication Concepts

One of the important issues arising from the workshop was the need for engineers to communicate with stakeholders in terminology that was comprehensible to them. The following two subsections provide recommendations on risk communication concepts for presenting earthquake hazard information and performance metrics. Terminology is provided that is intended to be acceptable to a majority of the stakeholders represented at the workshop.

4.4.1 Defining the Earthquake Hazard

In terms of defining earthquakes the stakeholders preferred the use of deterministic descriptors and felt comfortable with the following alternative methods of describing the hazard:

- The probability of a very damaging earthquake over the next 20 years is 33 percent.
- A very damaging (e.g. magnitude 7) earthquake can be expected, on average, once every 50 years.

Because the Product One Development Team recommends the use of a probabilistic approach to defining the earthquake hazard, the team attempted to develop methods of presenting the results of a probabilistic site hazard analysis in deterministic terminology. Based on the data that a design engineer would obtain from the probabilistic based USGS nationwide seismic hazards maps, the following suggestions are offered as a means of presenting the probabilistic data to a stakeholder, using an event with a 10% probability of being exceeded in 50 years for illustration purposes.[1] Two cities – Boston and Seattle – are used in the illustrations. As noted below this task is relatively simple when the hazard at a site is dominated by one fault or a random earthquake with an unknown location (e.g. as in the Boston

[1] This event is equivalent to one with a probability of 0.0021 of being exceeded in a given year, often referred to as a 475-yr return period event. The recommendation to specify the event in terms of its probability in 50 years is deliberate, as it reflects stakeholder discomfort in dealing with “annual” events and avoids the common misconception of the N-yr return period event as one that occurs every N years.

region) but is much more difficult if the hazard has contributions from several different sources (e.g. as in the Seattle region).

Boston Seismic Hazard Description for the Owner:

The data that can be obtained from a site specific hazard analysis using the USGS probabilistic maps is presented in three different formats. The first two are graphical deaggregated results of the hazard analysis and these are shown in Figures 4-2 and 4-3. Both figures present the same set of data for a given probabilistic event. Figure 4-2 provides a graphic representation, which enables the design engineer to quickly see the contribution to the hazard from various earthquakes that impact the hazard at the site. Figure 4-3 is the same set of information presented in magnitude and distance pairs. Table 4-2 presents the graphical information in tabular form, together with additional details on the contributions of various faults.

It is recommended that the hazard be described, at least initially, to the owner in terms such as the following:

"The earthquake risk to Boston, while very real, does not stem from a single, dominant, predictable event on a known fault. Each vertical bar shown in Figure 4-3 represents a possible earthquake; the possible events are of various magnitudes and are geographically dispersed. Boston's earthquake risks come from an earthquake that will occur in some unknown location somewhere within a 500-mile radius. As one can conclude from examining Figure 4-3, any one of many possible earthquakes will affect Boston at some time. On average, the most likely event, with a probability of one chance in ten over the next 50 years, would be a magnitude 6.2 earthquake (Richter Scale) centered approximately 200 kilometers from Boston."

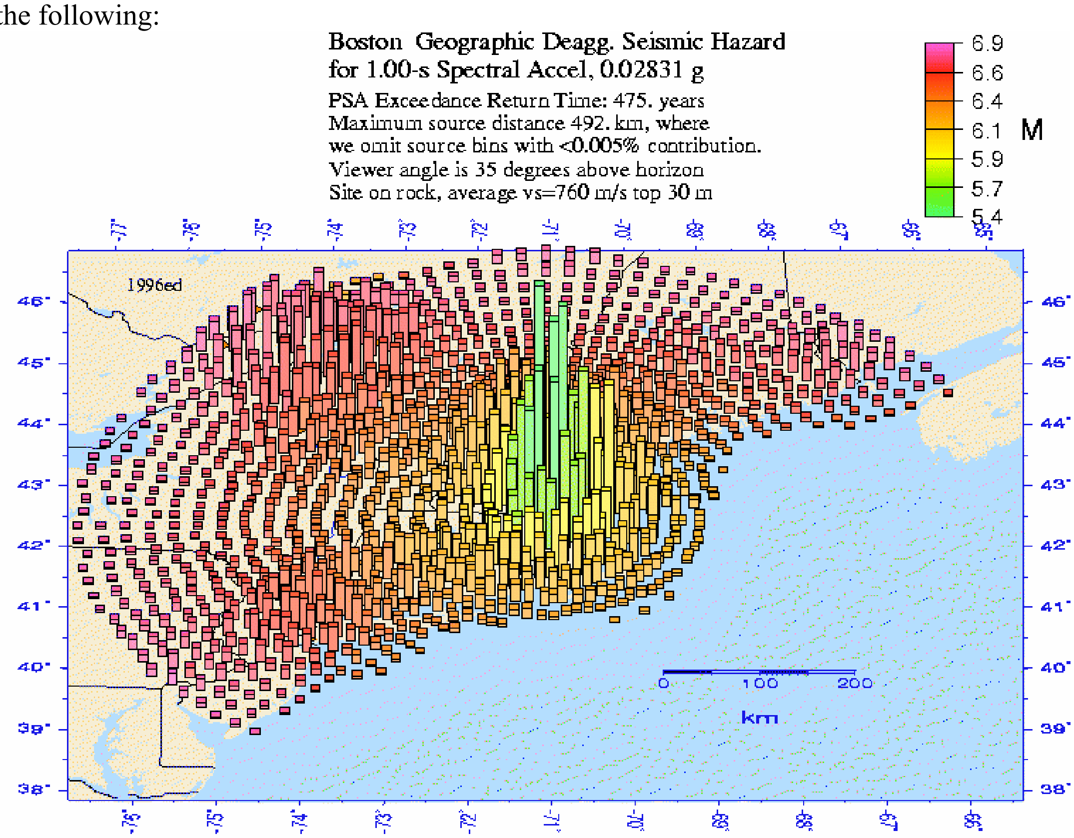

Figure 4-2 Geographic deaggregation of the seismic hazard for Boston.

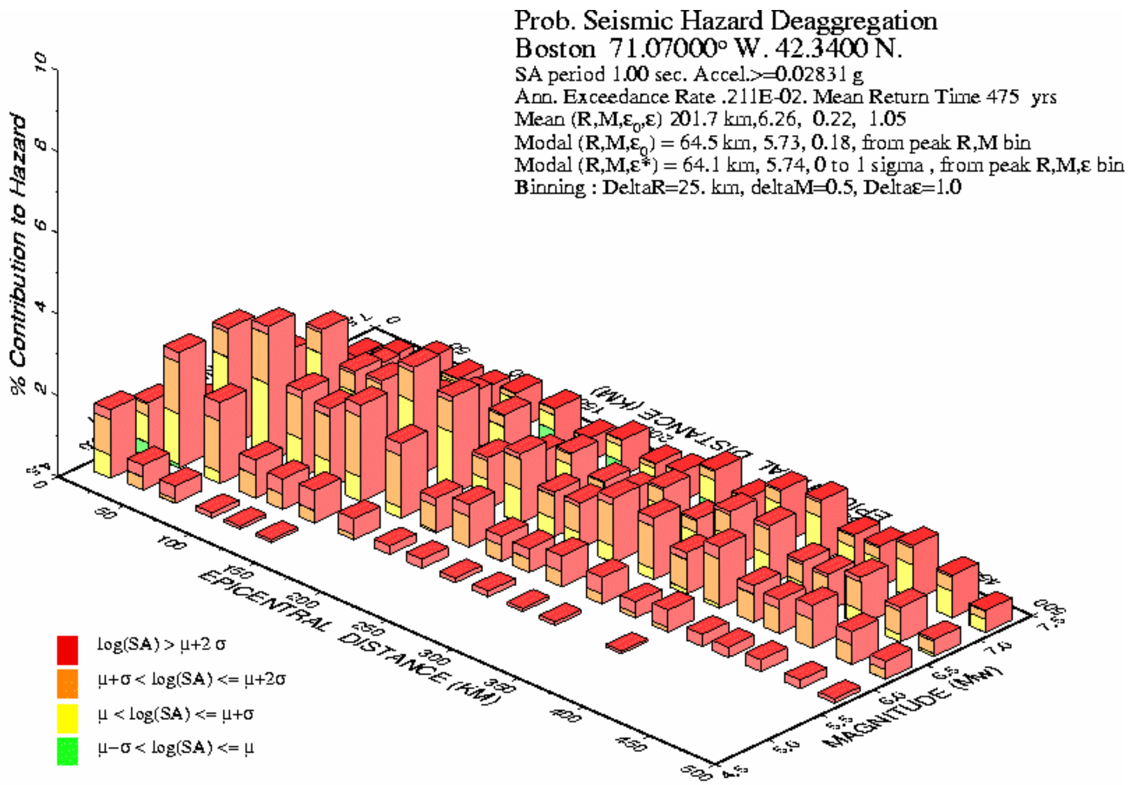

Figure 4-3 Magnitude and distance deaggregation for Boston.

Seattle Seismic Hazard Description for the Owner:

A geographic plot of the USGS site-specific seismic hazard data for Seattle is presented in Figure 4-4. Figure 4-5 is the same set of information presented in magnitude and distance pairs. Table 4-3 presents the same information in tabular form together with additional details on the contributions of various faults.

Using the USGS probabilistic data, the Product One Development Team proposes two alternatives for describing the 10% probability of exceedance in 50-year event. The first would include a discussion of all the faults that contribute to the hazard at this site, as follows.

> "The hazard at the site is affected by a magnitude 6.8 earthquake on the Seattle fault (at a distance of 2 km), a magnitude-6.4 earthquake on the intraplate (at a distance of 62 km), a magnitude-8.3 earthquake on the Cascadia fault (at a distance of 122 km) and a random earthquake occurring any where within a 50 mile radius. The most likely scenario of this random event is a 6.4-magnitude earthquake 14 km from the site."

The second alternative is to describe the probabilistic hazard in terms of a deterministic event on each of the various faults as follows:

> "The hazard at the site is equivalent to a magnitude X event occurring on the Y fault."

This second format involves execution of a relatively difficult task and, as a first step, the design engineer would need to decide at what period(s) this equivalency would be made because it could not be made for a full range of structural periods. Despite the necessity of making a number of compromises in the development of this statement, it is recommended that a future task of the ATC-58 project should be the investigation of how this could be accomplished.

Table 4-2 Tabulated Deaggregation Data for Boston

PSHA Deaggregation. %contributions. site: Boston long: 71.07000 W., lat: 42.3400 N.
Return period: 475yrs. 1.00 s. PSA =0.0283129g. Computed annual rate=.21070E-02

DIST(KM)	MAG(MW)	ALL-EPS	EPSILON>2	1<EPS<2	0<EPS<1	-1<EPS<0	-2<EPS<-1	EPS<-2
15.9	4.84	1.686	0.245	0.870	0.539	0.033	0.000	0.000
38.7	4.87	0.615	0.300	0.307	0.008	0.000	0.000	0.000
62.3	4.88	0.421	0.330	0.091	0.000	0.000	0.000	0.000
89.2	4.90	0.128	0.128	0.000	0.000	0.000	0.000	0.000
109.8	4.91	0.081	0.081	0.000	0.000	0.000	0.000	0.000
133.2	4.91	0.071	0.071	0.000	0.000	0.000	0.000	0.000
12.8	5.24	1.338	0.047	0.281	0.658	0.337	0.015	0.000
34.2	5.27	2.839	0.248	1.267	1.233	0.091	0.000	0.000
63.6	5.29	1.995	0.461	1.253	0.281	0.000	0.000	0.000
89.6	5.30	0.935	0.370	0.554	0.011	0.000	0.000	0.000
110.1	5.31	0.751	0.380	0.370	0.000	0.000	0.000	0.000
133.8	5.31	0.794	0.493	0.302	0.000	0.000	0.000	0.000
163.3	5.32	0.514	0.398	0.116	0.000	0.000	0.000	0.000
189.9	5.32	0.211	0.190	0.020	0.000	0.000	0.000	0.000
214.2	5.33	0.226	0.222	0.004	0.000	0.000	0.000	0.000
239.5	5.33	0.116	0.116	0.000	0.000	0.000	0.000	0.000
264.1	5.34	0.142	0.142	0.000	0.000	0.000	0.000	0.000
290.0	5.34	0.072	0.072	0.000	0.000	0.000	0.000	0.000
314.6	5.34	0.087	0.087	0.000	0.000	0.000	0.000	0.000
364.2	5.35	0.059	0.059	0.000	0.000	0.000	0.000	0.000
13.3	5.70	0.796	0.020	0.117	0.294	0.289	0.073	0.002
35.7	5.72	2.908	0.103	0.617	1.456	0.709	0.023	0.000
64.5	5.73	3.339	0.204	1.212	1.740	0.184	0.000	0.000
89.9	5.74	2.091	0.176	1.012	0.894	0.008	0.000	0.000
110.2	5.75	1.952	0.196	1.096	0.660	0.000	0.000	0.000
134.2	5.75	2.372	0.290	1.490	0.592	0.000	0.000	0.000
163.6	5.76	1.831	0.303	1.269	0.259	0.000	0.000	0.000
190.0	5.76	0.856	0.188	0.617	0.051	0.000	0.000	0.000
214.6	5.77	1.045	0.298	0.738	0.010	0.000	0.000	0.000
239.6	5.77	0.616	0.226	0.390	0.000	0.000	0.000	0.000
259.7	5.78	0.583	0.253	0.330	0.000	0.000	0.000	0.000
284.8	5.78	0.753	0.393	0.360	0.000	0.000	0.000	0.000
314.8	5.78	0.649	0.409	0.240	0.000	0.000	0.000	0.000
339.8	5.79	0.395	0.284	0.111	0.000	0.000	0.000	0.000
364.5	5.79	0.537	0.436	0.101	0.000	0.000	0.000	0.000
390.0	5.79	0.296	0.262	0.034	0.000	0.000	0.000	0.000
409.7	5.80	0.256	0.243	0.014	0.000	0.000	0.000	0.000
434.4	5.80	0.296	0.295	0.001	0.000	0.000	0.000	0.000
464.1	5.80	0.210	0.210	0.000	0.000	0.000	0.000	0.000
489.8	5.81	0.107	0.107	0.000	0.000	0.000	0.000	0.000
13.5	6.21	0.356	0.008	0.049	0.123	0.123	0.048	0.005
36.5	6.22	1.689	0.043	0.257	0.646	0.618	0.123	0.001
65.1	6.23	2.661	0.085	0.507	1.272	0.771	0.026	0.000
90.1	6.23	1.984	0.073	0.439	1.077	0.395	0.000	0.000
110.3	6.24	2.027	0.082	0.487	1.172	0.286	0.000	0.000
134.5	6.24	2.709	0.121	0.723	1.622	0.243	0.000	0.000
164.0	6.24	2.390	0.126	0.754	1.420	0.090	0.000	0.000
190.2	6.25	1.256	0.078	0.468	0.701	0.008	0.000	0.000
214.9	6.25	1.697	0.124	0.742	0.831	0.000	0.000	0.000
239.8	6.26	1.102	0.094	0.564	0.443	0.000	0.000	0.000
259.8	6.26	1.123	0.110	0.644	0.370	0.000	0.000	0.000
285.0	6.26	1.588	0.184	1.006	0.399	0.000	0.000	0.000
315.1	6.27	1.517	0.215	1.049	0.253	0.000	0.000	0.000
340.0	6.27	1.013	0.170	0.737	0.106	0.000	0.000	0.000
364.8	6.27	1.503	0.300	1.117	0.086	0.000	0.000	0.000
390.1	6.28	0.905	0.216	0.674	0.016	0.000	0.000	0.000
409.7	6.28	0.835	0.229	0.606	0.000	0.000	0.000	0.000
434.6	6.28	1.041	0.344	0.697	0.000	0.000	0.000	0.000

464.4	6.29	0.805	0.332	0.473	0.000	0.000	0.000	0.000
489.8	6.29	0.442	0.216	0.225	0.000	0.000	0.000	0.000
13.5	6.72	0.124	0.003	0.017	0.042	0.042	0.017	0.003
36.9	6.72	0.634	0.015	0.088	0.222	0.222	0.082	0.005
65.5	6.72	1.155	0.029	0.174	0.438	0.432	0.081	0.000
90.2	6.72	0.942	0.025	0.151	0.379	0.359	0.027	0.000
110.4	6.72	1.009	0.028	0.168	0.421	0.380	0.012	0.000
134.7	6.72	1.421	0.042	0.249	0.625	0.504	0.003	0.000
164.3	6.73	1.362	0.043	0.259	0.651	0.408	0.000	0.000
190.2	6.73	0.778	0.027	0.161	0.404	0.186	0.000	0.000
215.0	6.73	1.130	0.043	0.255	0.641	0.191	0.000	0.000
239.8	6.73	0.784	0.032	0.194	0.477	0.081	0.000	0.000
259.9	6.73	0.842	0.038	0.225	0.525	0.053	0.000	0.000
285.2	6.73	1.269	0.063	0.378	0.795	0.034	0.000	0.000
310.1	6.74	0.850	0.047	0.281	0.519	0.003	0.000	0.000
335.1	6.74	1.380	0.085	0.510	0.785	0.000	0.000	0.000
365.0	6.74	1.457	0.103	0.618	0.736	0.000	0.000	0.000
390.2	6.74	0.929	0.074	0.443	0.412	0.000	0.000	0.000
409.8	6.74	0.897	0.079	0.471	0.347	0.000	0.000	0.000
434.6	6.74	1.169	0.117	0.698	0.354	0.000	0.000	0.000
464.3	6.75	0.852	0.099	0.574	0.179	0.000	0.000	0.000
489.7	6.75	0.419	0.056	0.302	0.061	0.000	0.000	0.000
13.5	7.20	0.072	0.002	0.010	0.025	0.025	0.010	0.002
36.9	7.20	0.379	0.009	0.052	0.130	0.130	0.052	0.006
65.6	7.21	0.727	0.017	0.102	0.257	0.257	0.092	0.003
90.2	7.21	0.616	0.015	0.088	0.222	0.222	0.068	0.000
110.4	7.21	0.660	0.016	0.096	0.242	0.242	0.065	0.000
134.8	7.20	0.904	0.023	0.135	0.338	0.338	0.070	0.000
164.4	7.21	0.936	0.024	0.145	0.364	0.361	0.042	0.000
190.3	7.21	0.570	0.015	0.092	0.231	0.219	0.013	0.000
215.2	7.21	0.879	0.025	0.148	0.373	0.323	0.010	0.000
239.9	7.22	0.639	0.019	0.113	0.284	0.219	0.003	0.000
259.9	7.22	0.709	0.022	0.131	0.329	0.225	0.001	0.000
285.3	7.22	1.116	0.037	0.219	0.550	0.311	0.000	0.000
310.1	7.22	0.780	0.027	0.162	0.408	0.183	0.000	0.000
335.3	7.22	1.330	0.049	0.296	0.741	0.244	0.000	0.000
365.1	7.23	1.491	0.060	0.360	0.882	0.190	0.000	0.000
390.3	7.23	0.996	0.043	0.258	0.602	0.092	0.000	0.000
409.8	7.23	0.998	0.046	0.275	0.610	0.067	0.000	0.000
434.7	7.23	1.363	0.068	0.407	0.823	0.065	0.000	0.000
464.4	7.23	1.048	0.058	0.346	0.615	0.029	0.000	0.000
489.8	7.23	0.540	0.033	0.195	0.304	0.009	0.000	0.000

```
Summary statistics for above 1.0s PSA  deaggregation, R=distance, e=epsilon:
 Mean src-site R=  201.7 km; M= 6.26; e0=   0.22; e=  1.05 for all sources.
Modal src-site R=   64.5 km; M= 5.73; e0=   0.18 from peak (R,M) bin
Primary distance metric: EPICENTRAL
 MODE R*=  64.1km; M*= 5.74; EPS.INTERVAL: 0 to 1 sigma  % CONTRIB.=  1.740

Principal sources (faults, subduction, random seismicity having >10% contribution)
Source:                          % contr.   R(km)    M   epsilon0 (mean values)
CEUS gridded seismicity,Frankel    57.52   212.9   6.33    0.22
CEUS gridded seismicity,Toro att   42.48   186.6   6.16    0.23
```

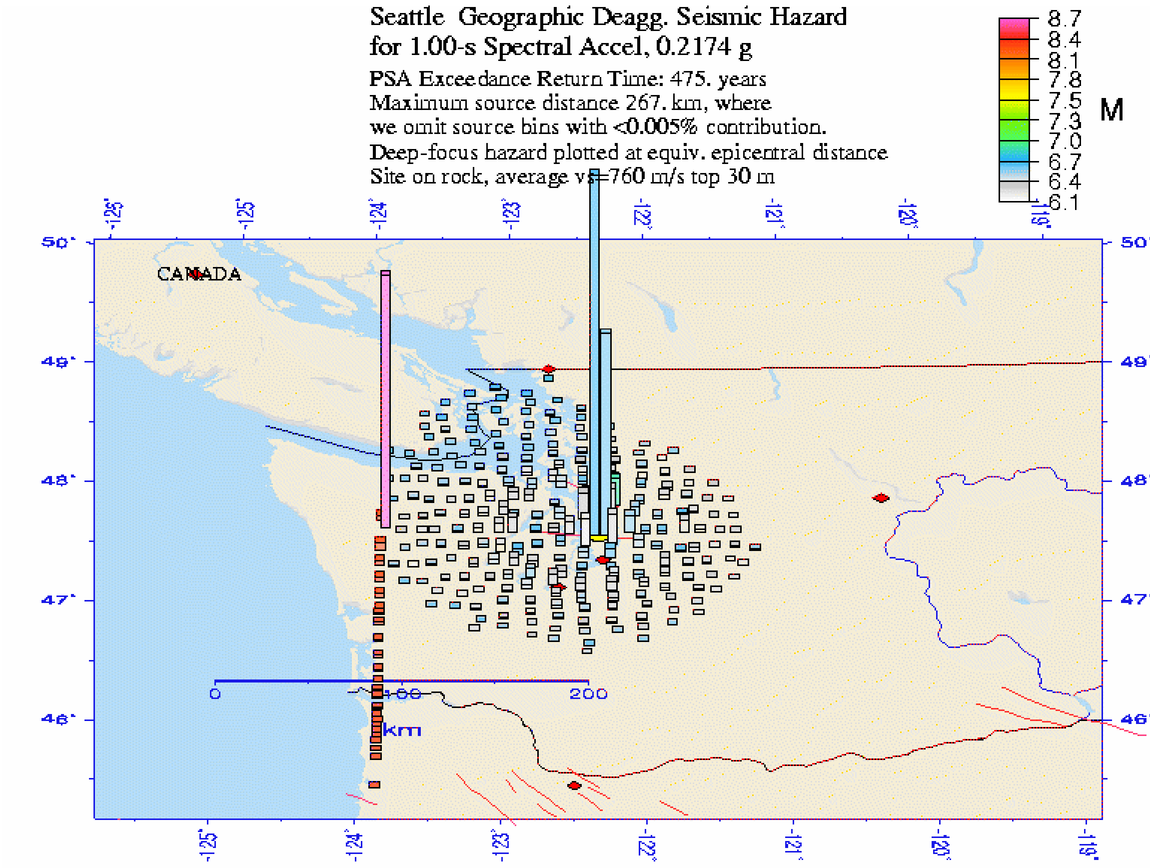

Figure 4-4 Geographic deaggregation of the seismic hazard for Seattle.

4.4.2 Presentation of Performance Metrics

Loss of life was one of the four key performance metrics recommended to be a part of the performance-based design criteria. The following two alternatives are recommended as acceptable methods of presenting the loss-of-life metric once it has been determined for a given design event:

- In the next 20 years, there is a 25 percent probability of 10 or more earthquake-related fatalities associated with this structure.
- If a magnitude-7 earthquake occurs, the expected number of fatalities for this structure is 20.

Two other key performance metrics that have been recommended and can be determined by the design engineer are the direct damage costs and the downtime associated with the design events. The following four options are recommended as acceptable methods for presenting the direct losses:

- The probability of a single earthquake loss exceeding $500,000 in the next 20 years is 33 percent.
- The probable maximum loss (90% confidence level) associated with a major earthquake (expected one time every 500 years) is $6,000,000.
- We are 90 percent confident that losses from an earthquake for this structure will not exceed $800,000.
- The dollar value of potential earthquake-caused losses for this structure are expected to be between $400,000 and $900,000.

The use of an absolute cost expressed in terms of a range of repair costs, and a probability-based expression of repair costs, are not mutually exclusive and both should be considered for presenting similar data. One of

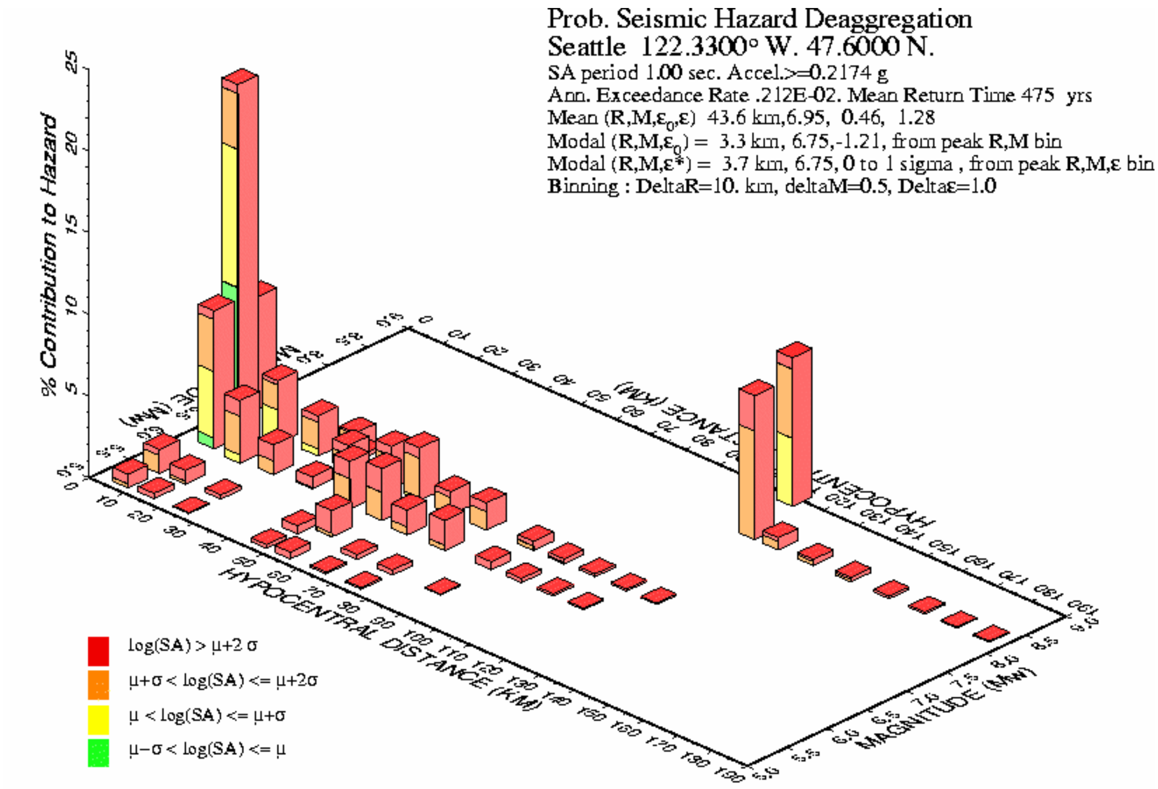

Figure 4-5 Magnitude and distance deaggregation for Seattle.

the workshop discussion groups had a very strong preference for the use of ranges rather than confidence intervals as a means of risk communication. The FEMA-funded ATC-58 project should explore if these alternate means of communication are able to convey the same result.

Table 4-3 Tabulated Deaggregation Data for Seattle

PSHA Deaggregation. %contributions. site: Seattle long: 122.3300 W., lat: 47.6000 N.
Return period: 475yrs. 1.00 s. PSA =0.2174839g. Computed annual rate=.21209E-02

DIST(KM)	MAG(MW)	ALL-EPS	EPSILON>2	1<EPS<2	0<EPS<1	-1<EPS<0	-2<EPS<-1	EPS<-2
6.8	5.22	0.825	0.590	0.236	0.000	0.000	0.000	0.000
14.1	5.23	0.331	0.331	0.000	0.000	0.000	0.000	0.000
24.1	5.23	0.070	0.070	0.000	0.000	0.000	0.000	0.000
46.7	5.22	0.238	0.238	0.000	0.000	0.000	0.000	0.000
53.6	5.22	0.417	0.417	0.000	0.000	0.000	0.000	0.000
63.7	5.23	0.114	0.114	0.000	0.000	0.000	0.000	0.000
73.8	5.23	0.103	0.103	0.000	0.000	0.000	0.000	0.000
6.9	5.61	1.480	0.379	1.063	0.038	0.000	0.000	0.000
14.2	5.62	0.835	0.648	0.187	0.000	0.000	0.000	0.000
24.2	5.63	0.241	0.241	0.000	0.000	0.000	0.000	0.000
46.7	5.61	0.479	0.476	0.003	0.000	0.000	0.000	0.000
52.8	5.78	1.607	1.409	0.198	0.000	0.000	0.000	0.000
63.7	5.62	0.290	0.290	0.000	0.000	0.000	0.000	0.000
74.0	5.62	0.297	0.297	0.000	0.000	0.000	0.000	0.000
87.5	5.63	0.056	0.056	0.000	0.000	0.000	0.000	0.000
7.2	6.28	8.458	0.557	3.166	4.078	0.657	0.000	0.000
15.6	6.24	3.825	0.966	2.345	0.513	0.000	0.000	0.000
24.2	6.28	1.814	0.987	0.826	0.000	0.000	0.000	0.000
34.6	6.33	0.721	0.651	0.071	0.000	0.000	0.000	0.000
46.7	6.27	2.936	1.074	1.862	0.000	0.000	0.000	0.000
55.1	6.31	3.165	1.462	1.703	0.000	0.000	0.000	0.000
63.5	6.26	1.531	1.045	0.486	0.000	0.000	0.000	0.000
74.1	6.27	1.848	1.555	0.294	0.000	0.000	0.000	0.000
87.0	6.29	0.481	0.477	0.004	0.000	0.000	0.000	0.000
95.8	6.29	0.264	0.264	0.000	0.000	0.000	0.000	0.000
104.7	6.30	0.148	0.148	0.000	0.000	0.000	0.000	0.000
113.6	6.29	0.089	0.089	0.000	0.000	0.000	0.000	0.000
3.3	6.75	20.876	0.547	3.426	8.472	7.117	1.314	0.000
14.9	6.75	3.828	0.265	1.539	1.913	0.110	0.000	0.000
25.1	6.81	2.467	0.412	1.634	0.420	0.000	0.000	0.000
34.0	6.81	1.480	0.581	0.889	0.011	0.000	0.000	0.000
46.4	6.80	2.600	0.588	1.659	0.354	0.000	0.000	0.000
54.3	6.82	3.209	0.632	2.408	0.169	0.000	0.000	0.000
63.6	6.80	1.420	0.356	1.064	0.000	0.000	0.000	0.000
73.7	6.81	1.656	0.537	1.120	0.000	0.000	0.000	0.000
87.3	6.81	0.564	0.301	0.263	0.000	0.000	0.000	0.000
96.1	6.81	0.300	0.215	0.085	0.000	0.000	0.000	0.000
104.8	6.82	0.168	0.143	0.025	0.000	0.000	0.000	0.000
114.1	6.81	0.124	0.123	0.002	0.000	0.000	0.000	0.000
122.8	6.81	0.075	0.075	0.000	0.000	0.000	0.000	0.000
1.1	7.08	6.896	0.152	0.962	2.417	2.417	0.931	0.018
29.2	7.10	1.140	0.134	0.683	0.323	0.000	0.000	0.000
30.5	7.05	0.269	0.038	0.177	0.055	0.000	0.000	0.000
116.8	8.30	8.807	2.161	6.646	0.000	0.000	0.000	0.000
123.7	8.30	0.754	0.224	0.530	0.000	0.000	0.000	0.000
133.8	8.30	0.373	0.149	0.224	0.000	0.000	0.000	0.000
144.6	8.30	0.276	0.149	0.127	0.000	0.000	0.000	0.000
155.7	8.30	0.150	0.101	0.049	0.000	0.000	0.000	0.000
165.9	8.30	0.113	0.085	0.028	0.000	0.000	0.000	0.000
175.2	8.30	0.059	0.051	0.009	0.000	0.000	0.000	0.000
184.5	8.30	0.068	0.067	0.001	0.000	0.000	0.000	0.000
111.9	9.00	9.101	0.708	4.229	4.164	0.000	0.000	0.000

Summary statistics for above 1.0s PSA deaggregation, R=distance, e=epsilon:
Mean src-site R= 43.6 km; M= 6.95; e0= 0.46; e= 1.28 for all sources.
Modal src-site R= 3.3 km; M= 6.75; e0= -1.21 from peak (R,M) bin
Primary distance metric: HYPOCENTRAL
MODE R*= 3.7km; M*= 6.75; EPS.INTERVAL: 0 to 1 sigma % CONTRIB.= 8.472

Principal sources (faults, subduction, random seismicity having >10% contribution)

Source:	% contr.	R(km)	M	epsilon0 (mean values)
Cascadia M 8.3 subduction	10.78	122.3	8.30	1.39
Western US gridded seismicity	29.96	14.9	6.37	0.73
Deep intraplate seismicity	23.51	61.9	6.39	1.63
Seattle fault	24.49	2.3	6.83	-1.49

Chapter 5
Summary and Conclusions

This report documents the results of an initial effort on the ATC-58 project to develop recommendations for the characterization of performance for use in performance-based seismic design. The recommendations are based on findings emanating from the ATC-58 Workshop on Communicating Earthquake Risk, which was held in Chicago, Illinois, on June 18, 2002, and on discussions amongst the Product One Development Team and other ATC-58 project participants.

The report contains a review of current performance characterization approaches (as documented in existing technical procedures for performance-based seismic design), a summary and evaluation of stakeholder input during the ATC-58 Workshop on Communicating Earthquake Risk, and recommendations developed by the Product One Development Team (report authors) for improved characterization of performance in performance-based seismic design. Also included as appendices are summaries of the performance characterization approaches documented in the FEMA 273 NEHRP *Guidelines for the Seismic Rehabilitation of Existing Buildings* (ATC/BSSC, 1997), the Vision 2000 Report, *Performance Based Design of New Buildings* (SEAOC, 1995), and the FEMA 250 *Recommended Seismic Design Criteria for New Steel Moment Frame Buildings* (SAC, 2000a).

The review of existing performance characterization approaches revealed the use of discrete performance levels, with associated explicit structural and non-structural design requirements. Rather than adopt discrete performance levels in the ATC-58 project, the Product One Development Team recommends the adoption of a continuum of performance levels. This approach will make possible a greater range of cost/benefit design options for the owner and may produce design options with only modest cost increases that produce significant improvements in performance. If the continuum approach proves to be impractical, four discrete performance levels are recommended:

1. Continued Operations and Continued Occupancy
2. Interrupted Operations and Continued Occupancy
3. Interrupted Operations and Interrupted Occupancy
4. Life Safety

The stakeholder input obtained during the ATC-58 Workshop on Communicating Earthquake Risk provides preliminary feedback from a cross section of stakeholders interested in the successful development and implementation of performance based seismic design – building owners, building users, regulators, underwriters, financiers, design professionals, and researchers. While the number of participants involved was relatively small, it is believed that the results of the workshop provide insight into the needs and preferences of the general stakeholders of performance-based engineering.

The workshop provided stakeholder input on communication preferences for a wide variety of issues, including life-safety, functionality, repair, loss of life, potential damage to facilities, likelihood of seismic events, and ways of communicating uncertainty. Based on the input received from stakeholders at the workshop, the following four performance metrics are considered to be of key concern:

- Direct losses including both the cost of damage and cost of repair.
- Downtime associated with the loss of use of a building.
- Indirect losses associated with the loss of use of a building.
- Life loss and injuries to the occupants and those in the immediate vicinity of a building.

The Product One Development Team believes that there is no one method of communicating the results of a performance based design that is clearly superior to others in all cases. The preferred method is strongly dependent on the stakeholder group and the desired application. However, it was clear from the workshop that a majority of the stakeholders had a strong preference to communicate and to receive information needed for decision purposes in deterministic rather than probabilistic language. That is, they would prefer to know the consequences resulting from a specific magnitude event (e.g., magnitude 7) that is representative of the largest event that could impact their facility, rather than to hear about a spectrum of hazards to which the facility might be exposed. The Product One Development Team felt that this need of the stakeholders could be met with improved communication language, while utilizing the recommended (and more quantitative) probabilistic design approach. Guidance is therefore provided on communication concepts pertaining to defining the seismic hazard and presentation of performance metrics.

In evaluating the alternative deterministic and probabilistic approaches that could be considered in the development of next-generation performance-based seismic design procedures and criteria, five different global analysis approaches (levels) were identified that involve consideration of various factors known to impact the design process and their uncertainties. The least complicated approach (Level 1) is a relatively straightforward approach that is similar to the Load and Resistance Factor Design (LRFD) method, whereas the most sophisticated (and not yet developed) Level 5 approach would include most factors known to impact the decision process as well as their uncertainties. If this most rigorous option is pursued by the ATC-58 guidelines development team and proves to be unattainable, then Level 4 is recommended as the next most desirable option. The most significant factor that distinguishes the recommended Level 5 option from the recommended Level 4 default option is the inclusion of the epistemic uncertainty in the earthquake ground motion in a Level 5 analysis. In the Western United States, where (it is believed that) most of the causative sources have been identified, this source of uncertainty may be relatively small and may have relatively little impact on the decision process. In contrast, in the Eastern United States, where hazard analysis is based on postulated seismotectonic provinces rather than causative sources, the epistemic uncertainty is very large and the decision process is likely to be affected by it.

It is recognized that other options exist for addressing uncertainties in the factors that affect building design and response. If other options are pursued during development of the next-generation performance-based design procedures and criteria to be developed under the FEMA-funded ATC-58 project, it is important that such uncertainties be addressed and minimized to the fullest extent possible.

Finally it is recommended that at periodic intervals during the ATC-58 project, this report and others that are developed during the conduct of the project be revisited with stakeholders to ensure that the end product satisfies the ultimate goal of communicating performance-based design issues in the most clearly understandable terms.

Appendix A
Performance Characterization in FEMA 273 Guidelines

The following sections summarize the performance characterization used in the FEMA 273 NEHRP *Guidelines for Seismic Rehabilitation of Buildings* (ATC/BSSC, 1997). In these *Guidelines,* building performance is characterized as a combination of the performance of both structural and nonstructural components. Table A-1 (extracted from FEMA 273) describes the overall levels of structural and nonstructural damage that may be expected of buildings rehabilitated to the levels defined in the FEMA 273 *Guidelines*. These performance descriptions are estimates rather than precise predictions, and variation among buildings

Table A-1 FEMA 273 Damage Control and Building Performance Levels

	Building Performance Levels			
	Collapse Prevention Level	*Life Safety Level*	*Immediate Occupancy Level*	*Operational Level*
Overall Damage	*Severe*	*Moderate*	*Light*	*Very Light*
General	Little residual stiffness and strength, but load-bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse.	Some residual strength and stiffness left in all stories. Gravity-load-bearing elements function. No out-of-plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable.	No permanent drift; structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. All systems important to normal operation are functional.
Nonstructural components	Extensive damage.	Falling hazards mitigated but many architectural, mechanical, and electrical systems are damaged.	Equipment and contents are generally secure, but may not operate due to mechanical failure or lack of utilities.	Negligible damage occurs. Power and other utilities are available, possibly from standby sources.
Comparison with performance intended for buildings designed, under the *NEHRP Provisions,* for the Design Earthquake	Significantly more damage and greater risk.	Somewhat more damage and slightly higher risk.	Much less damage and lower risk.	Much less damage and lower risk.

designed or rehabilitated to the same Performance Level are to be expected. For comparative purposes, the table includes estimated performance of a new building designed in accordance with the FEMA 302 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures (1997 Edition),* subjected to the same level of shaking as specified for the design-basis earthquake in the FEMA 273 *Guidelines*.

In FEMA 273 independent performance definitions are provided for structural and nonstructural components. To facilitate use of the document, structural performance levels are identified by both a reference (S-) and numerical designator. Nonstructural performance levels are identified by a reference (N-) and alphabetical designator. These same designators are used throughout the discussion in the sections that follow.

A.1 Structural Performance Levels and Ranges

Three discrete Structural Performance Levels and two intermediate Structural Performance Ranges are defined in the FEMA 273 *Guidelines*. Acceptance criteria, which relate to the permissible earthquake-induced forces and deformations for the various components and elements of the building, both existing and new, are tied directly to these Structural Performance Ranges and Levels.

Because a wide range of structural performance requirements could be desired by individual building owners, the three Structural Performance Levels defined in these *Guidelines* have been selected to correlate with the most commonly specified structural performance requirements. The two Structural Performance Ranges permit users with other requirements to customize their building Rehabilitation Objectives.

The Structural Performance Levels are the Immediate Occupancy Level (S-1), the Life Safety Level (S-3), and the Collapse Prevention Level (S-5). Table A-2 relates these Structural Performance Levels to the limiting damage states for common vertical elements of lateral-force-resisting systems. Table A-3 relates these Structural Performance Levels to the limiting damage states for common horizontal elements of building lateral-force-resisting systems. Later sections of the FEMA 273 *Guidelines* specify design parameters (such as *m* factors, component capacities, and inelastic deformation demands) recommended as limiting values for calculated structural deformations and stresses for different construction components, in order to attain these Structural Performance Levels for a known earthquake demand.

The drift values given in Table A-2 are typical values provided to illustrate the overall structural response associated with various performance levels. They are not provided in these tables as drift limit requirements of the *Guidelines*, and they do not supersede the specific drift limits or related component or element deformation limits that are specified in Chapters 5 through 9, and 11 of the FEMA 273 *Guidelines*. The expected postearthquake state of the buildings described in these tables is for design purposes and should not be used in the postearthquake safety evaluation process.

The Structural Performance Ranges are the Damage Control Range (S-2) and the Limited Safety Range (S-4). Specific acceptance criteria are not provided for design to these intermediate performance ranges. The engineer wishing to design for such performance needs to determine appropriate acceptance criteria. Acceptance criteria for performance within the Damage Control Range may be obtained by interpolating the acceptance criteria provided for the Immediate Occupancy and Life Safety Performance Levels. Acceptance criteria for performance within the Limited Safety Range may be obtained by interpolating the acceptance criteria for performance within the Life Safety and Collapse Prevention Performance Levels.

A.1.1 Immediate Occupancy Performance Level (S-1)

Structural Performance Level S-1, Immediate Occupancy, means the postearthquake damage state in which only very limited structural damage has occurred. The basic vertical-, and lateral-force-resisting systems of the building retain nearly all of their pre-earthquake strength and stiffness. The risk of life-threatening injury as a result of structural damage is very low, and although some minor structural repairs may be appropriate, these would generally not be required prior to re-occupancy.

Table A-2 FEMA 273 Structural Performance Levels and Damage[1]—Vertical Elements

		Structural Performance Levels		
Elements	*Type*	*Collapse Prevention S-5*	*Life Safety S-3*	*Immediate Occupancy S-1*
Concrete Frames	Primary	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Extensive damage to beams. Spalling of cover and shear cracking (< 1/8" width) for ductile columns. Minor spalling in nonductile columns. Joint cracks < 1/8" wide.	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003).
	Secondary	Extensive spalling in columns (limited shortening) and beams. Severe joint damage. Some reinforcing buckled.	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Minor spalling in a few places in ductile columns and beams. Flexural cracking in beams and columns. Shear cracking in joints < 1/16" width.
	Drift[2]	4% transient or permanent	2% transient; 1% permanent	1% transient; negligible permanent
Steel Moment Frames	Primary	Extensive distortion of beams and column panels. Many fractures at moment connections, but shear connections remain intact.	Hinges form. Local buckling of some beam elements. Severe joint distortion; isolated moment connection fractures, but shear connections remain intact. A few elements may experience partial fracture.	Minor local yielding at a few places. No fractures. Minor buckling or observable permanent distortion of members.
	Secondary	Same as primary.	Extensive distortion of beams and column panels. Many fractures at moment connections, but shear connections remain intact.	Same as primary.
	Drift[2]	5% transient or permanent	2.5% transient; 1% permanent	0.7% transient; negligible permanent

Table A-2 FEMA 273 Structural Performance Levels and Damage[1]—Vertical Elements (continued)

Elements	Type	*Structural Performance Levels* *Collapse Prevention S-5*	*Life Safety S-3*	*Immediate Occupancy S-1*
Braced Steel Frames	Primary	Extensive yielding and buckling of braces. Many braces and their connections may fail.	Many braces yield or buckle but do not totally fail. Many connections may fail.	Minor yielding or buckling of braces.
	Secondary	Same as primary.	Same as primary.	Same as primary.
	Drift[2]	2% transient or permanent	1.5% transient; 0.5% permanent	0.5% transient; negligible permanent
Concrete Walls	Primary	Major flexural and shear cracks and voids. Sliding at joints. Extensive crushing and buckling of reinforcement. Failure around openings. Severe boundary element damage. Coupling beams shattered and virtually disintegrated.	Some boundary element distress, including limited buckling of reinforcement. Some sliding at joints. Damage around openings. Some crushing and flexural cracking. Coupling beams: extensive shear and flexural cracks; some crushing, but concrete generally remains in place.	Minor hairline cracking of walls, < 1/16" wide. Coupling beams experience cracking < 1/8" width.
	Secondary	Panels shattered and virtually disintegrated.	Major flexural and shear cracks. Sliding at joints. Extensive crushing. Failure around openings. Severe boundary element damage. Coupling beams shattered and virtually disintegrated.	Minor hairline cracking of walls. Some evidence of sliding at construction joints. Coupling beams experience cracks < 1/8" width. Minor spalling.
	Drift[2]	2% transient or permanent	1% transient; 0.5% permanent	0.5% transient; negligible permanent
Unreinforced Masonry Infill Walls[3]	Primary	Extensive cracking and crushing; portions of face course shed.	Extensive cracking and some crushing but wall remains in place. No falling units. Extensive crushing and spalling of veneers at corners of openings.	Minor (<1/8" width) cracking of masonry infills and veneers. Minor spalling in veneers at a few corner openings.

Table A-2 FEMA 273 Structural Performance Levels and Damage[1]—Vertical Elements (continued)

Elements	Type	*Structural Performance Levels* Collapse Prevention S-5	Life Safety S-3	Immediate Occupancy S-1
Unreinforced Masonry Infill Walls[3] (continued)	Secondary	Extensive crushing and shattering; some walls dislodge.	Same as primary.	Same as primary.
	Drift[2]	0.6% transient or permanent	0.5% transient; 0.3% permanent	0.1% transient; negligible permanent
Unreinforced Masonry (Noninfill) Walls	Primary	Extensive cracking; face course and veneer may peel off. Noticeable in-plane and out-of-plane offsets.	Extensive cracking. Noticeable in-plane offsets of masonry and minor out-of-plane offsets.	Minor (< 1/8" width) cracking of veneers. Minor spalling in veneers at a few corner openings. No observable out-of-plane offsets.
	Secondary	Nonbearing panels dislodge.	Same as primary.	Same as primary.
	Drift[2]	1% transient or permanent	0.6% transient; 0.6% permanent	0.3% transient; 0.3% permanent
Reinforced Masonry Walls	Primary	Crushing; extensive cracking. Damage around openings and at corners. Some fallen units.	Extensive cracking (< 1/4") distributed throughout wall. Some isolated crushing.	Minor (< 1/8" width) cracking. No out-of-plane offsets.
	Secondary	Panels shattered and virtually disintegrated.	Crushing; extensive cracking; damage around openings and at corners; some fallen units.	Same as primary.
	Drift[2]	1.5% transient or permanent	0.6% transient; 0.6% permanent	0.2% transient; 0.2% permanent
Wood Stud Walls	Primary	Connections loose. Nails partially withdrawn. Some splitting of members and panels. Veneers dislodged.	Moderate loosening of connections and minor splitting of members.	Distributed minor hairline cracking of gypsum and plaster veneers.

Table A-2 FEMA 273 Structural Performance Levels and Damage[1]—Vertical Elements (continued)

		Structural Performance Levels		
Elements	*Type*	*Collapse Prevention S-5*	*Life Safety S-3*	*Immediate Occupancy S-1*
Wood Stud Walls (continued)	Secondary	Sheathing sheared off. Let-in braces fractured and buckled. Framing split and fractured.	Connections loose. Nails partially withdrawn. Some splitting of members and panels.	Same as primary.
	Drift[2]	3% transient or permanent	2% transient; 1% permanent	1% transient; 0.25% permanent
Precast Concrete Connections	Primary	Some connection failures but no elements dislodged.	Local crushing and spalling at connections, but no gross failure of connections.	Minor working at connections; cracks < 1/16" width at connections.
	Secondary	Same as primary.	Some connection failures but no elements dislodged.	Minor crushing and spalling at connections.
Foundations	General	Major settlement and tilting.	Total settlements < 6" and differential settlements < 1/2" in 30 ft.	Minor settlement and negligible tilting.

Notes:

1. The damage states indicated in this table are provided to allow an understanding of the severity of damage that may be sustained by various structural elements when present in structures meeting the definitions of the Structural Performance Levels. These damage states are not intended for use in postearthquake evaluation of damage nor for judging the safety of, or required level of repair to, a structure following an earthquake.
2. The drift values, differential settlements, and similar quantities indicated in these tables are not intended to be used as acceptance criteria for evaluating the acceptability of a rehabilitation design in accordance with the analysis procedures provided in these *Guidelines*; rather, they are indicative of the range of drift that typical structures containing the indicated structural elements may undergo when responding within the various performance levels. Drift control of a rehabilitated structure may often be governed by the requirements to protect nonstructural components. Acceptable levels of foundation settlement or movement are highly dependent on the construction of the superstructure. The values indicated are intended to be qualitative descriptions of the approximate behavior of structures meeting the indicated levels.
3. For limiting damage to frame elements of infilled frames, refer to the rows for concrete or steel frames.

A.1.2 Life Safety Performance Level (S-3)

Structural Performance Level S-3, Life Safety, means the postearthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains. Some structural elements and components are severely damaged, but this has not resulted in large falling debris hazards, either within or outside the building. Injuries may occur during the earthquake; however, it is expected that the overall risk of life-threatening injury as a result of structural damage is low. It should be possible to repair the structure; however, for economic reasons this may not be practical. While the damaged structure is not an imminent collapse risk, it would be prudent to implement structural repairs or install temporary bracing prior to re-occupancy.

A.1.3 Collapse Prevention Performance Level (S-5)

Structural Performance Level S-5, Collapse Prevention, means the building is on the verge of experiencing partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the

Table A-3 FEMA 273 Structural Performance Levels and Damage—Horizontal Elements

Element	Performance Levels: Collapse Prevention S-5	Life Safety S-3	Immediate Occupancy S-1
Metal Deck Diaphragms	Large distortion with buckling of some units and tearing of many welds and seam attachments.	Some localized failure of welded connections of deck to framing and between panels. Minor local buckling of deck.	Connections between deck units and framing intact. Minor distortions.
Wood Diaphragms	Large permanent distortion with partial withdrawal of nails and extensive splitting of elements.	Some splitting at connections. Loosening of sheathing. Observable withdrawal of fasteners. Splitting of framing and sheathing.	No observable loosening or withdrawal of fasteners. No splitting of sheathing or framing.
Concrete Diaphragms	Extensive crushing and observable offset across many cracks.	Extensive cracking (< 1/4" width). Local crushing and spalling.	Distributed hairline cracking. Some minor cracks of larger size (< 1/8″ width).
Precast Diaphragms	Connections between units fail. Units shift relative to each other. Crushing and spalling at joints.	Extensive cracking (< 1/4″ width). Local crushing and spalling.	Some minor cracking along joints.

lateral-force-resisting system, large permanent lateral deformation of the structure, and—to a more limited extent—degradation in vertical-load-carrying capacity. However, all significant components of the gravity-load-resisting system must continue to carry their gravity load demands. Significant risk of injury due to falling hazards from structural debris may exist. The structure may not be technically practical to repair and is not safe for re-occupancy, as aftershock activity could induce collapse.

A.1.4 Damage Control Performance Range (S-2)

Structural Performance Range S-2, Damage Control, means the continuous range of damage states that entail less damage than that defined for the Life Safety level, but more than that defined for the Immediate Occupancy level. Design for Damage Control performance may be desirable to minimize repair time and operation interruption; as a partial means of protecting valuable equipment and contents; or to preserve important historic features when the cost of design for Immediate Occupancy is excessive. Acceptance criteria for this range may be obtained by interpolating between the values provided for the Immediate Occupancy (S-1) and Life Safety (S-3) levels.

A.1.5 Limited Safety Performance Range (S-4)

Structural Performance Range S-4, Limited Safety, means the continuous range of damage states between the Life Safety and Collapse Prevention levels. Design parameters for this range may be obtained by interpolating between the values provided for the Life Safety (S-3) and Collapse Prevention (S-5) levels.

A.1.6 Structural Performance Not Considered (S-6)

Some owners may desire to address certain nonstructural vulnerabilities in a rehabilitation program—for example, bracing parapets, or anchoring hazardous materials storage containers—without addressing the performance of the structure itself. Such rehabilitation programs are sometimes attractive because they can permit a significant reduction in seismic risk at relatively low cost. The actual performance of the structure with regard to *Guidelines* requirements is not known and could range from a potential collapse hazard to a structure capable of meeting the Immediate Occupancy Performance Level.

A.2 Nonstructural Performance Levels

Four Nonstructural Performance Levels are defined in these FEMA 273 *Guidelines* and are summarized in Tables A-4 through A-6. Nonstructural components addressed in these performance levels include architectural components, such as partitions, exterior cladding, and ceilings; and mechanical and electrical components, including HVAC systems, plumbing, fire suppression systems, and lighting. Occupant contents and furnishings (such as inventory and computers) are included in these tables for some levels but are generally not covered with specific FEMA 273 *Guidelines* requirements.

A.2.1 Operational Performance Level (N-A)

Nonstructural Performance Level A, Operational, means the postearthquake damage state of the building in which the nonstructural components are able to support the building's intended function. At this level, most nonstructural systems required for normal use of the building—including lighting, plumbing, HVAC, and computer systems—are functional, although minor cleanup and repair of some items may be required. This performance level requires considerations beyond those that are normally within the sole province of the structural engineer. In addition to assuring that nonstructural components are properly mounted and braced within the structure, in order to achieve this performance it is often necessary to provide emergency standby utilities. In addition, it may be necessary to perform rigorous qualification testing of the ability of key electrical and mechanical equipment items to function during or after strong shaking.

Specific design procedures and acceptance criteria for this performance level are not included in the FEMA 273 *Guidelines*. Users wishing to design for this performance level will need to refer to appropriate criteria from other sources, such as equipment manufacturers' data, to ensure the performance of mechanical and electrical systems.

A.2.2 Immediate Occupancy Level (N-B)

Nonstructural Performance Level B, Immediate Occupancy, means the postearthquake damage state in which only limited nonstructural damage has occurred. Basic access and life safety systems, including doors, stairways, elevators, emergency lighting, fire alarms, and suppression systems, remain operable, provided that power is available. There could be minor window breakage and slight damage to some components. Presuming that the building is structurally safe, it is expected that occupants could safely remain in the building, although normal use may be impaired and some cleanup and inspection may be required. In general, components of mechanical and electrical systems in the building are structurally secured and should be able to function if necessary utility service is available. However, some components may experience misalignments or internal damage and be non-operable. Power, water, natural gas, communications lines, and other utilities required for normal building use may not be available. The risk of life-threatening injury due to nonstructural damage is very low.

A.2.3 Life Safety Level (N-C)

Nonstructural Performance Level C, Life Safety, is the postearthquake damage state in which potentially significant and costly damage has occurred to nonstructural components but they have not become dislodged and fallen, threatening life safety either within or outside the building. Egress routes within the building are not extensively blocked, but may be

Table A-4 FEMA 273 Nonstructural Performance Levels and Damage—Architectural Components

	Nonstructural Performance Levels			
Component	*Hazards Reduced Level N-D*	*Life Safety N-C*	*Immediate Occupancy N-B*	*Operational N-A*
Cladding	Severe damage to connections and cladding. Many panels loosened.	Severe distortion in connections. Distributed cracking, bending, crushing, and spalling of cladding elements. Some fracturing of cladding, but panels do not fall.	Connections yield; minor cracks (< 1/16" width) or bending in cladding.	Connections yield; minor cracks (< 1/16" width) or bending in cladding.
Glazing	General shattered glass and distorted frames. Widespread falling hazards.	Extensive cracked glass; little broken glass.	Some cracked panes; none broken.	Some cracked panes; none broken
Partitions	Severe racking and damage in many cases.	Distributed damage; some severe cracking, crushing, and racking in some areas.	Cracking to about 1/16" width at openings. Minor crushing and cracking at corners.	Cracking to about 1/16" width at openings. Minor crushing and cracking at corners.
Ceilings	Most ceilings damaged. Light suspended ceilings dropped. Severe cracking in hard ceilings.	Extensive damage. Dropped suspended ceiling tiles. Moderate cracking in hard ceilings.	Minor damage. Some suspended ceiling tiles disrupted. A few panels dropped. Minor cracking in hard ceilings.	Generally negligible damage. Isolated suspended panel dislocations, or cracks in hard ceilings.
Parapets and Ornamentation	Extensive damage; some fall in nonoccupied areas.	Extensive damage; some falling in nonoccupied areas.	Minor damage.	Minor damage.
Canopies & Marquees	Extensive distortion.	Moderate distortion.	Minor damage.	Minor damage.
Chimneys & Stacks	Extensive damage. No collapse.	Extensive damage. No collapse.	Minor cracking.	Negligible damage.
Stairs & Fire Escapes	Extensive racking. Loss of use.	Some racking and cracking of slabs, usable.	Minor damage.	Negligible damage.
Light Fixtures	Extensive damage. Falling hazards occur.	Many broken light fixtures. Falling hazards generally avoided in heavier fixtures (> 20 pounds).	Minor damage. Some pendant lights broken.	Negligible damage.
Doors	Distributed damage. Many racked and jammed doors.	Distributed damage. Some racked and jammed doors.	Minor damage. Doors operable.	Minor damage. Doors operable.

Table A-5 FEMA 273 Nonstructural Performance Levels and Damage—Mechanical, Electrical, and Plumbing Systems/Components

	Nonstructural Performance Levels			
System/Component	*Hazards Reduced N-D*	*Life Safety N-C*	*Immediate Occupancy N-B*	*Operational N-A*
Elevators	Elevators out of service; counter-weights off rails.	Elevators out of service; counterweights do not dislodge.	Elevators operable; can be started when power available.	Elevators operate.
HVAC Equipment	Most units do not operate; many slide or overturn; some suspended units fall.	Units shift on supports, rupturing attached ducting, piping, and conduit, but do not fall.	Units are secure and most operate if power and other required utilities are available.	Units are secure and operate; emergency power and other utilities provided, if required.
Ducts	Ducts break loose of equipment and louvers; some supports fail; some ducts fall.	Minor damage at joints of sections and attachment to equipment; some supports damaged, but ducts do not fall.	Minor damage at joints, but ducts remain serviceable.	Negligible damage.
Piping	Some lines rupture. Some supports fail. Some piping falls.	Minor damage at joints, with some leakage. Some supports damaged, but systems remain suspended.	Minor leaks develop at a few joints.	Negligible damage.
Fire Sprinkler Systems	Many sprinkler heads damaged by collapsing ceilings. Leaks develop at couplings. Some branch lines fail.	Some sprinkler heads damaged by swaying ceilings. Leaks develop at some couplings.	Minor leakage at a few heads or pipe joints. System remains operable.	Negligible damage.
Fire Alarm Systems	Ceiling mounted sensors damaged. System nonfunctional.	May not function.	System is functional.	System is functional.
Emergency Lighting	Some lights fall. Power may not be available.	System is functional.	System is functional.	System is functional.
Electrical Distribution Equipment	Units slide and/or overturn, rupturing attached conduit. Uninterruptible Power Source systems fail. Diesel generators do not start.	Units shift on supports and may not operate. Generators provided for emergency power start; utility service lost.	Units are secure and generally operable. Emergency generators start, but may not be adequate to service all power requirements.	Units are functional. Emergency power is provided, as needed.
Plumbing	Some fixtures broken; lines broken; mains disrupted at source.	Some fixtures broken, lines broken; mains disrupted at source.	Fixtures and lines serviceable; however, utility service may not be available.	System is functional. On-site water supply provided, if required.

Table A-6 FEMA 273 Nonstructural Performance Levels and Damage—Contents

	Nonstructural Performance Levels			
Contents Type	*Hazards Reduced N-D*	*Life Safety N-C*	*Immediate Occupancy N-B*	*Operational N-A*
Computer Systems	Units roll and overturn, disconnect cables. Raised access floors collapse.	Units shift and may disconnect cables, but do not overturn. Power not available.	Units secure and remain connected. Power may not be available to operate, and minor internal damage may occur.	Units undamaged and operable; power available.
Manufacturing Equipment	Units slide and overturn; utilities disconnected. Heavy units require reconnection and realignment. Sensitive equipment may not be functional.	Units slide, but do not overturn; utilities not available; some realignment required to operate.	Units secure, and most operable if power and utilities available.	Units secure and operable; power and utilities available.
Desktop Equipment	Units slide off desks.	Some equipment slides off desks.	Some equipment slides off desks.	Equipment secured to desks and operable.
File Cabinets	Cabinets overturn and spill contents.	Drawers slide open; cabinets tip.	Drawers slide open, but cabinets do not tip.	Drawers slide open, but cabinets do not tip.
Book Shelves	Shelves overturn and spill contents.	Books slide off shelves.	Books slide on shelves.	Books remain on shelves.
Hazardous Materials	Severe damage; no large quantity of material released.	Minor damage; occasional materials spilled; gaseous materials contained.	Negligible damage; materials contained.	Negligible damage; materials contained.
Art Objects	Objects damaged by falling, water, dust.	Objects damaged by falling, water, dust.	Some objects may be damaged by falling.	Objects undamaged.

impaired by lightweight debris. HVAC, plumbing, and fire suppression systems may have been damaged, resulting in local flooding as well as loss of function. While injuries may occur during the earthquake from the failure of nonstructural components, it is expected that, overall, the risk of life-threatening injury is very low. Restoration of the nonstructural components may take extensive effort.

A.2.4 Hazards Reduced Level (N-D)

Nonstructural Performance Level D, Hazards Reduced, represents a postearthquake damage state level in which extensive damage has occurred to nonstructural components, but large or heavy items that pose a falling hazard to a number of people—such as parapets, cladding panels, heavy plaster ceilings, or storage racks—are prevented from falling. While isolated serious injury could occur from falling debris, failures that could injure large numbers of persons—either inside or outside the structure—should be avoided. Exits, fire suppression systems, and similar life-safety issues are not addressed in this performance level.

A.2.5 Nonstructural Performance Not Considered (N-E)

In some cases, the decision may be made to rehabilitate the structure without addressing the vulnerabilities of nonstructural components. It may be desirable to do this when rehabilitation must be performed without interruption of building operation. In some cases, it is possible to perform all or most of the structural rehabilitation from outside occupied building areas, while extensive disruption of normal operation may be required to perform nonstructural rehabilitation. Also, since many of the most severe hazards to life safety occur as a result of structural vulnerabilities, some municipalities may wish to adopt rehabilitation ordinances that require structural rehabilitation only.

A.3 Building Performance Levels

Building Performance Levels are obtained by combining Structural and Nonstructural Performance Levels (see Figure A-1, which also includes building performance ranges). A large number of combinations is possible. Each Building Performance Level is designated alpha-numerically with a numeral representing the Structural Performance Level and a letter representing the Nonstructural Performance Level (e.g. 1-B, 3-C). Table A-7 indicates the possible combinations and provides names for those that are most likely to be selected as a basis for design. Several of the more common Building Performance Levels are described below.

A.3.1 Operational Level (1-A)

This Building Performance Level is a combination of the Structural Immediate Occupancy Level and the Nonstructural Operational Level. Buildings meeting this performance level are expected to sustain minimal or no damage to their structural and nonstructural components. The building is suitable for its normal occupancy and use, although possibly in a slightly impaired mode, with power, water, and other required utilities provided from emergency sources, and possibly with some nonessential systems not functioning. Buildings meeting this performance level pose an extremely low risk to life safety. Under very low levels of earthquake ground motion, most buildings should be able to meet or exceed this performance level. Typically, however, it will not be economically practical to design for this performance under severe levels of ground shaking, except for buildings that house essential services.

Building Performance Levels and Ranges

Performance Level: the intended post-earthquake condition of a building; a well-defined point on a scale measuring how much loss is caused by earthquake damage. In addition to casualties, loss may be in terms of property and operational capability.

Performance Range: a range or band of performance, rather than a discrete level.

Designations of Performance Levels and Ranges: Performance is separated into descriptions of damage of structural and nonstructural systems; structural designations are S-1 through S-5 and nonstructural designations are N-A through N-D.

Building Performance Level: The combination of a Structural Performance Level and a Nonstructural Performance Level to form a complete description of an overall damage level.

Rehabilitation Objective: The combination of a Performance Level or Range with Seismic Demand Criteria.

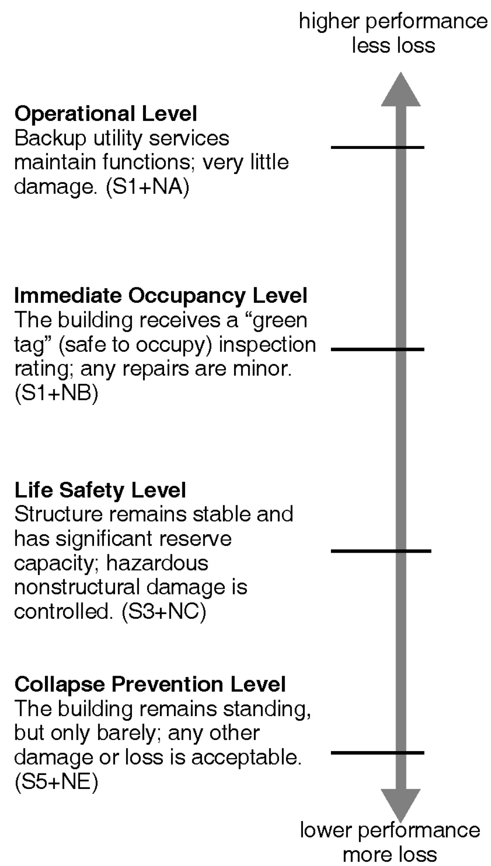

Figure A-1 FEMA 273 building performance levels and ranges.

Table A-7 FEMA 273 Building Performance Levels/Ranges

Nonstructural Performance Levels	Structural Performance Levels/Ranges: S-1 Immediate Occupancy	S-2 Damage Control Range	S-3 Life Safety	S-4 Limited Safety Range	S-5 Collapse Prevention	S-6 Not Considered
N-A Operational	Operational 1-A	2-A	Not recommended	Not recommended	Not recommended	Not recommended
N-B Immediate Occupancy	Immediate Occupancy 1-B	2-B	3-B	Not recommended	Not recommended	Not recommended
N-C Life Safety	1-C	2-C	Life Safety 3-C	4-C	5-C	6-C
N-D Hazards Reduced	Not recommended	2-D	3-D	4-D	5-D	6-D
N-E Not Considered	Not recommended	Not recommended	Not recommended	4-E	5-E Collapse Prevention	No rehabilitation

A.3.2 Immediate Occupancy Level (1-B)

This Building Performance Level is a combination of the Structural and Nonstructural Immediate Occupancy levels. Buildings meeting this performance level are expected to sustain minimal or no damage to their structural elements and only minor damage to their nonstructural components. While it would be safe to reoccupy a building meeting this performance level immediately following a major earthquake, nonstructural systems may not function due to either a lack of electrical power or internal damage to equipment. Therefore, although immediate re-occupancy of the building is possible, it may be necessary to perform some cleanup and repair, and await the restoration of utility service, before the building could function in a normal mode. The risk to life safety at this performance level is very low. Many building owners may wish to achieve this level of performance when the building is subjected to moderate levels of earthquake ground motion. In addition, some owners may desire such performance for very important buildings, under severe levels of earthquake ground shaking. This level provides most of the protection obtained under the Operational Level, without the cost of providing standby utilities and performing rigorous seismic qualification of equipment performance.

A.3.3 Life Safety Level (3-C)

This Building Performance Level is a combination of the Structural and Nonstructural Life Safety levels. Buildings meeting this level may experience extensive damage to structural and nonstructural components. Repairs may be required before re-occupancy of the building occurs, and repair may be deemed economically impractical. The risk to life in buildings meeting this performance level is low.

This performance level entails somewhat more damage than anticipated for new buildings that have been properly designed and constructed for seismic resistance when subjected to their design earthquakes. Many building owners will desire to meet this performance level for a severe level of ground shaking.

A.3.4 Collapse Prevention Level (5-E)

This Building Performance Level consists of the Structural Collapse Prevention Level with no consideration of nonstructural vulnerabilities, except that parapets and heavy appendages are rehabilitated. Buildings meeting this performance level may pose a significant hazard to life safety resulting from failure of nonstructural components. However, because the building itself does not collapse, gross loss of life should be avoided. Many buildings meeting this level will be complete economic losses.

This level has sometimes been selected as the basis for mandatory seismic rehabilitation ordinances enacted by municipalities, as it results in mitigation of the most severe life-safety hazards at relatively low cost.

Appendix B
Performance Characterization in Vision 2000 Report

Performance levels in Vision 2000 are defined in terms of damage to the structure and nonstructural components and in terms of consequences to the occupants and functions carried on within the facility. Four performance levels are identified and are described in detail in the Vision 2000 Report. These performance levels are as follows:

- **Fully Operational** – Facility continues in operation with negligible damage.
- **Operational** – Facility continues in operation with minor damage and minor disruption in nonessential services.
- **Life Safe** – Life Safety is substantially protected, damage is moderate to extensive.
- **Near Collapse** – Life safety is at risk, damage is severe, structural collapse is prevented.

Tables B-1 through B-5 further define these performance levels in terms of damage to the various components of the building. Figure B-1 provides a global summary of the interrelationships of the various performance levels.

The seismic hazard at a given site is represented as a set of earthquake ground motions and associated hazards with specified probabilities of occurrence. Four levels of probabilistic events are proposed as follows:

Event	*Recurrence Interval*	*Probability of Exceedence*
Frequent	43 years	50% In 30 years
Occasional	72 years	50% in 50 years
Rare	475 years	10% in 50 years
Very Rare	970 years	10% in 100 years

Performance objectives are composed of multiple goals; for example, fully operational in the 43-year event, life safe in the 475-year event, and collapse prevention in the 970-year event. For this Vision 2000 Report, a set of minimum objectives and enhanced objectives are identified:

- **Minimum Objectives** – The basic objective is defined as the minimum acceptable performance objective for typical new buildings. Essential/hazardous facility and safety critical objectives are defined as minimum objectives for facilities such as hospitals and nuclear material processing facilities, respectively.
- **Enhanced Objectives** – Other objectives that provide better performance or lower risk than the minimum objectives may be selected at the client's discretion. These objectives are termed enhanced objectives.

The selection of performance objectives sets the acceptance criteria for the design. The performance objectives represent performance levels, or damage levels, expected to result from design ground motions. The performance levels are keyed to limiting values of measurable structural response parameters, such as drift and ductility demand. When the performance objectives are selected, the associated limiting values become the acceptance criteria to be checked in later stages of the design. Limiting values of the response parameters that correlate with the defined performance levels must be established through research.

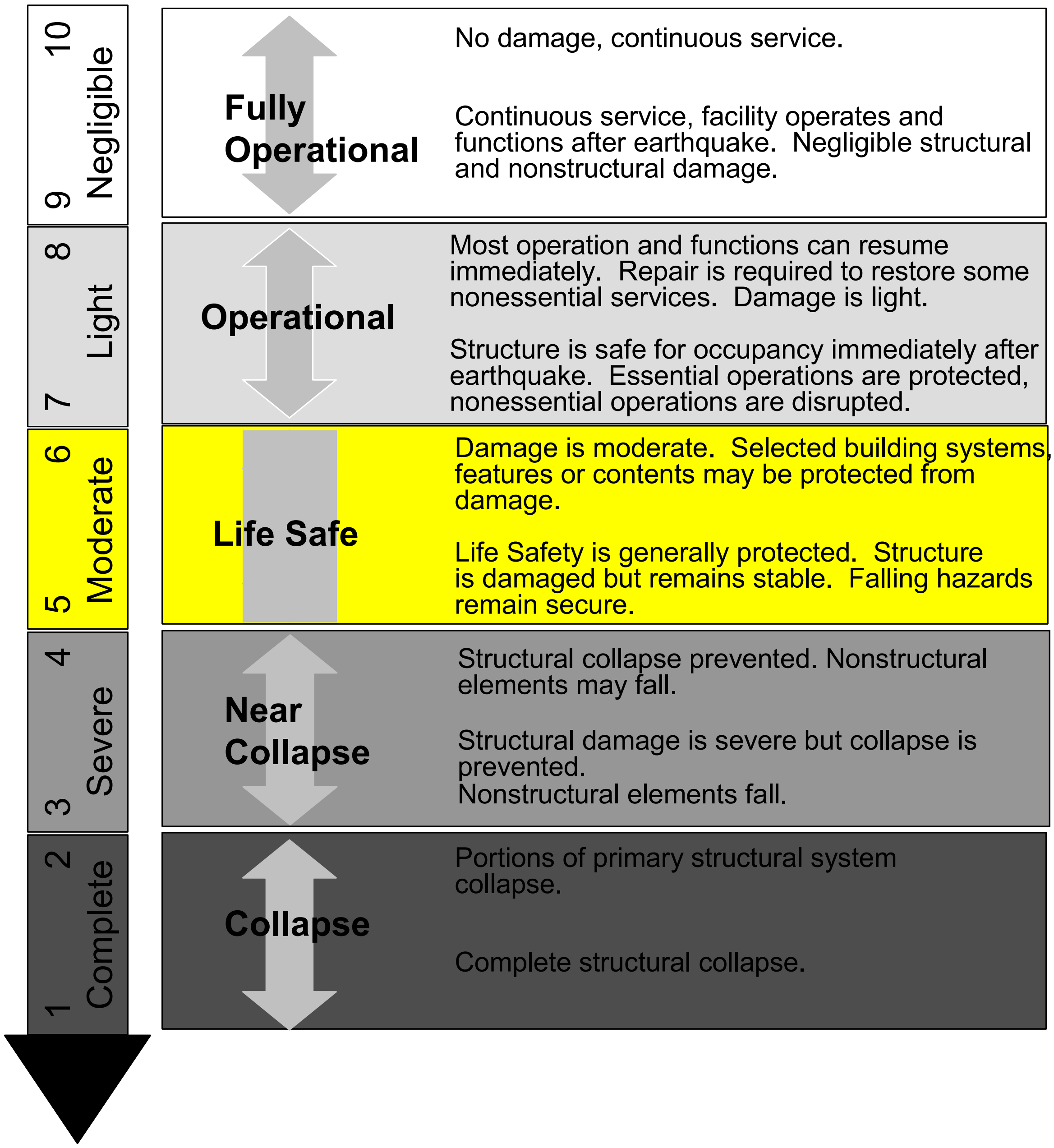

Figure B-1 Vision 2000 performance levels and damage states. Numbers above one-word damage state descriptors (left) are intended to represent a numeric damage-state scale.

Table B-1 Vision 2000 General Damage Descriptions by Performance Levels and Systems

	Performance Level				
System Description	*Fully Operational*	*Operational*	*Life Safe*	*Near Collapse*	*Collapse*
Overall Building Damage	Negligible	Light	Moderate	Severe	Complete
Permissible Transient Drift	< 0.2% ±	< 0.5% ±	< 1.5% ±	< 2.5% ±	> 2.5% ±
Permissible Permanent Drift	Negligible	Negligible	< 0.5% ±	< 2.5% ±	> 2.5% ±
Vertical Load-Carrying Element Damage	Negligible	Negligible	Light to moderate, but substantial capacity remains to carry gravity loads	Moderate to heavy, but elements continue to support gravity loads	Partial to total loss of gravity load support
Lateral Load-Carrying Element Damage	Negligible. Generally elastic response; no significant loss of strength or stiffness	Light. Nearly elastic response; original strength and stiffness substantially retained; minor cracking/ yielding of structural elements; repair implemented at convenience	Moderate. Reduced residual strength and stiffness, but lateral system remains functional	Negligible residual strength and stiffness; no story collapse mechanisms, but large permanent drift. Secondary structural elements may completely fail	Partial or total collapse; primary elements may require demolition
Damage to Architectural Systems	Negligible damage to cladding, glazing, partitions, ceilings, finishes, etc; Isolated elements may require repair at users convenience	Light to moderate damage to architectural systems; essential and select protected items undamaged; hazardous materials contained	Moderate to severe damage to architectural systems, but large falling hazards not created; major spills of hazardous materials contained	Severe damage to architectural systems; some elements may dislodge and fall	Highly dangerous falling hazards; destruction of components

(Table continued on next page)

Table B-1 Vision 2000 General Damage Descriptions by Performance Levels and Systems (continued)

System Description	*Performance Level*				
	Fully Operational	*Operational*	*Life Safe*	*Near Collapse*	*Collapse*
Egress Systems	Not Impaired	No major obstructions in exit corridors; elevators can be restarted perhaps following minor servicing	No major obstructions in exit corridors; elevators may be out of service for extended period	Egress may be obstructed	Egress may be highly or completely obstructed
Mechanical/ Electrical/ Plumbing/ Utility Services	Functional	Equipment essential to function and fire/life safety systems operate; other systems may require repair; temporary utility service provided as required	Some equipment dislodged or overturned; many systems not functional; piping conduit ruptured	Severe damage and permanent disruption of systems	Partial or total destruction of systems; permanent disruption of systems
Damage to Contents	Some light damage to contents may occur; hazardous materials secured and undamaged	Light to moderate damage; critical contents and hazardous materials secured	Moderate to severe damage to contents; major spills of hazardous materials contained	Severe damage to contents; hazardous materials may not be contained	Partial or total loss of contents
Repair	Not required	At owner/tenants convenience	Possible; building may be closed	Probably not practical	Not possible
Effect on Occupancy	No effect	Continuous occupancy possible	Short term to indefinite loss of use	Potential permanent loss of use	Permanent loss of use

Table B-2 Vision 2000 Performance Levels and Permissible Structural Damage – Vertical Elements

Elements	*Type*	*Performance Level* *Fully Operational*	*Operational*	*Life Safe*	*Near Collapse*
Concrete Frames	Primary	Negligible	Minor hairline cracking (0.02″); limited yielding possible at a few locations; no crushing (strains below 0.003)	Extensive damage to beams; spalling of cover and shear cracking (<1/8″) for ductile columns; minor spalling in nonductile columns; joints cracked < 1/8″ width	Extensive cracking and hinge formation in ductile elements; limited cracking and/or splice failure in some nonductile columns; severe damage in short columns
	Secondary	Negligible	Same as primary	Extensive cracking and hinge formation in ductile elements; limited cracking and/or splice failure in some nonductile columns; severe damage in short columns	Extensive spalling in columns (possible shortening) and beams; severe joint damage; some reinforcing buckled
Steel Moment Frames	Primary	Negligible	Minor local yielding at a few places; no observable fractures; minor buckling or observable permanent distortion of members	Hinges form; local buckling of some beam elements; severe joint distortion; isolated connection failures; a few elements may experience fracture	Extensive distortion of beams and column panels; many fractures at connections
	Secondary	Negligible	Minor local yielding at a few places; no fractures; minor buckling or observable permanent distortion of members	Extensive distortion of beams and column panels; many fractures at connections	Extensive distortion of beams and column panels; many fractures at connections
Braced Steel Frames	Primary	Negligible	Minor Yielding or buckling of braces; no out-of-pane distortions	Many braces yield or buckle but do not totally fail; many connections may fail	Extensive yielding and buckling of braces; many braces and their connections may fail
	Secondary	Negligible	Same as primary	Same as primary	Same as primary

(Table continued on next page)

Table B-2 Vision 2000 Performance Levels and Permissible Structural Damage – Vertical Elements (continued)

		Performance Level			
Elements	*Type*	*Fully Operational*	*Operational*	*Life Safe*	*Near Collapse*
Concrete Shear Walls	Primary	Negligible	Minor hairline cracking (0.02″) of walls; coupling beams experience cracking < 1/8″ width	Some boundary elements distress including limited bar buckling; some sliding at joints; damage around openings; some crushing and flexural cracking; coupling beams-extensive shear and flexural cracks; some crushing, but concrete generally remains in place	Major flexural and shear cracks and voids; sliding at joints; extensive crushing and buckling of rebar; failure around openings; severe boundary element damage; coupling beams shattered, virtually disintegrated
	Secondary	Negligible	Minor hairline cracking of walls, some evidence of sliding at construction joints; coupling beam experience cracks < 1/8″ width, minor spalling	Major flexural and shear cracks; sliding at joints; extensive crushing; failure around openings; severe boundary element damage; coupling beams shattered, virtually disintegrated	Panels shattered, virtually disintegrated

Table B-3 Vision 2000 Performance Levels and Permissible Damage – Architectural Elements

	Performance Level			
Element	*Fully Operational*	*Operational*	*Life Safe*	*Near Collapse*
Cladding	Negligible Damage	Connections yield; some cracks or bending in cladding	Severe distortion in connections; distributed cracking, bending, crushing and spalling of cladding elements; some fracturing of cladding, falling of panels prevented	Severe damage to connections and cladding; some falling of panels
Glazing	Generally no damage; isolated cracking possible	Some broken glass; falling hazards avoided	Extensive broken glass; some falling hazards	General shattered glass and distorted frames; widespread falling hazards
Partitions	Negligible damage; some hairline cracks at openings	Cracking to about 1/16″ at openings; crushing and cracking at corners	Distributed damage; some severe cracking; crushing and wracking in some areas	Severe wracking and damage in many areas
Ceilings	Generally negligible damage; isolated suspended panel dislocations or cracks in hard ceilings	Minor damage; some suspended ceilings disrupted, panels dropped; minor cracking in hard ceilings	Extensive damage; dropped suspended ceilings; distributed cracking in hard ceilings	Most ceilings damaged; most suspended ceilings dropped; severe cracking in hard ceilings
Light Fixtures	Negligible damage; pendant fixtures sway	Minor damage; some pendant lights broken; falling hazards prevented	Many broken light fixtures; falling hazards generally avoided in heavier fixtures (>20 lbs. ±)	Extensive damage; falling hazards occur
Doors	Negligible damage	Minor damage	Distributed damage; some racked and jammed doors	Distributed damage; many racked and jammed doors
Elevators	Elevators operational with isolated exceptions	Elevators generally operational; most can be restarted	Some elevators out of service	Many elevators out of service

Table B-4 Vision 2000 Performance Levels and Permissible Damage–Mechanical/Electrical/Plumbing Systems

	Performance Level			
Element	*Fully Operational*	*Operational*	*Life Safe*	*Near Collapse*
Mechanical Equipment	Negligible damage; all remain in service	Minor damage; some units not essential to function out-of-service	Many units nonoperational; some slide or overturn	Most units nonoperational; many slide or overturn; some pendant units fall
Ducts	Negligible damage	Minor damage, but systems remain in service	Some ducts rupture; some supports fail, but ducts do not fall	Most systems out of commission; some ducts fail
Piping	Negligible damage	Minor damage; minor leaking may occur	Some pipes rupture at connections; many supports fail; few fire sprinkler heads fail	Many pipes rupture; supports fail; some piping systems collapse
Fire Alarms Systems	Functional	Functional	Not functional	Not functional
Emergency Lighting Systems	Functional	Functional	Not functional	Not functional
Electrical Equipment	Negligible damage	Minor damage; panels restrained; isolated loss of function in secondary systems	Moderate damage; panels restrained from overturning; some loss of function and service in primary systems	Extensive damage and loss of service

Table B-5 Vision 2000 Performance Levels and Permissible Damage – Contents

	Performance Level			
Element	*Functional*	*Operational*	*Life Safe*	*Near Collapse*
Furniture	Negligible effects	Minor damage; some sliding and overturning	Extensive damage from sliding, overturning, leaks, falling debris, etc	Extensive damage from sliding, overturning, leaks falling debris, etc.
Office Equipment	Negligible effects	Minor damage; some sliding and overturning	Extensive damage from sliding, overturning, leaks, falling debris, etc.	Extensive damage from sliding, overturning, leaks falling debris, etc.
Computer Systems	Operational	Minor damage; some sliding and overturning; mostly functional	Extensive damage from sliding, overturning, leaks, falling debris, etc.	Extensive damage from sliding, overturning, leaks falling debris, etc.
File Cabinets	Negligible damage	Minor damage; some sliding and overturning	Extensive damage from sliding, overturning, leaks, falling debris, etc.	Extensive damage from sliding, overturning, leaks falling debris, etc.
Bookshelves	Negligible damage	Minor damage; some overturning and spilling	Extensive damage from leaks, falling debris, overturning, spilling, etc.	Extensive damage from leaks, falling debris, overturning, spilling, etc.
Storage Racks and Cabinets	Negligible damage; overturning and straining	Minor damage; overturning restrained; some spilling	Extensive damage from leaks, falling debris, overturning, spilling, etc.	Extensive damage from leaks, falling debris, overturning, spilling, etc.
Art Works, Collections	Minor damage; overturning restrained	Moderate damage; overturning restrained, some falling	Extensive damage from leaks, falling debris, overturning, spilling, etc.	Extensive damage from leaks, falling debris, overturning, spilling, etc.
Hazardous Materials	Negligible damage; overturning and spillage restrained	Negligible damage; overturning and spillage restrained	Negligible damage; overturning and spillage restrained	Severe damage; some hazardous materials released

Appendix C
Performance Characterization in FEMA 350/SAC Recommended Criteria

The performance evaluation procedures contained in the FEMA 350 Report, *Recommended Seismic Design Criteria for New Steel Moment Frame Buildings* (SAC, 2000a), permit estimation of a level of confidence that a structure will be able to achieve a desired performance objective. Each performance objective consists of the specification of a structural performance level and a corresponding hazard level, for which that performance level is to be achieved. For example, a design may be determined to provide a 95% level of confidence that the structure will provide Collapse Prevention or better performance for earthquake hazards with a 2% probability of exceedance in 50 years, or a 50% level of confidence that the structure will provide Immediate Occupancy or better performance, for earthquake hazards with a 50% probability of exceedance in 50 years.

The performance evaluation procedures are based on an approach first developed in FEMA-273 (ATC/BSSC, 1997); however, substantial modifications have been made. In FEMA-273, performance objectives are expressed in a deterministic manner. Each performance objective consists of the specification of a limiting damage state, termed a performance level, together with a specification of the ground motion intensity for which that (or better) performance is to be provided. This implies a warranty that if the specified ground motion is actually experienced by a building designed using the FEMA-273 procedures, damage will be no worse than that indicated in the performance objective. In reality, it is very difficult to predict with certainty how much damage a building will experience for a given level of ground motion. This is because there are many factors that affect the behavior and response of a building (such as the stiffness of nonstructural elements, the strength of individual building components, and the quality of construction) that cannot be precisely defined, and also because the analysis procedures used to predict building response are not completely accurate. In addition, the exact character of the ground motion that will actually affect a building is itself uncertain. Given these uncertainties, it is inappropriate to imply that performance can be predicted in an absolute sense, and correspondingly, that it is absolutely possible to produce designs that will achieve desired performance objectives.

In recognition of this, the SAC procedures adopt a reliability-based probabilistic approach to performance evaluation that explicitly acknowledges these inherent uncertainties. These uncertainties are expressed in terms of a confidence level. If an evaluation indicates a high level of confidence, for example 90 or 95% confidence that a performance objective can be achieved, then this means it is very likely (but not guaranteed) that the building will be capable of meeting the desired performance. If lower confidence is calculated, for example 50%, this is an indication that the building may not be capable of meeting the desired performance objective. If still lower confidence is calculated, for example 30% confidence, then this indicates the building will likely not be able to meet the desired performance objective. Increased confidence in a building's ability to provide specific performance can be obtained in three basic ways:

- providing the building with greater earthquake resistance, for example, by designing the structure to be stiffer and stronger;
- reducing some of the uncertainty inherent in the performance evaluation process through

the use of more accurate structural models and analyses and better data on the building's configuration, strength and stiffness; and

- more accurately characterizing the uncertainties inherent in the performance evaluation process by using the more exact procedures.

Building performance is a combination of the performance of both structural and nonstructural components. Table C-1 contains descriptions of the overall levels of structural and nonstructural damage that may be expected of buildings meeting two performance levels, termed Collapse Prevention and Immediate Occupancy. These performance descriptions are not precise and variation among buildings must be expected, within the same Performance Level. These building performance levels are discrete damage states selected from among the infinite spectrum of possible damage states that steel moment-frame buildings could experience as a result of earthquake response. The particular damage states identified as building performance levels have been selected because these performance levels have readily identifiable consequences associated with the postearthquake disposition of the building that are meaningful to the building user community and also because they are quantifiable in technical terms. These include the ability to resume normal functions within the building, the advisability of post earthquake occupancy, and the risk to life safety.

Two discrete structural performance levels, Collapse Prevention and Immediate Occupancy, are defined in the SAC *Recommended Criteria*. Table 2.3-2 relates these structural performance levels to the limiting damage states for common framing elements of steel moment-frame buildings. Acceptance criteria, which relate to the permissible inter-story drifts and earthquake-induced forces for the various elements of steel moment-frame buildings, are tied directly to these structural performance levels.

Collapse Prevention Performance Level

The Collapse Prevention structural performance level is defined as the post earthquake damage state in which the structure is on the verge of experiencing partial or total collapse. Substantial damage to the structure has occurred, potentially including significant degradation in the stiffness and strength of the lateral-force-resisting system, large permanent lateral deformation of the structure, and, to a more limited extent, degradation in the vertical-load carrying capacity. However, all significant components of the gravity-load-resisting system must continue to carry their gravity-load demands. The structure may not be technically or economically practical to repair and is not safe

Table C-1 SAC Building Performance Levels (from FEMA 350 Report)

	Building Performance Levels	
	Collapse Prevention	*Immediate Occupancy Level*
Overall Damage	Severe	Light
General	Little residual stiffness and strength, but gravity loads are supported. Large permanent drifts. Some exits may be blocked, Exterior cladding may be extensively damaged and some local failures may occur.	Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, ceilings, and structural elements. Elevators can be restarted. Fire protection operable.
Nonstructural components	Extensive damage.	Equipment and contents are generally secure, but may not operate due to mechanical failure or lack of utilities
Comparison with performance intended by *FEMA-302* for SUG[1]–I buildings when subjected to the Design Earthquake	Significantly more damage and greater risk.	Much less damage and lower risk.
Comparison with performance intended by *FEMA – 302* for SUG[1]–I buildings when subjected to the Maximum Considered Earthquake	Same level of performance.	Much less damage and lower risk.

Note: 1. SUG = Seismic Use Group

for re-occupancy; aftershock activity could credibly induce collapse.

Immediate Occupancy Performance Level

The Immediate Occupancy structural performance level is defined as the post earthquake damage state in which only limited structural damage has occurred. Damage is anticipated to be so slight that it would not be necessary to inspect the building for damage following the earthquake, and such little damage as may be present would not require repair. The basic vertical- and lateral-force-resisting systems of the building retain nearly all of their pre-earthquake strength and stiffness. The risk of life-threatening injury as a result of structural damage is very low. Buildings meeting this performance level should be safe for immediate postearthquake occupancy, presuming that damage to nonstructural components is suitably light and that needed utility services are available.

Confidence Levels

The probability that a building may experience damage more severe than that defined for a given performance level is a function of two principal factors. The first of these is the structure's vulnerability, that is, the probability that it will experience certain levels of damage given that it experiences ground motion of certain intensity. The second of these factors is the site hazard, that is, the probability that ground shaking of varying intensities may occur in a given time period. The probability that damage exceeding a given performance level may occur in a period of time is calculated as the integral over time of the building's vulnerability and the site's hazard. Mathematically, this may be expressed as:

$$P(D > PL) = \int P_{D>PL}(x)h(x)dx \qquad \text{(C-1)}$$

where:

P(D>PL) = Probability of damage exceeding a performance level in a period of length "t" years

$P_{D>PL}$ (x) = Probability of damage exceeding a performance level given that the ground motion intensity is level x, as a function of x

h(x)dx = probability of experiencing a ground motion intensity of level (x) to (x + dx) in a period of years, "t"

Vulnerability may be thought of as the capacity of the structure to resist damage, greater than that defining a performance level. Structural response parameters that may be used to measure capacity include global building drift, member forces, and inelastic deformations. Hazard, or the amount of global building drift, members forces and inelastic deformations produced by the hazard may be thought of as demands. If both the demands that a structure will experience over a period of time and the structure's capacity to resist these demands could be perfectly defined, then performance objectives, the probability that damage may exceed a performance level within a period of time, could be ascertained with perfect confidence. However, the process of predicting the capacity of a structure to resist ground shaking demands as well as the process of predicting the severity of demands that will actually be experienced entails significant uncertainties.

Confidence level is a measure of the extent of uncertainty inherent in this process. Perfect confidence may be expressed as 100% confidence. In reality, it is never possible to attain such confidence. Confidence levels on the order of 90 or 95% may be considered high, while confidence levels on the order of 50% or less would be considered low.

Generally, uncertainty can be reduced, and confidence increased, by obtaining better knowledge or using better procedures. For example, enhanced understanding and reduced uncertainty with regard to the prediction of the effects of ground shaking on a structure can be obtained by using a more accurate analytical procedure to predict the structure's response. Enhanced understanding of the capacity of a structure to resist ground shaking demands can be obtained by obtaining specific laboratory data on the physical properties of the materials of construction and on the damageability of individual beam-column connection assemblies.

The simplified performance evaluation procedures included in the SAC *Recommended Criteria* are based on the typical characteristics of standard buildings. Since they are based on the capacity characteristics of typical structures, the procedures contained inherently incorporate significant uncertainty in the performance prediction process. As a result of this significant uncertainty, it is anticipated that the actual ability of a structure to achieve a given performance objective may be significantly better than would be indicated by those simple procedures. The more detailed procedures provide may be used to better define the actual uncertainties incorporated in the prediction of performance for a specific structure and thereby to obtain better confidence with regard to the prediction of performance for an individual structure.

As an example, using the simplified procedures it may be found that for a specific structure, there is only a 50% level of confidence that there is less than a 10% chance in 50 years of poorer performance than the Collapse Prevention level. This rather low level of confidence may be more a function of the uncertainty inherent in the simplified procedures than the actual inadequate capacity of the building to provide Collapse Prevention performance. In such a case, it may be possible to use the more detailed procedures to reduce the uncertainty inherent in the performance estimation and find that instead, there may be as much as a 95% level of confidence, of obtaining such performance.

It must be noted that in both the simplified and detailed procedures the uncertainties associated with estimation of the intensity of ground motion have been neglected. These uncertainties can be quite large, on the order of those associated with structural performance or even larger. Thus, the confidence estimated using these procedures is really a confidence with regard to structural performance, given the seismicity as portrayed by the USGS seismic hazard maps that accompany FEMA 273 (ATC/BSSC, 1997) and FEMA 302 (BSSC, 1998).

C.1 Basic SAC Procedure

A demand and resistance factor design (DRFD) format is used to associate a level of confidence with the probability that a building will have less than a specified probability of exceedance of a desired performance level. The basic approach is to determine a confidence parameter, λ, which may then be used, to determine the confidence level that exists with regard to performance estimation. The confidence parameter, λ, is determined from the factored-demand-to-capacity equation:

$$\lambda = \frac{\gamma\gamma_a D}{\phi C} \qquad \text{(C-2)}$$

where:

C = median estimate of the capacity of the structure. This estimate may be obtained either by reference to default values or by more rigorous direct calculation of capacity.

D = calculated demand on the structure, obtained from a structural analysis,

γ = a demand variability factor that accounts for the variability inherent in the prediction of demand related to assumptions made in structural modeling and prediction of the character of ground shaking,

γ_a = an analytical uncertainty factor that accounts for the bias and uncertainty associated with the specific analytical procedure used to estimate structural demand as a function of ground shaking intensity,

ϕ = a resistance factor that accounts for the uncertainty and variability inherent in the prediction of structural capacity as a function of ground shaking intensity,

λ = a confidence index parameter from which a level of confidence can be obtained.

Several structural response parameters are used to evaluate structural performance. The primary parameter used for this purpose is interstory drift. Interstory drift is an excellent parameter for judging the ability of a structure to resist P-Δ. instability and collapse. It is also closely related to plastic rotation demand, or drift angle demand, on individual beam-column connection assemblies, and therefore a good predictor of the performance of beams, columns and connections. Other parameters used in these guidelines include column axial compression and column axial tension. In order to determine a level of confidence with regard to the probability that a building has less than a specified probability of exceeding a performance level over a period of time, the following steps are followed:

Step 1. The performance objective to be evaluated is selected. This requires selection of a performance level of interest, for example Collapse Prevention or Immediate Occupancy, and a desired probability that damage in a period of time will be worse than that performance level. Representative performance objectives may include:

- 2% probability of poorer performance than Collapse Prevention level in 50 years
- 50% probability of poorer performance than Immediate Occupancy level in 50 years

It is also possible to express performance objectives in a deterministic manner, where attainment of the performance is conditioned on the occurrence of a specific magnitude earthquake on an identified fault.

Step 2. Characteristic motion for the performance objective is determined. For probabilistic performance objectives, a median estimate of the ground shaking intensity at the probability of exceedance identified in the performance objective definition (Step 1) is determined. For example, if the performance objective is a 2% probability of poorer performance than Collapse Prevention level in 50 years, then a median estimate of ground shaking demands with a 2% probability of exceedance in 50 years would be determined. For deterministic performance objectives, a median estimate of the ground motion at the building site for the specific earthquake magnitude and fault location must be made.

Step 3. Structural demands for the characteristic earthquake ground motion are determined. A mathematical structural model is developed to represent the building structure. This model is then subjected to a structural analysis, using one of several acceptable methods of increasing complexity and accuracy. This analysis provides estimates of maximum interstory drift demand, maximum column compressive demand, and maximum column splice tensile demand, for the ground motion determined in Step 2.

Step 4. Median estimates of structural capacity are determined. Median estimates of the inter-story drift capacity of the moment-resisting connections and the building frame as a whole are determined, as are median estimates of column compressive capacity and column splice tensile capacity. Inter-story drift capacity for the building frame, as a hole, may be estimated using the default values for regular structures, or alternatively, the specified detailed procedures. These detailed procedures are required for irregular structures. Inter-story drift capacity for moment-resisting connections that are prequalified may be estimated using the default values, or alternatively, direct laboratory data on beam column connection assembly performance capability. Median estimates of column compressive capacity and column splice tensile capacity are made using the procedures specified

Step 5. A factored demand to capacity ratio, λ is determined. For each of the performance parameters, i.e., inter-story drift as related to global building frame performance, inter-story drift as related to connection performance, column compression, and, column splice tension, equation C-2 is independently applied to determine the value of the confidence parameter, λ. In each case, the calculated estimates of demand, *D*, and capacity, *C*, are determined using Steps 3, and 4 respectively.

Step 6. Evaluate confidence. The confidence obtained with regard to the ability of the structure to meet the performance objective is determined using the lowest of the λ values determined in accordance with Step 5, above, back-calculated from the equation:

$$\lambda = e^{\beta_{UT}\left(\kappa_x - \frac{\kappa}{2b}\beta_{UT}\right)} \qquad \text{(C-3)}$$

where:

b = a coefficient relating the incremental change in demand (drift, force, or deformation) to an incremental change in ground shaking intensity, at the hazard level of interest

β_{UT} = the standard deviation of the natural logarithm of demand and capacity as a function of uncertainty in estimation of demand and capacity

k = the slope of the hazard curve, in ln-ln coordinates, at the hazard level of interest, i.e., the ratio of incremental change in S_{aT1} to incremental change in annual probability of exceedance.

K_x = standard Gausian variate associated with probability x of not being exceeded as a function of number of standard deviations above or below the mean found in standard probability tables.

The SAC Guidelines provides a solution for this equation, for various values of the parameters, k, λ, and β_{UT}. The values of the parameter, β_{UT}, used in equation C-3, or Table C-2, are used to account for the uncertainties inherent in the estimation of demands and capacities. Uncertainty enters the process through a variety of assumptions that are made in the performance evaluation process, including assumed values of damping, structural period, properties used in structural modeling, strengths of materials, etc. Assuming that the amount of uncertainty introduced by each of the assumptions can be characterized, the parameter β_{UT} can be calculated using the equation:

$$\beta_{UT} = \sqrt{\sum_i \beta_{ui}^2} \qquad \text{(C-4)}$$

where β_{ui} are the standard deviations of the natural logarithms of the variation in demand and/or capacity resulting from each of these various sources of uncertainty.

Table C-2 Confidence Parameter, λ, as a Function of Confidence Level, Hazard Parameter, *k*, and Uncertainty, β_{UT}

Confidence Level	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	99%
$\beta_{UT} = 0.1$													
k=1	1.24	1.19	1.14	1.09	1.06	1.03	1.0	0.98	0.95	0.92	0.88	0.85	0.80
k=2	1.24	1.19	1.15	1.10	1.07	1.04	1.01	0.99	0.96	0.93	0.90	0.85	0.80
k=3	1.25	1.20	1.15	1.11	1.07	1.04	1.02	0.99	0.96	0.93	0.90	0.86	0.80
k=4	1.26	1.20	1.16	1.11	1.08	1.05	1.02	1.0	0.97	0.94	0.90	0.87	0.81
$\beta_{UT} = 0.2$													
k=1	1.55	1.41	1.32	1.21	1.13	1.07	1.02	0.97	0.92	0.86	0.79	0.73	0.64
k=2	1.58	1.45	1.34	1.23	1.16	1.09	1.04	0.99	0.94	0.88	0.81	0.75	0.66
k=3	1.61	1.48	1.37	1.26	1.18	1.12	1.06	1.01	0.96	0.90	0.82	0.76	0.67
k=4	1.64	1.51	1.40	1.28	1.20	1.14	1.08	1.03	0.97	0.91	0.84	0.78	0.68
$\beta_{UT} = 0.3$													
k=1	1.95	1.71	1.54	1.35	1.23	1.13	1.05	0.97	0.89	0.81	0.71	0.64	0.52
k=2	2.04	1.79	1.61	1.41	1.28	1.18	1.09	1.01	0.93	0.85	0.75	0.66	0.55
k=3	2.14	1.88	1.68	1.48	1.34	1.23	1.13	1.06	0.98	0.89	0.78	0.70	0.57
k=4	2.23	1.96	1.76	1.54	1.40	1.29	1.20	1.11	1.02	0.93	0.82	0.73	0.60
$\beta_{UT} = 0.4$													
k=1	2.49	2.10	1.81	1.52	1.33	1.20	1.08	0.98	0.88	0.77	0.65	0.56	0.43
k=2	2.70	2.27	1.96	1.65	1.45	1.30	1.17	1.06	0.95	0.84	0.70	0.61	0.47
k=3	2.92	2.46	2.12	1.78	1.57	1.40	1.27	1.15	1.03	0.90	0.76	0.66	0.50
k=4	3.16	2.66	2.30	1.93	1.70	1.52	1.38	1.25	1.11	0.98	0.83	0.71	0.55
$\beta_{UT} = 0.5$													
k=1	3.21	2.59	2.15	1.73	1.48	1.28	1.13	1.0	0.87	0.74	0.60	0.50	0.36
k=2	3.63	2.93	2.44	1.96	1.67	1.45	1.28	1.13	0.99	0.84	0.68	0.56	0.40
k=3	4.11	3.32	2.76	2.22	1.90	1.65	1.45	1.28	1.12	0.95	0.77	0.64	0.46
k=4	4.66	3.76	3.13	2.52	2.14	1.87	1.65	1.45	1.26	1.08	0.87	0.72	0.52
$\beta_{UT} = 0.6$													
k=1	4.17	3.22	2.58	1.99	1.65	1.39	1.20	1.03	0.87	0.72	0.56	0.44	0.30
k=2	5.00	3.86	3.09	2.39	1.97	1.67	1.43	1.23	1.04	0.86	0.66	0.53	0.36
k=3	5.98	4.62	3.70	2.86	2.35	2.00	1.72	1.48	1.25	1.03	0.80	0.64	0.43
k=4	7.15	5.52	4.42	3.42	2.82	2.39	2.05	1.76	1.49	1.23	0.95	0.76	0.52

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Applied Technology Council Projects and Report Information

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

Applied Technology Council conducts projects that meet the following criteria:

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

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

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

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

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

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

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

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

Seismic Safety Council in its refinement of the ATC-3-06 Tentative Provisions.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ATC-13-1: The report, *Commentary on the Use of ATC-13 Earthquake Damage Evaluation Data for Probable Maximum Loss Studies of California Buildings*, was developed with funding from ATC's Henry J. Degenkolb Memorial Endowment Fund. Available through the ATC office. (Published 2002, 66 pages)

ABSTRACT: This report provides guidance to consulting firms who are using ATC-13 expert-opinion data for probable maximum loss (PML) studies of California buildings. Included are discussions of the limitations of the ATC-13 expert-opinion data, and the issues associated with using the data for PML studies. Also included are three appendices containing information and data not included in the original ATC-13 report: (1) ATC-13 model building type descriptions, including methodology for estimating the expected performance of standard, nonstandard, and special construction; (2) ATC-13 Beta damage distribution parameters for model building types; and (3) PML values for ATC-13 model building types.

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

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

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

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

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

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

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

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

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

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

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

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

ATC-16: This project, "Development of a 5-Year Plan for Reducing the Earthquake Hazards Posed by Existing Nonfederal Buildings", was funded by FEMA and was conducted by a joint venture of ATC, the Building Seismic Safety Council and the Earthquake Engineering Research Institute. The project involved a workshop in Phoenix, Arizona, where approximately 50 earthquake specialists met to identify the major tasks and goals for reducing the earthquake hazards posed by existing nonfederal buildings nationwide. The plan was developed on the basis of nine issue papers presented at the workshop and workshop working group discussions. The Workshop Proceedings and Five-Year Plan are available through the Federal Emergency Management Agency, 500 "C" Street, S.W., Washington, DC 20472.

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

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

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

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

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

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

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

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

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

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

ATC-20: The report, *Procedures for Postearthquake Safety Evaluation of Buildings*, was developed under a contract from the California Office of Emergency Services (OES), California Office of Statewide Health Planning and Development (OSHPD) and FEMA. Available through the ATC office (Published 1989, 152 pages)

ABSTRACT: This report provides procedures and guidelines for making on-the-spot evaluations and decisions regarding continued use and occupancy of earthquake damaged buildings. Written specifically for volunteer structural engineers and building inspectors, the report includes rapid and detailed evaluation procedures for inspecting buildings and posting them as “inspected” (apparently safe, green placard), “limited entry” (yellow) or “unsafe” (red). Also included are special procedures for evaluation of essential buildings (e.g., hospitals), and evaluation procedures for nonstructural elements, and geotechnical hazards.

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

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

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

ABSTRACT: This report provides updated assessment forms, placards, including a revised yellow placard (“restricted use”) and procedures that are based on an in-depth review and evaluation of the widespread application of the ATC-20 procedures following five earthquakes occurring since the initial release of the ATC-20 report in 1989.

ATC-20-3: The report, *Case Studies in Rapid Postearthquake Safety Evaluation of Buildings,* was funded by ATC and R. P. Gallagher

Associates. Available through the ATC office. (Published 1996, 295 pages)

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

ATC-20-T: The *Postearthquake Safety Evaluation of Buildings Training CD* was developed by FEMA to replace the 1993 ATC-20-T Training Manual that included 160 35-mm slides. Available through the ATC office. (Published 2002, 230 PowerPoint slides with Speakers Notes)

ABSTRACT: This Training CD is intended to facilitate the presentation of the contents of the ATC-20 and ATC-20-2 reports in a 4½-hour training seminar. The Training CD contains 230 slides of photographs, schematic drawings and textual information. Topics covered include: posting system; evaluation procedures; structural basics; wood frame, masonry, concrete, and steel frame structures; nonstructural elements; geotechnical hazards; hazardous materials; and field safety.

ATC-21: The report, *Second Edition, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, was developed under a contract from FEMA. Available through the ATC office, or from FEMA by contacting 1-800-480-2520, as *FEMA 154 Second Edition*. (Published 2002, 161 pages)

ABSTRACT: This report describes a rapid visual screening procedure for identifying those buildings that might pose serious risk of loss of life and injury, or of severe curtailment of community services, in case of a damaging earthquake. The screening procedure utilizes a methodology based on a "sidewalk survey" approach that involves identification of the primary structural load-resisting system and its building material, and assignment of a basic structural hazards score and performance modifiers based on the observed building characteristics. Application of the methodology identifies those buildings that are potentially hazardous and should be analyzed in more detail by a professional engineer experienced in seismic design. In the Second Edition, the scoring system has been revised and the *Handbook* has been shortened and focused to ease its use.

ATC-21-1: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation*, *Second Edition*, was developed under a contract from FEMA. Available through the ATC office, or from FEMA by contacting 1-800-480-2520, as *FEMA 155 Second Edition*. (Published 2002, 117 pages)

ABSTRACT: Included in this report is the technical basis for the updated rapid visual screening procedure of ATC-21, including (1) a summary of the results from the efforts to solicit user feedback, and (2) a detailed description of the development effort leading to the basic structural hazard scores and the score modifiers.

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

ABSTRACT: Included in this report, a companion volume to the ATC-21 and ATC-21-1 reports, is state-of-the-art information on (1) the identification of those buildings that might collapse and trap victims in debris or generate debris of such a size that its handling would require special or heavy lifting equipment; (2) guidance in identifying these types of buildings, on the basis of their major exterior features, and (3) the types and life capacities of equipment required to remove the heavy portion of the debris that might result from the collapse of such buildings.

ATC-21-T: The report, *Rapid Visual Screening of Buildings for Potential Seismic Hazards Training Manual* was developed under a contract with FEMA. Available through the

ATC office. (Published 1996, 135 pages; 120 slides)

ABSTRACT: This training manual is intended to facilitate the presentation of the contents of the ATC-21 report (*First Edition*). The training materials consist of 120 slides and a companion training presentation narrative coordinated with the slides. Topics covered include: description of procedure, building behavior, building types, building scores, occupancy and falling hazards, and implementation.

ATC-22: The report, *A Handbook for Seismic Evaluation of Existing Buildings (Preliminary)*, was developed under a contract from FEMA. Available through the ATC office. (Originally published in 1989; revised by BSSC and published as FEMA 178: *NEHRP Handbook for the Seismic Evaluation of Existing Buildings* in 1992, 211 pages; revised by ASCE for FEMA and published as FEMA 310: *Handbook for the Seismic Evaluation of Buildings – a Prestandard* in 1998, 362 pages, available from FEMA by contacting 1-800-480-2520)

ABSTRACT: The ATC-22 handbook provides a methodology for seismic evaluation of existing buildings of different types and occupancies in areas of different seismicity throughout the United States. The methodology, which has been field tested in several programs nationwide, utilizes the information and procedures developed for the ATC-14 report and documented therein. The handbook includes checklists, diagrams, and sketches designed to assist the user.

ATC-22-1: The report, *Seismic Evaluation of Existing Buildings: Supporting Documentation*, was developed under a contract from FEMA and is available as the FEMA 175 report by contacting 1-800-480-2520. (Published 1989, 160 pages)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ATC-33: The reports, NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA 273), NEHRP Commentary on the Guidelines for the Seismic Rehabilitation of Buildings (FEMA 274), and Example Applications of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA 276), were developed under a contract with the Building Seismic Safety Council, for FEMA. Available through FEMA by contacting 1-800-480-2520 (Published 1997, Guidelines, 440 pages; Commentary, 492 pages; Example Applications, 295 pages.) FEMA 273 and portions of FEMA 274 have been revised by ASCE for FEMA as FEMA 356 Prestandard and Commentary for the Seismic Rehabilitation of Buildings. Available through FEMA by contacting 1-800-480-2520 (Published 2000, 509 pages)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

SAC-95-02, *Interim Guidelines: Evaluation, Repair, Modification and Design of Welded Steel Moment-Frame Structures* (FEMA 267 report) (Published 1995, 215 pages, available through FEMA by contacting 1-800-480-2520)

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

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

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

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

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

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

SAC-95-09, *Background Reports: Metallurgy, Fracture Mechanics, Welding, Moment Connections and Frame systems, Behavior* (FEMA 288 report) (Published 1995, 361 pages, available through FEMA by contacting 1-800-480-2520)

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

SAC-96-02, *Connection Test Summaries* (FEMA 289 report) (Published 1996, available through FEMA by contacting 1-800-480-2520)

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

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

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

FEMA-350, *Recommended Seismic Design Criteria for New Steel Moment-Frame Buildings*. (Published 2000, 190 pages, available through FEMA: 1-800-480-2520)

FEMA-351, *Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings*. (Published 2000, 210 pages, available through FEMA: 1-800-480-2520)

FEMA-352, *Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings*. (Published 2000, 180 pages, available through FEMA: 1-800-480-2520)

FEMA-353, *Recommended Specifications and Quality Assurance Guidelines for Steel Moment-Frame Construction for Seismic Applications*. (Published 2000, 180 pages, available through FEMA: 1-800-480-2520)

FEMA-354, *A Policy Guide to Steel Moment-Frame Construction*. (Published 2000, 27 pages, available through FEMA: 1-800-480-2520)

FEMA-355A, *State of the Art Report on Base Materials and Fracture*. Available from the ATC office. (Published 2000, 107 pages; available on CD-ROM through FEMA: 1-800-480-2520)

FEMA-355B, *State of the Art Report on Welding and Inspection*. Available from the ATC office. (Published 2000, 185 pages; available on CD-ROM through FEMA: 1-800-480-2520)

FEMA-355C, *State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking*. Available from the ATC office. (Published 2000, 322 pages; available on CD-ROM through FEMA: 1-800-480-2520)

FEMA-355D, *State of the Art Report on Connection Performance*. Available from the ATC office. (Published 2000, 292 pages; available on CD-ROM through FEMA: 1-800-480-2520)

FEMA-355E, *State of the Art Report on Past Performance of Steel Moment-Frame Buildings in Earthquakes*. Available from the ATC office. (Published 2000, 190 pages; available on CD-ROM through FEMA: 1-800-480-2520)

FEMA-355F, *State of the Art Report on Performance Prediction and Evaluation of Steel Moment-Frame Structures*. Available from the ATC office. (Published 2000, 347 pages; available on CD-ROM through FEMA: 1-800-480-2520)

ATC-43: The reports, *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual* (FEMA 306), *Evaluation of Earthquake-Damaged Concrete and Masonry Wall Buildings, Technical Resources* (FEMA 307), and *The Repair of Earthquake Damaged Concrete and Masonry Wall Buildings* (FEMA 308), were developed for FEMA under a contract with the Partnership for Response and Recovery, a Joint Venture of Dewberry & Davis and Woodward-Clyde. Available on CD-ROM through ATC; printed versions available through FEMA by contacting 1-800-480-2520 (Published, 1998, *Evaluation Procedures Manual*, 270 pages; *Technical Resources*, 271 pages, *Repair Document*, 81 pages)

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

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

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

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

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

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

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

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

ABSTRACT: The report addresses one of the short-term recommendations — planning for emergency response and postearthquake inspection — made in the first phase of the ATC-51 project, and considers both current practices for emergency response planning in the United States and available NSS information and regulations pertaining to hospital emergency response planning in Italy. The report contains: (1) descriptions of current procedures and concepts for emergency response planning in the United States and Italy, (2) an overview of relevant procedures for both countries for evaluating and predicting the seismic vulnerability of buildings, including procedures for postearthquake inspection, (3) recommended procedures for earthquake emergency response planning and postearthquake assessment of hospitals, to be implemented through the use of a Postearthquake Inspection Notebook and demonstrated through the application on two representative hospital facilities; and (4) recommendations for emergency response training, postearthquake inspection training, and the mitigation of seismic hazards.

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

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

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

ATC-57: The report, *The Missing Piece: Improving Seismic Design and Construction*

Practices, was developed under a contract with NIST. Available through the ATC office. (Published 2003, 102 pages)

> ABSTRACT: The report was developed to provide a framework for eliminating the technology transfer gap that has emerged within the National Earthquake Hazards Reduction Program (NEHRP) that limits the adaptation of basic research knowledge into practice. The report defines a much-expanded problem-focused knowledge development, synthesis and transfer program to improve seismic design and construction practices. Two subject areas, with a total of five Program Elements, are proposed: (1) systematic support of the seismic code development process; and (2) improve seismic design and construction productivity.

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

> ABSTRACT: This report documents ATC's first self-directed research program: a series of static and dynamic tests of narrow plywood wall panels having the standard 3.5-to-1 height-to-width ratio and anchored to the sill plate using typical bolted, 9-inch, 5000-lb. capacity hold-down devices. The report provides a description of the testing program and a summary of results, including comparisons of drift ratios found during testing with those specified in the seismic provisions of the 1991 *Uniform Building Code*. The report served as a catalyst for changes in code-specified aspect ratios for narrow plywood wall panels and for new thinking in the design of hold-down devices. It also stimulated widespread interest in laboratory testing of wood-frame structures.

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

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

ATC TechBrief 1: The ATC TechBrief 1, *Liquefaction Maps*, was developed under a contract with the United States Geological Survey. Available free of charge through the ATC office. (Published 1996, 12 pages)

> ABSTRACT: The technical brief inventories and describes the available regional liquefaction hazard maps in the United States and gives information on how to obtain them.

ATC TechBrief 2: The ATC TechBrief 2, *Earthquake Aftershocks − Entering Damaged Buildings*, was developed under a contract with the United States Geological Survey. Available free of charge through the ATC office. (Published 1996, 12 pages)

> ABSTRACT: The technical brief offers guidelines for entering damaged buildings under emergency conditions during the first hours and days after the initial damaging event.

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