



PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Seismic Performance Objectives for Tall Buildings

A Report for the Tall Buildings Initiative

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ABSTRACT

The Pacific Earthquake Engineering Research Center is leading an initiative to develop guidelines for new high-rise construction that will meet intended safety and performance objectives following future earthquakes, particularly when alternative means of design are employed. An initial task of this initiative was to investigate the issues associated with identifying seismic performance equivalent to that achieved by code and whether a higher seismic performance should be targeted for these buildings. Many stakeholders were interviewed for this purpose, and a workshop was convened to discuss the results and to establish a direction for the technical design portions of the overall initiative. The investigation found that the establishment of a higher seismic performance objective for certain buildings was a public-policy issue that should not be decided by engineering studies, but also that many owners, tenants, and other stakeholders did not understand standard code building-performance objectives and thought that even a small chance of collapse was unacceptable for any building. Many thought that even building closure due to damage should not be expected or tolerated and that seismic risk should be disclosed to owners and tenants in an understandable format.

It is recommended that procedures to predict collapse (or to prevent collapse) be improved, that risks from cladding in tall buildings be investigated, and that the Tall Buildings Initiative cooperate with multidisciplinary efforts to minimize risks from egress and ingress characteristics of tall buildings.

ACKNOWLEDGMENTS

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation.

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FOREWORD

by

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Several West Coast cities in the U.S. are seeing a resurgence in the construction of high-rise buildings that involve a variety of configurations, innovative structural systems, and high-performance materials. To meet architectural requirements and achieve construction economy, many of these designs do not follow the prescriptive building code provisions but instead use the alternative design clause of the building code. Currently there is no industry standard for these alternative designs, requiring early adopters to experiment while designs are progressing, resulting in scheduling and cost uncertainties. Recognizing this urgent situation, several organizations and leading engineers have joined together with the Pacific Earthquake Engineering Research (PEER) Center to form the Tall Buildings Initiative. This initiative will develop a consensus on performance objectives, ground motion selection and modification procedures, modeling procedures, acceptance criteria, and, ultimately, seismic design guidelines suitable for adoption by building codes and local jurisdictions (Moehle et al. 2007)¹.

Currently the Tall Buildings Initiative has several active tasks ranging from ground motion issues for nonlinear structural analysis of tall buildings to computer modeling of components and systems, and to development of seismic design guidelines for tall buildings. A series of reports on various tasks will be published by PEER and other participating organizations.

One of the fundamental tasks in the Tall Buildings Initiative is the Seismic Performance Objectives for Tall Buildings. William Holmes has been the leader of this task, with the support of a group of researchers and practitioners. The scope of this task has been to investigate the issues related to the seismic performance objectives of tall buildings, and whether a higher seismic performance should be targeted for these buildings as compared with that implied by the prescriptive provisions of the seismic code. The current report is the final report for this task by Holmes et al. Currently PEER is organizing other tasks under the Tall Buildings Initiative to

¹ Moehle, J. P., Y. Bozorgnia, and T. Yang. The Tall Buildings Initiative, *Proceedings of the 2007 Convention of the Structural Engineers Association of California*, September 26–29, 2007, Lake Tahoe, California.

follow up Holmes's study to quantify some qualitative findings of this report. The extensive efforts and the cooperation of Bill Holmes and his group for successful completion of this task of the Tall Buildings Initiative are gratefully appreciated.

1 Background and Purpose

Economic and demographic trends in major West Coast cities in the last decade have created demands for middle- to high-cost housing near city centers. High-rise concrete condominium structures appeared to best suit this demand and, starting in the Northwest, the preferred structural system evolved to be a concrete core with minimal perimeter beams. Although seismic design regulations of building codes require a moment-frame structural system to be incorporated in taller structures (160 ft or 240 ft depending on conditions), systems without the girders required in moment frames were preferred by developers because lower floor-to-floor heights and floor to ceiling windows were possible at equal or lower construction cost. Such systems were developed and approvals obtained from local jurisdictions under the “Alternate Materials and Methods of Construction” (called Alternative Means in this report) provisions of the International Building Code (IBC), which is commonly used in the U.S. This code allows any rational seismic design if it is demonstrated to be at least equal in seismic resistance to that required by code. The IBC states:

104.11 Alternative materials, design and methods of construction and equipment.

The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety. (ICC 2006).

The approval requirements and process for these alternative designs have not been well developed, so issues were identified regarding code-equivalent seismic performance and the

methods of demonstrating such equivalence. Although buildings have been designed and constructed that employed alternative design methods using approval methods based primarily on a peer review process, no systematic study of performance-based design as applied to tall buildings exists. The Pacific Earthquake Engineering Research Center is responding to this void by leading an initiative to develop design guidelines that will lead to safe and usable tall buildings following future earthquakes.

The specific tasks of this initiative are:

- Task 1 Establish and Operate the Tall Buildings Project Advisory Committee (T-PAC)
- Task 2 Develop consensus on performance objectives
- Task 3 Conduct baseline assessment of dynamic response characteristics of tall buildings
- Task 4 Create synthetically generated ground motions
- Task 5 Review and validate synthetically generated ground motions
- Task 6 Develop guidelines on selection and modification of ground motions
- Task 7 Develop guidelines on modeling and acceptance values
- Task 8 Generate input ground motions for tall buildings with subterranean levels
- Task 9 Increase presentations at conferences, workshops, and seminars
- Task 10 Develop document Performance-Based Seismic Design Guidelines for Tall Buildings

This report documents Task 2 of this program, which is intended to develop consensus on performance objectives for tall buildings. In order to design without certain prescriptive code limitations, whether intended to satisfy the alternative design requirements of the code or to generally improve the design, various forms of performance-based design techniques have been employed. The extent to which performance-based design is used is dependent on the specific prescriptive requirements that are not met, and the acceptance process of the approval authority. Generally, the requirements for approval are worked out in advance of submittal. The basis of the performance-based designs, when used, is the establishment of a performance objective consisting of design ground motion and a performance level. Equivalence to the code for alternative designs can then be shown by designing to meet the code performance objective. However, the performance objective of the code has never been formally established using engineering parameters and is open for individual interpretation. In addition, the recent focus of performance-based designs for qualification as alternative design methodologies has been on whether tall buildings should be considered as “normal” buildings or as buildings expected to

have superior seismic performance, like schools, high-occupancy buildings, fire stations, or even hospitals. Task 2 is intended to clarify these issues as a basis for the balance of the tasks of the Tall Buildings Initiative.

The initial task description was as follows:

Using an appropriate methodology, develop a consensus on performance objectives. Document methodology and performance objectives in a final report. Considered performance objectives should include serviceability and safety margin. Deliberations should include conventional performance objectives and alternative ways of expressing objectives. Alternative performance considerations may include reparability and re-occupancy. Final objectives should clearly define confidence levels associated with objectives. Some analysis of socio-economic impacts associated with tall building performance should be considered.

As documented in this report, the task group determined during the study that a “consensus performance objective,” considering the breadth of stakeholders involved, could not be developed within this project. In addition, whether tall buildings should perform better than normal code buildings, and if so, how much better, is either a model code issue, to be debated on a national stage, or a local public-policy issue that could vary from city to city. Therefore, Task 2 was not concluded with the specificity suggested by the initial task description, and nothing in this report can be considered a consensus minimum standard of practice. However, significant input from representative stakeholders was obtained concerning seismic performance of tall buildings, and this information will be documented in this report. In response to this input, this report contains recommendations to the Tall Buildings Initiative regarding seismic performance issues.

2 Work Plan

As discussed in Chapter 1, the products of Task 2 were refined to be more pragmatic. Similarly, the original work plan was adapted to respond to input received during the task. However, the main subtasks of the work plan remained as originally formulated, as described below.

2.1 FORM CORE GROUP

The Core Group will formulate the activities in more detail and implement the work plan. The original Core Group consisted of the following members:

William T. Holmes, Structural Engineer, Rutherford & Chekene, Task Leader

Charles Kircher, Kircher and Associates

Laurence Kornfield, Chief Building Inspector, City of San Francisco

William Petak, Professor Emeritus, School of Policy Planning and Development, USC

Nabih Youssef, Structural Engineer, Nabih Youssef Associates

Karl Telleen, Staff Engineer, Rutherford & Chekene, who assisted the Task Leader and the
Core Group

Mr. Kornfield, who retired from the Core Group because of reassignment of duties by the
City and County of San Francisco

2.2 DEVELOP BACKGROUND ON EXPECTED SEISMIC PERFORMANCE OF CODE-DESIGNED BUILDINGS

A short primer on the development of building codes and seismic performance expectations is needed as background material for stakeholders prior to being interviewed by the Core Group. A more detailed review of this type of information will also be useful at the planned workshop. In order to discuss with stakeholders the adequacy of “normal” building design criteria for tall

buildings, or the need for a superior design criterion, they must first understand the range of performance that could be possible for normal buildings.

Finally, a description of code seismic performance in engineering terms is needed for use in the performance-based design procedures used to show code-equivalence in designs using the alternative means of compliance provisions in the code.

2.3 OBTAIN INPUT REGARDING SEISMIC PERFORMANCE OF TALL BUILDINGS FROM SELECTED STAKEHOLDERS

Stakeholders in the determination of appropriate seismic performance for tall buildings, in addition to the designers themselves, include owners, tenants, neighbors, financial institutions, insurers, city governments and planners, community advocates, and many others. It is not practical to get formal input from these groups, but a sampling of input can be obtained by interviewing members of the various stakeholder groups. A standard interview procedure should be developed to obtain consistent and comparable input. Background material on current practice and performance expectation should be provided to stakeholders prior to the interview.

2.4 HOLD WORKSHOP TO DISCUSS AND CONSOLIDATE INTERVIEW MATERIAL

In the past, workshops to establish “acceptable seismic risk” or other seismic performance standards have had limited success largely because the topics of discussion were unfocused and open ended. Given specific input from stakeholders through the interview process, a workshop will be useful to expose and potentially resolve conflicts and to facilitate discussion between the stakeholder and the engineering community.

2.5 SYNTHESIZE INPUT TO FORMULATE CONCLUSIONS AND RECOMMENDATIONS REGARDING SEISMIC PERFORMANCE OF TALL BUILDINGS

Based on the input from the interviews, the workshop, and general knowledge of research and professional practice in the seismic design of tall buildings, recommendations will be made to the Tall Buildings Initiative regarding seismic performance of tall buildings.

3 Findings

The findings of this study include documentation of the expected seismic performance of code-designed buildings, the input received from interviews of stakeholders, and the opinions concerning seismic performance of tall buildings reached by consensus of the workshop participants.

3.1 EXPECTED SEISMIC PERFORMANCE OF CODE-DESIGNED BUILDINGS

3.1.1 Background of Building Codes and Seismic Provisions

A devastating fire in London in 1666 resulted in the first comprehensive building code enforced by government. Its purpose (performance intent) was clearly and narrowly framed to prevent another such disaster. Government control of design and construction (primarily of buildings) gradually spread throughout the world largely based on the London precedent. However, each country has its own, often unique, history and legal authorization for building code development and implementation (Meacham 2004).

In the U.S., an important principle of the Constitution, resulting from the original compromises concerning federal and state control of government, is the delegation of police power to the states. Police power is the authority to regulate for the health, the safety, and the general welfare of citizens. Building codes have always been interpreted as falling under the police power of the states, which is why the federal government does not promulgate building codes. Although the exact wording has varied between model codes, a typical statement of purpose in U.S. building codes is as shown below:

The purpose of this code is to provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures...

The development of seismic codes in general has also been in reaction to catastrophic events, beginning after a 1755 earthquake destroyed much of Lisbon, after which prescriptive rules for construction of the most common building type (gaiola construction) were promulgated. Earthquakes in Messina, Italy (1911), and Tokyo, Japan (1923), resulted in the development of more technical guidelines that included the design of buildings for lateral forces of about 10% of the building weight. These developments were no more sophisticated than attempts to minimize the death and destruction observed in these events in future earthquakes.

In the U.S., earthquakes in the San Francisco Bay Area (1868, 1906), Charleston, South Carolina (1886), Santa Barbara (1925), and Long Beach (1933) all featured massive falls of masonry walls onto the streets and in many cases complete collapses of buildings. The intent of early U.S. codes clearly was to prevent such life-threatening and destructive failures in earthquakes. The size or frequency of the events was not considered, partially because determination of these parameters was not generally possible, but also because it did not matter to the code proponents—the serious damage was to be avoided in any case. The first code provisions in the U.S. appeared as a voluntary appendix (the Lateral Bracing Appendix) in the 1927 Uniform Building Code and contained the following introduction:

The design of buildings for earthquake shocks is a moot question but the following provisions will provide adequate additional strength when applied to the design of buildings or structures (PCBOC 1928, p. 218).

3.1.2 SEAOC Blue Book

The 1933 Long Beach earthquake resulted in strict seismic design for schools in California (the Field Act) and began mandatory seismic design for all buildings in California (the Riley Act). These laws and the continuing occurrence of earthquakes in California generated continuous code development activity, primarily by the Structural Engineers Association of California (SEAOC), culminating with the publication of the *Recommended Lateral Force Requirements and Commentary* (the “Blue Book”) in 1960 that contained a relatively clear performance objective:

The SEAOC recommendations are intended to provide criteria to fulfill the purposes of building codes generally. More specifically with regard to earthquakes, structures designed in conformance with the provisions and principles set forth therein should be able to:

1. Resist minor earthquakes without damage;
2. Resist moderate earthquakes without structural damage, but with some non-structural damage; and
3. Resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as non-structural damage.

In most structures, it is expected that structural damage, even in a major earthquake, could be limited to repairable damage. This, however, depends on a number of factors, including the type of construction selected for the structure (SEAOC 1960).

Since 1960 the Blue Book has continued to evolve, but the performance objective for new code-conforming buildings has remained similar. The parameter “earthquake” in the three-level description has been refined to “ground motion,” the strongest level revised to include both “experienced” and “forecast” ground motions, and the somewhat speculative phrase, “expected that structural damage ...could be limited to repairable damage” further diluted by adding “In some instances, damage may not be economically repairable.” Finally, due to a growing realization of the great uncertainty in the exact nature of ground motions as well as a rapidly expanding inventory of various structural systems and building configurations, it was clarified that conformance with the Blue Book provisions should not be taken as a guarantee of the protection of life and limb:

...While damage to the primary structural system may be either negligible or significant, repairable or virtually irreparable, it is reasonable to expect that a well planned and constructed structure will not collapse in a major earthquake. The protection of life is reasonably provided, but not with complete assurance (SEAOC. 1988).

This addition is significant because it documented the concept that building codes cannot provide a zero-risk building inventory even for the primary goal of providing life safety.

3.1.3 ATC 3 and Zero Risk

A major effort to update seismic design concepts and make them more applicable on a national level was funded by the federal government in the 1970s. The resulting document, *Tentative Provisions for the Development of Seismic Regulations for Buildings* (commonly known as

ATC 3) expanded and clarified the premise that seismic building codes should not be expected to produce a zero-risk environment. The commentary of ATC 3 includes the following discussion:

It is not possible by means of a building code to provide a guarantee that buildings will not fail in some way that will endanger people as a result of an earthquake. While a code cannot ensure the absolute safety of buildings, it may be desirable that it should not do so as the resources to construct buildings are limited. Society must decide how it will allocate the available resources among the various ways in which it desires to protect life safety. One way or another, the anticipated benefits of various life protecting programs must be weighed against the cost of implementing such programs...

If the design ground motion were to occur, there might be life-threatening damage in 1 to 2 percent of buildings designed in accordance with the provisions. If ground motions two or three times as strong as the design ground motions were to occur, the percentage of buildings with life-threatening damage might rise to about 10 to 50 percent, respectively (ATC 1978, p. 309).

There is no evidence that the writer of the above commentary calculated these probabilities based on detailed analyses of buildings designed in accordance with the provisions, and there is certainly no indication that the writers of the ATC 3 provisions tuned each requirement to provide this level of safety. Similarly, code writers improving and expanding the basic concepts of ATC 3 since 1978 have not had the resources or the methodology to test each new or revised provision against the stated performance objectives. Rather, code changes have resulted from observation of performance judged unacceptable in earthquakes or inferred from research. In many cases, the relationship between the code change and the governing performance objective has been unclear.

3.1.4 ATC 63

Only recently has a methodology been developed to calculate in a detailed manner the expected performance of buildings designed in accordance with the current code in the probabilistic framework suggested by ATC 3 (*Recommended Methodology for Quantification of Building System Performance and Response Parameters*, ATC 63, in progress) (ATC 2007). The preliminary results of application of this methodology on several structural systems defined in

the current code indicate that for ground motions of 150% of our code design level, about 10% of buildings could collapse. Interestingly, this is of the same order of magnitude as estimated in ATC 3 in 1978. However, when considering the wide variety of lateral-force-resisting systems included in the code over the years (over 80 systems), each controlled by a complex patchwork of prescriptive design requirements and limitations, the large configuration variations allowed for in each system, and the large variation of seismic conditions in the U.S. for which they are designed, it is likely that this methodology if implemented on every system would show large inconsistencies in the code-defined collapse margin.

3.1.5 Definition of Ground Motions for Performance Objectives

An important aspect of defining performance expectations for code-designed buildings is the definition of ground motions. Initially (e.g., the 1927 UBC), the threat from ground motions was defined simply as earthquake shaking, and no intensity or probability was defined. The Blue Book used Minor, Moderate, and Major earthquakes, later revised to Minor, Moderate, and Major ground motion, but these levels were never defined in engineering terms. When the “code ground shaking” was finally tied down by specifying a 10% probability of exceedance in 50 years (in both ATC 3 and the Blue Book), it was probably not coincident with any of the three performance levels but somewhere between levels 2 and 3. This level of shaking, often called the design basis earthquake (DBE) ground motion, remained the code design level from the late 1970s until 1997, when a new national mapping was completed using the parameter, maximum considered earthquake ground motion (MCE). This work was associated with updating the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* by the Building Seismic Safety Council (BSSC 1997). These provisions are a direct descendant of ATC 3 and form the basis of seismic provisions in the International Building Code, presently used as the basis for building design throughout most of the U.S.

The MCE is mapped using probabilistic concepts (2% chance of exceedance in 50 years) except near well-defined active faults where ground motions expected from specific events on those faults are used (called deterministic motions). The code design philosophy, as defined in the NEHRP provisions, was then to provide a uniform margin against collapse for the MCE, which was implemented, in simple terms, by using traditional design methods for motions 2/3 of the MCE. The 2/3 factor is based on a presumed margin of collapse of 1.5 in traditional designs

based on the less intense DBE. More significantly, preventing collapse (considered the predominant cause of casualties) even for very rare ground motion, became the key performance objective for normal buildings.

3.1.6 FEMA 273

Parallel with but slightly ahead of the development of the MCE map for new buildings, a document was developed that provided guidelines for the retrofit of existing buildings (*NEHRP Guidelines for the Seismic Rehabilitation of Buildings*, BSSC 1997b). Due to the high cost and disruption of seismic rehabilitation, the document provided for retrofit to many different performance objectives, depending on the needs and resources of the owner. Performance objectives were highly flexible, defined by the selection of a limiting performance level and a ground motion intensity. Primary performance levels of Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) were defined, although designs could be accomplished for in-between levels as well. The performance of both structural and non-structural systems was considered, as shown in Table 3.1. Similarly, any ground motion intensity could be used, but a DBE and MCE was defined. The DBE could be the motion with a 10% chance of exceedance (to tie into old mapping) or the motion with intensity $2/3$ MCE (to tie into the building code for new buildings). The MCE was defined to agree with that used in mapping for new buildings.

FEMA 273 defined a recommended, but not mandatory, performance objective called the Basic Safety Objective (BSO), which consisted of meeting both LS at the DBE and CP at the MCE. While FEMA 273 suggests that the BSO should provide a similar level of safety as new buildings, it also stipulates that the BSO should be considered to have a smaller margin against collapse, less reliability, and be susceptible to more economic loss than a new building.

Table 3.1 Combinations of structural and non-structural performance from FEMA 273 (BSSC 1997b)

Table C1-8 Target Building Performance Levels and Ranges						
Nonstructural Performance Levels	Structural Performance Levels and 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	Collapse Prevention 5-E	No rehabilitation

3.1.7 Vision 2000

Following the 1994 Northridge earthquake, primarily in response to public concern over economic damage levels observed, the Structural Engineers Association of California developed a comprehensive blueprint for performance-based engineering called Vision 2000 (SEAOC 1995). Performance levels (damage states) were defined similar to those in FEMA 273 but labeled Fully Operational, Operational, Life Safe, Near Collapse, and Collapse. Among other products of Vision 2000 was a table of recommended performance objectives for buildings. Four design levels (ground motion intensities) were shown, rather than the three levels previously used by SEAOC in the Blue Book and previously described. The four design levels were matched with limiting performance levels as shown in Figure 3.1. The basic objective for normal buildings, defined as Life Safe for Rare ground motion plus Near Collapse for Very Rare ground motion is not unlike the BSO from FEMA 273. The concept of the Very Rare event is similar to the MCE later developed for national mapping but is defined with a 970-year return period versus the 2475-year return (2% chance of exceedance in 50 years) used for the MCE.

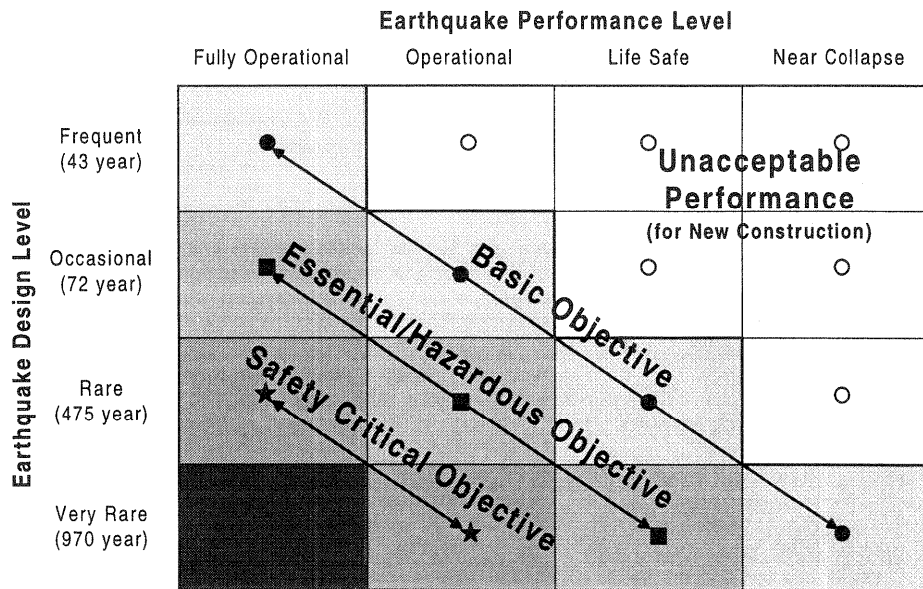


Figure 3.1 Seismic performance objectives from Vision 2000 (SEAOC 1995).

3.1.8 The ICC Performance Code

The International Code Council (ICC), developers of the International Building Code, also developed a performance code, the *International Code Council Performance Code for Buildings and Facilities*, an effort initiated in 1996 and culminating with the first edition in 2001. The performance matrix used in this document is intended for use in performance-based design of all aspects of buildings and facilities, including structure, fire safety, egress, moisture protection, and mechanical systems, and is therefore generalized as shown in Table 3.2.

The terminology in Table 3.2, when applied for use in earthquake design, is very similar, but not identical, to the Vision 2000 table shown in Figure 3.1. The design events and levels of performance are described in Table 3.3.

site. For smaller, more frequent shaking levels, the *Provisions* covering design and installation of both structural and non-structural systems seek to reasonably control damage that would lead to risks to life safety, economic losses, and loss of function. These design requirements include minimum lateral strength and stiffness for structural systems and guidance for anchoring, bracing, and accommodations of structural drift for non-structural systems.

Requirements for non-structural seismic protection have been in codes since the mid-1970s, mainly affecting components and systems representing only a small risk to life safety. However, previously published code performance objectives have not suggested that anchorage and bracing of non-structural systems is partially aimed at minimizing dollar losses, even for frequent events. If specific serviceability checks become common in performance-based Alternate Means designs, the performance of non-structural systems should be included. Since basic anchorage of components will easily satisfy demands of the commonly used frequent ground motion (43-year return) and drifts will be small, it may be appropriate to define non-structural performance objectives for larger ground motions.

3.1.10 PEER Methodology and ATC 58—Next Generation of Seismic Performance-Based Design

The Pacific Earthquake Engineering Research (PEER) Center, the manager and director of the Tall Buildings Initiative, has had a major thrust toward the development of performance-based seismic design. With input from the private sector, PEER decided to develop methods to predict performance-based guidelines on losses, rather than on predefined performance states (Immediate Occupancy, Life Safety, etc.). The losses to be considered were repair costs, buildings downtime, and casualties. In addition, unlike previous performance-based assessment methodologies, uncertainties in the calculation parameters would be explicitly considered, including the probability that shaking of a given intensity will occur, the possible variation in structural response due to the specific dynamic characteristics of the shaking, the uncertainty in structural response analysis and resulting damage patterns, and the uncertainty as to what losses would accrue. Such a method was conceptually developed and implemented for several case studies.

The Federal Emergency Management Agency (FEMA) also has an interest in performance-based seismic design and began planning for its development for practical use with two community-based action plans (FEMA 283, 1996, and FEMA 349, 2000). The project began in 2002 as the *Development of Performance-Based Seismic Design Guidelines*, and, being implemented by the Applied Technology Council, is currently known as ATC 58 (ATC 2006). Considering input from stakeholders similar to that used by PEER, the ATC 58 project decided to build on the previous work done by PEER and to develop a similar loss-based probabilistic methodology for use by the design profession. To date, no one has attempted to translate traditional code performance objectives into acceptable losses, but eventually this system will allow a much more direct calculation of equivalence with target code performance objectives. The current action plan for the ongoing ATC 58 project is contained in FEMA 445, *Next-Generation-Performance-Based Seismic Design Guidelines: Program Plan for New and Existing Buildings* (ATC 2006).

3.1.11 Guidelines for Qualifying Designs under *Alternate Materials and Methods of Construction*

As previously indicated, the main impetus for the Tall Buildings Initiative was the increasing use of the Alternative Means section of the code to design tall buildings that exceed prescriptive height limits. Although these buildings have been subject to detailed peer review, there has been little or no guidance for jurisdictions or peer reviewers to determine appropriate equivalence with a code-designed building, as required by this section of the code. In response to this issue, the Los Angeles Tall Buildings Structural Design Council has developed a guideline document primarily for the City of Los Angeles, and the Structural Engineers Association of Northern California has developed a guideline document for use by the City of San Francisco. These documents contain recommendations for determination of site-specific ground motions, analysis procedures, and acceptability criteria that are intended to achieve code equivalence but will also significantly contribute to the reliability of designs. Although equivalence is primarily achieved by requirements parallel to the code itself, target performance objectives are also directly or indirectly described. These performance objectives are described below.

It should also be noted that these documents are relatively new and not well tested; with increased use and trials, they may be refined.

An Alternate Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region. 2005 Edition (LATABSCD 2005)

The stated intent of this guideline is to provide equivalence to the code by meeting the three-step performance objective given by SEAOC in the Blue Book (see Section 3.1.2). Since this performance objective lacks technical definition, the four-level SEAOC performance-based design recommendations for “basic objective” are specified (see Fig. 3.1). However, specific checks are required at only three levels as described below:

- Evaluation Step 1 is intended to show that the building remains serviceable when subjected to frequent ground motion (50% exceedance in 30 years or 43-year return period). Acceptability criteria for continued serviceability are given.
- Evaluation Step 2 is intended to provide life safety during a design basis earthquake ground motion (10% exceedance in 50 years or 475-year return period). This is achieved essentially by a check of prescriptive code requirements, although fixed minimum base shears will govern over code pseudo-dynamic formula in the tall building period ranges. This procedure will achieve life safety only to the extent that prescriptive code requirement will be successful in providing adequate life safety in tall buildings but is not a true performance-based assessment. However, this document specifies use of less than the standard code minimum base shear and direct correlation with the code is thus tenuous
- Evaluation Step 3 is intended to assure that the building does not experience collapse during Very Rare ground motion (the MCE as defined nationally by NEHRP). This design level is significantly different from the 970-year return shown in Figure 3.1, but is conceptually aligned with step 3 in the Blue Book performance objective and is nationally accepted as the largest ground motion to be considered in design. Due to the deterministic limits used for MCE, in the Los Angeles region the MCE often has about a 600-year return period.

Recommended Administrative Bulletin on the Seismic Design and Review of Tall Buildings Using Non-Prescriptive Procedures—AB 083 (SFDBI 2007)

Adopted in July 2007, this administrative bulletin will be used by the City of San Francisco to guide the design and review of tall buildings under the Alternative Means provisions of the code.

The bulletin does not describe itself as performance based. It outlines procedures, requirements, and guidelines for seismic design, with commentary, that are aimed at producing seismic performance at least equivalent to that of code-prescriptive seismic designs. This is the standard required by the building code for “non-prescriptive” seismic designs. The preface to the bulletin notes that it is not an effort “to create more purely ‘performance-based’ guidelines for seismic design.”

It is similar in concept to the Los Angeles document in that three design levels are specified. However, the performance objectives and/or related acceptability criteria at each level are less specific, as discussed below (in the order presented in the AB).

- **Code-Level Evaluation:** A code-level evaluation/design is used to identify the exceptions being taken to the prescriptive rules and to identify the minimum required strength and stiffness for earthquake resistance. If nonlinear response is anticipated under MCE demands, capacity design principles shall be used to create suitable ductile yielding mechanisms. This code-level analysis will determine the required minimum strength of these mechanisms. The specified ground motion is the DBE for the San Francisco Building Code or motion with a 475-year return period. No performance level—as defined by FEMA 273 or Vision 2000—is specified.
- **Serviceability Evaluation:** The serviceability ground motion is defined as having a 43-year return period. The evaluation shall demonstrate that the elements being evaluated exhibit serviceable behavior, which could include minor yielding and minor repair. Tall buildings designs to date show that when primarily designed for code-level requirements, performance at this level is seldom a concern.
- **MCE-Level Evaluation:** The MCE is currently defined as ground motion with a 10% chance of exceedance in 100 years or a 975-year return period. When San Francisco updates their code to be compatible with the 2007 California Building Code, which in turn is based on the 2006 International Building Code, the MCE will likely be updated to agree with the national definition as previously discussed.

The MCE-level evaluation “uses nonlinear response-history analysis to demonstrate an acceptable mechanism of nonlinear lateral deformation and to determine the maximum forces to be considered for structural elements and actions designed to remain elastic.” The evaluation level is included in the bulletin because all involved agreed that intended building code performance includes preventing collapse at the MCE level of ground motion. Realizing that

there is no such thing as zero risk, this performance level is described in the bulletin with the words “an acceptably low probability of collapse.” Further interpretation of this probability is not given and it is unclear if a calculation of the probability will ever be required by the city.

At the MCE level, the bulletin requires capacity design and advanced seismic analysis methods, which are not required for most code-prescriptive tall buildings. Thus, although the target of the bulletin is “at least equivalent” performance, the developers of the document think that it is likely to result in buildings that have more reliable performance against collapse compared with code-prescriptive designs.

3.1.12 Expected Seismic Performance of Code-Designed Buildings

This paragraph contains a summary of current trends in defining expected code-level performance based upon the documents reviewed in this section. The distinction should be emphasized between code objectives as described in code prefaces and commentaries, and actual performance of code-designed buildings in earthquakes. As previously noted almost all code development work has been done by judgment without the availability of analytical tools or sufficient field observations to test the results against stated objectives.

3.1.12.1 Structural

The primary concentration for structural performance is preventing collapse, with the ambiguous “life-safety” level being de-emphasized. The shaking intensity used for this performance level is consistently the MCE. However, California until recently has used a code based on the 1997 UBC and the MCE has been the 1000-year return ground motion. This definition differs from the national mapping of MCE done for the NEHRP provisions and the IBC. Beginning in 2007, when California adopted the IBC, the same rules for ground motion definition have applied in all of the U.S. With increased consideration of uncertainties in performance-based designs, the acceptable reliability of preventing collapse in the MCE will soon become an issue. The only study of this issue are the draft results of ATC 63, which indicate that code designs theoretically are providing approximately a 90% probability of preventing collapse in the MCE motion.

Code performance levels also include a consistent consideration of a serviceability level performance, although it is poorly defined. Use of prescriptive code design rules to achieve a consistent serviceability near-elastic response is difficult, given the many code design adjustment factors (e.g., R factor, drift limits, load factors, phi factors). The 43-year return motion (50% chance of exceedance in 30 years) has often been cited as an appropriate demand, but prescriptive site modifications due to soil conditions result in particularly wide variations in the spectra at low accelerations levels. The acceptability criteria for serviceability are not clear, although, conceptually, near-elastic behavior or behavior requiring little or no structural repair appears to be the goal.

3.1.12.2 Non-structural

Although non-structural performance has been part of published code performance expectations for some time, specific performance objectives are poorly defined.

Code design rules suggest that for 2/3 MCE, (a) anchored items will stay in place, (b) “designated systems” will stay operational, and (c) drift-related items will suffer only minor damage. These limit states do not translate well to a performance level, although the code development philosophy has been focused on preventing hazardous conditions and, in an unspecified way, limiting damage.

The *Intent* paragraph of the 2008 NEHRP provisions currently in preparation includes the statement “to minimize non-structural repair costs when practical to do so.”

For consistency with structural performance objectives, a serviceability event with a 43-year return could be chosen, which, logically, would correspond to SEAOC’s “minor earthquake” with no damage.

3.2 INPUT FROM INTERVIEWS

(See Appendix A for detailed description of interview process.)

The interviews followed a set questionnaire, but, in fact, were often free flowing. The content of the answers depended largely on the perspective of the interviewee, and often were not comparable from one interview to the next. Each answer could therefore not be tabulated in a

coherent summary. The summary in this section is therefore based on the whole of the interview contents as interpreted by the Task 2 Core Group.

3.2.1 Authority of Model Codes or Local Jurisdiction to Increase Performance Objectives beyond Life Safety

Each state's authority to regulate buildings comes from the Constitution's delegation of police power to the state. As explained in Section 3.1, police power has long been interpreted as the authority to regulate for the health, safety, and general welfare of its citizens. "General welfare" can be interpreted as including concern for most types of earthquake losses, not only on a building-by-building basis but on a regional basis.

An example of the extension of building code coverage beyond protection of life safety can be found in the IBC occupancy categories, which, as measured by a building's importance, determine the performance objective. As defined in the International Code Council's performance code, Occupancy Category II is intended for "normal buildings" and Occupancy Category IV is for "essential facilities needed to be operational after an earthquake." Occupancy Category III is reserved for "buildings or facilities of an increased level of societal benefit or importance." This is a much broader definition than used in other current codes that use Occupancy Category III for "buildings or structures representing a substantial hazard to human life." The IBC itself places large buildings (occupancy load greater than 5000) in Category III. Thus, the IBC could also increase the performance objectives for tall buildings by placing them in Occupancy Category III, assuming such a change would be successful in the normal code change process.

California (and many other states) adopts a model code, or a model code with amendments, as the minimum standard for the state. Most states in turn give authority to local jurisdictions to make additional restrictive or conservative amendments considering local conditions. Using this process, a local jurisdiction could also increase the seismic performance objectives for tall buildings assuming that such a local public policy was desired and passed through the legislative process.

3.2.2 Expected Code Performance for Purpose of Interviews

Many various stakeholders were scheduled to be interviewed that would likely not have knowledge of the background and intent of seismic building codes. Two pre-interview background documents were prepared, one giving the philosophical background of building codes, and the second describing potential damage in tall buildings in the local city given a major earthquake. To emphasize that, due to many factors, damage would not be the same in all tall buildings, potential damage states were described for an inventory of 40 tall buildings, all designed to current code. The fragility relationship used to estimate the damage distribution was an average, but reasonable, fragility for normal buildings from the studies done in the ATC 63 project, previously described. It has been argued that tall buildings, on average, would demonstrate better performance than other buildings due to the likelihood of dynamic analysis, more careful design (due to prominence or icon status), and/or peer review. If so, this improved performance would not be due to requirements or intent, and the interview was directed at whether the standard code *intended* performance was adequate for tall buildings.

Among other descriptive information (see Appendix A), the damage distributions shown in Table 3.4 were included in the background paper. Data in the table represent three different performance objectives, Level C being the lowest and Level A the highest. For the purpose of the interview, Level B was intended to represent average performance for normal code buildings, based on a combination of fragilities developed in ATC 63 (see paragraph 3.1.4) and for HAZUS, a seismic-loss-estimating methodology developed by FEMA (www.fema.gov/plan/prevent/hazus/). The interviewees were not told this prior to the interview.

Table 3.4 Rare earthquake scenario damage, one in ten chance of occurring during life of condominium towers (e.g., 50 years)

Hypothetical Performance	Expected No. of Bldgs in each Structural Damage State				
	None/Slight	Moderate	Extensive	Complete	Collapse
Level A	20	15	4	1	0
Level B	19	9	7	4	1
Level C	12	6	9	9	4

3.2.3 Understanding of Expected Code Performance (Zero Risk)

In general, interviewees guessed that Level A in Table 3.4 represented the code. Although they could accept that some buildings could be damaged (many had seen such buildings in person or on television), they could not accept collapse as a real possibility, regardless of the size of the inventory, so Level B and C were not considered realistic.

Further generalizations by the task group concerning the interviewees include a complete lack of knowledge of the uncertainties in seismic design, disbelief that “modern science” couldn’t prevent collapse, and the absence of ever relating normal benefit-to-cost relationships to safety in buildings. This “zero-risk” attitude about seismic performance of new buildings perhaps can be attributed to the infrequency of earthquakes and/or building collapses—unlike other risks like car or airplane crashes, or other natural hazards like tornado, hurricane, or flood. Although not directly asked, it is unlikely that the stakeholders would expect a wood frame house to withstand a tornado, or for that matter, a tall building to withstand a direct hit from a Boeing 767. The typical commercial building-safety stakeholder apparently doesn’t think about the seismic threat enough to develop a realistic mental damage framework.

Not only was collapse of a new tall building in an earthquake unthinkable, but also, to the several condominium owners interviewed, the possible long-term closure of their building for structural repairs.

The task group concludes that the general public has a poor understanding of the possibility of serious structural damage to tall buildings in a major earthquake.

3.2.4 Communication of Risk to Users

When notified during the interviews that there was a risk, although small, of serious structural damage in tall buildings, there was general agreement that this risk—as well as information on a range of damage states—should somehow be communicated to potential owners or tenants. Currently, seismic performance disclosures are limited to very few situations relating to hazardous sites or older buildings. The arcane probable maximum loss (PML) rating is often assigned to an entire building for financial transactions, but this communicates little concerning safety and building closure and is seldom seen by tenants.

Several interviewees thought that a standardized seismic building rating system, understandable by the general public would be useful in this regard, and could eventually create a marketplace value on seismic performance.

A consistent seismic performance rating system that could be used both by the financial community and by building owners, buyers, tenants, and users has been discussed by the earthquake engineering community for years. In fact, the 2007–2008 Existing Buildings Committee of the Structural Engineers Association of Northern California is actively exploring the idea. The driving issues of this system include the development of adequate risk-measurement scales, economically feasible rating methodologies, and an infrastructure to assure standardization and quality control. The continuing development of performance-based earthquake engineering may eventually enable development of such a system (see Section 3.1.10).

Lacking a formalized seismic-rating system, the technical community there clearly still needs to greatly improve communication of risks and performance levels to the user community.

3.2.5 Financing

A broad cross section of the financial community was not interviewed. However, input was received that indicated that the current financial markets have developed complex risk dilution devices that minimize the effect of relatively small changes in performance expectations, particularly of only a small cross section of buildings. The conclusion is that tall buildings, although normally of high value, do not have any special characteristic that would make the financial community an interested stakeholder in setting the seismic performance objective.

3.2.6 Insurance Issues

3.2.6.1 Condominium Residential Buildings

Earthquake insurance is available both for individual owners of units and for the condominium association that is interested and responsible for buildings as a whole. The insurance coverage is normally broken down in accordance with responsibilities outlined in the covenants, conditions and restrictions agreement (CC&Rs). These agreements usually place responsibility for tenant improvements and contents of units on the individual owner and responsibility for the balance of

the building on the tenant association. Generally, owners are responsible for finishes and contents within their unit. However, regardless of their location, the structure and exterior cladding are almost always the association's responsibility.

Condo owner's insurance consists of three main features, not all of which are included in every policy:

- (a) Coverage for damage to tenant improvements and contents.
- (b) Allowance for living expenses should the unit be uninhabitable due to damage in the unit or prohibited access. The duration covered varies but is often 60 days.
- (c) Allowance to cover an assessment by the association for building damage repair (or the deductible on building-wide insurance coverage). The amount varies but is often 20% of the overall policy. This can be triggered only by a formal assessment of all tenants by the association.

Condominium association insurance, on the other hand, is limited to repair of damage in public spaces, building spaces such as mechanical rooms or the roof, cladding, and the structure. There normally is no living expense coverage for tenants with these policies.

Many potential conflicts or overlaps exist in these coverages, the most obvious being repair of structural damage within the space of a unit. Apparently the clarity of coverage varies with policies, but conflicts concerning repair of any kind of damage in condominiums are common.

Except for life-safety issues or exceptionally long building closures, it appears that losses in tall condominium buildings are insurable. The reasonableness of this solution for condo owners is, of course, dependent on the cost of insurance. Identifying these rates and comparing them with potential losses or with the owner's willingness and ability to pay was beyond the scope of this task group.

3.2.6.2 Commercial Buildings

Earthquake insurance for tall commercial buildings is not unlike that available for condos, with an owner or owner group similar to the condo association and building tenants similar to individual condo owners. The motives and attitudes concerning earthquake insurance in the case of commercial buildings will be governed by "business decisions" and is likely to be risk-based to some degree.

The relationship between insurance rates and risk for either residential or commercial tall buildings is unclear because there is limited ability to estimate potential losses and little or no experience data. It is not clear at the present time if buildings built to a higher-than-code standard could get better rates. Therefore, it is concluded, similar to the financing issues, there is negligible influence from insurance issues for the determination of appropriate seismic performance objectives for tall buildings.

3.2.7 Desired Performance of Tall Buildings Based on Interviews

Almost all of the interviewees thought that the performance expectation for normal buildings suggested by the task group (Table 3.4) was inadequate for tall buildings. Many thought this performance was inadequate even for normal buildings. As previously indicated, the judged inadequacy was focused on the possibility of collapse or unreparable damage.

The interviews therefore would suggest that tall buildings should be designed to not collapse in any foreseeable earthquake with a high reliability (perhaps unrealistically high). Long-term or permanent closure (with eventual demolition), although not characterized as *unacceptable*, were viewed as having similar negative impacts far beyond those directly affected. Special characteristics of tall buildings that influenced the opinion of the interviewees included the following:

- Tall buildings should be considered a special class of buildings. The approval of tall buildings requires resolution of many issues having greater impacts on occupants, neighbors, and the city than other/low-rise buildings.
- Tall buildings have a great impact on a city and city services; and they produce high-occupant loads on small land area in these buildings, contributing to their overall importance.
- Because of few exits and other special conditions of high-rises, there is a need to increase resistance to the potential impacts of building fire or significant structural damage or failure.
- Many stakeholders felt that the loss consequences of collapse, long-term closure, or even serious damage would be devastating for commercial property owners, condo owners, and the community.

The interviewees were in general unable to relate to risk levels. Although many said that they had difficulty considering an event that might happen on average every 500 years as a realistic threat, at the same time they were judging that relatively rare cases of collapse were unacceptable. Similarly, moderate damage that might occur from events with a high probability was acceptable as “the price for living in earthquake country.”

3.2.8 Residential versus Other Occupancies

Although residential (condominium) occupancies in tall buildings have different characteristics than commercial buildings, such as owner occupancy, 24-hour occupancy, more elderly occupancy on average, and the provision of permanent housing, the interviewees, in general, thought that these characteristics by themselves were not the dominant cause for their opinion on performance. Commercial tall buildings share all the characteristics listed in the previous section and the temporary or permanent loss of space would have a large economic impact on the city.

Therefore, the enhanced performance recommended for tall buildings by the interviewees was not dependent on occupancy.

3.2.9 Acceptable Premium Costs

Each interviewee was asked how much reliable, enhanced seismic performance was worth to them. This worth may be reflected in the cost of a building, the cost of a condominium, or the rental of space. The answers were “off the tops of their heads,” since the task group did not present to them any estimates of the cost of improved seismic performance or any benefit-cost data. Nevertheless, most interviewees were willing to provide an answer, which fell between 5% and 10%. This range is larger than normally associated with the public’s perception of the importance of seismic performance, and may have been influenced by the previous detailed discussion of seismic performance during the interview.

3.2.10 Implementation Options

Concern was expressed from enforcement, development, design, and construction stakeholders that a recommendation concerning seismic performance of tall buildings coming from the Tall Buildings Initiative would represent a standard of practice. The Core Group assured them that

this study cannot be construed as representing a national or even regional consensus. The arguments for enhanced performance for tall buildings identified during the interviews are a reflection of appropriate public policy as perceived by the individuals interviewed. Legal adoption of such policy could only occur through the national code adoption process or by local ordinance, both of which would involve public input.

Implementation of enhanced performance objectives for tall buildings could also be market driven. This outcome is unlikely, however, until there is a reliable and consensus rating system to measure performance.

3.3 INPUT FROM WORKSHOP

(See Appendix B for detailed description of Workshop.)

As noted in Appendix B, the workshop brought together the Core Group, representatives of the interviewees, representatives of the Tall Buildings Initiative Project Advisory Committee, several other structural engineers familiar with tall building design and/or review, and other interested parties.

A plenary session included descriptions of the Tall Buildings Initiative as a whole and the purpose of the present study. A presentation on the background of seismic codes and performance expectations was given to serve as a common backdrop for all participants. Finally, the interview process was described and selected “consensus” opinions and issues were summarized. Five topics from this summary were identified by the Core Group for discussion at the workshop. Three break-out groups discussed the topics simultaneously. The leaders of the break-out groups reported on discussions in their groups in a final plenary session and after the workshop wrote summaries of their sessions, which are included in Appendix B.

3.3.1 Break-out Discussions

Break-out Number 1: Is the current performance objective of the building code acceptable?

The discussions indicated that stakeholders in general were not familiar with building code philosophy or performance expectations. The perception is that modern buildings will not be seriously damaged in earthquakes and that collapses would not occur unless mistakes were made

in the design. However, at the same time, the stakeholders agreed with engineers and building designers who were present that a “zero-risk” philosophy is unrealistic. This apparent paradox exists because lay persons seldom think about the safety of buildings, particularly new buildings when under earthquake loading, and their first response considering safety does not take into consideration the possibility of low-frequency failures. In addition, while the risks of driving or flying are immediately and constantly perceived, the everyday stability of buildings may give an unrealistic confidence in their stability under extreme loading.

Stakeholders have difficulty combining the small probabilities of the occurrence of the big earthquake (MCE) with the probability of failure from that shaking level, and tend to relate only to the probability of collapse *given the MCE*. A 10% failure rate, as potentially suggested by ATC 63, was perceived by the majority of stakeholders at this workshop as not acceptable. These difficulties in understanding and relating to seismic risk were also noted in the interviews and led to the subject of Break-out Number 2.

Break-out Number 2: Issues relating to understanding risk and disclosing risk

As discussed in Break-out Number 1, stakeholders had difficulty relating to seismic risk, particularly the collapse of a building. The majority agreed that, if there is a real risk of serious damage and closure of a given building due to earthquake shaking, this risk should be disclosed to potential tenants. This may be truer in condominium buildings where tenants are making significant long-term investments in their unit and are depending on its availability for their domicile.

However, several individuals thought that disclosure in the format of a small probability would go un-noticed and suggested that a building rating system that would facilitate understanding the relative risk among all buildings would be necessary for effective disclosure. All break-out groups agreed that this would be a good idea, not only for tall buildings, but for all buildings. Technical representatives in the sessions noted that the idea of a building seismic-rating system has been suggested before, but that there are many practical difficulties in the development and implementation of such a system.

Break-out Number 3: Should tall buildings have better performance than normal buildings?

Two of the three break-out groups reported that there was general agreement within their group that tall buildings should be designed to provide better performance than normal buildings, not only in terms of reliability against collapse and protection of life safety, but also in terms of functionality. Primary reasons cited included:

- There will be an extreme demand on city services in case of collapse, instability, or need of evacuation.
- Occupants are more difficult to evacuate than in other types of buildings.
- The “neighborhood” affected by poor performance of a tall building is larger than that of other buildings.
- The resilience of the city, as measured by potential loss of residents or tenants, business activity, tourism, or general image, is more affected by poor seismic performance of tall buildings than by other measures of performance.

Arguments against this premise included:

- The ramifications of poor performance of tall buildings were not sufficiently different from all other buildings to warrant singling out.
- Development is governed by economics. Additional costs will reduce or eliminate construction of such buildings.
- Local adoption of such requirements will give a development advantage to neighboring cities, counties, or regions.

Break-out Number 4: Are residential buildings different from other tall buildings?

From a public-policy standpoint, it was agreed that residential buildings should not be treated differently with respect to seismic performance. Most arguments for better performance (see Break-out Number 3) apply to all tall buildings. Although condominium owners in tall buildings are concerned about both their long-term investment and the potential loss of their primary residence, it was argued that these concerns are not unique to tall buildings.

Break-out Number 5: How much of a cost premium is acceptable for enhanced seismic performance?

No economic analyses were available of building costs, potential seismic performance premiums, or cost-benefit relationships for enhanced performance. Therefore, the opinions given were not well-founded and were given primarily by potential building tenants, as opposed to owners or developers of buildings. Nevertheless, a premium of as much as 10% for enhanced seismic safety was often suggested as acceptable.

4 Task 2 Conclusions and Recommendations

Considering the totality of input obtained under this task, we make the following conclusions and recommendations:

4.1 SELECTION OF SEISMIC PERFORMANCE OBJECTIVES FOR CLASSES OF BUILDINGS IS PUBLIC POLICY

The primary purpose of this task, to establish seismic performance objectives for tall buildings, generated significant concern with some stakeholders, including:

- A building official was concerned that the Tall Buildings Initiative would recommend enhanced performance for tall buildings for specific jurisdictions that would place the jurisdiction in a difficult and controversial position.
- Structural engineers expressed concern that a recommendation by the Tall Buildings Initiative would become a standard of practice, even if not required by code.
- Designers and builders of tall buildings expressed concern that the potential extra cost of enhanced performance would significantly change the economic viability of such buildings and/or limit the locations where such buildings could be built.

Most of the unique characteristics of tall buildings that were identified during discussions of seismic performance are clearly related to public policy, most on a local level. Examples include details of emergency response plans, regional image, and control or limitation of the intensity and location of development. In addition, concern was expressed over precedent-setting consideration of the economic consequences of seismic performance for one class of building.

We therefore conclude that the establishment of mandatory enhanced structural seismic performance levels for tall buildings is a public-policy issue that should be publicly debated

either on a national scale—through the model building codes—or at a local scale—through an ordinance process in local government.

However, given that the primary purpose of building codes is protection of life safety and public welfare, characteristics of tall buildings that present higher risks than normal buildings could be the targets of further study and recommendations by the technical community itself. Examples of such characteristics of tall buildings that fall into this category are cladding and its anchorage, and emergency ingress and egress.

4.2 EXPECTED CODE PERFORMANCE FOR NORMAL BUILDINGS

Current trends in defining the intent of the code seismic design rules are summarized in detail in Section 3.1.12.

4.2.1 Primary Objective Relating to Avoidance of Collapse

An objective of the Tall Buildings Initiative is to provide the tools to execute Alternative Means designs with improved clarity and reliability. It is clear that seismic provisions in building codes from their beginning have developed around the intent of protecting life safety in large earthquakes. However, it should be noted that the performance that now predominates descriptions of the intent of codes for normal buildings is structural Collapse Prevention, acting as a better-defined surrogate for Life Safety. Thus, if the Tall Buildings Initiative, for the purpose of improving Alternative Means designs, seeks to match the code intent independently of code prescriptive rules, conditions potentially leading to collapse should be identified and models developed to reliably predict them.

The seismic demand specified in recent code performance objectives for normal buildings is consistently the maximum considered earthquake motion (MCE), presumably intended to represent a reasonable worst case. The technical specification for the MCE, however, has been inconsistent, with the Uniform Building Code and its derivatives (notably the California Building Code) specifying motion with a 1000-year return, and the International Building Code specifying motion with a 2500-year return as modified by certain near-fault deterministic considerations.

New national probabilistic hazard mapping has been developed by USGS that includes the next generation attenuation (NGA) relationships developed by PEER. Currently, these data are being used to develop MCE maps for the IBC, and definitions are being proposed in committee that are different than previously used (1997, 2002) as follows:

- It is proposed that for the probabilistic regions, the nominal 2500-year return motions will be modified to create a more consistent risk of non-collapse. This would be achieved by considering the combination of a standard code collapse fragility and the local site hazard curve (the so-called “risk integral”) and adjusting the 2500-year motions to achieve a uniform risk of collapse of 1% in 50 years. (Luco et al. 2007).
- It is proposed that response accelerations for both the probabilistic and deterministic MCE be determined using the maximum direction of ground motion rather than the geomean (GMRotI50) used in the NGA and by USGS.
- It is proposed that in near-fault regions the MCE spectral response accelerations be calculated as the 84th percentile of the controlling characteristic earthquake motions rather than 150% previously used.

Considering the concern among stakeholders (see Section 3.2.3) about the reliability against collapse of tall buildings and the dependence of most designs on the analysis results from scaled response histories, the ramifications of these proposed changes on the selection, the scaling, and the use of ground motion pairs for tall buildings should be studied.

4.2.2 Serviceability Objective

As noted in Section 3.1.12, it is generally accepted that the objectives of the building code, in addition to protection of life safety by avoiding collapse, include provision of avoiding significant losses in more frequent ground motions. This protection is often equilibrated to prescriptive design elastic behavior for code force levels (using the code response reduction factor, R).

When real earthquake motions are specified in guidelines for use in performance-based design or Alternative Means design, they are most often defined as demands with a 50% chance of exceedance in 30 years (43-year return). For serviceability, losses considered are primarily economic and include costs of repair of damage or lost use of the building. Such losses are

generally not required to be zero, but needed repairs should be minor, should not be widespread in the building, and should not interfere with normal use of the building.

However, due to highly nonlinear code site coefficients (particularly F_v), amplification of small motions for C, D, and E sites create demands far greater than prescriptive code design values, which have been derived from large motions reduced by an R value. Performance-based design techniques for the serviceability check may therefore be inconsistent with the result of prescriptive design. In addition, if response histories are used for this check (given that nonlinearity may be allowed for serviceability), commonly used databases of ground motions may be inappropriate for scaling to small spectral ordinates.

It is recommended that the Tall Buildings Initiative investigate the response of tall buildings to small input motions to enable better definition of a useful serviceability check.

4.2.3 Stakeholder Concerns Regarding Seismic Performance of Tall Buildings

As discussed in Sections 3.2 and 3.3 covering the interview process and the workshop, a strong majority of stakeholders were very concerned about the risk of collapse suggested by code fragilities currently developed by the ATC 63 project. There was similar concern, most specifically directed at condominium towers, about the risk suggested for serious damage and building closure. Although we have concluded that recommendations concerning mandatory minimum seismic performance as specified in the building code is a public-policy issue, it is clear that there is great interest among stakeholders regarding the details of expected damage and its consequences in buildings, particularly tall or otherwise iconic buildings.

It should be noted that significant concerns were also expressed about the potentially negative effects of increased building costs due to the provision of enhanced performance. Such increased costs could suppress development of tall buildings completely, or cause development of tall buildings to locate in jurisdictions where enhanced performance is not required.

4.2.4 Additional Recommendations to Tall Buildings Initiative

The recommendations from this study regarding engineering analysis and design fit completely within the capabilities of the vision for performance-based design methodologies developed by

PEER and the ATC 58 project, and development of practical implementation methods for these visions should continue.

More specifically, the Tall Buildings Initiative should improve understanding and measurement of reliability of designs against collapse and develop approximations of the contributions to this reliability from:

- Targeting enhanced performance;
- Peer review or other quality control of the design process; and
- Quality control of the construction process.

In addition, potential damage patterns that could lead to significant repair costs or closure of the building should be understood and be reasonably predictable.

We have also concluded that the risk to life safety from falling hazards created by damage to cladding is potentially higher in tall buildings than in normal buildings due to increased uncertainty regarding drift amplitude and patterns and due to a larger falling radius. The Tall Buildings Initiative should study and quantify these risks. If cladding is confirmed to present a higher risk, the Tall Buildings Initiative should recommend measures to reduce the risk to be approximately the same as for normal buildings.

As previously mentioned, issues surrounding emergency ingress and egress in tall buildings is also completely different from other buildings. The risks presented by this unique characteristic of tall buildings should also be studied and the risk mitigated to the extent practicable. It is our understanding that other organizations are currently studying this issue. It is recommended that the Tall Buildings Initiative coordinate with these efforts and offer input concerning the seismic aspects of the overall problem.

4.2.5 Implementation Options

Regardless of the public-policy implications of adding mandatory enhanced seismic performance for tall buildings into national building codes and standards, a more specific code issue would make implementation difficult. Currently, buildings judged important or otherwise representing a high risk are given a special occupancy category in national codes and standards, which in turn triggers various special code requirements. Occupancy Category I consists of low-risk buildings with little or no occupancy; II includes all “normal” buildings; III is for buildings presenting a substantial hazard to human life; and IV is for buildings considered essential after disasters. For

structural seismic design, a distinction between Occupancy Categories is made by use of an importance factor, up to 1.5, to be applied to design loading and varying drift limitations. There is additional specification of special requirements for certain non-structural components.

It is generally acknowledged that an importance factor of 1.25 or 1.5, by itself, would not necessarily provide improved performance in tall buildings, and that enhanced performance could be assured only by some form of performance-based design. There is no precedent for the requirement of performance-based design for any building type or occupancy in national model codes (although there is such a requirement in codes used by the military (DOD 2006)), and establishment of such a requirement would create additional complications.

If the Tall Buildings Initiative concludes that cladding in tall buildings presents a higher risk than normal buildings, mitigating design requirements could be proposed to national code committees. However, to be acceptable, it is likely that these special design requirements will have to be within the framework of normal code design parameters and not be dependent on the result of performance-based analysis or design techniques.

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