1. Rehabilitation Requirements

1.1 Scope

This *Prestandard for the Seismic Rehabilitation of Buildings*, referred to herein as "this standard," specifies nationally applicable provisions for the rehabilitation of buildings to improve seismic performance. It is intended for use by code officials in directed seismic rehabilitation programs, or for reference by building owners and design professionals in voluntary rehabilitation efforts.

This chapter sets forth requirements for selecting a Rehabilitation Objective and conducting the seismic rehabilitation process.

Symbols, acronyms, definitions, and references used throughout this standard are cited separately in sections located at the end of this standard.

C1.1 Scope

This standard is intended to serve as a nationally applicable tool for design professionals, code officials, and building owners undertaking the seismic rehabilitation of existing buildings. It consists of two parts: provisions, which contain the technical requirements, and commentary, intended to explain the provisions. Commentary for a given section is located in a shaded box immediately following the section, and is identified by the same section number preceded by the letter "C."

It is expected that most buildings rehabilitated in accordance with this standard would perform within the desired levels when subjected to the design earthquakes. However, compliance with the standard does not guarantee such performance. The practice of earthquake engineering is rapidly evolving, and both our understanding of the behavior of buildings subjected to strong earthquakes and our ability to predict this behavior are advancing. In the future, new knowledge and technology will provide more reliable methods of accomplishing these goals.

The procedures contained in this standard are specifically applicable to the rehabilitation of existing buildings and are, in general, more appropriate for that purpose than are new building codes. New building codes are primarily intended to regulate the design and construction of new buildings; as such, they include many provisions that encourage the development of designs with features important for good seismic performance, including regular configuration, structural continuity, ductile detailing, and materials of appropriate quality. Many existing buildings were designed and constructed without these features and contain characteristics such as unfavorable configuration and poor detailing that preclude application of building code provisions for their seismic rehabilitation.

While it is intended to be used as a follow-up to a previous seismic evaluation, this standard can also be used as an evaluation tool that ascertains compliance with a selected rehabilitation objective. A *FEMA 310*, Tier 3 evaluation is an example of this use. It should be noted, however, that an evaluation using this standard may be more stringent than other evaluation methodologies because the provisions have been calibrated for use in design. Historically, criteria for evaluation have been set lower than those for design to minimize the need to strengthen buildings that would otherwise have only modest deficiencies.

The expertise of the design professional in earthquake engineering is an important prerequisite for the appropriate use of this standard in assisting a building owner to select voluntary seismic criteria or to design and analyze seismic rehabilitation projects.

This standard is intended to be generally applicable to seismic rehabilitation of all buildings—regardless of importance, occupancy, historic status, or other classifications of use. However, application of these provisions should be coordinated with other requirements that may be in effect, such as ordinances governing historic structures or hospital construction. In addition to the direct effects of ground shaking, this standard also considers the effects of local geologic site hazards such as liquefaction.

This standard applies to the seismic rehabilitation of both the overall structural system of a building and its nonstructural components including ceilings, partitions, mechanical, electrical, and plumbing systems.

With careful extrapolation, the procedures of this standard may also be applied to many nonbuilding structures such as pipe racks, steel storage racks, structural towers for tanks and vessels, piers, wharves, and electrical power generating facilities. However, the applicability of these procedures has not been fully examined for every type of structure, particularly those that have generally been covered by specialized codes or standards, such as bridges and nuclear power plants.

In addition to techniques for increasing the strength and ductility of systems, this standard provides techniques for reducing seismic demand, such as the introduction of isolation or damping devices. Design of new buildings and evaluation of components for gravity and wind forces in the absence of earthquake demands are beyond the scope of this standard.

This standard does not explicitly address the determination of whether or not a rehabilitation project should be undertaken for a particular building. Guidance on the use of this standard in voluntary or directed risk-mitigation programs is provided in Appendix A. Determining when these provisions should be required or desired is beyond the scope of this standard. Once the decision to rehabilitate a building has been made, this standard can be referenced for detailed engineering guidance on how to conduct a seismic rehabilitation analysis and design.

Featured in this standard are descriptions of damage states in relation to specific performance levels. These descriptions are intended to aid design professionals and owners in selecting appropriate performance levels for rehabilitation design. They are not intended to be used for condition assessment of earthquake-damaged buildings. Although there may be similarities between these damage descriptions and those used for post-earthquake damage assessment, many factors enter into the processes of assessing seismic performance. No single parameter in this standard should be cited as defining either a performance level or the safety or usefulness of an earthquake-damaged building.

Techniques for repair of earthquake- damaged buildings are not included in this standard, but are referenced in the commentary of Chapters 5 through 8 when such guidelines exist. If the mechanical properties of repaired components are known, acceptability criteria for use with this standard can be either deduced by comparison with other similar components, or derived. Any combination of repaired elements, undamaged existing elements, and new elements can be modeled using this standard, and each checked against performance level acceptance criteria.

1.2 Design Basis

Seismic rehabilitation of buildings shall comply with the design criteria and procedures of this standard for achieving the performance-based Rehabilitation Objectives defined in Section 1.4. The use of alternative performance-based criteria and procedures shall be permitted as approved by the code official.

C1.2 Design Basis

Provisions of this standard for seismic rehabilitation are based on a performance-based design methodology that differs from seismic design procedures for the design of new buildings currently specified in national building codes and standards.

The framework in which these requirements are specified is purposefully broad so that Rehabilitation Objectives can accommodate buildings of different types, that satisfy a variety of performance levels, and consider the variation of seismic hazards across the United States and Territories.

The provisions and commentary of this standard are primarily based on the *FEMA 273 Guidelines* with limited material taken from the *FEMA 274 Commentary*. This standard is intended to supersede *FEMA 273*, but *FEMA 274* remains a valid explanation for the provisions in this standard unless indicated otherwise in the relevant commentary of this standard. For this reason, section numbers in this standard remain essentially the same as in *FEMA 273*, with the exception of Chapters 1 and 2, which were reorganized for clarity.

FEMA 273 was developed by a large team of specialists in earthquake engineering and seismic rehabilitation. The most advanced analytical techniques considered practical for production use have been incorporated. The acceptance criteria have been specified using actual laboratory test results, where available, supplemented by the engineering judgment of various development teams. Certain buildings damaged in the 1994 Northridge earthquake and a limited number of designs using codes for new buildings have been checked using the procedures of *FEMA 273*. A comprehensive program of case studies was undertaken by FEMA in 1998 to test more thoroughly the various analysis techniques and acceptability criteria. The results of this study are reported in FEMA 343, *Case Studies: An Assessment of the NEHRP Guidelines for the Seismic Rehabilitation of Buildings*. The results of the *FEMA 343* case studies have been incorporated in the provisions of this standard, where possible. Similarly, information from *FEMA 350*, *FEMA 351*, and other reports published by the SAC Joint Venture project, formed as a result of the Northridge steel moment frame damage, has been incorporated where applicable. Engineering judgment should be exercised in determining the applicability of various analysis techniques and material acceptability criteria in each situation.

The commentary to this standard contains specific references to many other documents. In addition, this standard is also related generically to the following publications.

1. FEMA 222A and 223A, *NEHRP Recommended Provisions for Seismic Regulations for New Buildings*, 1994 Edition. For the purposes of the design of new components, this standard has been designed to be as compatible as possible with the companion Provisions for new buildings and its reference design documents. Detailed references to the use of specific sections of the Provisions document will be found in subsequent sections of this standard.

2. FEMA 302 and 303, 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* referred to herein as the *1997 NEHRP Recommended Provisions*.

3. FEMA 237, *Development of Guidelines for Seismic Rehabilitation of Buildings, Phase I: Issues Identification and Resolution*, which underwent an American Society of Civil Engineers (ASCE) consensus approval process, provided policy direction for this standard.

4. *ATC-28-2, Proceedings of the Workshop to Resolve Seismic Rehabilitation Sub-issues* provided recommendations to the writers of this standard on more detailed sub-issues.

5. FEMA 172, *NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings*, originally produced by URS/Blume and reviewed by BSSC, contains construction techniques for implementing engineering solutions to the seismic deficiencies of existing buildings.

6. FEMA 178, *NEHRP Handbook for the Seismic Evaluation of Existing Buildings*, which was originally developed by ATC and underwent the consensus approval process of the BSSC, covered the subject of evaluating existing buildings to determine if they are seismically deficient in terms of life safety. This document has been updated by FEMA as a prestandard, *FEMA 310, Handbook for the Seismic Evaluation of Existing Buildings*, which underwent an ASCE consensus approval process. (The model building types and other information from *FEMA 310* are used or referred to extensively in this standard in Chapter 10.)

7. FEMA 156 and 157, *Typical Costs for Seismic Rehabilitation of Existing Buildings*, Second Edition, reports statistical analysis of the costs of rehabilitation of over 2,000 buildings based on construction costs or detailed studies. Several different seismic zones and performance levels are included in the data. Since the data were developed in 1994, none of the data are based on buildings rehabilitated specifically in accordance with the *FEMA 273 Guidelines* document. Performance Levels defined in this standard are not intended to be significantly different from parallel levels used previously, and costs still should be reasonably representative.

8. FEMA 275, *Planning for Seismic Rehabilitation: Societal Issues*, discusses societal and implementation issues associated with rehabilitation and describes several case histories.

9. FEMA 276, *Guidelines for the Seismic Rehabilitation of Buildings: Example Applications*, intended as a companion document to *FEMA 273* and *FEMA 274*, describes examples of buildings that have been seismically rehabilitated in various seismic regions and for different Rehabilitation Objectives. Costs of the work are given and references made to *FEMA 156* and *157*. Because this document is based on previous case histories, none of the examples was rehabilitated specifically in accordance with this standard. However, Performance Levels defined in this standard are not intended to be significantly different from parallel levels used previously, and the case studies are therefore considered representative.

10. ATC 40, *Seismic Evaluation and Retrofit of Concrete Buildings*, incorporates performance levels almost identical to those shown in Table C1-8 and employs "pushover" nonlinear analysis techniques. The capacity spectrum method for determining the displacement demand is treated in detail. This document covers only concrete buildings.

1.3 Seismic Rehabilitation Process

Seismic rehabilitation of an existing building shall be conducted in accordance with the process outlined in Sections 1.3.1 through 1.3.6. Before embarking on a rehabilitation design, seismic deficiencies shall have been identified through a prior seismic evaluation performed using an evaluation methodology considering a combination of building performance and seismic hazard.

C1.3 Seismic Rehabilitation Process

The steps are presented in this section in the order in which they would typically be followed in the rehabilitation process. However, the criteria for performing these steps are presented in a somewhat different order to facilitate presentation of the concepts.

Figure C1-1 depicts the rehabilitation process specified in this standard and shows specific chapter references in parentheses at points where input from this standard is to be obtained.

This standard requires the building owner or the code official to select a Rehabilitation Objective for a building that has been previously identified as needing seismic rehabilitation.

Prior to embarking on a rehabilitation program, an evaluation should be performed to determine whether the building, in its existing condition, has the desired seismic performance capability. *FEMA 310* is an example of an evaluation methodology that may be used for this purpose. It should be noted, however, that a building may meet certain performance objectives using the methodology of *FEMA 310*, but may not meet those same performance objectives when an evaluation is performed using the procedures of this standard. This is largely because *FEMA 310* is specifically intended to accept somewhat greater levels of damage within each performance level than permitted by this standard, which is consistent with the historic practice of evaluating existing buildings for slightly lower criteria than those used for design of new buildings. *FEMA 310* quantifies this difference with the use of a 0.75 factor on demands when using this standard in a Tier 3 evaluation. This essentially lowers the reliability of achieving the selected performance level from about 90% to 60%. This practice minimizes the need to rehabilitate structures with relatively modest deficiencies relative to the desired performance level.

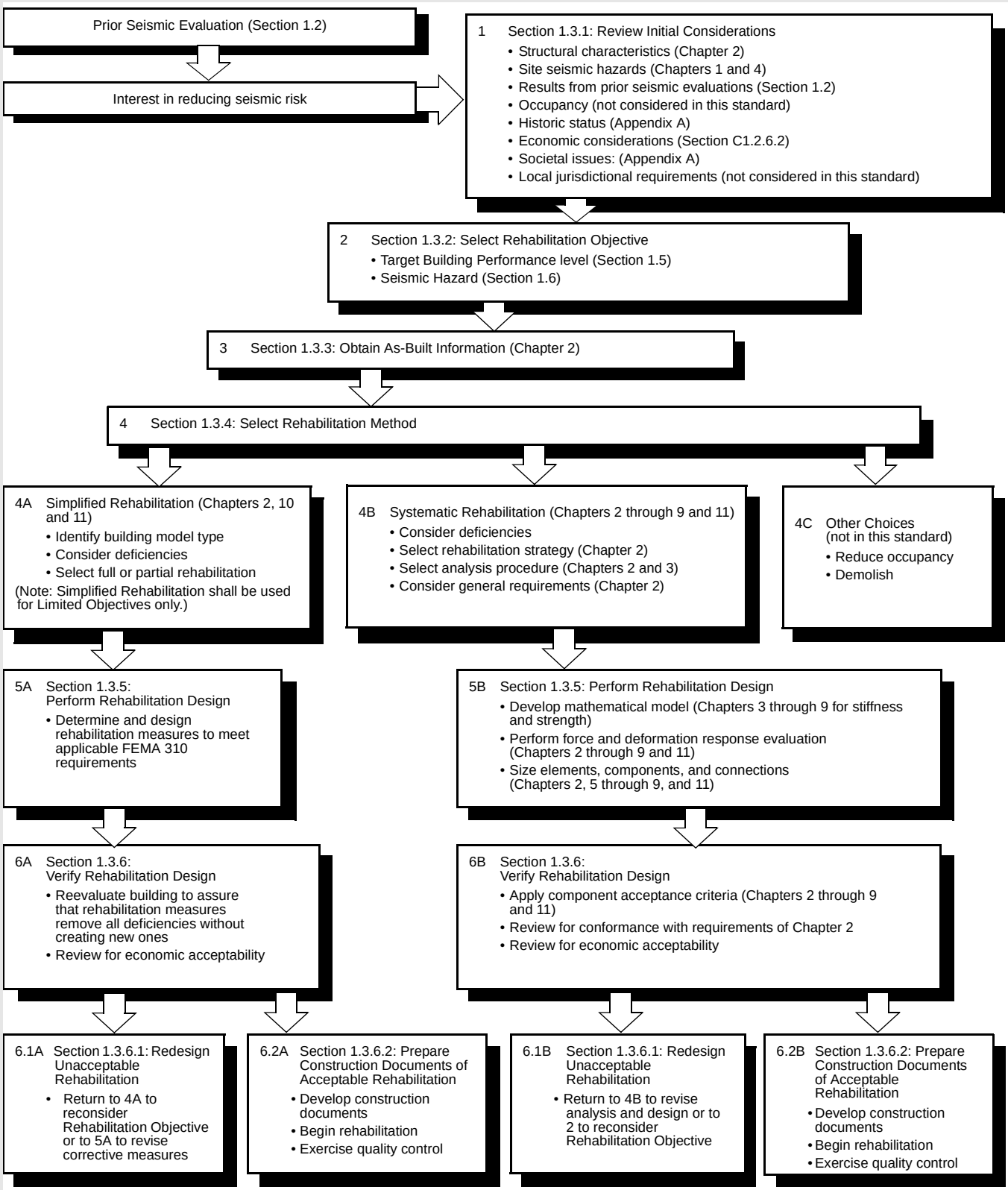

Figure C1-1 Rehabilitation Process

1.3.1 Review Initial Considerations

The design professional shall review initial considerations with the building owner or code official to determine any restrictions that exist on the design of rehabilitation measures. Initial considerations shall include structural characteristics of the building, seismic hazards including geologic site hazards known to be present at the site, results of prior seismic evaluations, building use and occupancy requirements, historic status, economic considerations, societal issues, and local jurisdictional requirements.

C1.3.1 Review Initial Considerations

The process of building rehabilitation will be simplified and made more efficient if information that significantly affects the rehabilitation design is obtained and considered prior to beginning the process. Rehabilitation requirements mandated by local jurisdictions would be particularly important to determine in the initial stages of a project.

The building owner should be aware of the range of costs and impacts of rehabilitation, including both the variation associated with different Rehabilitation Objectives and the potential additional costs often associated with seismic rehabilitation, such as other life safety upgrades, hazardous material removal, work associated with the Americans with Disabilities Act, and nonseismic building remodeling. Also to be considered are potential federal tax incentives for the rehabilitation of historic buildings and for some other older nonresidential buildings.

Seismic hazards other than ground shaking may exist at the building site. The risk and possible extent of damage from geologic site hazards identified in Section 4.2.2 should be considered before undertaking a rehabilitation aimed solely at reducing damage due to shaking. In some cases it may be feasible to mitigate the site hazard or rehabilitate the building and still meet the selected performance level. In other cases the risk due to site hazards may be so extreme and difficult to control that rehabilitation is neither cost-effective nor feasible.

The use of the building must be considered in weighing the significance of potential temporary or permanent disruptions associated with various risk mitigation schemes. Other limitations on modifications to the building due to historic or aesthetic features must also be understood. The historic status of every building at least 50 years old should be determined (see Appendix A, Section A.6, Considerations for Historic Buildings). This determination should be made early as it could influence the choices of rehabilitation approaches and techniques.

There are many ways to reduce seismic risk, whether the risk is to property, life safety, or post- earthquake use of the building. The occupancy of vulnerable buildings can be reduced, redundant facilities can be provided, and nonhistoric buildings can be demolished and replaced. The risks posed by nonstructural components and contents can be reduced. Seismic site hazards other than shaking can be mitigated.

Most often, however, when all alternatives are considered, the options of modifying the building to reduce the risk of damage should be studied. Such corrective measures include stiffening or strengthening the structure, adding local elements to eliminate irregularities or tie the structure together, reducing the demand on the structure through the use of seismic isolation or energy dissipation devices, and reducing the height or mass of the structure. Rehabilitation strategies are discussed in Chapter 2.

1.3.2 Select Rehabilitation Objective

The building owner or code official shall select a seismic Rehabilitation Objective for the building as specified in Section 1.4. The selection of a Rehabilitation Objective shall consist of the selection of a target Building Performance Level from a range of performance levels defined in Section 1.5 and on the selection of an anticipated Earthquake Hazard Level from a range of seismic hazards defined in Section 1.6.

C1.3.2 Select Rehabilitation Objective

The concepts and terminology of performance-based design are new and should be carefully studied and discussed with building owners before use. The terminology used for target Building Performance Levels is intended to represent goals of design. The actual ground motion will seldom be comparable to that specified in the Rehabilitation Objective, so in most events, designs targeted at various damage states may only determine relative performance. Even given a ground motion similar to that specified in the Rehabilitation Objective and used in design, variations from stated performance objectives should be expected and compliance with this standard should not be considered a guarantee of performance. Variations in actual performance could be associated with unknown geometry and member sizes in existing buildings, deterioration of materials, incomplete site data, variation of ground motion that can occur within a small area, and incomplete knowledge and simplifications related to modeling and analysis. Information on the expected reliability of achieving various target Building Performance Levels when the requirements are followed can be found in Chapter 2 of *FEMA 274*.

1.3.3 Obtain As-Built Information

Available as-built information for the building shall be obtained and a site visit shall be conducted as specified in Section 2.2.

1.3.4 Select Rehabilitation Method

An applicable rehabilitation method shall be determined in accordance with Section 2.3.

C1.3.4 Select Rehabilitation Method

Rehabilitation can consist of the Simplified Rehabilitation Method or the Systematic Rehabilitation Method. These methods are defined in Section 2.3 and further explained in the associated commentary of that section.

1.3.5 Perform Rehabilitation Design

Rehabilitation measures shall be designed using the applicable rehabilitation method.

1.3.6 Verify Rehabilitation Design

The rehabilitation design shall be verified to meet the requirements of this standard through an analysis of the building, including rehabilitation measures. The analysis shall be consistent with the procedures for the applicable rehabilitation method specified in Section 2.3. A separate analytical evaluation shall be performed for each combination of building performance and seismic hazard specified in the selected Rehabilitation Objective.

1.3.6.1 Redesign Unacceptable Rehabilitation

If the rehabilitation design fails to comply with the acceptance criteria for the selected Rehabilitation Objective, the rehabilitation measures shall be redesigned or an alternative rehabilitation strategy shall be implemented. This process shall be repeated until the design is in compliance with the acceptance criteria for the selected Rehabilitation Objective.

1.3.6.2 Prepare Construction Documents of Acceptable Rehabilitation

If the rehabilitation design meets the acceptance criteria for the selected Rehabilitation Objective, and the decision is made to proceed with the rehabilitation, construction documents shall be prepared and shall include requirements for construction quality assurance in accordance with Section 2.7.

C1.3.6.2 Prepare Construction Documents of Acceptable Rehabilitation

At this stage, a cost estimate can be made to review the economic acceptability of the design. Cost estimating or reviewing economic acceptability of the rehabilitation design is not included in the standard, but is an essential part of the rehabilitation process shown in Figure C1-1.

Construction costs are discussed in Example Applications, *FEMA 276* and Typical Costs for Seismic Rehabilitation, *FEMA 156* and *157*.

If the design proves uneconomical or otherwise not feasible, further refinement may be considered in analysis, a different rehabilitation scheme may be designed or a different Rehabilitation Objective may be considered.

Section 2.7 specifies provisions for a quality assurance program during the construction or implementation of the rehabilitation design. Other aspects of the implementation process, including details of the preparation of construction documents, obtaining a building permit, selection of a contractor, details of historic preservation techniques for particular kinds of materials, and financing are not covered in this standard.

1.4 Rehabilitation Objectives

A seismic Rehabilitation Objective shall be selected for the building, consisting of one or more rehabilitation goals. Each goal shall consist of a target Building Performance Level defined in Section 1.5 and an Earthquake Hazard Level defined in Section 1.6. Goals shall be selected considering basic, enhanced, or limited objectives defined in Sections 1.4.1 through 1.4.3.

C1.4 Rehabilitation Objectives

Recommendations regarding the selection of a Rehabilitation Objective for any building are beyond the scope of this standard. *FEMA 274* discusses issues to consider when combining various performance and seismic hazard levels. It should be noted that not all combinations constitute reasonable or cost-effective Rehabilitation Objectives. This standard is written under the premise that greater flexibility is required in seismic rehabilitation than in the design of new buildings. However, given that flexibility, once a Rehabilitation Objective is selected, this standard provides internally consistent procedures with the necessary specificity to perform a rehabilitation analysis and design.

Building performance can be described qualitatively in terms of the safety afforded building occupants during and after the event; the cost and feasibility of restoring the building to pre-earthquake condition; the length of time the building is removed from service to effect repairs; and economic, architectural, or historic impacts on the larger community. These performance characteristics are directly related to the extent of damage that would be sustained by the building.

In this standard, the extent of damage to a building is categorized as a Building Performance Level. A broad range of target Building Performance Levels may be selected when determining Rehabilitation Objectives.

Probabilistic Earthquake Hazard Levels frequently used in this standard and their corresponding mean return periods (the average number of years between events of similar severity) are as follows:

Earthquake Having Probability of Exceedance	Mean Return Period (years)
50%/50 year	72
20%/50 year	225
10%/50 year	474
2%/50 year	2,475

These mean return periods are typically rounded to 75, 225, 500, and 2,500 years, respectively.

The Rehabilitation Objective selected as a basis for design will determine, to a great extent, the cost and feasibility of any rehabilitation project, as well as the benefit to be obtained in terms of improved safety, reduction in property damage, and interruption of use in the event of future earthquakes. Table C1-1 indicates the range of Rehabilitation Objectives that may be used in this standard.

Table C1-1 Rehabilitation Objectives

		Target Building Performance Levels			
		Operational Performance Level (1-A)	Immediate Occupancy Performance Level (1-B)	Life Safety Performance Level (3-C)	Collapse Prevention Performance Level (5-E)
Earthquake Hazard Level	50%/50 year	a	b	c	d
	20%/50 year	e	f	g	h
	BSE-1 (~10%/50 year)	i	j	k	l
	BSE-2 (~2%/50 year)	m	n	o	p

Notes:

1. Each cell in the above matrix represents a discrete Rehabilitation Objective.
2. The Rehabilitation Objectives in the matrix above may be used to represent the three specific Rehabilitation Objectives defined in Sections 1.4.1, 1.4.2, and 1.4.3, as follows:

   k + p = Basic Safety Objective (BSO)
   k + p + any of a, e, i, b, f, j, or n = Enhanced Objectives
   o alone or n alone or m alone = Enhanced Objective
   k alone or p alone = Limited Objectives
   c, g, d, h, l = Limited Objectives

1.4.1 Basic Safety Objective

The Basic Safety Objective (BSO) is a Rehabilitation Objective that achieves the dual rehabilitation goals of Life Safety Building Performance Level (3-C) for the BSE-1 Earthquake Hazard Level and Collapse Prevention Building Performance Level (5-E) for the BSE-2 Earthquake Hazard Level.

C1.4.1 Basic Safety Objective

The BSO is intended to approximate the earthquake risk to life safety traditionally considered acceptable in the United States. Buildings meeting the BSO are expected to experience little damage from relatively frequent, moderate earthquakes, but significantly more damage and potential economic loss from the most severe and infrequent earthquakes that could affect them. The level of damage and potential economic loss experienced by buildings rehabilitated to the BSO may be greater than that expected in properly designed and constructed new buildings.

1.4.2 Enhanced Rehabilitation Objectives

Rehabilitation that provides building performance exceeding that of the BSO is termed an Enhanced Objective. Enhanced Rehabilitation Objectives shall be achieved using one or a combination of the following two methods:

1. By designing for target Building Performance Levels that exceed those of the BSO at either the BSE-1 or BSE-2 hazard levels, or both.
2. By designing for the target Building Performance Levels of the BSO using an Earthquake Hazard Level that exceeds either the BSE-1 or BSE-2 hazard levels, or both.

C1.4.2 Enhanced Rehabilitation Objectives

Enhanced Rehabilitation Objectives can be obtained by designing for higher target Building Performance Levels (method 1) or by designing using higher Earthquake Hazard Levels (method 2) or any combination of these two methods.

1.4.3 Limited Rehabilitation Objectives

Rehabilitation that provides building performance less than that of the BSO is termed a Limited Objective. Limited Rehabilitation Objectives shall be achieved using Reduced Rehabilitation specified in Section 1.4.3.1 or Partial Rehabilitation specified in Section 1.4.3.2, and shall comply with the following conditions:

1. The rehabilitation measures shall not result in a reduction in the performance level of the existing building;

2. The rehabilitation measures shall not create a new structural irregularity or make an existing structural irregularity more severe;

3. The rehabilitation measures shall not result in an increase in the seismic forces to any component that is deficient in capacity to resist these forces;

4. All new or rehabilitated structural components and elements shall be detailed and connected to the existing structure in compliance with the requirements of this standard.

1.4.3.1 Reduced Rehabilitation Objective

Rehabilitation that addresses the entire building structural and nonstructural systems, but uses a lower seismic hazard or lower target Building Performance Level than the BSO, is termed Reduced Rehabilitation Objective. Reduced Rehabilitation shall be designed for one or more of the following objectives:

1. Life Safety Building Performance Level (3-C) for earthquake demands that are less severe (more probable) than the BSE-1;

2. Collapse Prevention Building Performance Level (5-E) for earthquake demands that are less severe (more probable) than the BSE-2;

3. Building Performance Levels 4-C, 4-D, 4-E, 5-C, 5-D, 5-E, 6-D, or 6-E for BSE-1 or less severe (more probable) earthquake demands.

1.4.3.2 Partial Rehabilitation Objective

Rehabilitation that addresses a portion of the building without rehabilitating the complete lateral-force-resisting system is termed Partial Rehabilitation. A Partial Rehabilitation shall be designed and constructed considering future completion of a Rehabilitation Objective intended to improve the performance of the entire structure.

1.5 Target Building Performance Levels

A target Building Performance Level shall consist of a combination of a Structural Performance Level selected from the levels specified in Section 1.5.1 and a Nonstructural Performance Level selected from the levels specified in Section 1.5.2. The target Building Performance Level shall be designated alphanumerically in accordance with Section 1.5.3.

C1.5 Target Building Performance Levels

Building performance is a combination of the performance of both structural and nonstructural components. Table C1-2 describes the approximate limiting levels of structural and nonstructural damage that may be expected of buildings rehabilitated to the levels defined in the standard. On average, the expected damage would be less. For comparative purposes, the estimated performance of a new building subjected to the BSE-1 level of shaking is indicated. Performance descriptions in Table C1-2 are estimates rather than precise predictions, and variation among buildings of the same target Building Performance Level must be expected.

Building performance in this standard is expressed in terms of target Building Performance Levels. These target Building Performance Levels are discrete damage states selected from among the infinite spectrum of possible damage states that buildings could experience during an earthquake. The particular damage states identified as target Building Performance Levels in this standard have been selected because they have readily identifiable consequences associated with the post-earthquake disposition of the building that are meaningful to the building community. These include the ability to resume normal functions within the building, the advisability of post-earthquake occupancy, and the risk to life safety.

Due to inherent uncertainties in prediction of ground motion and analytical prediction of building performance, some variation in actual performance should be expected. Compliance with this standard should not be considered a guarantee of performance. Information on the reliability of achieving various Performance Levels can be found Chapter 2 of *FEMA 274*).

1.5.1 Structural Performance Levels and Ranges

The Structural Performance Level of a building shall be selected from four discrete Structural Performance Levels and two intermediate Structural Performance Ranges defined in this section.

The discrete Structural Performance Levels are Immediate Occupancy (S-1), Life Safety (S-3), Collapse Prevention (S-5), and Not Considered (S-6). Design procedures and acceptance criteria corresponding to these Structural Performance Levels shall be as specified in Chapters 4 through 10.

The intermediate Structural Performance Ranges are the Damage Control Range (S-2) and the Limited Safety Range (S-4). Acceptance criteria for performance within the Damage Control Structural Performance Range shall be obtained by interpolating the acceptance criteria provided for the Immediate Occupancy and Life Safety Structural Performance Levels. Acceptance criteria for performance within the Limited Safety Structural Performance Range shall be obtained by interpolating the acceptance criteria provided for the Life Safety and Collapse Prevention Structural Performance Levels.

C1.5.1 Structural Performance Levels and Ranges

A wide range of structural performance requirements could be desired by individual building owners. The four Structural Performance Levels defined in this standard 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.

Table C1-3 relates these Structural Performance Levels to the limiting damage states for common vertical elements of lateral-force-resisting systems. Table C1-4 relates these Structural Performance Levels to the limiting damage states for common horizontal elements of building lateral-force-resisting systems. Later sections of this standard specify design parameters (such as *m*-factors, component capacities, and inelastic deformation demands) specified as limiting values for attaining these Structural Performance Levels for a known earthquake demand.

The drift values given in Table C1-3 are typical values provided to illustrate the overall structural response associated with various Structural Performance Levels. They are not provided in these tables as drift limit requirements for this standard, and do not supersede component or element deformation limits that are specified in Chapters 4 through 9, and 11.

The expected post-earthquake state of the buildings described in these tables is for comparative purposes and should not be used in the post-earthquake safety evaluation process.

1.5.1.1 Immediate Occupancy Structural Performance Level (S-1)

Structural Performance Level S-1, Immediate Occupancy, shall be defined as the post-earthquake damage state that remains safe to occupy, essentially retains the pre-earthquake design strength and stiffness of the structure, and is in compliance with the acceptance criteria specified in this standard for this Structural Performance Level.

C1.5.1.1 Immediate Occupancy Structural Performance Level (S-1)

Structural Performance Level S-1, Immediate Occupancy, means the post-earthquake 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 reoccupancy.

1.5.1.2 Damage Control Structural Performance Range (S-2)

Structural Performance Range S-2, Damage Control, shall be defined as the continuous range of damage states between the Life Safety Structural Performance Level (S-3) and the Immediate Occupancy Structural Performance Level (S-1).

C1.5.1.2 Damage Control Structural Performance Range (S-2)

Design for the Damage Control Structural Performance Range 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.

1.5.1.3 Life Safety Structural Performance Level (S-3)

Structural Performance Level S-3, Life Safety, shall be defined as the post-earthquake damage state that includes damage to structural components but retains a margin against onset of partial or total collapse in compliance with the acceptance criteria specified in this standard for this Structural Performance Level.

C1.5.1.3 Life Safety Structural Performance Level (S-3)

Structural Performance Level S-3, Life Safety, means the post-earthquake 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, the overall risk of life-threatening injury as a result of structural damage is expected to be 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 reoccupancy.

1.5.1.4 Limited Safety Structural Performance Range (S-4)

Structural Performance Range S-4, Limited Safety, shall be defined as the continuous range of damage states between the Life Safety Structural Performance Level (S-3) and the Collapse Prevention Structural Performance Level (S-5).

1.5.1.5 Collapse Prevention Structural Performance Level (S-5)

Structural Performance Level S-5, Collapse Prevention, shall be defined as the post-earthquake damage state that includes damage to structural components such that the structure continues to support gravity loads but retains no margin against collapse in compliance with the acceptance criteria specified in this standard for this Structural Performance Level.

C1.5.1.5 Collapse Prevention Structural Performance Level (S-5)

Structural Performance Level S-5, Collapse Prevention, means the post-earthquake damage state in which the building is on the verge of 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 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 reoccupancy, as aftershock activity could induce collapse.

1.5.1.6 Structural Performance Not Considered (S-6)

A building rehabilitation that does not address the performance of the structure shall be classified as Structural Performance Not Considered (S-6).

C1.5.1.6 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.

Table C1-2 Damage Control and Building Performance Levels

	Target Building Performance Levels			
	Collapse Prevention Level (5-E)	**Life Safety Level (3-C)**	**Immediate Occupancy Level (1-B)**	**Operational Level (1-A)**
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.	Less damage and lower risk.	Much less damage and lower risk.

Table C1-3 Structural Performance Levels and Damage[1, 2, 3]—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	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	5% transient or permanent	2.5% transient; 1% permanent	0.7% transient; negligible permanent
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% transient or permanent	1.5% transient; 0.5% permanent	0.5% transient; negligible permanent

Table C1-3 Structural Performance Levels and Damage[1, 2, 3]—Vertical Elements (continued)

		Structural Performance Levels		
Elements	**Type**	**Collapse Prevention S-5**	**Life Safety S-3**	**Immediate Occupancy S-1**
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 stress, 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% transient or permanent	1% transient; 0.5% permanent	0.5% transient; negligible permanent
Unreinforced Masonry Infill Walls	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.
	Secondary	Extensive crushing and shattering; some walls dislodge.	Same as primary.	Same as primary.
	Drift	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	1% transient or permanent	0.6% transient; 0.6% permanent	0.3% transient; 0.3% permanent

Table C1-3 Structural Performance Levels and Damage[1, 2, 3]—Vertical Elements (continued)

		Structural Performance Levels		
Elements	**Type**	**Collapse Prevention S-5**	**Life Safety S-3**	**Immediate Occupancy S-1**
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	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.
	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	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.

1. 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 post-earthquake evaluation of damage or for judging the safety of, or required level of repair to, a structure following an earthquake.

2. Drift values, differential settlements, crack widths, 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 this standard; rather, they are indicative of the range of drift that typical structures containing the indicated structural elements may undergo when responding within the various Structural 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.

Table C1-4 Structural Performance Levels and Damage[1, 2]—Horizontal Elements

	Structural Performance Levels		
Element	**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.

1. 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 post-earthquake evaluation of damage or for judging the safety of, or required level of repair to, a structure following an earthquake.
2. Drift values, differential settlements, crack widths, 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 this standard; rather, they are indicative of the range of drift that typical structures containing the indicated structural elements may undergo when responding within the various Structural 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.

1.5.2 Nonstructural Performance Levels

The Nonstructural Performance Level of a building shall be selected from five discrete Nonstructural Performance Levels, consisting of Operational (N-A), Immediate Occupancy (N-B), Life Safety (N-C), Hazards Reduced (N-D), and Not Considered (N-E). Design procedures and acceptance criteria for rehabilitation of nonstructural components shall comply with the requirements of Chapters 10 and 11.

C1.5.2 Nonstructural Performance Levels

Nonstructural Performance Levels other than Not Considered (N-E) are summarized in Table C1-5 through C1-7. Nonstructural components addressed in this standard 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 requirements.

1.5.2.1 Operational Nonstructural Performance Level (N-A)

Nonstructural Performance Level N-A, Operational, shall be defined as the post-earthquake damage state in which the nonstructural components are able to support the pre-earthquake functions present in the building.

C1.5.2.1 Operational Nonstructural Performance Level (N-A)

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 Nonstructural 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, it is often necessary to provide emergency standby utilities. It also 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 Nonstructural Performance Level are not included in this standard. Users wishing to design for this Nonstructural 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.

1.5.2.2 Immediate Occupancy Nonstructural Performance Level (N-B)

Nonstructural Performance Level N-B, Immediate Occupancy, shall be defined as the post-earthquake damage state that includes damage to nonstructural components, but building access and life safety systems—including doors, stairways, elevators, emergency lighting, fire alarms, and suppression systems—generally remain available and operable, provided that power is available.

C1.5.2.2 Immediate Occupancy Nonstructural Performance Level (N-B)

Minor window breakage and slight damage could occur to some components. Presuming that the building is structurally safe, 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 nonoperable. 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.

1.5.2.3 Life Safety Nonstructural Performance Level (N-C)

Nonstructural Performance Level N-C, Life Safety, shall be defined as the post-earthquake damage state that includes damage to nonstructural components but the damage is non-life threatening.

C1.5.2.3 Life Safety Nonstructural Performance Level (N-C)

Nonstructural Performance Level C, Life Safety, is the post-earthquake 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 inside or outside the building. Egress routes within the building are not extensively blocked, but may be 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, overall, the risk of life-threatening injury is very low. Restoration of the nonstructural components may take extensive effort.

1.5.2.4 Hazards Reduced Nonstructural Performance Level (N-D)

Nonstructural Performance Level N-D, Hazards Reduced, shall be defined as the post-earthquake damage state that includes damage to nonstructural components that could potentially create falling hazards, but high hazard nonstructural components identified in Table 11-1 are secured and will not fall into areas of public assembly. Preservation of egress, protection of fire suppression systems, and similar life-safety issues are not addressed in this Nonstructural Performance Level.

C1.5.2.4 Hazards Reduced Nonstructural Performance Level (N-D)

Nonstructural Performance Level D, Hazards Reduced, represents a post-earthquake damage state in which extensive damage has occurred to nonstructural components, but large or heavy items that pose a high risk of falling hazard to a large number of people—such as parapets, cladding panels, heavy plaster ceilings, or storage racks—are prevented from falling. The hazards associated with exterior elements along portions of the exterior of the building that are available for public occupancy have been reduced. 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.

Nonstructural components that are small, lightweight, or close to the ground may fall, but should not cause serious injury. Larger nonstructural components in areas that are less likely to be populated may also fall.

The intent of the Hazards Reduced Performance Level is to address significant nonstructural hazards without needing to rehabilitate all of the nonstructural components in a building. When using this performance level, it will generally be appropriate to consider Hazards Reduced Performance as equivalent to Life Safety Performance for the most hazardous, highest risk subset of the nonstructural components in the building.

1.5.2.5 Nonstructural Performance Not Considered (N-E)

A building rehabilitation that does not address nonstructural components shall be classified as Nonstructural Performance Not Considered (N-E).

C1.5.2.5 Nonstructural Performance Not Considered (N-E)

In some cases, the decision to rehabilitate the structure may be made 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. 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.

Table C1-5 Nonstructural Performance Levels and Damage[1]—Architectural Components

Component	Nonstructural Performance Levels			
	Hazards Reduced[2] N-D	**Life Safety N-C**	**Immediate Occupancy N-B**	**Operational N-A**
Cladding	Severe distortion in connections. Distributed cracking, bending, crushing, and spalling of cladding elements. Some fracturing of cladding, but panels do not fall in areas of public assembly.	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 in unoccupied areas. Extensive cracked glass; little broken glass in occupied areas.	Extensive cracked glass; little broken glass.	Some cracked panes; none broken.	Some cracked panes; none broken.
Partitions	Distributed damage; some severe cracking, crushing, and racking in some areas.	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	Extensive damage. Dropped suspended ceiling tiles. Moderate 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 & Ornamentation	Extensive damage; some falling in unoccupied areas.	Extensive damage; some falling in unoccupied areas.	Minor damage.	Minor damage.
Canopies & Marquees	Moderate damage.	Moderate damage.	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.
Doors	Distributed damage. Many racked and jammed doors.	Distributed damage. Some racked and jammed doors.	Minor damage. Doors operable.	Minor damage. Doors operable.

1. Damage states indicated in this table are provided to allow an understanding of the severity of damage that may be sustained by various nonstructural elements meeting the Nonstructural Performance Levels defined in this standard. These damage states are not intended for use in post-earthquake evaluation of damage or for judging the safety or required level of repair following an earthquake.

2. For the Hazards Reduced Performance Level, high hazard nonstructural components evaluated or rehabilitated to the Life Safety criteria will have Hazards Reduced performance identical to that expected for the Life Safety Performance Level.

Table C1-6 Nonstructural Performance Levels and Damage[1]—Mechanical, Electrical, and Plumbing Systems/Components

	Nonstructural Performance Levels			
System/Component	**Hazards Reduced[2] N-D**	**Life Safety N-C**	**Immediate Occupancy N-B**	**Operational N-A**
Elevators	Elevators out of service; counterweights 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.
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.
Ducts	Ducts break loose of equipment and louvers; some supports fail; some ducts fall.	Ducts break loose of equipment and louvers; some supports fail; some ducts 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	Some 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. May not function.	Ceiling mounted sensors damaged. May not function.	System is functional.	System is functional.
Emergency Lighting	Some lights fall. Power may not be available.	Some lights fall. Power may be available from emergency generator.	System is functional.	System is functional.
Electrical Distribution Equipment	Units slide and/or overturn, rupturing attached conduit. Uninterruptable 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.
Light Fixtures	Many broken light fixtures. Falling hazards generally avoided in heavier fixtures (>20 pounds) in areas of public assembly.	Many broken light fixtures. Falling hazards generally avoided in heavier fixtures (> 20 pounds).	Minor damage. Some pendant lights broken.	Negligible damage.

Table C1-6 Nonstructural Performance Levels and Damage[1]—Mechanical, Electrical, and Plumbing Systems/Components (continued)

	Nonstructural Performance Levels			
System/Component	**Hazards Reduced[2] N-D**	**Life Safety N-C**	**Immediate Occupancy N-B**	**Operational N-A**
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.

1. Damage states indicated in this table are provided to allow an understanding of the severity of damage that may be sustained by various nonstructural elements meeting the Nonstructural Performance Levels defined in this standard. These damage states are not intended for use in post-earthquake evaluation of damage or for judging the safety or required level of repair following an earthquake.
2. For the Hazards Reduced Performance Level, high hazard nonstructural components evaluated or rehabilitated to the Life Safety criteria will have Hazards Reduced performance identical to that expected for the Life Safety Performance Level.

Table C1-7 Nonstructural Performance Levels and Damage[1]—Contents

	Nonstructural Performance Levels			
Contents	**Hazards Reduced[2] 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. Power not available.	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.
Desktop Equipment	Some equipment slides 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.	Cabinets overturn and spill contents.	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	Minor damage; occasional materials spilled; gaseous materials contained.	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.

1. Damage states indicated in this table are provided to allow an understanding of the severity of damage that may be sustained by various nonstructural elements meeting the Nonstructural Performance Levels defined in this standard. These damage states are not intended for use in post-earthquake evaluation of damage or for judging the safety or required level of repair following an earthquake.
2. For the Hazards Reduced Performance Level, high hazard nonstructural components evaluated or rehabilitated to the Life Safety criteria will have Hazards Reduced performance identical to that expected for the Life Safety Performance Level.

1.5.3 Designation of Target Building Performance Levels

A target Building Performance Level shall be designated alphanumerically with a numeral representing the Structural Performance Level and a letter representing the Nonstructural Performance Level (e.g., 1-B, 3-C). If a Structural Performance Level other than Immediate Occupancy (S-1), Life Safety (S-3), or Collapse Prevention (S-5) is selected, the numerical designation shall represent the extent of structural damage expected in the selected Structural Performance Range.

C1.5.3 Designation of Target Building Performance Levels

Several common target Building Performance Levels described in this Section are shown in Figure C1-2. Many combinations are possible as structural performance can be selected at any level in the two Structural Performance Ranges. Table C1-8 indicates the possible combinations of target Building Performance Levels and provides names for those most likely to be selected as the basis for design.

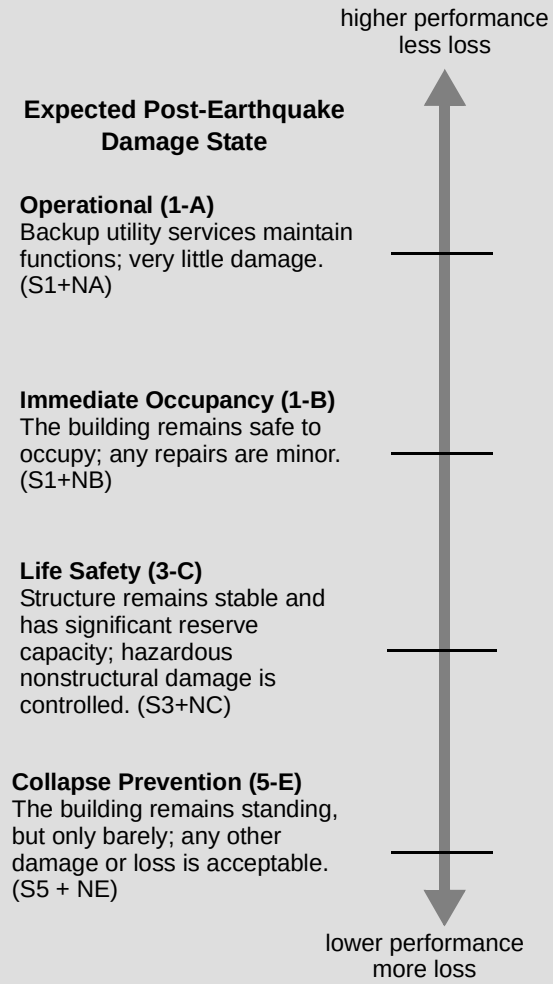

Figure C1-2 Target Building Performance Levels and Ranges

1.5.3.1 Operational Building Performance Level (1-A)

To attain the Operational Building Performance Level (1-A), the structural components of the building shall meet the requirements of Section 1.5.1.1 for the Immediate Occupancy Structural Performance Level (S-1) and the nonstructural components shall meet the requirements of Section 1.5.2.1 for the Operational Nonstructural Performance Level (N-A).

C1.5.3.1 Operational Building Performance Level (1-A)

Buildings meeting this target Building 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 non-essential systems not functioning. Buildings meeting this target Building 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 target Building Performance Level. Typically, however, it will not be economically practical to design for this target Building Performance Level for severe ground shaking, except for buildings that house essential services.

1.5.3.2 Immediate Occupancy Building Performance Level (1-B)

To attain the Immediate Occupancy Building Performance Level (1-B), the structural components of the building shall meet the requirements of Section 1.5.1.1 for the Immediate Occupancy Structural Performance Level (S-1) and the nonstructural components of the building shall meet the requirements of Section 1.5.2.2 for the Immediate Occupancy Nonstructural Performance Level (N-B).

C1.5.3.2 Immediate Occupancy Building Performance Level (1-B)

Buildings meeting this target Building 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 target Building Performance Level immediately following a major earthquake, nonstructural systems may not function, either because of the lack of electrical power or internal damage to equipment. Therefore, although immediate reoccupancy 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 can function in a normal mode. The risk to life safety at this target Building Performance Level is very low.

Many building owners may wish to achieve this level of performance when the building is subjected to moderate earthquake ground motion. In addition, some owners may desire such performance for very important buildings under severe earthquake ground shaking. This level provides most of the protection obtained under the Operational Building Performance Level without the cost of providing standby utilities and performing rigorous seismic qualification of equipment performance.

1.5.3.3 Life Safety Building Performance Level (3-C)

To attain the Life Safety Building Performance Level (3-C), the structural components of the building shall meet the requirements of Section 1.5.1.3 for the Life Safety Structural Performance Level (S-3) and the nonstructural components shall meet the requirements of Section 1.5.2.3 for the Life Safety Nonstructural Performance Level (N-C).

C1.5.3.3 Life Safety Building Performance Level (3-C)

Buildings meeting this level may experience extensive damage to structural and nonstructural components. Repairs may be required before reoccupancy of the building occurs, and repair may be deemed economically impractical. The risk to life safety in buildings meeting this target Building Performance Level is low.

This target Building 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 target Building Performance Level for severe ground shaking.

1.5.3.4 Collapse Prevention Building Performance Level (5-E)

To attain the Collapse Prevention Building Performance Level (5-E), the structural components of the building shall meet the requirements of Section 1.5.1.5 for the Collapse Prevention Structural Performance Level (S-5). Nonstructural components are not considered.

C1.5.3.4 Collapse Prevention Building Performance Level (5-E)

Buildings meeting this target Building 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 may well be avoided. Many buildings meeting this level will be complete economic losses.

This level has been sometimes 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.

Table C1-8 Target Building Performance Levels and Ranges

	Structural Performance Levels and Ranges					
Nonstructural Performance Levels	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

1.6 Seismic Hazard

Seismic hazard due to ground shaking shall be based on the location of the building with respect to causative faults, the regional and site-specific geologic characteristics, and a selected Earthquake Hazard Level. Assessment of seismic hazard due to earthquake-induced geologic site hazards shall be performed in accordance with Chapter 4.

Seismic hazard due to ground shaking shall be defined as acceleration response spectra or acceleration time-histories on either a probabilistic or deterministic basis. Acceleration response spectra shall be developed in accordance with either the General Procedure of Section 1.6.1 or the Site-Specific Procedure of Section 1.6.2. Acceleration time-histories shall be developed in accordance with Section 1.6.2.2. The seismic zone of the building shall be determined as specified in Section 1.6.3.

Unless otherwise approved, the site-specific procedure shall be used where any of the following conditions apply.

1. The building is located on Type E soils (as defined in Section 1.6.1.4) and the mapped BSE-2 spectral response acceleration at short periods (S_S) exceeds 2.0g.

2. The building is located on Type F soils as defined in Section 1.6.1.4.

   Exception: Where S_S determined in accordance with Section 1.6.1.1 is less than 0.20g, use of a Type E soil profile shall be permitted.

3. A time-history response analysis of the building will be performed as part of the design.

C1.6 Seismic Hazard

The analysis and design procedures of this standard are primarily aimed at improving performance of buildings under loads and deformations imposed by seismic shaking. However, other seismic hazards could exist at the building site that could damage the building regardless of its ability to resist ground shaking. These hazards include fault rupture, liquefaction or other shaking-induced soil failures, landslides, and inundation from offsite effects such as dam failure or tsunami.

This standard requires hazards due to earthquake shaking to be defined on either a probabilistic or deterministic basis. Probabilistic hazards are defined in terms of the probability that more severe demands will be experienced (probability of exceedance) in a 50-year period. Deterministic demands are defined within a level of confidence in terms of a specific magnitude event on a particular major active fault.

This standard defines two basic Earthquake Hazard Levels: Basic Safety Earthquake 1 (BSE-1) and Basic Safety Earthquake 2 (BSE-2).

In addition to the BSE-1 and BSE-2 Earthquake Hazard Levels, Rehabilitation Objectives may be formed considering ground shaking due to Earthquake Hazard Levels with any defined probability of exceedance, or based on any deterministic event on a specific fault.

1.6.1 General Procedure for Hazard Due to Ground Shaking

The seismic hazard due to ground shaking shall be defined for any Earthquake Hazard Level using approved spectral response acceleration contour maps of 5%-damped response spectrum ordinates for short-period (0.2 second) and long-period (1 second) response.

The short-period response acceleration parameter, S_S, and the long-period response acceleration parameter, S_1, shall be determined as follows:

1. If the desired Earthquake Hazard Level corresponds with one of the mapped Earthquake Hazard Levels, obtain spectral response acceleration parameters directly from the maps. Values between contour lines shall be interpolated in accordance with the procedure in Section 1.6.1.1.

2. If the desired Earthquake Hazard Level does not correspond with the mapped levels of hazard, then obtain the spectral response acceleration parameters from the available maps, and modify them to the desired hazard level, either by logarithmic interpolation or extrapolation, in accordance with Section 1.6.1.3.

3. Obtain design spectral response acceleration parameters by adjusting the mapped or modified spectral response acceleration parameters for site class effects, in accordance with Section 1.6.1.4.

4. If the desired Earthquake Hazard Level is the Basic Safety Earthquake 2 (BSE-2), obtain spectral response acceleration parameters in accordance with Section 1.6.1.1.

5. If the desired Earthquake Hazard Level is the Basic Safety Earthquake 1 (BSE-1), obtain the spectral response acceleration parameters in accordance with Section 1.6.1.2.

6. Using the design spectral response acceleration parameters that have been adjusted for site class effects, develop the general response spectrum in accordance with Section 1.6.1.5.

C1.6.1 General Procedure for Hazard Due to Ground Shaking

This standard uses the latest national earthquake hazard maps developed by the United States Geological Survey (USGS) as part of a joint effort with the Building Seismic Safety Council, known as Project 97. National probabilistic maps were developed for ground motions with a 10% chance of exceedance in 50 years, a 10% chance of exceedance in 100 years (which can also be expressed as a 5% chance of exceedance in 50 years) and a 10% chance of exceedance in 250 years (which also can be expressed as a 2% chance of exceedance in 50 years). These probabilities correspond to motions that are expected to occur, on average, about once every 500, 1,000, and 2,500 years. In addition, local ground motions in regions with well-defined earthquake sources, known as deterministic motions, were used to develop Maximum Considered Earthquake (MCE) maps.

The Rehabilitation Objective options featured in this standard allow consideration of any ground motion that may be of interest. However, for defining BSE-1 and BSE-2 Earthquake Hazard Levels, and for convenience in defining the ground motion for other Earthquake Hazard Levels, the 10%/50-year probabilistic maps and the MCE maps developed in Project 97 are referenced in this standard. This collection of maps, referred to as the National Earthquake Hazards Reduction Program (NEHRP) design map set (Maps 1 through 32), is available from the FEMA Distribution Center at 1-800-480-2520, online at http://geohazards.cr.usgs.gov/eq, or on CD-ROM from the USGS.

The MCE ground motion maps, were developed by the USGS in conjunction with the Seismic Design Procedure Group (SDPG) appointed by BSSC. The effort utilized the latest seismological information to develop design response acceleration parameters with the intent of providing a uniform margin against collapse in all areas of the United States. The MCE ground motion maps are based on seismic hazard maps, which are (1) 2%/50 year earthquake ground motion hazard maps for regions of the United States that have different ground motion attenuation relationships, and (2) deterministic ground motion maps in regions of high seismicity with the appropriate ground motion attenuation relationships for each region. The deterministic maps are used in regions of high seismicity where frequent large earthquakes are known to occur, and the rare earthquake ground motions corresponding to the 2%/50 year hazard are controlled by the large uncertainties in the hazard studies, which results in unusually high ground motions. These high ground motions were judged by the Seismic Design Procedure Group to be inappropriate for use in design. The use of these different maps to develop the MCE maps required the Seismic Design Procedure Group to define guidelines for integrating the maps into the design ground motion maps.

The most rigorous guideline developed was for integrating the probabilistic and the deterministic maps. To integrate the probabilistic maps and the deterministic map, a transition zone set at 150% of the level of the *1994 NEHRP Provisions* was used and is extensively discussed in the *1997 NEHRP Provisions* Commentary. The goal of this guideline was to not exceed the deterministic ground motion in these areas of high seismicity where earthquake faults and maximum magnitudes are relatively well defined. The remaining guidelines were more subjective, and were related to smoothing irregular contours, joining contours in areas where closely spaced contours of equal values occurred (particularly in areas where faults are known to exist, but the hazard parameters are not well defined), increasing the response acceleration parameters in small areas surrounded by higher parameters, etc.

Based on the process used to develop the MCE maps, there are some locations where the mapped acceleration response parameters in the MCE maps exceed the probabilistic 2%/50-years seismic hazard maps. These locations occur primarily in the New Madrid, Missouri, area; the Salt Lake City, Utah, area; coastal California; and the Seattle, Washington, area. This is an intended result of the process and the mapped values represent the appropriate values as determined by the Seismic Design Procedure Group.

This standard requires earthquake shaking demands to be expressed in terms of ground motion response spectra or suites of ground motion time histories, depending on the analysis procedure selected. While the maps provide a ready source for this type of information, this standard may be used with approved seismic hazard data from any source, as long as it is expressed as a response spectrum.

1.6.1.1 BSE-2 Response Acceleration Parameters

The design short-period response acceleration parameter, S_{XS}, and design response acceleration parameter at a one-second period, S_{X1}, for the BSE-2 Earthquake Hazard Level shall be determined using values of S_S and S_1 taken from approved MCE spectral response acceleration contour maps and modified for site class in accordance with Section 1.6.1.4.

Parameters S_S and S_1 shall be obtained by interpolating between the values shown on the map for the response acceleration contour lines on either side of the site, or by using the value shown on the map for the higher contour adjacent to the site.

C1.6.1.1 BSE-2 Response Acceleration Parameters

The latest MCE contour maps are contained in Maps 1 through 24 of the NEHRP design map set.

The BSE-2 Earthquake Hazard Level is consistent with MCE in *FEMA 302*. In most areas of the United States, the BSE-2 Earthquake Hazard Level has a 2% probability of exceedance in 50 years (2%/50 year). In regions close to known faults with significant slip rates and characteristic earthquakes with magnitudes in excess of about 6.0, the BSE-2 Earthquake Hazard Level is limited by a deterministic estimate of ground motion based on 150% of the median attenuation of the shaking likely to be experienced as a result of such a characteristic event. Ground shaking levels determined in this manner will typically correspond to a probability of exceedance greater than 2% in 50 years.

1.6.1.2 BSE-1 Response Acceleration Parameters

The design short-period response acceleration parameter, S_{XS}, and design response acceleration parameter at a one-second period, S_{X1}, for the BSE-1 Earthquake Hazard Level shall be taken as the smaller of the following:

1. The values of S_S and S_1 taken from approved 10%/50 year spectral response acceleration contour maps and modified for site class in accordance with Section 1.6.1.4. Values between contour lines shall be interpolated in accordance with the procedure in Section 1.6.1.1.

2. Two-thirds of the values of the parameters for the BSE-2 earthquake hazard level, determined in accordance with Section 1.6.1.1.

C1.6.1.2 BSE-1 Response Acceleration Parameters

The latest 10%/50 year contour maps are contained in Maps 25 through 30 of the NEHRP design map set. In determining BSE-1 parameters, the modification for site class shall be made prior to application of the two-thirds factor on BSE-2 parameters.

This standard has not directly adopted the concept of a design earthquake solely based on 2/3 of the MCE level as in *FEMA 302*. This design earthquake would have a different probability of exceedance throughout the nation, depending on the seismicity of the particular region, which would be inconsistent with the intent of this standard to permit design for specific levels of performance for hazards that have specific probabilities of exceedance. The BSE-1 Earthquake Hazard Level is similar, but not identical to the concept of the *FEMA 302* design earthquake. It is defined as ground shaking having a 10% probability of exceedance in 50 years (10%/50 year), but not exceeding values used for new buildings taken as 2/3 of the BSE-2 motion (i.e., 2/3 MCE).

1.6.1.3 Adjustment of Mapped Response Acceleration Parameters for Other Probabilities of Exceedance

Acceleration response spectra for earthquake hazard level corresponding to probabilities of exceedance other than 2%/50 years and 10%/50 years shall be determined using the following procedures specified in Sections 1.6.1.3.1 or 1.6.1.3.2.

1.6.1.3.1 Probabilities of Exceedance Between 2%/50 Years and 10%/50 Years

For probabilities of exceedance, P_{EY}, between 2%/50 years and 10%/50 years, when the mapped BSE-2 short-period response acceleration parameter, S_S, is less than 1.5g, the modified mapped short-period response acceleration parameter, S_S, and modified mapped response acceleration parameter at a one-second period, S_1, shall be determined from Equation (1-1):

$$1n(S_i) = 1n(S_{i10/50}) + [1n(S_{iBSE\text{-}2}) - 1n(S_{i10/50})] \; [0.606\ 1n(P_R) - 3.73] \qquad (1\text{-}1)$$

where:

$1n(S_i)$ = Natural logarithm of the spectral acceleration parameter ("i" = "s" for short-period or "i" = 1 for 1 second period) at the desired probability of exceedance

$1n(S_{i10/50})$ = Natural logarithm of the spectral acceleration parameter ("i" = "s" for short-period or "i" = 1 for 1 second period) at a 10%/50 year exceedance rate

$1n(S_{iBSE\text{-}2})$ = Natural logarithm of the spectral acceleration parameter ("i" = "s" for short-period or "i" = 1 for 1 second period) for the BSE-2 hazard level

$1n(P_R)$ = Natural logarithm of the mean return period corresponding to the exceedance probability of the desired earthquake hazard level

and the mean return period, P_R, at the desired exceedance probability shall be calculated from Equation (1-2):

$$P_R = \frac{-Y}{\ln(1 - P_{EY})} \tag{1-2}$$

where P_{EY} is the probability of exceedance (expressed as a decimal) in time Y (years) for the desired earthquake hazard level.

When the mapped BSE-2 short-period response acceleration parameter, S_S, is greater than or equal to 1.5g, the modified mapped short-period response acceleration parameter, S_S, and modified mapped response acceleration parameter at a one-second period, S_1, for probabilities of exceedance between 2%/50 years and 10%/50 years shall be determined from Equation (1-3):

$$S_i = S_{i10/50}\left(\frac{P_R}{475}\right)^n \tag{1-3}$$

where S_i, $S_{i10/50}$ and P_R are as defined above and n shall be obtained from Table 1-1.

C1.6.1.3.1 Probabilities of Exceedance Between 2%/50 Years and 10%/50 Years

Tables 1-1 through 1-3 specify five regions, three of which are not yet specifically defined, namely Intermountain, Central US, and Eastern US.

1.6.1.3.2 Probabilities of Exceedance Greater than 10%/50 Years

For probabilities of exceedance greater than 10%/50 years and when the mapped short-period response acceleration parameter, S_S, is less than 1.5g, the modified mapped short-period response acceleration parameter, S_S, and modified mapped response acceleration parameter at a one-second period, S_1, shall be determined from Equation (1-3), where the exponent n is obtained from Table 1-2.

For probabilities of exceedance greater than 10%/50 years and when the mapped short-period response acceleration parameter, S_S, is greater than or equal to 1.5g, the modified mapped short-period response acceleration parameter, S_S, and modified mapped response acceleration parameter at a one-second period, S_1, shall be determined from Equation (1-3), where the exponent n is obtained from Table 1-3.

1.6.1.4 Adjustment for Site Class

The design short-period spectral response acceleration parameter, S_{XS}, and the design spectral response acceleration parameter at one-second, S_{X1}, shall be obtained from Equations (1-4) and (1-5), respectively, as follows:

$$S_{XS} = F_a S_S \tag{1-4}$$

$$S_{X1} = F_v S_1 \tag{1-5}$$

where F_a and F_v are site coefficients determined respectively from Tables 1-4 and 1-5, based on the site class and the values of the response acceleration parameters S_S and S_1 for the selected return period.

1.6.1.4.1 Site Classes

Site classes shall be defined as follows:

1. **Class A:** Hard rock with average shear wave velocity, $\overline{v_s}$ > 5,000 ft/sec

2. **Class B:** Rock with 2,500 ft/sec < $\overline{v_s}$ < 5,000 ft/sec

3. **Class C:** Very dense soil and soft rock with 1,200 ft/sec < $\overline{v_s}$ ≤ 2,500 ft/sec or with either standard blow count $\overline{N}$ > 50 or undrained shear strength $\overline{s_u}$ > 2,000 psf

4. **Class D:** Stiff soil with 600 ft/sec < $\overline{v_s}$ ≤ 1,200 ft/sec or with 15 < $\overline{N}$ ≤ 50 or 1,000 psf ≤ $\overline{s_u}$ < 2,000 psf

5. **Class E:** Any profile with more than 10 feet of soft clay defined as soil with plasticity index *PI* > 20, or water content w > 40 percent, and $\overline{s_u}$ < 500 psf or a soil profile with $\overline{v_s}$ < 600 ft/sec.

6. **Class F:** Soils requiring site-specific evaluations:

   6.1. Soils vulnerable to potential failure or collapse under seismic loading, such as liquefiable soils, quick and highly-sensitive clays, collapsible weakly-cemented soils

   6.2. Peats and/or highly organic clays (H > 10 feet of peat and/or highly organic clay, where H = thickness of soil)

   6.3. Very high plasticity clays (H > 25 feet with PI > 75)

   6.4. Very thick soft/medium stiff clays (H > 120 feet).

The parameters $\overline{v_s}$, $\overline{N}$, and $\overline{s_u}$ are, respectively, the average values of the shear wave velocity, Standard Penetration Test (SPT) blow count, and undrained shear strength of the upper 100 feet of soils at the site. These values shall be calculated from Equation (1-6), below:

$$\overline{v_s}, \overline{N}, \overline{s_u} = \frac{\sum_{i=1}^{n} d_i}{\sum_{n} \frac{d_i}{v_{si}}, \frac{d_i}{N_i}, \frac{d_i}{s_{ui}}} \qquad (1\text{-}6)$$

where:

N_i = SPT blow count in soil layer "i"

n = Number of layers of similar soil materials for which data is available

d_i = Depth of layer "i"

s_{ui} = Undrained shear strength in layer "i"

v_{si} = Shear wave velocity of the soil in layer "i"

and

$$\sum_{i=1}^{n} d_i = 100\ ft \qquad (1\text{-}7)$$

Where v_s data are available for the site, such data shall be used to classify the site. If such data are not available, *N* data shall be used for cohesionless soil sites (sands, gravels), and s_u data for cohesive soil sites (clays). For rock in profile classes B and C, classification shall be based either on measured or estimated values of v_s. Classification of a site as Class A rock shall be based on measurements of v_s either for material at the site itself, or for rock having the same formation adjacent to the site; otherwise, Class B rock shall be assumed. Class A or B profiles shall not be assumed to be present if there is more than 10 feet of soil between the rock surface and the base of the building.

1.6.1.4.2 Default Site Class

If there is insufficient data available to classify a soil profile as Class A through C, and there is no evidence of soft clay soils characteristic of Class E in the vicinity of the site, the default site class shall be taken as Class D. If there is evidence of Class E soils in the vicinity of the site, and no other data supporting selection of Class A through D, the default site class shall be taken as Class E.

1.6.1.5 General Response Spectrum

A general response spectrum shall be developed as specified in Sections 1.6.1.5.1 through 1.6.1.5.3.

1.6.1.5.1 General Horizontal Response Spectrum

A general horizontal response spectrum as shown in Figure 1-1 shall be developed using Equations (1-8), (1-9), and (1-10) for spectral response acceleration, S_a, versus structural period, T, in the horizontal direction.

$$S_a = S_{XS}\left[\left(\frac{5}{B_S} - 2\right)\frac{T}{T_S} + 0.4\right] \quad (1\text{-}8)$$

for $0 < T < T_0$, and

$$S_a = S_{XS}/B_S \text{ for } (T < T_S)\text{, and} \quad (1\text{-}9)$$

$$S_a = (S_{X1}/(B_1 T)) \text{ for } T > T_S \quad (1\text{-}10)$$

where T_S and T_0 are given by Equations (1-11) and (1-12)

$$T_S = (S_{X1}B_S)/(S_{XS}B_1) \quad (1\text{-}11)$$

$$T_0 = 0.2T_S \quad (1\text{-}12)$$

and where B_S and B_1 shall be taken from Table 1-6.

Use of spectral response accelerations calculated using Equation (1-8) in the extreme short period range ($T < T_0$) shall only be permitted in dynamic analysis procedures and only for modes other than the fundamental mode.

1.6.1.5.2 General Vertical Response Spectrum

Where a vertical response spectrum is required, it shall be developed by taking two-thirds of the spectral ordinates, at each period, obtained for the horizontal response spectrum.

1.6.1.5.3 Damping Ratios

A 5% damped response spectrum shall be used for the rehabilitation design of all buildings and structural systems except those meeting the following criteria:

1. For structures without exterior cladding, an effective viscous damping ratio, β, equal to 2% of critical damping shall be assumed.

2. For structures with wood diaphragms and interior partitions and cross walls that interconnect the diaphragm levels at a maximum spacing of 40 feet on center transverse to the direction of motion, an effective viscous damping ratio, β, equal to 10% of critical damping shall be permitted.

3. For structures rehabilitated using seismic isolation technology or enhanced energy dissipation technology, an equivalent effective viscous damping ratio, β, shall be calculated using the procedures specified in Chapter 9.

Table 1-1 Values of Exponent* n *for Determination of Response Acceleration Parameters at Earthquake Hazard Levels between 10%/50 years and 2%/50 years; Sites where Mapped BSE-2 Values of S_S ≥1.5g

	Values of Exponent *n* for	
Region	S_S	S_1
California	0.29	0.29
Pacific Northwest	0.56	0.67
Intermountain	0.50	0.60
Central US	0.98	1.09
Eastern US	0.93	1.05

Table 1-2 ***Values of Exponent* n *for Determination of Response Acceleration Parameters at Probabilities of Exceedance Greater than 10%/50 years; Sites where Mapped BSE-2 Values of S_S < 1.5g***

Region	Values of Exponent *n* for S_S	S_1
California	0.44	0.44
Pacific Northwest and Intermountain	0.54	0.59
Central and Eastern US	0.77	0.80

Table 1-3 ***Values of Exponent* n *for Determination of Response Acceleration Parameters at Probabilities of Exceedance Greater than 10%/50 years; Sites where Mapped BSE-2 Values of S_S ≥1.5g***

Region	Values of Exponent *n* for S_S	S_1
California	0.44	0.44
Pacific Northwest	0.89	0.96
Intermountain	0.54	0.59
Central US	0.89	0.89
Eastern US	1.25	1.25

Table 1-4 ***Values of F_a as a Function of Site Class and Mapped Short-Period Spectral Response Acceleration S_S***

Site Class	Mapped Spectral Acceleration at Short-Periods S_S				
	S_S ≤ 0.25	S_S = 0.50	S_S = 0.75	S_S = 1.00	S_S ≥ 1.25
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	*	*	*	*	*

NOTE: Straight-line interpolation shall be used for intermediate values of S_S.

* Site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Table 1-5 ***Values of F_v as a Function of Site Class and Mapped Spectral Response Acceleration at One-Second Period S_1***

Site Class	Mapped Spectral Acceleration at One-Second Period S_1				
	S_1 ≤ 0.1	S_1 = 0.2	S_1 = 0.3	S_1 = 0.4	S_1 ≥ 0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	*	*	*	*	*

NOTE: Straight-line interpolation shall be used for intermediate values of S_1.

* Site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Table 1-6 Damping Coefficients B_S and B_1 as a Function of Effective Damping β

Effective Viscous Damping β (percentage of critical damping)[1]	B_S	B_1
≤ 2	0.8	0.8
5	1.0	1.0
10	1.3	1.2
20	1.8	1.5
30	2.3	1.7
40	2.7	1.9
≥ 50	3.0	2.0

1. Damping coefficients shall be based on linear interpolation for effective viscous damping values other than those given.

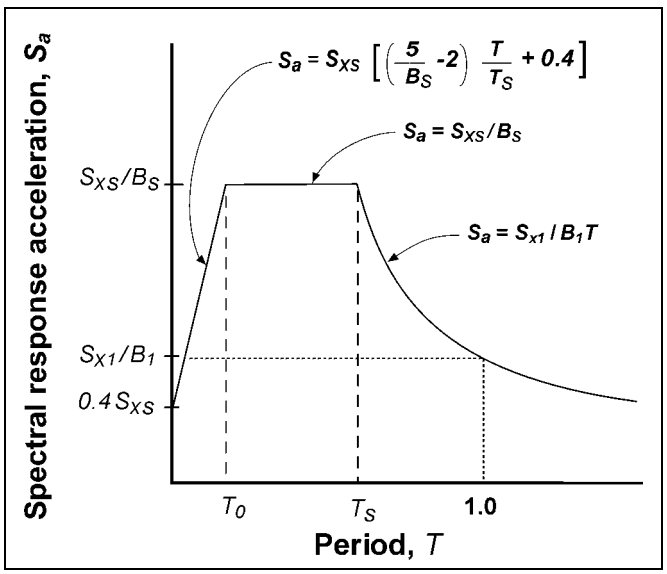

Figure 1-1 General Horizontal Response Spectrum

1.6.2 Site-Specific Procedure for Hazard Due to Ground Shaking

Where site-specific ground shaking characterization is selected or required by the code official as the basis of rehabilitation design, the characterization shall be developed in accordance with this section.

1.6.2.1 Site-Specific Response Spectra

Development of site-specific response spectra shall be based on the geologic, seismologic, and soil characteristics associated with the specific site and as specified in Sections 1.6.2.1.1 through 1.6.2.1.4.

1.6.2.1.1 Damping Ratios

Response spectra shall be developed for an effective viscous damping ratio of 5% of critical damping and for other damping ratios appropriate to the indicated structural behavior, as discussed in Section 1.6.1.5.

1.6.2.1.2 Minimum Spectral Amplitude

The 5% damped site-specific spectral amplitudes in the period range of greatest significance to the structural response shall not be specified less than 70 percent of the spectral amplitudes of the General Response Spectrum.

1.6.2.1.3 Basis of the Response Spectra

Probabilistic site-specific spectra that represent the BSE-1 Earthquake Hazard Level shall be mean spectra at the 10%/50 year probability of exceedance. Probabilistic site-specific spectra that represent the BSE-2 Earthquake Hazard Level shall be mean spectra at the 2%/50 year probability of exceedance. Deterministic BSE-2 site-specific spectra shall be taken as 150% of the median spectra for the characteristic event on the controlling fault.

1.6.2.1.4 Site-Specific Response Acceleration Parameters and Construction of Response Spectra

The design response acceleration parameters, S_{XS}, S_{X1}, and T_S shall be obtained using the site-specific response spectra in accordance with this section. Values of the design response acceleration parameter at short-periods, S_{XS}, shall be taken as the response acceleration obtained from the site-specific spectra at a period of 0.2 seconds, except that it shall not be taken as less than 90% of the peak response acceleration at any period. In order to obtain values for the design spectral response acceleration parameter S_{X1}, a curve of the form $S_a = S_{X1}/T$ shall be graphically overlaid on the site-specific spectra such that at any period, the value of S_a obtained from the curve is not less than 90% of that which would be obtained directly from the spectra. The value of T_S shall be determined in accordance with Equation (1-13).

$$T_S = S_{X1}/S_{XS} \qquad (1\text{-}13)$$

1.6.2.1.5 Site-Specific BSE-2 Response Acceleration Parameters

The site-specific response acceleration parameters for the BSE-2 Earthquake Hazard Level shall be taken as the smaller of the following:

1. The values of the parameters from mean probabilistic site-specific spectra at the 2%/50 year probability of exceedance.

2. The values of the parameters from 150% of median deterministic site-specific spectra.

1.6.2.1.6 Site-Specific BSE-1 Response Acceleration Parameters

The site-specific response acceleration parameters for the BSE-1 Earthquake Hazard Level shall be taken as the smaller of the following:

1. The values of the parameters from mean probabilistic site-specific spectra at the 10%/50 year probability of exceedance.

2. Two-thirds of the values of the parameters determined for the BSE-2 Earthquake Hazard Level.

C1.6.2.1 Procedure for Site-Specific Response Spectrum

The code official should consider an independent third-party review of the site-specific spectra by an individual with expertise in the evaluation of ground motion.

1.6.2.2 Acceleration Time Histories

Time history analysis shall be performed with no fewer than three data sets (each containing two horizontal components or, if vertical motion is to be considered, two horizontal components and one vertical component) of ground motion time histories that shall be selected and scaled from no fewer than three recorded events. Time histories shall have magnitude, fault distances, and source mechanisms that are equivalent to those that control the design earthquake ground motion. Where three recorded ground-motion time history data sets having these characteristics are not available, simulated time history data sets having equivalent duration and spectral content shall be used to make up the total number required. For each data set, the square root of the sum of the squares (SRSS) of the 5%-damped site-specific spectrum of the scaled horizontal components shall be constructed. The data sets shall be scaled such that the average value of the SRSS spectra does not fall below 1.4 times the 5%-damped spectrum for the design earthquake for periods between $0.2T$ seconds and $1.5T$ seconds (where T is the fundamental period of the building).

Where three time history data sets are used in the analysis of a structure, the maximum value of each response parameter (e.g., force in a member, displacement at a specific level) shall be used to determine design acceptability. Where seven or more time history data sets are employed, the average value of each response parameter shall be permitted to determine design acceptability.

1.6.3 Zones of Seismicity

The zone of seismicity shall be defined as High, Moderate, or Low as specified in Sections 1.6.3.1, 1.6.3.2, and 1.6.3.3, respectively.

1.6.3.1 Zones of High Seismicity

Buildings shall be considered to be located within zones of high seismicity where the 10%/50 year, design short-period response acceleration, S_{XS}, and the 10%/50 year design one-second period response acceleration, S_{X1}, are as specified in Equation (1-14):

$$S_{XS} \geq 0.5\text{g} \quad \text{and} \quad S_{X1} \geq 0.2\text{g} \tag{1-14}$$

1.6.3.2 Zones of Moderate Seismicity

Buildings shall be considered to be located within zones of moderate seismicity where the 10%/50 year, design short-period response acceleration, S_{XS}, and the 10%/50 year, design one-second period response acceleration, S_{X1}, are as specified in Equation (1-15):

$$0.167 \leq S_{XS} < 0.5\text{g} \quad \text{or}$$
$$0.067 \leq S_{X1} < 0.2\text{g} \qquad (1\text{-}15)$$

1.6.3.3 Zones of Low Seismicity

Buildings shall be considered to be located within zones of low seismicity where the 10%/50 year, design short-period response acceleration, S_{XS}, and the 10%/50 year, design one-second period response acceleration, S_{X1}, are as specified in Equation (1-16):

$$S_{XS} < 0.167\text{g} \quad \text{and}$$
$$S_{X1} < 0.067\text{g} \qquad (1\text{-}16)$$