2. General Requirements (Simplified and Systematic Rehabilitation)

2.1 Scope

This chapter presents the *Guidelines'* general requirements for rehabilitating existing buildings. The framework in which these requirements are specified is purposefully broad in order to accommodate buildings of many different types, satisfy a broad range of performance levels, and include consideration of the variety of seismic hazards throughout the United States and Territories.

Criteria for the following general issues regarding the seismic rehabilitation of buildings are included in this chapter:

- **Rehabilitation Objectives:** Selection of desired performance levels for given earthquake severity levels
  - **Performance Levels:** Definition of the expected behavior of the building in the design earthquake(s) in terms of limiting levels of damage to the structural and nonstructural components
  - **Seismic Hazard:** Determination of the design ground shaking and other site hazards, such as landsliding, liquefaction, or settlement
- **As-Built Characteristics:** Determination of the basic construction characteristics and earthquake resistive capacity of the existing building
- **Rehabilitation Methods:** Selection of the Simplified or Systematic Method
- **Rehabilitation Strategies:** Selection of a basic strategy for rehabilitation, e.g., providing additional lateral-load-carrying elements, seismic isolation, or reducing the mass of the building
- **Analysis and Design Procedures:** For Systematic Rehabilitation approaches, selection among Linear Static, Linear Dynamic, Nonlinear Static, or Nonlinear Dynamic Procedures
- **General Analysis and Design:** Specification of the force and deformation actions for which given components of a building must be evaluated, and minimum design criteria for interconnection of structural components
- **Building Interaction:** Guidelines for buildings that share elements with neighboring structures, and buildings with performance affected by the presence of adjacent structures
- **Quality Assurance:** Guidelines for ensuring that the design intent is appropriately implemented in the construction process
- **Alternative Materials and Methods:** Guidelines for evaluating and designing structural components not specifically covered by other sections of the *Guidelines*

2.2 Basic Approach

The basic approach for seismic rehabilitation design includes the steps indicated below. Note that these steps are presented here in the order in which they would typically be followed in the rehabilitation process. However, the guidelines for actually performing these steps are presented in a somewhat different order, to facilitate presentation of the concepts.

- Obtain as-built information on the building and determine its characteristics, including whether the building has historic status (Section 2.7).
- Select a Rehabilitation Objective for the building (Section 2.4).
- Select an appropriate Rehabilitation Method (Section 2.8).
- If a Simplified Method is applicable, follow the procedures of Chapter 10; or,
- If a Systematic Method is to be followed:
  - Select a Rehabilitation Strategy (Section 2.10) and perform a preliminary design of corrective measures.
  - Select an appropriate Analysis Procedure (Section 2.9).

- Perform an analysis of the building, including the corrective measures, to verify its adequacy to meet the selected Rehabilitation Objective (Chapter 3).
- If the design is inadequate, revise the corrective measures or try an alternative strategy and repeat the analysis until an acceptable design solution is obtained.

Prior to embarking on a rehabilitation program, an evaluation should be performed to determine whether the building, in its existing condition, has the desired level of seismic resistance. FEMA 178 (BSSC, 1992) is an example of an evaluation methodology that may be used for this purpose. However, FEMA 178 currently does not address objectives other than the Life Safety Performance Level for earthquakes with a 10% probability of exceedance in 50 years (10%/50 year), whereas these *Guidelines* may be used for other performance levels and ground shaking criteria. FEMA 178 is being revised to include the Damage Control Performance Range.

Table 2-1 gives an overview of guidelines and criteria included in this chapter and their relation to guidelines and criteria in other chapters of the *Guidelines*.

2.3 Design Basis

The *Guidelines* are intended to provide a nationally applicable approach for the seismic rehabilitation of buildings. It is expected that most buildings rehabilitated in accordance with the *Guidelines* would perform within the desired levels when subjected to the design earthquakes. However, compliance with the *Guidelines* 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 the *Guidelines* are specifically applicable to the rehabilitation of existing buildings and are, in general, more appropriate for that purpose than are building codes for the seismic design of new buildings. 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 to 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.

A Rehabilitation Objective must be selected as the basis for a rehabilitation design in order to use the provisions of these *Guidelines*. Each Rehabilitation Objective consists of one or more specifications of a seismic demand (hazard level) and corresponding damage state (building performance level). The *Guidelines* present a Basic Safety Objective (BSO), which has performance and hazard levels consistent with seismic risk traditionally considered acceptable in the United States. Alternative objectives that provide lower levels (Limited Objectives) and higher levels (Enhanced Objectives) of performance are also described in the *Guidelines*.

Each structural component and element of the building, including its foundations, shall be classified as either primary or secondary. In a typical building, nearly all elements, including many nonstructural components, will contribute to the building's overall stiffness, mass, and damping, and consequently its response to earthquake ground motion. However, not all of these elements are critical to the ability of the structure to resist collapse when subjected to strong ground shaking. For example, exterior cladding and interior partitions can add substantial initial stiffness to a structure, yet this stiffness is not typically considered in the design of new buildings for lateral force resistance because the lateral strength of these elements is often small. Similarly, the interaction of floor framing systems and columns in shear wall buildings can add some stiffness, although designers typically neglect such stiffness when proportioning the building's shear walls. In the procedures contained in these *Guidelines*, the behavior of all elements and components that participate in the building's lateral response is considered, even if they are not normally considered as part of the lateral-force-resisting system. This is to allow evaluation of the extent of damage likely to be experienced by each of these elements. The concept of primary and secondary elements permits the engineer to differentiate between the performance required of elements that are critical to the building's ability to resist collapse and of those that are not.

Table 2-1 Guidelines and Criteria in Chapter 2 and Relation to Guidelines and Criteria in Other Chapters

	Chapter 2 Criteria Section		Detailed Implementation Criteria in Other Chapters	
Action	**Section**	**Information Presented**	**Chapter(s)**	**Information Presented**
Select Rehabilitation Objective	Section 2.4	Detailed Guidelines		
Select Performance Level	Section 2.5	Detailed Guidelines		
Select Shaking Hazard	Section 2.6	Detailed Criteria		
Evaluate Other Seismic Hazards	Section 2.6	General Discussion	Chapter 4	Evaluation and Mitigation Methods
Obtain As-Built Information, Including Historic Status	Section 2.7	Detailed Criteria	Chapters 4–8 and 11	Material Property Guidelines Testing Guidelines
Select Rehabilitation Method	Section 2.8	Rehabilitation Methods		
Simplified			Chapters 10 and 11	Detailed Guidelines
Systematic	Section 2.11	General Analysis and Design Criteria	Chapters 3–9 and 11	Implementation of Systematic Method
Select Analysis Procedure	Section 2.9	Detailed Criteria		
Select Rehabilitation Strategy	Section 2.10	Detailed Guidelines		
Create Mathematical Model	Section 2.11	General Analysis and Design Criteria	Chapter 3 Chapters 4–9 and 11	Detailed Requirements Stiffness and Strength of Components
Perform Force and Deformation Evaluation	Section 2.11	General Analysis and Design Criteria	Chapter 3	Detailed Criteria
Apply Component Acceptance Criteria	Section 2.9	General Criteria	Chapter 3 Chapters 4–9 and 11	Detailed Criteria Component Strength and Deformation Criteria
Apply Quality Assurance	Section 2.12	Detailed Criteria		
Use Alternative Materials and Methods of Construction	Section 2.13	Detailed Criteria		

- The primary elements and components are those that provide the structure's overall ability to resist collapse under earthquake-induced ground motion. Although damage to these elements, and some degradation of their strength and stiffness, may be permitted to occur, the overall function of these elements in resisting structural collapse should not be compromised.
- Other elements and components of the existing building are designated as secondary. For some structural performance levels, substantial degradation of the lateral-force-resisting stiffness and strength of secondary elements and components is permissible, as this will not inhibit the entire building's capacity to withstand the design ground motions. However, the ability of these secondary elements and components to support gravity loads, under the maximum deformations that the design earthquake(s) would induce in the building, must be preserved.

For a given performance level, acceptance criteria for primary elements and components will typically be more restrictive (i.e., less damage is permissible) than those for secondary elements and components.

In order to comply with the BSO or any Enhanced Rehabilitation Objective, the rehabilitated building shall be provided with a continuous load path, or paths, with adequate strength and stiffness to transfer seismically induced forces caused by ground motion in any direction, from the point of application to the final point of resistance. It shall be demonstrated that all primary and secondary elements of the structure are capable of resisting the forces and deformations corresponding to the earthquake hazards within the acceptance criteria contained in the *Guidelines* for the applicable performance levels. Nonstructural components and building contents shall also be adequately anchored or braced to the structure to control damage as required by the acceptance criteria for the applicable performance level.

2.4 Rehabilitation Objectives

As stated earlier, a Rehabilitation Objective shall be selected as the basis for design. Rehabilitation Objectives are statements of the desired building performance (see Section 2.5) when the building is subjected to earthquake demands of specified severity (see Section 2.6).

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 sustained by the building.

In these *Guidelines*, the extent of damage to a building is categorized as a Building Performance Level. A broad range of Building Performance Levels may be selected when determining Rehabilitation Objectives. Each Building Performance Level consists of a Structural Performance Level, which defines the permissible damage to structural systems, and a Nonstructural Performance Level, which defines the permissible damage to nonstructural building components and contents.

Section 2.5.1 defines a series of three discrete Structural Performance Levels that may be used in constructing project Rehabilitation Objectives. These are Immediate Occupancy (S-1), Life Safety (S-3), and Collapse Prevention (S-5). Two Structural Performance Ranges are defined to allow design for structural damage states intermediate to those represented by the discrete performance levels. These are Damage Control (S-2) and Limited Safety (S-4). In addition, there is the designation of S-6, Structural Performance Not Considered, to cover the situation where only nonstructural improvements are made.

Section 2.5.2 defines a series of three discrete Nonstructural Performance Levels. These are: Operational Performance Level (N-A), Immediate Occupancy Performance Level (N-B), and Life Safety Performance Level (N-C). There is also a Hazards Reduced Performance Range (N-D) and a fifth level or category (N-E) in which nonstructural damage is not limited.

Section 2.5.3 indicates how Structural and Nonstructural Performance Levels may be combined to form designations for Building Performance Levels. Numerals indicate the Structural Performance Level and letters the Nonstructural Performance Level. Four Performance Levels commonly used in the formation of Building Rehabilitation Objectives are described; these are the Operational Performance Level (1-A), Immediate Performance Occupancy Level (1-B), Life Safety Performance Level (3-C), and Collapse Prevention Performance Level (5-E).

Section 2.6, Seismic Hazard, presents methods for determining earthquake shaking demands and considering other seismic hazards, such as liquefaction and landsliding. Earthquake shaking demands are expressed in terms of ground motion response spectra, discrete parameters that define these spectra, or suites of ground motion time histories, depending on the analysis procedure selected. For sites with significant potential for ground failure, demands should also be expressed in terms of the anticipated permanent differential ground deformations.

Earthquake demands are a function of the location of the building with respect to causative faults, the regional and site-specific geologic characteristics, and the ground motion hazard level(s) selected in the Rehabilitation Objective. In the *Guidelines*, hazard levels may 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 fault, which is most appropriate for buildings located within a few miles of a major active fault. Probabilistic hazard levels frequently used in these *Guidelines* 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 *Guidelines* make frequent reference to two levels of earthquake hazard that are particularly useful for the formation of Rehabilitation Objectives. These are defined in terms of both probabilistic and deterministic approaches. They are termed a Basic Safety Earthquake 1 (BSE-1) and Basic Safety Earthquake 2 (BSE-2). The BSE-1 and BSE-2 earthquakes are typically taken as 10%/50 and 2%/50 year events, respectively, except in regions near major active faults. In these regions the BSE-1 and BSE-2 may be defined based on deterministic estimates of earthquakes on these faults. More detailed discussion of ground motion hazards is presented in Section 2.6.

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 2-2 presents a matrix indicating the broad range of Rehabilitation Objectives that may be used in these *Guidelines*. (See Section 2.5.3 for definitions of Building Performance Levels.) Each cell in this matrix represents a single Rehabilitation Objective. The goal of a rehabilitation project may be to satisfy a single Rehabilitation Objective—for example, Life Safety for the BSE-1 earthquake—or multiple Rehabilitation Objectives—for example, Life Safety for the BSE-1 earthquake, Collapse Prevention for the BSE-2 earthquake, and Immediate Occupancy for an earthquake with a 50% probability of exceedance in 50 years. A specific

analytical evaluation should be performed to confirm that a rehabilitation design is capable of meeting each desired Rehabilitation Objective selected as a goal for the project.

Table 2-2 Rehabilitation Objectives

		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

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

2.4.1 Basic Safety Objective

A desirable goal for rehabilitation is to achieve the Basic Safety Objective (BSO). In order to achieve this objective, building rehabilitation must be designed to achieve both the Life Safety Performance Level (3-C) for BSE-1 earthquake demands and the Collapse Prevention Level (5-E) for BSE-2 earthquake demands. Buildings that have been properly designed and constructed in conformance with the latest edition of the *National Building Code* (BOCA, 1993), *Standard Building Code* (SBCC, 1994), or *Uniform Building*

Code (ICBO, 1994), including all applicable seismic provisions of those codes, may be deemed by code enforcement agencies to meet the BSO.

Building rehabilitation programs designed to the BSO are intended to provide a low risk of danger for any earthquake likely to affect the site. This approximately represents the earthquake risk to life safety traditionally considered acceptable in the United States. Buildings meeting the BSO are expected to experience little damage from the relatively frequent, moderate earthquakes that may occur, but significantly more damage from the most severe and infrequent earthquakes that could affect them.

The level of damage to buildings rehabilitated to the BSO may be greater than that expected in properly designed and constructed new buildings.

When it is desired that a building be able to resist earthquakes with less damage than implied by the BSO, rehabilitation may be designed to one or more of the Enhanced Rehabilitation Objectives of Section 2.4.2.

2.4.2 Enhanced Rehabilitation Objectives

Any Rehabilitation Objective intended to provide performance superior to that of the BSO is termed an Enhanced Objective. An Enhanced Objective must provide better than BSO-designated performance at either the BSE-1 or BSE-2, or both. Enhanced performance can be obtained in two ways:

- Directly, by design for the BSE-1 or BSE-2 earthquakes. Examples include designing for a higher Performance Level than Life Safety for the BSE-1 or a higher Performance Level than Collapse Prevention for the BSE-2.

- Indirectly, by having the design controlled by some other selected Performance Level and hazard that will provide better than BSO performance at the BSE-1 or BSE-2. For example, if providing Immediate Occupancy for a 50%/50 year event controlled the rehabilitation acceptability criteria in such a way that deformation demand were less than that allowed by the BSO, the design would be considered to have an Enhanced Objective.

The *Guidelines* do not incorporate Enhanced Rehabilitation Objectives in any formal procedure, but the definition is included to facilitate discussion of the concept of variable Performance Levels both in the *Guidelines* and the *Commentary*.

2.4.3 Limited Rehabilitation Objectives

Any Rehabilitation Objective intended to provide performance inferior to that of the BSO is termed a Limited Objective. A Limited Objective may consist of either Partial Rehabilitation (Section 2.4.3.1) or Reduced Rehabilitation (Section 2.4.3.2). Limited Rehabilitation Objectives should be permissible if the following conditions are met:

- The rehabilitation measures do not create a structural irregularity or make an existing structural irregularity more severe;

- The rehabilitation measures do not result in a reduction in the capability of the structure to resist lateral forces or deformations;

- The rehabilitation measures do not result in an increase in the seismic forces to any component that does not have adequate capacity to resist these forces, unless this component's behavior is still acceptable considering overall structural performance;

- All new or rehabilitated structural elements are detailed and connected to the existing structure, as required by the *Guidelines*;

- An unsafe condition is not created or made more severe by the rehabilitation measures; and

- Locally adopted and enforced building regulations do not preclude such rehabilitation.

2.4.3.1 Partial Rehabilitation

Any rehabilitation program that does not fully address the lateral-force-resisting capacity of the complete structure is termed Partial Rehabilitation. The portion of the structure that is addressed in Partial Rehabilitation should be designed for a target Rehabilitation Objective and planned so that additional rehabilitation could be performed later to meet fully that objective.

2.4.3.2 Reduced Rehabilitation

Reduced Rehabilitation programs address the entire building's lateral-force-resisting capacity, but not at the levels required for the BSO. Reduced Rehabilitation may be designed for one or more of the following objectives:

- Life Safety Performance Level (3-C) for earthquake demands that are less severe (more probable) than the BSE-1
- Collapse Prevention Performance Level (5-E) for earthquake demands that are less severe (more probable) than the BSE-2
- 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

2.5 Performance Levels

Building performance is a combination of the performance of both structural and nonstructural components. Table 2-3 describes the overall levels of structural and nonstructural damage that may be expected of buildings rehabilitated to the levels defined in the *Guidelines*. For comparative purposes, the estimated performance of a new building subjected to the BSE-1 level of shaking is indicated. These performance descriptions are estimates rather than precise predictions, and variation among buildings of the same Performance Level must be expected.

Independent performance definitions are provided for structural and nonstructural components. Structural performance levels are identified in these *Guidelines* by both a name and numerical designator (following S-) in Section 2.5.1. Nonstructural performance levels are identified by a name and alphabetical designator (following N-) in Section 2.5.2.

2.5.1 Structural Performance Levels and Ranges

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

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

The Structural Performance Levels are the Immediate Occupancy Level (S-1), the Life Safety Level (S-3), and the Collapse Prevention Level (S-5). Table 2-4 relates these Structural Performance Levels to the limiting damage states for common vertical elements of lateral-force-resisting systems. Table 2-5 relates these Structural Performance Levels to the limiting damage states for common horizontal elements of building lateral-force-resisting systems. Later sections of these *Guidelines* specify design parameters (such as *m* factors, component capacities, and inelastic deformation demands) recommended as limiting values for calculated structural deformations and stresses for different construction components, in order to attain these Structural Performance Levels for a known earthquake demand.

The drift values given in Table 2-4 are typical values provided to illustrate the overall structural response associated with various performance levels. They are not provided in these tables as drift limit requirements of the *Guidelines*, and they do not supersede the specific drift limits or related component or element deformation limits that are specified in Chapters 5 through 9, and 11. The expected post-earthquake state of the buildings described in these tables is for design purposes and should not be used in the post-earthquake safety evaluation process.

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

2.5.1.1 Immediate Occupancy 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.

2.5.1.2 Life Safety 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, it is expected that the overall risk of life-threatening injury as a result of structural damage is low. It should be possible to repair the structure; however, for economic reasons this may not be practical. While the damaged structure is not an imminent collapse risk, it would be prudent to implement structural repairs or install temporary bracing prior to reoccupancy.

2.5.1.3 Collapse Prevention Performance Level (S-5)

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

2.5.1.4 Damage Control Performance Range (S-2)

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

2.5.1.5 Limited Safety Performance Range (S-4)

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

2.5.1.6 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. The actual performance of the structure with regard to *Guidelines* requirements is not known and could range from a potential collapse hazard to a structure capable of meeting the Immediate Occupancy Performance Level.

2.5.2 Nonstructural Performance Levels

Four Nonstructural Performance Levels are defined in these *Guidelines* and are summarized in Tables 2-6 through 2-8. Nonstructural components addressed in these performance levels include architectural components, such as partitions, exterior cladding, and ceilings; and mechanical and electrical components, including HVAC systems, plumbing, fire suppression systems, and lighting. Occupant contents and furnishings (such as inventory and computers) are included in these tables for some levels but are generally not covered with specific *Guidelines* requirements. Design procedures and acceptance criteria for rehabilitation of nonstructural components to the Life Safety Performance Level are contained in Chapter 11. General guidance only is provided for other performance levels.

2.5.2.1 Operational Performance Level (N-A)

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

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

2.5.2.2 Immediate Occupancy Level (N-B)

Nonstructural Performance Level B, Immediate Occupancy, means the post-earthquake damage state in which only limited nonstructural damage has occurred. Basic access and life safety systems, including doors, stairways, elevators, emergency lighting, fire alarms, and suppression systems, remain operable, provided that power is available. There could be minor window breakage and slight damage to some components. Presuming that the building is structurally safe, it is expected that occupants could safely remain in the building, although normal use may be impaired and some cleanup and inspection may be required. In general, components of mechanical and electrical systems in the building are structurally secured and should be able to function if necessary utility service is available. However, some components may experience misalignments or internal damage and be 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.

2.5.2.3 Life Safety 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 within 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, it is expected that, overall, the risk of life-threatening injury is very low. Restoration of the nonstructural components may take extensive effort.

2.5.2.4 Hazards Reduced Level (N-D)

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

2.5.2.5 Nonstructural Performance Not Considered (N-E)

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

2.5.3 Building Performance Levels

Building Performance Levels are obtained by combining Structural and Nonstructural Performance Levels. A large number of combinations is possible. Each Building Performance Level is designated alpha-numerically with a numeral representing the Structural Performance Level and a letter representing the Nonstructural Performance Level (e.g. 1-B, 3-C). Table 2-9 indicates the possible combinations and provides names for those that are most likely to be selected as a basis for design. Several of the more common Building Performance Levels are described below.

2.5.3.1 Operational Level (1-A)

This Building Performance Level is a combination of the Structural Immediate Occupancy Level and the Nonstructural Operational Level. Buildings meeting this performance level are expected to sustain minimal or no damage to their structural and nonstructural components. The building is suitable for its normal occupancy and use, although possibly in a slightly impaired mode, with power, water, and other required utilities provided from emergency sources, and possibly with some nonessential systems not functioning. Buildings meeting this performance level pose an extremely low risk to life safety.

Under very low levels of earthquake ground motion, most buildings should be able to meet or exceed this performance level. Typically, however, it will not be economically practical to design for this performance under severe levels of ground shaking, except for buildings that house essential services.

2.5.3.2 Immediate Occupancy Level (1-B)

This Building Performance Level is a combination of the Structural and Nonstructural Immediate Occupancy levels. Buildings meeting this performance level are expected to sustain minimal or no damage to their structural elements and only minor damage to their nonstructural components. While it would be safe to reoccupy a building meeting this performance level immediately following a major earthquake, nonstructural systems may not function due to either a lack of electrical power or internal damage to equipment. Therefore, although immediate 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 could function in a normal mode. The risk to life safety at this performance level is very low.

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

2.5.3.3 Life Safety Level (3-C)

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

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

2.5.3.4 Collapse Prevention Level (5-E)

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

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

Table 2-3 Damage Control and Building Performance Levels

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

Table 2-4 Structural Performance Levels and Damage[1]—Vertical Elements

		Structural Performance Levels		
Elements	**Type**	**Collapse Prevention S-5**	**Life Safety S-3**	**Immediate Occupancy S-1**
Concrete Frames	Primary	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Extensive damage to beams. Spalling of cover and shear cracking (< 1/8" width) for ductile columns. Minor spalling in nonductile columns. Joint cracks < 1/8" wide.	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003).
	Secondary	Extensive spalling in columns (limited shortening) and beams. Severe joint damage. Some reinforcing buckled.	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Minor spalling in a few places in ductile columns and beams. Flexural cracking in beams and columns. Shear cracking in joints < 1/16" width.
	Drift[2]	4% transient or permanent	2% transient; 1% permanent	1% transient; negligible permanent

Table 2-4 Structural Performance Levels and Damage[1]—Vertical Elements (continued)

Elements	Type	Structural Performance Levels		
		Collapse Prevention S-5	**Life Safety S-3**	**Immediate Occupancy S-1**
Steel Moment Frames	Primary	Extensive distortion of beams and column panels. Many fractures at moment connections, but shear connections remain intact.	Hinges form. Local buckling of some beam elements. Severe joint distortion; isolated moment connection fractures, but shear connections remain intact. A few elements may experience partial fracture.	Minor local yielding at a few places. No fractures. Minor buckling or observable permanent distortion of members.
	Secondary	Same as primary.	Extensive distortion of beams and column panels. Many fractures at moment connections, but shear connections remain intact.	Same as primary.
	Drift[2]	5% transient or permanent	2.5% transient; 1% permanent	0.7% transient; negligible permanent
Braced Steel Frames	Primary	Extensive yielding and buckling of braces. Many braces and their connections may fail.	Many braces yield or buckle but do not totally fail. Many connections may fail.	Minor yielding or buckling of braces.
	Secondary	Same as primary.	Same as primary.	Same as primary.
	Drift[2]	2% transient or permanent	1.5% transient; 0.5% permanent	0.5% transient; negligible permanent
Concrete Walls	Primary	Major flexural and shear cracks and voids. Sliding at joints. Extensive crushing and buckling of reinforcement. Failure around openings. Severe boundary element damage. Coupling beams shattered and virtually disintegrated.	Some boundary element distress, including limited buckling of reinforcement. Some sliding at joints. Damage around openings. Some crushing and flexural cracking. Coupling beams: extensive shear and flexural cracks; some crushing, but concrete generally remains in place.	Minor hairline cracking of walls, < 1/16" wide. Coupling beams experience cracking < 1/8" width.
	Secondary	Panels shattered and virtually disintegrated.	Major flexural and shear cracks. Sliding at joints. Extensive crushing. Failure around openings. Severe boundary element damage. Coupling beams shattered and virtually disintegrated.	Minor hairline cracking of walls. Some evidence of sliding at construction joints. Coupling beams experience cracks < 1/8" width. Minor spalling.
	Drift[2]	2% transient or permanent	1% transient; 0.5% permanent	0.5% transient; negligible permanent

Table 2-4 Structural Performance Levels and Damage[1]—Vertical Elements (continued)

Elements	Type	Structural Performance Levels		
		Collapse Prevention S-5	**Life Safety S-3**	**Immediate Occupancy S-1**
Unreinforced Masonry Infill Walls[3]	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[2]	0.6% transient or permanent	0.5% transient; 0.3% permanent	0.1% transient; negligible permanent
Unreinforced Masonry (Noninfill) Walls	Primary	Extensive cracking; face course and veneer may peel off. Noticeable in-plane and out-of-plane offsets.	Extensive cracking. Noticeable in-plane offsets of masonry and minor out-of-plane offsets.	Minor (< 1/8" width) cracking of veneers. Minor spalling in veneers at a few corner openings. No observable out-of-plane offsets.
	Secondary	Nonbearing panels dislodge.	Same as primary.	Same as primary.
	Drift[2]	1% transient or permanent	0.6% transient; 0.6% permanent	0.3% transient; 0.3% permanent
Reinforced Masonry Walls	Primary	Crushing; extensive cracking. Damage around openings and at corners. Some fallen units.	Extensive cracking (< 1/4") distributed throughout wall. Some isolated crushing.	Minor (< 1/8" width) cracking. No out-of-plane offsets.
	Secondary	Panels shattered and virtually disintegrated.	Crushing; extensive cracking; damage around openings and at corners; some fallen units.	Same as primary.
	Drift[2]	1.5% transient or permanent	0.6% transient; 0.6% permanent	0.2% transient; 0.2% permanent
Wood Stud Walls	Primary	Connections loose. Nails partially withdrawn. Some splitting of members and panels. Veneers dislodged.	Moderate loosening of connections and minor splitting of members.	Distributed minor hairline cracking of gypsum and plaster veneers.
	Secondary	Sheathing sheared off. Let-in braces fractured and buckled. Framing split and fractured.	Connections loose. Nails partially withdrawn. Some splitting of members and panels.	Same as primary.
	Drift[2]	3% transient or permanent	2% transient; 1% permanent	1% transient; 0.25% permanent

Table 2-4 Structural Performance Levels and Damage[1]—Vertical Elements (continued)

Elements	Type	Structural Performance Levels		
		Collapse Prevention S-5	**Life Safety S-3**	**Immediate Occupancy S-1**
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. The damage states indicated in this table are provided to allow an understanding of the severity of damage that may be sustained by various structural elements when present in structures meeting the definitions of the Structural Performance Levels. These damage states are not intended for use in post-earthquake evaluation of damage nor for judging the safety of, or required level of repair to, a structure following an earthquake.
2. The drift values, differential settlements, and similar quantities indicated in these tables are not intended to be used as acceptance criteria for evaluating the acceptability of a rehabilitation design in accordance with the analysis procedures provided in these *Guidelines*; rather, they are indicative of the range of drift that typical structures containing the indicated structural elements may undergo when responding within the various performance levels. Drift control of a rehabilitated structure may often be governed by the requirements to protect nonstructural components. Acceptable levels of foundation settlement or movement are highly dependent on the construction of the superstructure. The values indicated are intended to be qualitative descriptions of the approximate behavior of structures meeting the indicated levels.
3. For limiting damage to frame elements of infilled frames, refer to the rows for concrete or steel frames.

Table 2-5 Structural Performance Levels and Damage—Horizontal Elements

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

Table 2-6 Nonstructural Performance Levels and Damage—Architectural Components

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

Table 2-7 Nonstructural Performance Levels and Damage—Mechanical, Electrical, and Plumbing Systems/Components

	Nonstructural Performance Levels			
System/Component	**Hazards Reduced N-D**	**Life Safety N-C**	**Immediate Occupancy N-B**	**Operational N-A**
Elevators	Elevators out of service; 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.
Ducts	Ducts break loose of equipment and louvers; some supports fail; some ducts fall.	Minor damage at joints of sections and attachment to equipment; some supports damaged, but ducts do not fall.	Minor damage at joints, but ducts remain serviceable.	Negligible damage.
Piping	Some lines rupture. Some supports fail. Some piping falls.	Minor damage at joints, with some leakage. Some supports damaged, but systems remain suspended.	Minor leaks develop at a few joints.	Negligible damage.
Fire Sprinkler Systems	Many sprinkler heads damaged by collapsing ceilings. Leaks develop at couplings. Some branch lines fail.	Some sprinkler heads damaged by swaying ceilings. Leaks develop at some couplings.	Minor leakage at a few heads or pipe joints. System remains operable.	Negligible damage.
Fire Alarm Systems	Ceiling mounted sensors damaged. System nonfunctional.	May not function.	System is functional.	System is functional.
Emergency Lighting	Some lights fall. Power may not be available.	System is functional.	System is functional.	System is functional.
Electrical Distribution Equipment	Units slide and/or overturn, rupturing attached conduit. 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.
Plumbing	Some fixtures broken; lines broken; mains disrupted at source.	Some fixtures broken, lines broken; mains disrupted at source.	Fixtures and lines serviceable; however, utility service may not be available.	System is functional. On-site water supply provided, if required.

Table 2-8 Nonstructural Performance Levels and Damage—Contents

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

Table 2-9 Building Performance Levels/Ranges

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

2.6 Seismic Hazard

The most common and significant cause of earthquake damage to buildings is ground shaking; thus, the effects of ground shaking form the basis for most building code requirements for seismic design. As stated in Section 2.4, two levels of earthquake shaking hazard are used to satisfy the BSO for these *Guidelines*. These are termed Basic Safety Earthquake 1 (BSE-1) and Basic Safety Earthquake 2 (BSE-2). BSE-2 earthquake ground shaking, also termed Maximum Considered Earthquake (MCE) ground shaking, is similar to that defined for the MCE in the 1997 *NEHRP Recommended Provisions* (BSSC, 1997). In most areas of the United States, BSE-2 earthquake ground motion 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 ground shaking is limited by a conservative estimate (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 that is greater than 2% in 50 years. The BSE-1 earthquake is similar, but not identical to the concept of a design earthquake contained in the *NEHRP Provisions*. It is defined as that ground shaking having a 10% probability of exceedance in 50 years (10%/50 year). The motions need not exceed those used for new buildings, defined as 2/3 of the BSE-2 motion.

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

Response spectra are used to characterize earthquake shaking demand on buildings in the *Guidelines*. Ground shaking response spectra for use in seismic rehabilitation design may be determined in accordance with either the General Procedure of Section 2.6.1 or the Site-Specific Procedure of Section 2.6.2. Seismic zones are defined in Section 2.6.3. Other seismic hazards (e.g., liquefaction) are discussed in Section 2.6.4.

In the General Procedure, ground shaking hazard is determined from available response spectrum acceleration contour maps. Maps showing 5%-damped response spectrum ordinates for short-period (0.2 second) and long-period (1 second) response distributed with the *Guidelines* can be used directly with the General Procedure of Section 2.6.1 for developing design response spectra for either or both the BSE-1 and BSE-2, or for earthquakes of any desired probability of exceedance. Alternatively, other maps and other procedures can be used, provided that 5%-damped response spectra are developed that represent the ground shaking for the desired earthquake return period, and the site soil classification is considered. In the Site-Specific Procedure, ground shaking hazard is determined using a specific study of the faults and seismic source zones that may affect the site, as well as evaluation of the regional and geologic conditions that affect the character of the site ground motion caused by events occurring on these faults and sources.

The General Procedure may be used for any building. The Site-Specific Procedure may also be used for any building and should be considered where any of the following apply:

- Rehabilitation is planned to an Enhanced Rehabilitation Objective, as defined in Section 2.4.2.
- The building site is located within 10 kilometers of an active fault.
- The building is located on Type E soils (as defined in Section 2.6.1.4) and the mapped BSE-2 spectral response acceleration at short periods (S_S) exceeds 2.0g.
- The building is located on Type F soils as defined in Section 2.6.1.4.

  Exception: Where S_S, determined in accordance with Section 2.6.1.1, < 0.20g. In these cases, a Type E soil profile may be assumed.
- A time history response analysis of the building will be performed as part of the design.

Other site-specific seismic hazards that may cause damage to buildings include:

- surface fault rupture
- differential compaction of the foundation material
- landsliding

- liquefaction
- lateral spreading
- flooding

If the potential for any of these, or other, seismic hazards exists at a given site, then they also should be considered in the rehabilitation design, in accordance with Section 2.6.4 and Chapter 4.

2.6.1 General Ground Shaking Hazard Procedure

The general procedures of this section may be used to determine acceleration response spectra for any of the following hazard levels:

- Basic Safety Earthquake 1 (BSE-1)
- Basic Safety Earthquake 2 (BSE-2)
- Earthquake with any defined probability of exceedance in 50 years

Deterministic estimates of earthquake hazard, in which an acceleration response spectrum is obtained for a specific magnitude earthquake occurring on a defined fault, shall be made using the Site-Specific Procedures of Section 2.6.2.

The basic steps for determining a response spectrum under this general procedure are:s

1. Determine whether the desired hazard level corresponds to one of the levels contained in the ground shaking hazard maps distributed with the *Guidelines*. The package includes maps for BSE-2 (MCE) ground shaking hazards as well as for hazards with 10%/50 year exceedance probabilities.
2. If the desired hazard level corresponds with one of the mapped hazard levels, obtain spectral response acceleration parameters directly from the maps, in accordance with Section 2.6.1.1.
3. If the desired hazard level is the BSE-1, then obtain the spectral response acceleration parameters from the maps, in accordance with Section 2.6.1.2.
4. If the desired 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 2.6.1.3.
5. Obtain design spectral response acceleration parameters by adjusting the mapped, or modified mapped spectral response acceleration parameters for site class effects, in accordance with Section 2.6.1.4.
6. Using the design spectral response acceleration parameters that have been adjusted for site class effects, construct the response spectrum in accordance with Section 2.6.1.5.

2.6.1.1 BSE-2 and 10%/50 Response Acceleration Parameters

The mapped short-period response acceleration parameter, S_S, and mapped response acceleration parameter at a one-second period, S_1, for BSE-2 ground motion hazards may be obtained directly from the maps distributed with the *Guidelines*. The mapped short-period response acceleration parameter, S_S, and mapped response acceleration parameter at a one-second period, S_1, for 10%/50 year ground motion hazards may also be obtained directly from the maps distributed with the *Guidelines*.

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

2.6.1.2 BSE-1 Response Acceleration Parameters

The mapped short-period response acceleration parameter, S_S, and mapped response acceleration parameter at a one-second period, S_1, for BSE-1 ground shaking hazards shall be taken as the smaller of the following:

- The values of the parameters S_S and S_1, respectively, determined for 10%/50 year ground motion hazards, in accordance with Section 2.6.1.1.
- Two thirds of the values of the parameters S_S and S_1, respectively, determined for BSE-2 ground motion hazards, in accordance with Section 2.6.1.1.

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

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, for probabilities of exceedance between 2%/50 years and 10%/50 years may be determined from the equation:

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

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 hazard level

and the mean return period P_R at the desired exceedance probability may be calculated from the equation:

$$P_R = \frac{1}{1 - e^{0.02\ 1n(1 - P_{E50})}} \qquad (2\text{-}2)$$

where P_{E50} is the probability of exceedance in 50 years of the desired 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 may be determined from the equation:

$$S_i = S_{i10/50}\left(\frac{P_R}{475}\right)^n \qquad (2\text{-}3)$$

where S_i, $S_{i10/50}$, and P_R are as defined above and n may be obtained from Table 2-10.

Table 2-10 and the two following specify five regions, three of which are not yet specifically defined, namely Intermountain, Central US, and Eastern US. For states or areas that might lie near the regional borders, care will be necessary.

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

	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

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, for probabilities of exceedance greater than 10%/50 years may be determined from Equation 2-3, where the exponent n is obtained from Table 2-11.

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 greater than 10%/50

Table 2-11 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

	Values of Exponent *n* for	
Region	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 2-12 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 $S_S \geq$ 1.5g

	Values of Exponent *n* for	
Region	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

years may be determined from Equation 2-3, where the exponent *n* is obtained from Table 2-12.

2.6.1.4 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 respectively from Equations 2-4 and 2-5 as follows:

$$S_{XS} = F_a S_S \tag{2-4}$$

$$S_{X1} = F_v S_1 \tag{2-5}$$

where F_a and F_v are site coefficients determined respectively from Tables 2-13 and 2-14, based on the site class and the values of the response acceleration parameters S_S and S_1.

Table 2-13 Values of F_a as a Function of Site Class and Mapped Short-Period Spectral Response Acceleration S_S

	Mapped Spectral Acceleration at Short Periods S_S				
Site Class	$S_S \leq 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \geq 1.25$
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	*
F	*	*	*	*	*

NOTE: Use straight-line interpolation for intermediate values of S_S.

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

Table 2-14 Values of F_v as a Function of Site Class and Mapped Spectral Response Acceleration at One-Second Period S_1

	Mapped Spectral Acceleration at One-Second Period S_1				
Site Class	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.50$
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	*
F	*	*	*	*	*

NOTE: Use straight-line interpolation for intermediate values of S_1.

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

Site classes shall be defined as follows:

- **Class A:** Hard rock with measured shear wave velocity, $\bar{v}_s$ > 5,000 ft/sec
- **Class B:** Rock with 2,500 ft/sec < $\bar{v}_s$ < 5,000 ft/sec

- **Class C:** Very dense soil and soft rock with 1,200 ft/sec < $\bar{v}_s \le$ 2,500 ft/sec or with either standard blow count $\bar{N}$ > 50 or undrained shear strength $\bar{s}_u$ > 2,000 psf

- **Class D:** Stiff soil with 600 ft/sec < $\bar{v}_s \le$ 1,200 ft/sec or with 15 < $\bar{N} \le$ 50 or 1,000 psf ≤ $\bar{s}_u$ < 2,000 psf

- **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 $\bar{s}_u$ < 500 psf or a soil profile with $\bar{v}_s$ < 600 ft/sec. If insufficient data are available to classify a soil profile as type A through D, a type E profile should be assumed.

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

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

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

  – Very high plasticity clays (H > 25 feet with PI > 75 percent)

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

The parameters $\bar{v}_s$, $\bar{N}$, and $\bar{s}_u$ 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 may be calculated from Equation 2-6, below:

$$\bar{v}_s, \bar{N}, \bar{s}_u = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}, \frac{d_i}{N_i}, \frac{d_i}{s_{ui}}} \qquad (2\text{-}6)$$

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

$$\sum_{i=1}^{n} d_i = 100\ ft \qquad (2\text{-}7)$$

Where reliable v_s data are available for the site, such data should be used to classify the site. If such data are not available, *N* data should preferably 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 may be based either on measured or estimated values of v_s. Classification of a site as Class A rock should be based on measurements of v_s either for material at the site itself, or for similar rock materials in the vicinity; otherwise, Class B rock should be assumed. Class A or B profiles should 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.

2.6.1.5 General Response Spectrum

A general, horizontal response spectrum may be constructed by plotting the following two functions in the spectral acceleration vs. structural period domain, as shown in Figure 2-1. Where a vertical response spectrum is required, it may be constructed by taking two-thirds of the spectral ordinates, at each period, obtained for the horizontal response spectrum.

$$S_a = (S_{XS}/B_S)(0.4 + 3T/T_o) \quad \text{for } 0 < T \le 0.2T_o \qquad (2\text{-}8)$$

$$S_a = (S_{X1}/(B_1 T)) \quad \text{for } T > T_o \qquad (2\text{-}9)$$

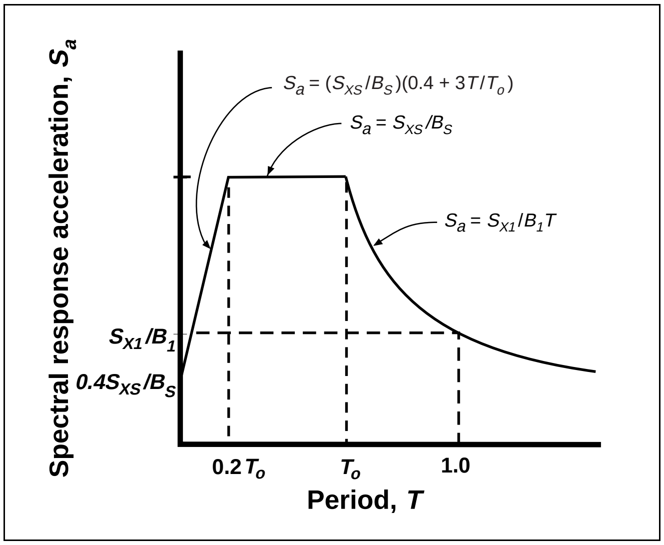

Figure 2-1 General Response Spectrum

where T_o is given by the equation

$$T_o = (S_{X1}B_S)/(S_{XS}B_1) \tag{2-10}$$

where B_S and B_1 are taken from Table 2-15.

Table 2-15 Damping Coefficients B_S and B_1 as a Function of Effective Damping β

Effective Damping β (percentage of critical)[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. The damping coefficient should be based on linear interpolation for effective damping values other than those given.

In general, it is recommended that a 5% damped response spectrum be used for the rehabilitation design of most buildings and structural systems. Exceptions are as follows:

- For structures without exterior cladding an effective viscous damping ration, β, of 2% should be assumed.
- For structures with wood diaphragms and a large number of interior partitions and cross walls that interconnect the diaphragm levels, an effective viscous damping ratio, β, of 10% may be assumed.
- For structures rehabilitated using seismic isolation technology or enhanced energy dissipation technology, an equivalent effective viscous damping ratio, β, should be calculated using the procedures contained in Chapter 9.

In Chapter 9 of the *Guidelines*, the analytical procedures for structures rehabilitated using seismic isolation and/or energy dissipation technology make specific reference to the evaluation of earthquake demands for the BSE-2 and user-specified design earthquake hazard levels. In that chapter, the parameters: S_{aM}, S_{MS}, S_{M1}, refer respectively to the value of the spectral response acceleration parameters S_a, S_{XS}, and S_{X1}, evaluated for the BSE-2 hazard level, and the parameters S_{aD}, S_{DS}, S_{D1} in Chapter 9, refer respectively to the value of the spectral response acceleration parameters S_a, S_{XS}, and S_{X1}, evaluated for the user-specified design earthquake hazard level.

2.6.2 Site-Specific Ground Shaking Hazard

Where site-specific ground shaking characterization is used as the basis of rehabilitation design, the characterization shall be developed in accordance with this section.

2.6.2.1 Site-Specific Response Spectrum

Development of site-specific response spectra shall be based on the geologic, seismologic, and soil characteristics associated with the specific site. Response spectra should be developed for an equivalent viscous damping ratio of 5%. Additional spectra should be developed for other damping ratios appropriate to the indicated structural behavior, as discussed in Section 2.6.1.5. When the 5% damped site-specific spectrum has spectral amplitudes in the period range of greatest significance to the structural response that are less than 70 percent of the spectral amplitudes of the General Response Spectrum, an independent third-party review of the spectrum should be made by an individual with expertise in the evaluation of ground motion.

When a site-specific response spectrum has been developed and other sections of these *Guidelines* require values for the spectral response parameters, S_{XS}, S_{X1}, or T_0, they may be obtained in accordance with this section. The value of the design spectral response acceleration at short periods, S_{XS}, shall be taken as the response acceleration obtained from the site-specific spectrum at a period of 0.2 seconds, except that it should be taken as not less than 90% of the peak response acceleration at any period. In order to obtain a value for the design spectral response acceleration parameter S_{X1}, a curve of the form $S_a = S_{X1}/T$ should be graphically overlaid on the site-specific spectrum 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 spectrum. The value of T_0 shall be determined in accordance with Equation 2-11. Alternatively, the values obtained in accordance with Section 2.6.1 may be used for all of these parameters.

$$T_0 = S_{X1} / S_{XS} \qquad (2\text{-}11)$$

2.6.2.2 Acceleration Time Histories

Time-History Analysis shall be performed with no fewer than three data sets (two horizontal components or, if vertical motion is to be considered, two horizontal components and one vertical component) of appropriate ground motion time histories that shall be selected and scaled from no fewer than three recorded events. Appropriate time histories shall have magnitude, fault distances, and source mechanisms that are consistent with those that control the design earthquake ground motion. Where three appropriate recorded ground-motion time history data sets are not available, appropriate simulated time history data sets may 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 0.2*T* seconds and 1.5*T* 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 may be used to determine design acceptability.

2.6.3 Seismicity Zones

In these *Guidelines*, seismicity zones are defined as follows.

2.6.3.1 Zones of High Seismicity

Buildings located on sites for which the 10%/50 year, design short-period response acceleration, S_{XS}, is equal to or greater than 0.5g, or for which the 10%/50 year design one-second period response acceleration, S_{X1}, is equal to or greater than 0.2g shall be considered to be located within zones of high seismicity.

2.6.3.2 Zones of Moderate Seismicity

Buildings located on sites for which the 10%/50 year, design short-period response acceleration, S_{XS}, is equal to or greater than 0.167g but is less than 0.5g, or for which the 10%/50 year, design one-second period response acceleration, S_{X1}, is equal to or greater than 0.067g but less than 0.2g shall be considered to be located within zones of moderate seismicity.

2.6.3.3 Zones of Low Seismicity

Buildings located on sites that are not located within zones of high or moderate seismicity, as defined in Sections 2.6.3.1 and 2.6.3.2, shall be considered to be located within zones of low seismicity.

2.6.4 Other Seismic Hazards

In addition to ground shaking, seismic hazards can include ground failure caused by surface fault rupture, liquefaction, lateral spreading, differential settlement, and landsliding. Earthquake-induced flooding, due to tsunami, seiche, or failure of a water-retaining structure, can also pose a hazard to a building site. The process of rehabilitating a building shall be based on the understanding that either the site is not exposed to a significant earthquake-induced flooding hazard or ground failure, or the site may be stabilized or protected from such hazards at a cost that is included along with the other rehabilitation costs. Chapter 4 describes, and provides guidance for evaluating and mitigating, these and other on-site and off-site seismic hazards.

2.7 As-Built Information

Existing building characteristics pertinent to its seismic performance—including its configuration, and the type, detailing, material strengths, and condition of the various structural and nonstructural elements, including foundations and their interconnections—shall be determined in accordance with this section. The project calculations should include documentation of these characteristics in drawings or photographs, supplemented by appropriate descriptive text. Existing characteristics of the building and site should be obtained from the following sources, as appropriate:

- Field observation of exposed conditions and configuration
- Available construction documents, engineering analyses, reports, soil borings and test logs, maintenance histories, and manufacturers' literature and test data
- Reference standards and codes from the period of construction as cited in Chapters 5 through 8
- Destructive and nondestructive examination and testing of selected building components
- Interviews with building owners, tenants, managers, the original architect and engineer, contractor(s), and the local building official

As a minimum, at least one site visit should be performed to obtain detailed information regarding building configuration and condition, site and geotechnical conditions, and any issues related to adjacent structures, and to confirm that the available construction documents are generally representative of existing conditions. If the building is a historic structure, it is also important to identify the locations of historically significant features and fabric. Care should be taken in the design and investigation process to minimize the impact of work on these features. Refer to the Secretary of the Interior's *Standards for the Treatment of Historic Properties* as discussed in Chapter 1.

2.7.1 Building Configuration

The as-built building configuration consists of the type and arrangement of existing structural elements and components composing the gravity- and lateral-load-resisting systems, and the nonstructural components. The structural elements and components shall be identified and categorized as either primary or secondary, using the criteria described in Section 2.3, with any structural deficiencies potentially affecting seismic performance also identified.

It is important, in identifying the building configuration, to account for both the intended load-resisting elements and components and the effective elements and components. The effective load-resisting systems may include building-code-conforming structural elements, nonconforming structural elements, and those nonstructural elements that actually participate in resisting gravity, lateral, or combined gravity and lateral loads, whether or not they were intended to do so by the original designers. Existing load paths should be identified, considering the effects of any modifications (e.g., additions, alterations, rehabilitation, degradation) since original construction. Potential discontinuities and weak links should also be identified, as well as irregularities that may have a detrimental effect on the building's response to lateral demands. FEMA 178 (BSSC, 1992) offers guidance for these aspects of building evaluation.

2.7.2 Component Properties

Meaningful structural analysis of a building's probable seismic behavior and reliable design of rehabilitation measures requires good understanding of the existing components (e.g., beams, columns, diaphragms), their interconnection, and their material properties (strength, deformability, and toughness). The strength and deformation capacity of existing components should be computed, as indicated in Chapters 4 through 9 and 11, based on derived material properties and detailed component knowledge. Existing component action strengths must be determined for two basic purposes: to allow calculation of their ability to deliver load to other elements and components, and to allow determination of their capacity to resist forces and deformations.

Component deformation capacity must be calculated to allow validation of overall element and building deformations and their acceptability for the selected Rehabilitation Objectives. In general, component capacities are calculated as "expected values" that account for the mean material strengths as well as the probable effects of strain hardening and/or degradation. The exception to this is the calculation of strengths used to evaluate the adequacy of component force actions with little inherent ductility (force-controlled behaviors). For these evaluations, lower-bound strength estimates—taking into account the possible variation in material strengths—are used for determination of capacity. Guidance on how to obtain these expected and lower-bound values is provided in Chapters 5 through 8 for the commonly used structural materials and systems.

Knowledge of existing component configuration, quality of construction, physical condition, and interconnection to other structural components is necessary to compute strength and deformation capacities. This knowledge should be obtained by visual surveys of condition, destructive and nondestructive testing, and field measurement of dimensions, as appropriate. Even with an exhaustive effort to maximize knowledge, uncertainty will remain regarding the validity of computed component strength and deformation capacities. To account for this uncertainty, a knowledge factor, κ, is utilized in the capacity evaluations. Two possible values exist for κ, based on the reliability of available knowledge—classified as either minimum or comprehensive.

When only a minimum level of knowledge is available, a κ value of 0.75 shall be included in component capacity and deformation analyses. The following characteristics represent the minimum appropriate level of effort in gaining knowledge of structural configuration:

- Records of the original construction and any modifications, including structural and architectural drawings, are generally available. In the absence of structural drawings, a set of record drawings and/or sketches is prepared, documenting both gravity and lateral systems.

- A visual condition survey is performed on the accessible primary elements and components, with verification that the size, location, and connection of these elements is as indicated on the available documentation.

- A limited program of in-place testing is performed, as indicated in Chapters 5 through 8, to quantify the material properties, component condition, and dimensions of representative primary elements with quantification of the effects of any observable deterioration. Alternatively, default values provided in Chapters 5 through 8 are utilized for material strengths, taking into account the observed condition of these materials; if significant variation is found in the condition or as-tested properties of materials, consideration should be given to grouping those components with similar condition or properties so that the coefficient of variation within a group does not exceed 30%.

- Knowledge of any site-related concerns—such as pounding from neighboring structures, party wall effects, and soil or geological problems including risks of liquefaction—has been gained through field surveys and research.

- Specific foundation- and material-related concerns cited in Chapters 4 through 8, as applicable, have been examined, and knowledge of their influence on building performance has been gained.

A κ value of 1.0 may be used where comprehensive knowledge and understanding of component configuration has been obtained. Comprehensive knowledge may be assumed when all of the following factors exist:

- Original construction records, including drawings and specifications, as well as any post-construction modification data, are available and explicitly depict as-built conditions. Where such documents are not available, drawings and sketches are developed based on detailed surveys of the primary structural elements. Such surveys include destructive and/or nondestructive investigation as required to determine the size, number, placement, and type of obscured items such as bolts and reinforcing bars. In addition, documentation is developed for representative secondary elements.

- Extensive in-place testing is performed as indicated in Chapters 4 through 8 to quantify material properties, and component conditions and dimensions or records of the results of quality assurance tests constructed during testing are available. Coefficients of variability for material strength test results are less than 20%, or components are grouped and additional testing is performed such that the material strength test results for each group have coefficients of variation within this limit.

- Knowledge of any site-related concerns—such as pounding from neighboring structures, party wall effects, and soil or geological problems including risks of liquefaction—has been gained from thorough visual survey and research efforts.

- Specific foundation- and material-related concerns cited in Chapters 4 through 8, as applicable, have been examined and knowledge of their influence on building performance has been gained.

Whenever practical, investigation should be sufficiently thorough to allow the use of a single value of κ for all building components and elements. If extenuating circumstances prevent use of a common κ value for certain components, multiple κ values should be used in the analysis, as appropriate to the available knowledge of the individual components. When a nonlinear analysis procedure is employed, the level of investigation should be sufficient to allow comprehensive knowledge of the structure ($\kappa = 1.0$).

2.7.3 Site Characterization and Geotechnical Information

Data on surface and subsurface conditions at the site, including the configuration of foundations, shall be obtained for use in building analyses. Data shall be obtained from existing documents, visual site reconnaissance, or a program of subsurface investigation. If adequate geotechnical data are not available from previous investigations, a program of site-specific subsurface investigation should be considered for sites in areas subject to liquefaction, lateral spreading, or landsliding, and for all buildings with an Enhanced Rehabilitation Objective. Additional guidelines for site characterization and subsurface investigation are contained in Chapter 4.

A site reconnaissance should always be performed. In the course of this reconnaissance, variances from the building drawings should be noted. Such variances could include foundation modifications that are not shown on the existing documentation. Off-site development that should be noted could include buildings or grading activities that may impose a load or reduce the level of lateral support to the structure. Indicators of poor foundation performance—such as settlements of floor slabs, foundations or sidewalks, suggesting distress that could affect building performance during a future earthquake—should be noted.

2.7.4 Adjacent Buildings

Data should be collected on the configuration of adjacent structures when such structures have the potential to influence the seismic performance of the rehabilitated building. Data collected should be sufficient to permit analysis of the potential interaction issues identified below, as applicable. In some cases, it may not be possible to obtain adequate information on adjacent structures to permit a meaningful evaluation. In such cases, the owner should be notified of the potential consequences of these interactions.

2.7.4.1 Building Pounding

Data on adjacent structures should be collected to permit investigation of the potential effects of building pounding whenever the side of the adjacent structure is located closer to the building than 4% of the building height above grade at the location of potential impacts.

Building pounding can alter the basic response of the building to ground motion, and impart additional inertial loads and energy to the building from the adjacent structure. Of particular concern is the potential for extreme local damage to structural elements at the zones of impact. (See Section 2.11.10.)

2.7.4.2 Shared Element Condition

Data should be collected on all adjacent structures that share elements in common with the building. Buildings sharing common elements, such as party walls, have several potential problems. If the buildings attempt to move independently, one building may pull the shared element away from the other, resulting in a partial collapse. If the buildings behave as an integral unit, the additional mass and inertial loads of one structure may result in extreme demands on the lateral-force-resisting system of the other. (See Section 2.11.9.)

2.7.4.3 Hazards from Adjacent Structure

Data should be collected on all structures that have the potential to damage the building with falling debris, or other earthquake-induced physical hazards such as aggressive chemical leakage, fire, or explosion.

Consideration should be given to hardening those portions of the building that may be impacted by debris or other hazards from adjacent structures. Where Immediate Occupancy of the building is desired, and ingress to the building may be impaired by such hazards, consideration should be given to providing for suitably resistant access to the building. Sufficient information must be collected on adjacent structures to allow preliminary evaluation of the likelihood and nature of hazards such as potential falling debris, fire, and blast pressures. Evaluations similar to those in FEMA 154, *Rapid Visual Screening of Buildings for Seismic Hazards: A Handbook* (ATC, 1988), should be adequate for this purpose.

2.8 Rehabilitation Methods

The scope of building structural alterations and modifications required to meet the selected Rehabilitation Objective shall be determined in accordance with one of the methods described in this section. In addition, rehabilitation of historic buildings should be carefully considered in accordance with the discussion in Chapter 1.

2.8.1 Simplified Method

The Simplified Method allows for design of building rehabilitation measures without requiring analyses of the entire building's response to earthquake hazards. This method is not applicable to all buildings and can be used only to achieve Limited Rehabilitation Objectives (Section 2.4.3).

The Simplified Method may be used to achieve a Rehabilitation Objective consisting of the Life Safety Performance Level (3-C) for a BSE-1 earthquake for buildings meeting all of the following conditions:

- The building conforms to one of the Model Building Types indicated in Table 10-1, as well as all limitations indicated in that table with regard to number of stories, regularity, and seismic zone; and
- A complete evaluation of the building is performed in accordance with FEMA 178 (BSSC, 1992), and all deficiencies identified in that evaluation are addressed by the selected Simplified Rehabilitation Methods.

Any building may be partially rehabilitated to achieve a Limited Rehabilitation Objective using the Simplified Method, subject to the limitations of Section 2.4.3.

The Simplified Method may not be used for buildings intended to meet the BSO or any Enhanced Rehabilitation Objectives. For those buildings and other buildings not meeting the limitations for the Simplified Method, the Systematic Method shall be used.

2.8.2 Systematic Method

Rehabilitation programs for buildings and objectives that do not qualify for Simplified Rehabilitation under Section 2.8.1 shall be designed in accordance with this section. The basic approach shall include the following:

- The structure shall be analyzed to determine if it is adequate to meet the selected Rehabilitation Objective(s) and, if it is not adequate, to identify specific deficiencies. If initial analyses indicate that key elements or components of the structure do not meet the acceptance criteria, it may be possible to demonstrate acceptability by using more detailed and accurate analytical procedures. Section 2.9 provides information on alternative analytical procedures that may be used.
- One or more rehabilitation strategies shall be developed to address the deficiencies identified in the preliminary evaluation. Alternative rehabilitation strategies are presented in Section 2.10.
- A preliminary rehabilitation design shall be developed that is consistent with the rehabilitation strategy.
- The structure and the preliminary rehabilitation measures shall be analyzed to determine whether the rehabilitated structure will be adequate to meet the selected Rehabilitation Objective(s).
- The process shall be repeated as required until a design solution is obtained that meets the selected Rehabilitation Objective(s), as determined by the analysis.

2.9 Analysis Procedures

An analysis of the structure shall be conducted to determine the distribution of forces and deformations induced in the structure by the design ground shaking and other seismic hazards corresponding with the selected Rehabilitation Objective(s). The analysis shall address the seismic demands and the capacity to resist these demands for all elements in the structure that either:

- Are essential to the lateral stability of the structure (primary elements); or
- Are essential to the vertical load-carrying integrity of the building; or
- Are otherwise critical to meeting the Rehabilitation Objective and could be subject to damage as a result of the building's response to the earthquake hazards.

The analysis procedure shall consist of one of the following:

- Linear analysis, in accordance with Section 3.3, including Linear Static Procedure (LSP) (see Section 3.3.1), and Linear Dynamic Procedure (LDP) (see Section 3.3.2), including:
  - Response Spectrum Analysis (see Section 3.3.2.2C), and
  - Linear Time-History Analysis (see Section 3.3.2.2D), or
- Nonlinear analysis, in accordance with Section 3.3, including Nonlinear Static Procedure (NSP) in Section 3.3.3 and Nonlinear Dynamic Procedure (NDP) in Section 3.3.4, or
- Alternative rational analysis

Limitations with regard to the use of these procedures are given in Sections 2.9.1, 2.9.2, and 2.9.3. Criteria used to determine whether the results of an analysis indicate acceptable performance for the building are discussed in Section 2.9.4.

2.9.1 Linear Procedures

Linear procedures may be used for any of the rehabilitation strategies contained in Section 2.10 except those strategies incorporating the use of supplemental energy dissipation systems and some types of seismic isolation systems. For the specific analysis procedures applicable to these rehabilitation strategies, refer to Chapter 9.

The results of the linear procedures can be very inaccurate when applied to buildings with highly irregular structural systems, unless the building is capable of responding to the design earthquake(s) in a nearly elastic manner. Therefore, linear procedures should not be used for highly irregular buildings, unless the earthquake ductility demands on the building are suitably low.

2.9.1.1 Method to Determine Applicability of Linear Procedures

The methodology indicated in this section may be used to determine whether a building can be analyzed with sufficient accuracy by linear procedures. The basic approach is to perform a linear analysis using the loads defined in either Section 3.3.1 or 3.3.2 and then to examine the results of this analysis to identify the magnitude and uniformity of distribution of inelastic demands on the various components of the primary lateral-force-resisting elements. The magnitude and distribution of inelastic demands are indicated by demand-capacity ratios (DCRs), as defined below. Note that these DCRs are not used to determine the acceptability of component behavior. The adequacy of structural components and elements must be evaluated using the procedures contained in Chapter 3, together with the acceptance criteria provide in Chapters 4 through 8. DCRs are used only to determine a structure's regularity. It should be noted that for complex structures, such as buildings with perforated shear walls, it may be easier to use one of the nonlinear procedures than to ensure that the building has sufficient regularity to permit use of linear procedures.

DCRs for existing and added building components shall be computed in accordance with the equation:

$$DCR = \frac{Q_{UD}}{Q_{CE}} \qquad (2\text{-}12)$$

where:

Q_{UD} = Force calculated in accordance with Section 3.4, due to the gravity and earthquake loads of Section 3.3

Q_{CE} = Expected strength of the component or element, calculated in accordance with Chapters 5 through 8

DCRs should be calculated for each controlling action (such as axial force, moment, shear) of each component. If all of the computed controlling DCRs for a component are less than or equal to 1.0, then the component is expected to respond elastically to the earthquake ground shaking being evaluated. If one or more of the computed DCRs for a component are greater than 1.0, then the component is expected to respond inelastically to the earthquake ground shaking. The largest DCR calculated for a given component defines the critical action for the component, i.e., the mode in which the component will first yield, or fail. This DCR is termed the critical component DCR. If an element is composed of multiple components, then the component with the largest computed DCR is the critical component for the element, i.e., this will be the first component in the element to yield, or fail. The largest DCR for any component in an element at a particular story is termed the critical element DCR at that story.

If the DCRs computed for all of the critical actions (axial force, moment, shear) of all of the components (such as beams, columns, wall piers, braces, and connections) of the primary elements are less than 2.0, then linear procedures are applicable, regardless of considerations of regularity. If some computed DCRs exceed 2.0, then linear procedures should not be used if any of the following apply:

- There is an in-plane discontinuity in any primary element of the lateral-force-resisting system. In-plane discontinuities occur whenever a lateral-force-resisting element is present in one story, but does not continue, or is offset, in the story immediately below. Figure 2-2 depicts such a condition. This limitation need not apply if the coefficient *J* in Equation 3-15 is taken as 1.0.

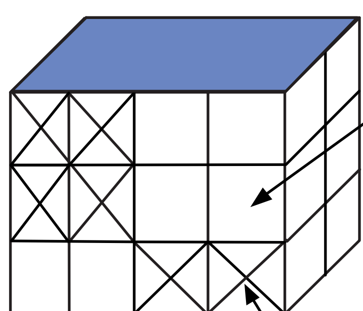

Figure 2-2 In-Plane Discontinuity in Lateral System

- There is an out-of-plane discontinuity in any primary element of the lateral-force-resisting system. An out-of-plane discontinuity exists when an element in one story is offset relative to the continuation of that element in an adjacent story, as depicted in Figure 2-3. This limitation need not apply if the coefficient *J* in Equation 3-15 is taken as 1.0.

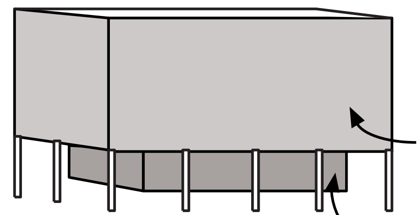

Figure 2-3 Typical Building with Out-of-Plane Offset Irregularity

- There is a severe weak story irregularity present at any story in any direction of the building. A severe weak story irregularity may be deemed to exist if the ratio of the average shear DCR for any story to that for an adjacent story in the same direction exceeds 125%. The average DCR for a story may be calculated by the equation:

$$\overline{DCR} = \frac{\sum_{1}^{n} DCR_i V_i}{\sum_{1}^{n} V_i} \tag{2-13}$$

where:

$\overline{DCR}$ = Average DCR for the story

DCR_i = Critical action DCR for element *i*

V_i = Total calculated lateral shear force in an element *i* due to earthquake response, assuming that the structure remains elastic

n = Total number of elements in the story

For buildings with flexible diaphragms, each line of framing should be independently evaluated.

- There is a severe torsional strength irregularity present in any story. A severe torsional strength irregularity may be deemed to exist in a story when the diaphragm above the story is not flexible and the ratio of the critical element DCRs for primary elements on one side of the center of resistance in a given direction for a story, to those on the other side of the center of resistance for the story, exceeds 1.5.

If the guidelines above indicate that a linear procedure is applicable, then either the LSP or the LDP may be used, unless one or more of the following apply, in which case the LSP should not be used:

- The building height exceeds 100 feet.
- The ratio of the building's horizontal dimension at any story to the corresponding dimension at an adjacent story exceeds 1.4 (excluding penthouses).
- The building is found to have a severe torsional stiffness irregularity in any story. A severe torsional stiffness irregularity may be deemed to exist in a story if the diaphragm above the story is not flexible and the results of the analysis indicate that the drift along any side of the structure is more than 150% of the average story drift.
- The building is found to have a severe vertical mass or stiffness irregularity. A severe vertical mass or stiffness irregularity may be deemed to exist when the average drift in any story (except penthouses) exceeds that of the story above or below by more than 150%.
- The building has a nonorthogonal lateral-force-resisting system.

2.9.2 Nonlinear Procedures

Nonlinear Analysis Procedures may be used for any of the rehabilitation strategies contained in Section 2.10. Nonlinear procedures are especially recommended for analysis of buildings having irregularities as identified in Section 2.9.1.1. The NSP is mainly suitable for buildings without significant higher-mode response. The NDP is suitable for any structure, subject to the limitations in Section 2.9.2.2.

2.9.2.1 Nonlinear Static Procedure (NSP)

The NSP may be used for any structure and any Rehabilitation Objective, with the following exceptions and limitations.

- The NSP should not be used for structures in which higher mode effects are significant, unless an LDP evaluation is also performed. To determine if higher modes are significant, a modal response spectrum analysis should be performed for the structure using sufficient modes to capture 90% mass participation, and a second response spectrum analysis should be performed considering only the first mode participation. Higher mode effects should be considered significant if the shear in any story calculated from the modal analysis considering all modes required to obtain 90% mass participation exceeds 130% of the corresponding story shear resulting from the analysis considering only the first mode response. When an LDP is performed to supplement an NSP for a structure with significant higher mode effects, the acceptance criteria values for deformation-controlled actions (*m* values), provided in Chapters 5 through 9, may be increased by a factor of 1.33.
- The NSP should not be used unless comprehensive knowledge of the structure has been obtained, as indicated in Section 2.7.2.

2.9.2.2 Nonlinear Dynamic Procedure (NDP)

The NDP may be used for any structure and any Rehabilitation Objective, with the following exceptions and limitations.

- The NDP is not recommended for use with wood frame structures.
- The NDP should not be utilized unless comprehensive knowledge of the structure has been obtained, as indicated in Section 2.7.2.
- The analysis and design should be subject to review by an independent third-party professional engineer with substantial experience in seismic design and nonlinear procedures.

2.9.3 Alternative Rational Analysis

Nothing in the *Guidelines* should be interpreted as preventing the use of any alternative analysis procedure that is rational and based on fundamental principles of engineering mechanics and dynamics. Such alternative analyses should not adopt the acceptance criteria contained in the *Guidelines* without careful review as to their applicability. All projects using alternative rational analysis procedures should be subject to review by an independent third-party professional engineer with substantial experience in seismic design.

2.9.4 Acceptance Criteria

The Analysis Procedures indicate the building's response to the design earthquake(s) and the forces and deformations imposed on the various components, as well as global drift demands on the structure. When LSP or LDP analysis is performed, acceptability of component behavior is evaluated for each of the component's various actions using Equation 3-18 for ductile (deformation-controlled) actions and Equation 3-19 for nonductile (force-controlled) actions. Figure 2-4 indicates typical idealized force-deformation curves for various types of component actions.

The type 1 curve is representative of typical ductile behavior. It is characterized by an elastic range (point 0 to point 1 on the curve), followed by a plastic range (points 1 to 3) that may include strain hardening or softening (points 1 to 2), and a strength-degraded range (points 2 to 3) in which the residual force that can be resisted is significantly less than the peak strength, but still substantial. Acceptance criteria for primary elements that exhibit this behavior are typically within the elastic or plastic ranges between points 1 and 2, depending on the Performance Level. Acceptance criteria for secondary elements can be within any of the ranges. Primary component actions exhibiting this behavior are considered deformation-controlled if the strain-hardening or strain-softening range is sufficiently large $e > 2g$; otherwise, they are considered force-controlled. Secondary component actions exhibiting this behavior are typically considered to be deformation-controlled.

The type 2 curve is representative of another type of ductile behavior. It is characterized by an elastic range and a plastic range, followed by a rapid and complete loss of strength. If the plastic range is sufficiently large ($e \geq 2g$), this behavior is categorized as deformation-controlled. Otherwise it is categorized as force-controlled. Acceptance criteria for primary and secondary components exhibiting this behavior will be within the elastic or plastic ranges, depending on the performance level.

The type 3 curve is representative of a brittle or nonductile behavior. It is characterized by an elastic range, followed by a rapid and complete loss of strength. Component actions displaying this behavior are always categorized as force-controlled. Acceptance criteria for primary and secondary components exhibiting this behavior are always within the elastic range.

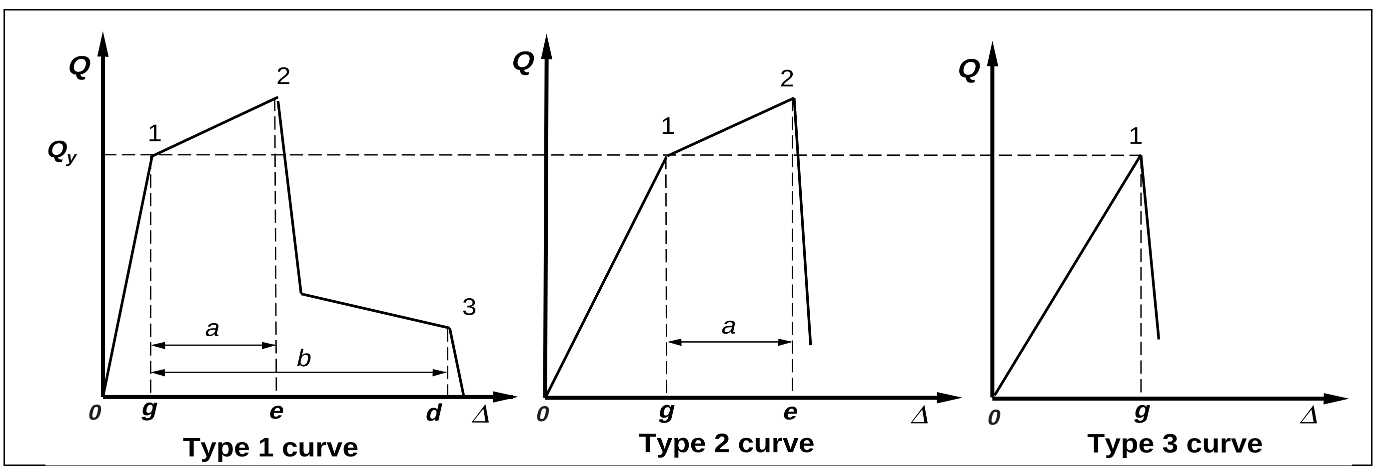

Figure 2-4 General Component Behavior Curves

Figure 2-5 shows an idealized force versus deformation curve that is used throughout the *Guidelines* to specify acceptance criteria for deformation-controlled component and element actions for any of the four basic types of materials. Linear response is depicted between point *A* (unloaded component) and an effective yield point *B*. The slope from *B* to *C* is typically a small percentage (0–10%) of the elastic slope, and is included to represent phenomena such as strain hardening. *C* has an ordinate that represents the strength of the component, and an abscissa value equal to the deformation at which significant strength degradation begins (line *CD*). Beyond point *D*, the component responds with substantially reduced strength to point *E*. At deformations greater than point *E*, the component strength is essentially zero.

In Figure 2-4, Q_y represents the yield strength of the component. In a real structure, the yield strength of individual elements that appear similar will actually have some variation. This is due to inherent variability in the material strength comprising the individual elements as well as differences in workmanship and physical condition. When evaluating the behavior of deformation-controlled components, the expected strength, Q_{CE}, rather than the yield strength Q_y is used. Q_{CE} is defined as the mean value of resistance at the deformation level anticipated, and includes consideration of the variability discussed above as well as phenomena such as strain hardening and plastic section development. When evaluating the behavior of force-controlled components, a lower bound estimate of the component strength, Q_{CL}, is considered. Q_{CL} is statistically defined as the mean minus one standard deviation of the yield strengths Q_y for a population of similar components.

For some components it is convenient to prescribe acceptance criteria in terms of deformation (e.g., θ or Δ), while for others it is more convenient to give criteria in terms of deformation ratios. To accommodate this, two types of idealized force versus deformation curves are used in the *Guidelines* as illustrated in Figures 2-5(a) and (b). Figure 2-5(a) shows normalized force (Q/Q_{CE}) versus deformation (θ or Δ) and the parameters *a*, *b*, and *c*. Figure 2-5(b) shows normalized force (Q/Q_{CE}) versus deformation ratio (θ/θ_y, Δ/Δ_y, or Δ/h) and the parameters *d*, *e*, and *c*. Elastic stiffnesses and values for the parameters *a*, *b*, *c*, *d*, and *e* that can be used for modeling components are given in Chapters 5 through 8.

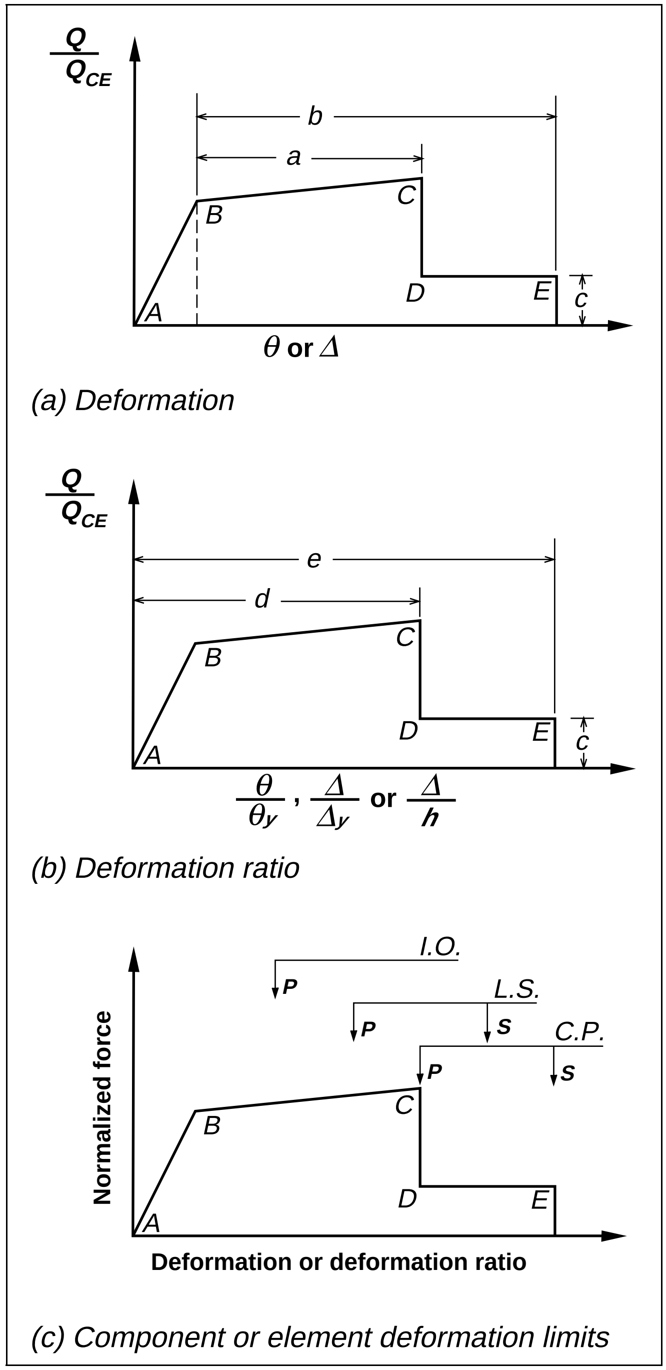

Figure 2-5 ***Idealized Component Load versus Deformation Curves for Depicting Component Modeling and Acceptability***

Figure 2-5(c) graphically shows the approximate deformation or deformation ratio, in relation to the idealized force versus deformation curve, that are deemed acceptable in the *Guidelines* for Primary (*P*) and Secondary (*S*) components for Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) Performance Levels. Numerical values of the acceptable deformations or deformation ratios are given in Chapters 5 through 8 for all types of components and elements.

If nonlinear procedures are used, component capacities consist of permissible inelastic deformation demands for deformation-controlled components, and of permissible strength demands for force-controlled components. If linear procedures are used, capacities are defined as the product of factors *m* and expected strengths Q_{CE} for deformation-controlled components and as permissible strength demands for force-controlled components. Tables 2-16 and 2-17 summarize these capacities. In this table, κ is the knowledge-based factor defined in Section 2.7.2, and σ is the standard deviation of the material strengths. Detailed guidelines on the calculation of individual component force and deformation capacities may be found in the individual materials chapters as follows:

- Foundations—Chapter 4
- Elements and components composed of steel or cast iron—Chapter 5
- Elements and components composed of reinforced concrete—Chapter 6
- Elements and components composed of reinforced or unreinforced masonry—Chapter 7
- Elements and components composed of timber, light metal studs, gypsum, or plaster products—Chapter 8
- Seismic isolation systems and energy dissipation systems—Chapter 9
- Nonstructural (architectural, mechanical, and electrical) components—Chapter 11
- Elements and components comprising combinations of materials—covered in the chapters associated

Table 2-16 Calculation of Component Action Capacity—Linear Procedures

Parameter	Deformation-Controlled	Force-Controlled
Existing Material Strength	Expected mean value with allowance for strain hardening	Lower bound value (approximately -1σ level)
Existing Action Capacity	$\kappa \cdot Q_{CE}$	$\kappa \cdot Q_{CE}$
New Material Strength	Expected material strength	Specified material strength
New Action Capacity	Q_{CE}	Q_{CE}

Note: Capacity reduction (ϕ) factors are typically taken as unity in the evaluation of capacities.

Table 2-17 Calculation of Component Action Capacity—Nonlinear Procedures

Parameter	Deformation-Controlled	Force-Controlled
Deformation Capacity—Existing Component	$\kappa \cdot$ deformation limit	N/A
Deformation Capacity—New Component	deformation limit	N/A
Strength Capacity—Existing Component	N/A	$\kappa \cdot Q_{CL}$
Strength Capacity—New Element	N/A	Q_{CL}

Note: Capacity reduction (ϕ) factors are typically taken as unity in the evaluation of capacities.

Acceptance criteria for elements and components for which criteria are not presented in the *Guidelines* shall be determined by a qualification testing program, in accordance with the procedures of Section 2.13.

2.10 Rehabilitation Strategies

Rehabilitation of buildings may be achieved by one or more of the strategies indicated in this section. Although not specifically required by any of the strategies, it is very beneficial for the rehabilitated building's lateral-force-resisting system to have an appropriate level of redundancy, so that any localized failure of a few elements of the system will not result in local collapse or an instability. This should be considered when developing rehabilitation designs.

2.10.1 Local Modification of Components

Some existing buildings have substantial strength and stiffness; however, some of their components do not have adequate strength, toughness, or deformation capacity to satisfy the Rehabilitation Objectives. An appropriate strategy for such structures may be to perform local modifications of those components that are inadequate, while retaining the basic configuration of the building's lateral-force-resisting system. Local modifications that can be considered include improvement of component connectivity, component strength, and/or component deformation capacity. This strategy tends to be the most economical approach to rehabilitation when only a few of the building's components are inadequate.

Local strengthening allows one or more understrength elements or connections to resist the strength demands predicted by the analysis, without affecting the overall response of the structure. This could include measures such as cover plating steel beams or columns, or adding plywood sheathing to an existing timber diaphragm. Such measures increase the strength of the element or component and allow it to resist more earthquake-induced force before the onset of damage.

Local corrective measures that improve the deformation capacity or ductility of a component allow it to resist large deformation levels with reduced amounts of damage, without necessarily increasing the strength. One such measure is placement of a confinement jacket around a reinforced concrete column to improve its ability to deform without spalling or degrading reinforcement splices. Another measure is reduction of the cross section of selected structural components to increase their flexibility and response displacement capacity.

2.10.2 Removal or Lessening of Existing Irregularities and Discontinuities

Stiffness, mass, and strength irregularities are common causes of undesirable earthquake performance. When reviewing the results of a linear analysis, the irregularities can be detected by examining the distribution of structural displacements and DCRs. When reviewing the results of a nonlinear analysis, the irregularities can be detected by examining the distribution of structural displacements and inelastic deformation demands. If the values of structural displacements, DCRs, or inelastic deformation demands predicted by the analysis are unbalanced, with large concentrations of high values within one story or at one side of a building, then an irregularity exists. Such irregularities are often, but not always, caused by the presence of a discontinuity in the structure, as for example, termination of a perimeter shear wall above the first story. Simple removal of the irregularity may be sufficient to reduce demands predicted by the analysis to acceptable levels. However, removal of discontinuities may be inappropriate in the case of historic buildings, and the effect of such alterations on important historic features should be considered carefully.

Effective corrective measures for removal or reduction of irregularities and discontinuities, such as soft or weak stories, include the addition of braced frames or shear walls within the soft/weak story. Torsional irregularities can be corrected by the addition of moment frames, braced frames, or shear walls to balance the distribution of stiffness and mass within a story. Discontinuous components such as columns or walls can be extended through the zone of discontinuity.

Partial demolition can also be an effective corrective measure for irregularities, although this obviously has significant impact on the appearance and utility of the building, and this may not be an appropriate alternative for historic structures. Portions of the structure that create the irregularity, such as setback towers or side wings, can be removed. Expansion joints can be created to transform a single irregular building into multiple regular structures; however, care must be taken to avoid the potential problems associated with pounding.

2.10.3 Global Structural Stiffening

Some flexible structures behave poorly in earthquakes because critical components and elements do not have adequate ductility or toughness to resist the large lateral deformations that ground shaking induces in the structure. For structures comprising many such elements, an effective way to improve performance is to stiffen the structure so that its response produces less lateral deformation. Construction of new braced frames or shear walls within an existing structure are effective measures for adding stiffness.

2.10.4 Global Structural Strengthening

Some existing buildings have inadequate strength to resist lateral forces. Such structures exhibit inelastic behavior at very low levels of ground shaking. Analyses of such buildings indicate large DCRs (or inelastic deformation demands) throughout the structure. By providing supplemental strength to such a building's lateral-force-resisting system, it is possible to raise the threshold of ground motion at which the onset of damage occurs. Shear walls and braced frames are effective elements for this purpose; however, they may be significantly stiffer than the structure to which they are added, requiring that they be designed to provide nearly all of the structure's lateral resistance. Moment-resisting frames, being more flexible, may be more compatible with existing elements in some structures; however, such flexible elements may not become effective in the building's response until existing brittle elements have already been damaged.

2.10.5 Mass Reduction

Two of the primary characteristics that control the amount of force and deformation induced in a structure by ground motion are its stiffness and mass. Reductions in mass result in direct reductions in both the amount of force and deformation demand produced by earthquakes, and therefore can be used in lieu of structural strengthening and stiffening. Mass can be reduced through demolition of upper stories, replacement of heavy cladding and interior partitions, or removal of heavy storage and equipment loads.

2.10.6 Seismic Isolation

When a structure is seismically isolated, compliant bearings are inserted between the superstructure and its foundations. This produces a system (structure and isolation bearings) with fundamental response that consists of nearly rigid body translation of the structure above the bearings. Most of the deformation induced in the isolated system by the ground motion occurs within the compliant bearings, which have been specifically designed to resist these concentrated displacements. Most bearings also have excellent energy dissipation characteristics (damping). Together, this results in greatly reduced demands on the existing elements of the structure, including contents and nonstructural components. For this reason, seismic isolation is often an appropriate strategy to achieve Enhanced Rehabilitation Objectives that include protection of historic fabric, valuable contents, and equipment, or for buildings that contain important operations and functions. This technique is most effective for relatively stiff buildings with low profiles and large mass. It is less effective for light, flexible structures.

2.10.7 Supplemental Energy Dissipation

A number of technologies are available that allow the energy imparted to a structure by ground motion to be dissipated in a controlled manner through the action of special devices—such as fluid viscous dampers (hydraulic cylinders), yielding plates, or friction pads—resulting in an overall reduction in the displacements of the structure. The most common devices dissipate energy through frictional, hysteretic, or viscoelastic processes. In order to dissipate substantial energy, dissipation devices must typically undergo significant deformation (or stroke) which requires that the structural experience substantial lateral displacements. Therefore, these systems are most effective in structures that are relatively flexible and have some inelastic deformation capacity. Energy dissipaters are most commonly installed in structures as components of braced frames. Depending on the characteristics of the device, either static or dynamic stiffness is added to the structure as well as energy dissipation capacity (damping). In some cases, although the structural displacements are reduced, the forces delivered to the structure can actually be increased.

2.11 General Analysis and Design Requirements

The detailed guidelines of this section apply to all buildings rehabilitated to achieve either the BSO or any Enhanced Rehabilitation Objectives. Though compliance with the guidelines in this section is not required for buildings rehabilitated to Limited Rehabilitation Objectives, such compliance should be considered. Unless otherwise noted, all numerical values apply to the Life Safety Performance Level, and must be multiplied by 1.25 to apply to Immediate Occupancy.

2.11.1 Directional Effects

The lateral-load-resisting system shall be demonstrated to be capable of responding to ground-motion-producing lateral forces in any horizontal direction. For buildings with orthogonal primary axes of resistance, this may be satisfied by evaluating the response of the structure to such forces in each of the two orthogonal directions. As a minimum, the effects of structural response in each of these orthogonal directions shall be considered independently. In addition, the combined effect of simultaneous response in both directions shall be considered, in accordance with the applicable procedures of Section 3.2.7.

2.11.2 P-Δ Effects

The structure shall be investigated to ensure that lateral drifts induced by earthquake response do not result in a condition of instability under gravity loads. At each story, the quantity θ_i shall be calculated for each direction of response, as follows:

$$\theta_i = \frac{P_i \delta_i}{V_i h_i} \qquad (2\text{-}14)$$

where:

P_i = Portion of the total weight of the structure including dead, permanent live, and 25% of transient live loads acting on the columns and bearing walls within story level *i*

V_i = Total calculated lateral shear force in the direction under consideration at story *i* due to earthquake response, assuming that the structure remains elastic

h_i = Height of story *i*, which may be taken as the distance between the centerline of floor framing at each of the levels above and below, the distance between the top of floor slabs at each of the levels above and below, or similar common points of reference

δ_i = Lateral drift in story *i*, in the direction under consideration, at its center of rigidity, using the same units as for measuring h_i

In any story in which θ_i is less than or equal to 0.1, the structure need not be investigated further for stability concerns. When the quantity θ_i in a story exceeds 0.1, the analysis of the structure shall consider P-Δ effects, in accordance with the applicable procedures of Section 3.2.5. When the value of θ_i exceeds 0.33, the structure should be considered potentially unstable and the rehabilitation design modified to reduce the computed lateral deflections in the story.

2.11.3 Torsion

Analytical models used to evaluate the response of the building to earthquake ground motion shall account for the effects of torsional response resulting from differences in the plan location of the center of mass and center of rigidity of the structure at all diaphragm levels that are not flexible.

2.11.4 Overturning

The effects of overturning at each level of the structure shall be evaluated cumulatively from the top of the structure to its base (See the commentary and further guidance in the sidebar, “Overturning Issues and Alternative Methods.”)

2.11.4.1 Linear Procedures

When a linear procedure is followed, each primary element at each level of the structure shall be investigated for stability against overturning under the effects of seismic forces applied at and above the level under consideration. Overturning effects may be resisted either through the stabilizing effect of dead loads or through positive connection of the element to structural components located below.

Where dead loads are used to resist the effects of overturning, the following shall be satisfied:

$$M_{ST} > M_{OT} / (C_1 C_2 C_3 J) \qquad (2\text{-}15)$$

where

M_{OT} = Total overturning moment induced on the element by seismic forces applied at and above the level under consideration

M_{ST} = Stabilizing moment produced by dead loads acting on the element, calculated as the sum of the products of each separate dead load and the horizontal distance between its vertical line of action and the centroid of the resisting

Overturning Issues and Alternative Methods

Response to earthquake ground motion results in a tendency for structures, and individual vertical elements of structures, to overturn about their bases. Although actual overturning is very rare, overturning effects can result in significant stresses, which have caused some local and global failures. In new building design, earthquake effects, including overturning, are evaluated for lateral forces that are significantly reduced (by the *R*-factor) from those which may actually develop in the structure.

For elements with positive attachment between levels, that behave as single units, such as reinforced concrete walls, the overturning effects are resolved into component forces (e.g., flexure and shear at the base of the wall) and the element is then proportioned with adequate strength to resist these overturning effects resulting from the reduced force levels.

Some elements, such as wood shear walls and foundations, may not be provided with positive attachment between levels. For them, an overturning stability check is performed. If the element has sufficient dead load to remain stable under the overturning effects of the design lateral forces and sufficient shear connection to the level below, then the design is deemed adequate. However, if dead load is inadequate to provide stability, then hold-downs, piles, or other types of uplift anchors are provided to resist the residual overturning caused by the design forces.

In the linear and nonlinear procedures of the *Guidelines*, lateral forces are not reduced by an *R*-factor, as they are for new buildings. Thus, computed overturning effects are larger than typically calculated for new buildings. Though the procedure used for new buildings is not completely rational, it has resulted in successful performance. Therefore, it was felt inappropriate to require that structures and elements of structures remain stable for the full lateral forces used in the linear procedures. Instead, the designer must determine if positive direct attachment will be used to resist overturning effects, or if dead loads will be used. If positive direct attachment is to be used, then this attachment is treated just as any other element or component action.

However, if dead loads alone are used to resist overturning, then overturning is treated as a force-controlled behavior and the overturning demands are reduced to an estimate of the real overturning demands which can be transmitted to the element, considering the overall limiting strength of the structure.

There is no rational method available, that has been shown to be consistent with observed behavior, to design or evaluate elements for overturning effects. The method described in the *Guidelines* is rational, but inconsistent with procedures used for new buildings. To improve damage control, the *Guidelines* method is recommended for checking acceptability for Performance Levels higher than Life Safety.

A simplified alternative, described below, for evaluating the adequacy of dead load to provide stability against overturning for Collapse Prevention or Life Safety Performance Levels is to use procedures similar to those used for the design of new buildings:

The load combination represented by

$$Q = 0.9Q_D + \frac{Q_E}{R_{OT}}$$

where Q_D and Q_E have opposite signs, and R_{OT} = 7.5 for Collapse Prevention Performance Level, or 6.0 for Life Safety, is used for evaluating the adequacy of the dead load alone. In the event that the dead load is inadequate, the design of any required hold-downs, piles, or other types of uplift anchors is performed according to the *Guidelines*. Acceptability criteria for components shall be taken from Chapters 5 through 8 with m = 1.

Additional studies are needed on the parameters that control overturning in seismic rehabilitation. These alternative methods are tentative, pending results from this future research.

force at the toe of the element about which the seismic forces tend to cause overturning

C_1, C_2, and C_3 = Coefficients defined in Section 3.3.1.3

J = Coefficient defined in Equation 3-17

The quantity M_{OT}/J need not exceed the overturning moment that can be applied to the element, as limited by the expected strength of the structure responding with an acceptable inelastic mechanism. The element shall be evaluated for the effects of compression on the toe about which it is being overturned. For this purpose, compression at the toe of the element shall be considered a force-controlled action, and shall be evaluated in accordance with the procedures of

Section 3.4.2.1. Refer to Chapter 4 for special considerations related to overturning effects on foundations.

Where dead loads acting on an element are insufficient to provide stability, positive attachment of the element to the structure located above and below the level under consideration shall be provided. These attachments shall be evaluated either as force-controlled or deformation-controlled actions, in accordance with the applicable guidelines provided in Chapters 5 through 8.

2.11.4.2 Nonlinear Procedures

When a nonlinear procedure is followed, the effect of earthquake-induced rocking of elements shall be included in the analytical model as a nonlinear degree of freedom, whenever such rocking can occur. The adequacy of elements above and below the level at which rocking occurs, including the foundations, shall be evaluated for any redistribution of loads that occurs as a result of this rocking in accordance with the procedures of Section 3.4.3.

2.11.5 Continuity

All elements of the structure shall be thoroughly and integrally tied together to form a complete path for the lateral inertial forces generated by the building's response to earthquake demands as follows:

- Every smaller portion of a structure, such as an outstanding wing, shall be tied to the structure as a whole with components capable of resisting horizontal forces equal, at a minimum, to $0.133S_{XS}$ times the weight of the smaller portion of the structure, unless the individual portions of the structure are self-supporting and are separated by a seismic joint.

- Every component shall be connected to the structure to resist a horizontal force in any direction equal, at a minimum, to $0.08S_{XS}$ times the weight of the component. For connections resisting concentrated loads, a minimum force of 1120 pounds shall be used; for distributed load connections, the minimum force shall be 280 pounds per lineal foot.

- Where a sliding support is provided at the end(s) of a component, the bearing length shall be sufficient to accommodate the expected differential displacements of the component relative to its support.

2.11.6 Diaphragms

Diaphragms shall be provided at each level of the structure as necessary to connect building masses to the primary vertical elements of the lateral-force-resisting system. The analytical model used to analyze the building shall account for the behavior of the diaphragms, which shall be evaluated for the forces and displacements indicated by the Analysis Procedure. In addition, the following shall apply:

- **Diaphragm Chords:** Except for diaphragms evaluated as “unchorded” using Chapter 8 of the *Guidelines*, a component shall be provided to develop horizontal shear stresses at each diaphragm edge (either interior or exterior). This component shall consist of either a continuous diaphragm chord, a continuous wall or frame element, or a continuous combination of wall, frame, and chord elements. The forces accumulated in these components and elements due to their action as diaphragm boundaries shall be considered in the evaluation of their adequacy. At re-entrant corners in diaphragms, and at the corners of openings in diaphragms, diaphragm chords shall be extended into the diaphragm a sufficient distance beyond the corner to develop the accumulated diaphragm boundary stresses through the attachment of the extended portion of the chord to the diaphragm.

- **Diaphragm Collectors:** At each vertical element to which a diaphragm is attached, a diaphragm collector shall be provided to transfer to the vertical element those calculated diaphragm forces that cannot be transferred directly by the diaphragm in shear. The diaphragm collector shall be extended into and attached to the diaphragm sufficiently to transfer the required forces.

- **Diaphragm Ties:** Diaphragms shall be provided with continuous tension ties between their chords or boundaries. Ties shall be spaced at a distance not exceeding three times the length of the tie. Ties shall be designed for an axial tensile force equal to $0.4S_{XS}$ times the weight tributary to that portion of the diaphragm located halfway between the tie and each adjacent tie or diaphragm boundary. Where diaphragms of timber, gypsum, or metal deck construction provide lateral support for walls of masonry or concrete construction, ties shall be designed for the wall anchorage forces specified in

Section 2.11.7 for the area of wall tributary to the diaphragm tie.

2.11.7 Walls

Walls shall be anchored to the structure as described in this section, and evaluated for out-of-plane inertial forces as indicated in Chapters 5 through 8.

- Walls shall be positively anchored to all diaphragms that provide lateral support for the wall or are vertically supported by the wall. Walls shall be anchored to diaphragms at horizontal distances not exceeding eight feet, unless it can be demonstrated that the wall has adequate capacity to span longitudinally between the supports for greater distances. Walls shall be anchored to each diaphragm for the larger of $400S_{XS}$ pounds per foot of wall or χS_{XS} times the weight of the wall tributary to the anchor, where χ shall be taken from Table 2-18. The anchorage forces shall be developed into the diaphragm. For flexible diaphragms, the anchorage forces shall be taken as three times those specified above and shall be developed into the diaphragm by continuous diaphragm crossties. For this purpose, diaphragms may be partitioned into a series of subdiaphragms. Each subdiaphragm shall be capable of transmitting the shear forces due to wall anchorage to a continuous diaphragm tie. Subdiaphragms shall have length-to-depth ratios of three or less. Where wall panels are stiffened for out-of-plane behavior by pilasters and similar elements, anchors shall be provided at each such element and the distribution of out-of-plane forces to wall anchors and diaphragm ties shall consider the stiffening effect. Wall anchor connections should be considered force-controlled.

Table 2-18 Coefficient χ for Calculation of Out-of-Plane Wall Forces

Performance Level	χ
Collapse Prevention	0.3
Life Safety	0.4
Immediate Occupancy	0.6

- A wall shall have a strength adequate to span between locations of out-of-plane support when subjected to out-of-plane forces equal to $0.4S_{XS}$ times the unit weight of the wall, over its area.

2.11.8 Nonstructural Components

Nonstructural components, including architectural, mechanical and electrical components, shall be anchored and braced to the structure in accordance with the provisions of Chapter 11. Post-earthquake operability of these components, as required for some Performance Levels, shall also be provided for in accordance with the requirements of Chapter 11 and the project Rehabilitation Objectives.

2.11.9 Structures Sharing Common Elements

Where two or more buildings share common elements, such as party walls or columns, and either the BSO or Enhanced Rehabilitation Objectives are desired, one of the following approaches shall be followed.

- The structures shall be thoroughly tied together so as to behave as an integral unit. Ties between the structures at each level shall be designed for the forces indicated in Section 2.11.5. Analyses of the buildings' response to earthquake demands shall account for the interconnection of the structures and shall evaluate the structures as integral units.

- The buildings shall be completely separated by introducing seismic joints between the structures. Independent lateral-force-resisting systems shall be provided for each structure. Independent vertical support shall be provided on each side of the seismic joint, except that slide bearings to support loads from one structure off the other may be used if adequate bearing length is provided to accommodate the expected independent lateral movement of each structure. It shall be assumed for such purposes that the structures may move out of phase with each other in each direction simultaneously. The original shared element shall be either completely removed or anchored to one of the structures in accordance with the applicable requirements of Section 2.11.5.

2.11.10 Building Separation

2.11.10.1 General

Buildings intended to meet either the BSO or Enhanced Objectives shall be adequately separated from adjacent structures to prevent pounding during response to the design earthquakes, except as indicated in Section 2.11.10.2. Pounding may be presumed not to occur whenever the buildings are separated at any level i by a distance greater than or equal to s_i as given by the equation:

$$s_i = \sqrt{\Delta_{i1}^2 + \Delta_{i2}^2} \quad (2\text{-}16)$$

where:

Δ_{i1} = Estimated lateral deflection of building 1 relative to the ground at level i

Δ_{i2} = Estimated lateral deflection of building 2 relative to the ground at level i

The value of s_i calculated by Equation 2-16 need not exceed 0.04 times the height of the buildings above grade at the zone of potential impacts.

2.11.10.2 Special Considerations

Buildings not meeting the separation requirements of Section 2.11.10.1 may be rehabilitated to meet the BSO, subject to the following limitations.

A properly substantiated analysis shall be conducted that accounts for the transfer of momentum and energy between the structures as they impact, and either:

- The diaphragms of the structures shall be located at the same elevations and shall be demonstrated to be capable of transferring the forces resulting from impact; or
- The structures shall be demonstrated to be capable of resisting all required vertical and lateral forces independent of any elements and components that may be severely damaged by impact of the structures.

2.11.11 Vertical Earthquake Effects

The effects of the vertical response of a structure to earthquake ground motion should be considered for any of the following cases:

- Cantilever elements and components of structures
- Pre-stressed elements and components of structures
- Structural components in which demands due to dead and permanent live loads exceed 80% of the nominal capacity of the component

2.12 Quality Assurance

Quality assurance of seismic rehabilitation construction for all buildings and all Rehabilitation Objectives should, as a minimum, conform to the recommendations of this section. These recommendations supplement the recommended testing and inspection requirements contained in the reference standards given in Chapters 5 through 11. The design professional responsible for the seismic rehabilitation of a specific building may find it appropriate to specify more stringent or more detailed requirements. Such additional requirements may be particularly appropriate for those buildings having Enhanced Rehabilitation Objectives.

2.12.1 Construction Quality Assurance Plan

The design professional in responsible charge should prepare a Quality Assurance Plan (QAP) for submittal to the regulatory agency as part of the overall submittal of construction documents. The QAP should specify the seismic-force-resisting elements, components, or systems that are subject to special quality assurance requirements. The QAP should, as a minimum, include the following:

- Required contractor quality control procedures
- Required design professional construction quality assurance services, including but not limited to the following:
  - Review of required contractor submittals
  - Monitoring of required inspection reports and test results
  - Construction consultation as required by the contractor on the intent of the construction documents
  - Procedures for modification of the construction documents to reflect the demands of unforeseen field conditions discovered during construction
  - Construction observation in accordance with Section 2.12.2.1.
- Required special inspection and testing requirements

2.12.2 Construction Quality Assurance Requirements

2.12.2.1 Requirements for the Structural Design Professional

The design professional in responsible charge, or a design professional designated by the design professional in responsible charge, should perform structural observation of the rehabilitation measures shown on the construction documents. Construction observation should include visual observation of the structural system, for general conformance to the conditions assumed during design, and for general conformance to the approved construction documents. Structural observation should be performed at significant construction stages and at completion of the structural/seismic system. Structural construction observation does not include the responsibilities for inspection required by other sections of the *Guidelines*.

Following such structural observations, the structural construction observer should report any observed deficiencies in writing to the owner's representative, the special inspector, the contractor, and the regulatory agency. The structural construction observer should submit to the building official a written statement attesting that the site visits have been made, and identifying any reported deficiencies that, to the best of the structural construction observer's knowledge, have not been resolved or rectified.

2.12.2.2 Special Inspection

The owner should employ a special inspector to observe the construction of the seismic-force-resisting system in accordance with the QAP for the following construction work:

- Items designated in Sections 1.6.2.1 through 1.6.2.9 in the 1994 and 1997 *NEHRP Recommended Provisions* (BSSC, 1995, 1997)
- All other elements and components designated for such special inspection by the design professional
- All other elements and components required by the regulatory agency

2.12.2.3 Testing

The special inspector(s) shall be responsible for verifying that the special test requirements, as described in the QAP, are performed by an approved testing agency for the types of work in the seismic-force-resisting system listed below:

- All work described in Sections 1.6.3.1 through 1.6.3.6 of the 1994 and 1997 *NEHRP Recommended Provisions* (BSSC, 1995, 1997)
- Other types of work designated for such testing by the design professional
- Other types of work required by the regulatory agency

2.12.2.4 Reporting and Compliance Procedures

The special inspector(s) should furnish to the regulatory agency, the design professional in responsible charge, the owner, the persons preparing the QAP, and the contractor copies of progress reports of observations, noting therein any uncorrected deficiencies and corrections of previously reported deficiencies. All observed deficiencies should be brought to the immediate attention of the contractor for correction.

At the completion of construction, the special inspector(s) should submit a final report to the regulatory agency, owner, and design professional in responsible charge indicating the extent to which inspected work was completed in accordance with approved construction documents. Any work not in compliance should be described.

2.12.3 Regulatory Agency Responsibilities

The regulatory agency having jurisdiction over construction of a building that is to be seismically rehabilitated should act to enhance and encourage the protection of the public that is represented by such rehabilitation. These actions should include those described in the following subsections.

2.12.3.1 Construction Document Submittals—Permitting

As part of the permitting process, the regulatory agency should require that construction documents be submitted for a permit to construct the proposed seismic rehabilitation measures. The documents should include a statement of the design basis for the rehabilitation, drawings (or adequately detailed sketches), structural/seismic calculations, and a QAP as recommended by Section 2.12.1. Appropriate structural construction specifications are also recommended, if structural requirements are not adequately defined by notes on drawings.

The regulatory agency should require that it be demonstrated (in the design calculations, by third-party review, or by other means) that the design of the seismic rehabilitation measures has been performed in conformance with local building regulations, the stated design basis, the intent of the *Guidelines*, and/or accepted engineering principles. The regulatory agency should be aware that compliance with the building code provisions for new structures is often not possible nor is it required by the *Guidelines*. It is not intended that the regulatory agency assure compliance of the submittals with the structural requirements for new construction.

The regulatory agency should maintain a permanent public file of the construction documents submitted as part of the permitting process for construction of the seismic rehabilitation measures.

2.12.3.2 Construction Phase Role

The regulatory agency having jurisdiction over the construction of seismic rehabilitation measures should monitor the implementation of the QAP. In particular, the following actions should be taken.

- Files of inspection reports should be maintained for a defined length of time following completion of construction and issuance of a certificate of occupancy. These files should include both reports submitted by special inspectors employed by the owner, as in Section 2.12.2.2, and those submitted by inspectors employed by the regulatory agency.

- Prior to issuance of certificates of occupancy, the regulatory agency should ascertain that either all reported noncompliant aspects of construction have been rectified, or such noncompliant aspects have been accepted by the design professional in responsible charge as acceptable substitutes and consistent with the general intent of the construction documents.

- Files of test reports prepared in accordance with Section 2.12.2.3 should be maintained for a defined length of time following completion of construction and issuance of a certificate of occupancy.

2.13 Alternative Materials and Methods of Construction

When an existing building or rehabilitation scheme contains elements and/or components for which structural modeling parameters and acceptance criteria are not provided in these *Guidelines*, the required parameters and acceptance criteria should be based on the experimentally derived cyclic response characteristics of the assembly, determined in accordance with this section. Independent third-party review of this process, by persons knowledgeable in structural component testing and the derivation of design parameters from such testing, shall be required under this section. The provisions of this section may also be applied to new materials and systems to assess their suitability for seismic rehabilitation.

2.13.1 Experimental Setup

When relevant data on the inelastic force-deformation behavior for a structural subassembly (elements or components) are not available, such data should be obtained based on experiments consisting of physical tests of representative subassemblies. Each subassembly should be an identifiable portion of the structural element or component, the stiffness of which is to be modeled as part of the structural analysis process. The objective of the experiment should be to permit estimation of the lateral-force-displacement relationships (stiffness) for the subassemblies at different loading increments, together with the strength and deformation capacities for the desired performance levels. These properties are to be used in developing an analytical model of the structure's response to earthquake ground motions, and in judging the acceptability of this predicted behavior. The limiting strength and deformation capacities should be determined from the experimental program from the average values of a minimum of three identical or similar tests performed for a unique design configuration.

The experimental setup should simulate, to the extent practical, the actual construction details, support conditions, and loading conditions expected in the building. Specifically, the effects of axial load, moment, and shear, if expected to be significant in the building, should be properly simulated in the experiments. Full-scale tests are recommended. The loading should consist of fully reversed cyclic loading at increasing displacement levels. The test protocol for number of cycles and displacement levels shall conform to generally accepted procedures. Increments should be continued until the subassembly exhibits complete failure, characterized by a complete (or near-complete) loss of lateral- and gravity-load-resisting ability.

2.13.2 Data Reduction and Reporting

A report should be prepared for each experiment. The report should include the following:

- Description of the subassembly being tested
- Description of the experimental setup, including:
  - Details on fabrication of the subassembly
  - Location and date of experiment
  - Description of instrumentation employed
  - Name of the person in responsible charge of the test
  - Photographs of the specimen, taken prior to testing
- Description of the loading protocol employed, including:
  - Increment of loading (or deformation) applied
  - Rate of loading application
  - Duration of loading at each stage
- Description, including photographic documentation, and limiting deformation value for all important behavior states observed during the test, including the following, as applicable:
  - Elastic range with effective stiffness reported
  - Plastic range
  - Onset of apparent damage
  - Loss of lateral-force-resisting capacity
  - Loss of vertical-load-carrying capacity
  - Force deformation plot for the subassembly (noting the various behavior states)
  - Description of limiting behavior states and failure modes

2.13.3 Design Parameters and Acceptance Criteria

The following procedure should be followed to develop design parameters and acceptance criteria for subassemblies based on experimental data:

1. An idealized lateral-force-deformation pushover curve should be developed from the experimental data for each experiment, and for each direction of loading with unique behavior. The curve should be plotted in a single quadrant (positive force versus positive deformation, or negative force versus negative deformation). The curve should be constructed as follows:

   a. The appropriate quadrant of data from the lateral-force-deformation plot from the experimental report should be taken.

   b. A smooth "backbone" curve should be drawn through the intersection of the first cycle curve for the (i)th deformation step with the second cycle curve of the (i-1)th deformation step, for all i steps, as indicated in Figure 2-6.

   c. The backbone curve so derived shall be approximated by a series of linear segments, drawn to form a multisegmented curve conforming to one of the types indicated in Figure 2-4.

2. The approximate multilinear curves derived for all experiments involving the subassembly should be compared and an average multilinear representation of the subassembly behavior should be derived based on these curves. Each segment of the composite curve should be assigned the average stiffness (either positive or negative) of the similar segments in the approximate multilinear curves for the various experiments. Each segment on the composite curve shall terminate at the average of the deformation levels at which the similar segments of the approximate multilinear curves for the various experiments terminate.

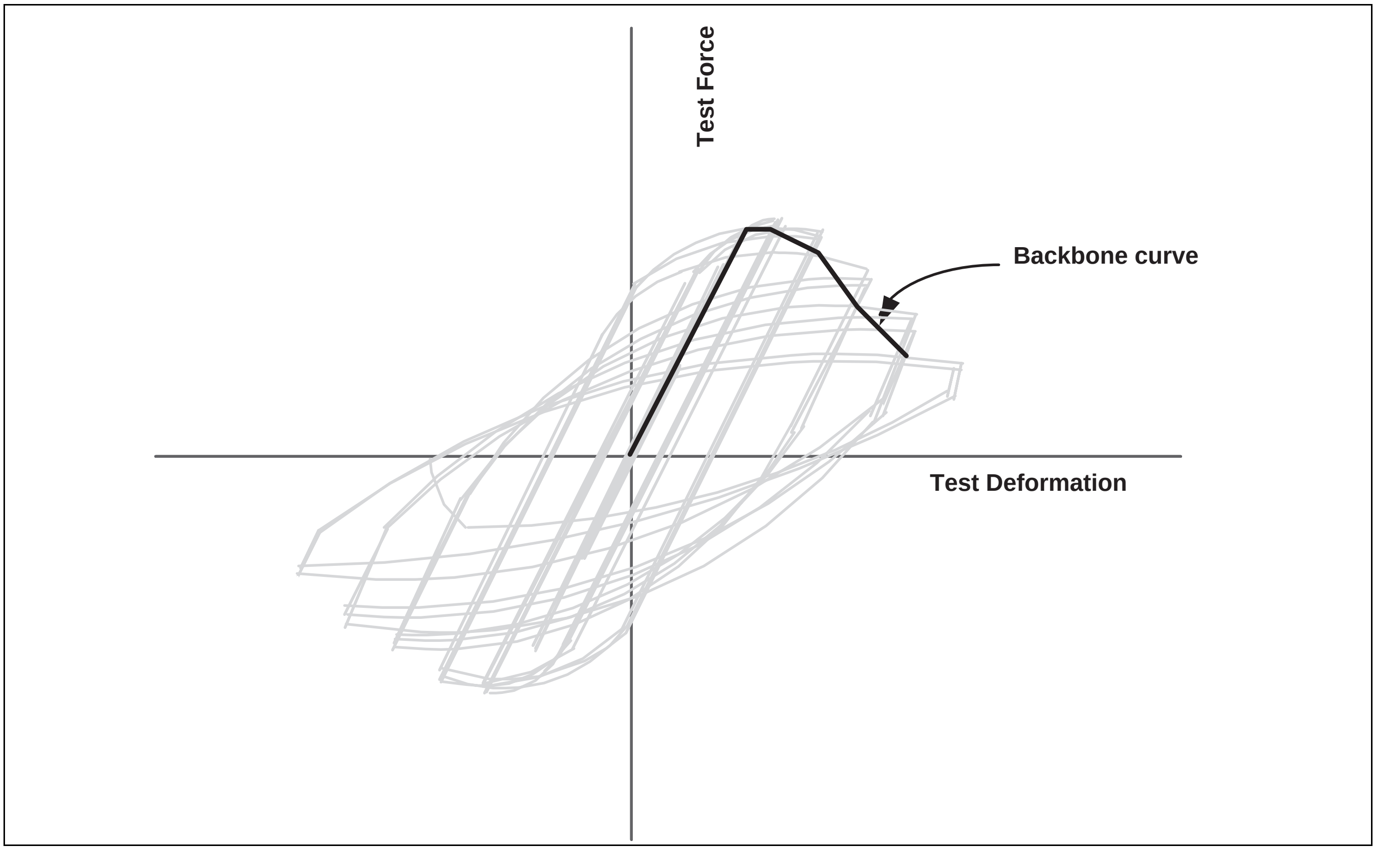

Figure 2-6 Backbone Curve for Experimental Data

3. The stiffness of the subassembly for use in linear procedures should be taken as the slope of the first segment of the composite curve.

4. For the purpose of determining acceptance criteria, assemblies should be classified as being either force-controlled or deformation-controlled. Assemblies should be classified as force-controlled unless any of the following apply.

   – The composite multilinear force-deformation curve for the assembly, determined in accordance with (2), above, conforms to either Type 1 or Type 2, as indicated in Figure 2-4; and the deformation parameter *e*, as indicated in Figure 2-4, is at least twice the deformation parameter *g*, as also indicated in Figure 2-4.

   – The composite multilinear force-deformation curve for the assembly determined in accordance with (2), above, conforms to Type 1, as indicated in Figure 2-4, and the deformation parameter *e* is less than twice the deformation parameter *g*, but the deformation parameter *d* is at least twice the deformation parameter *g*. In this case, acceptance criteria may be determined by redrawing the force-deformation curve as a Type 2 curve, with that portion of the original curve between points 2 and 3 extended back to intersect the first linear segment at point 1' as indicated in Figure 2-7. The parameters a' and Q'_y shall be taken as indicated in Figure 2-7 and shall be used in place of *a* and Q_y in Figure 2-4.

5. The strength capacity, Q_{CL}, for force-controlled elements evaluated using either the linear or nonlinear procedures shall be taken as follows:

   – For any Performance Level or Range, the lowest strength Q_y determined from the series of representative assembly tests

6. The acceptance criteria for deformation-controlled assemblies used in nonlinear procedures shall be the

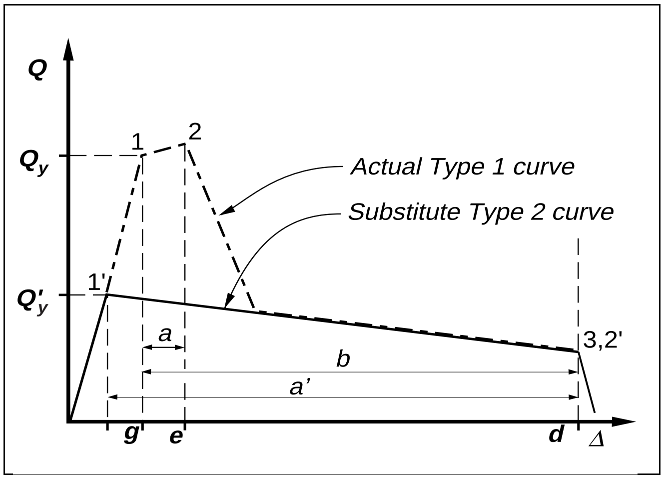

Figure 2-7 Alternative Force Deformation Curve

deformations corresponding with the following points on the curves of Figure 2-4:

a. Primary Elements

- Immediate Occupancy: the deformation at which significant, permanent, visible damage occurred in the experiments
- Life Safety: 0.75 times the deformation at point 2 on the curves
- Collapse Prevention: 0.75 times the deformation at point 3 on the Type 1 curve, but not greater than point 2

b. Secondary Elements

- Immediate Occupancy: the deformation at which significant, permanent, visible damage occurred in the experiments
- Life Safety: 100% of the deformation at point 2 on the Type 1 curve, but not less than 75% of the deformation at point 3
- Collapse Prevention: 100% of the deformation at point 3 on the curve

7. The *m* values used as acceptance criteria for deformation-controlled assemblies in the linear procedures shall be taken as 0.75 times the ratio of the deformation acceptance criteria, given in (6) above, to the deformation at yield, represented by the deformation parameter *g* in the curves shown in Figure 2-4.

2.14 Definitions

Acceptance criteria: Permissible values of such properties as drift, component strength demand, and inelastic deformation used to determine the acceptability of a component's projected behavior at a given Performance Level.

Action: Sometimes called a generalized force, most commonly a single force or moment. However, an action may also be a combination of forces and moments, a distributed loading, or any combination of forces and moments. Actions always produce or cause displacements or deformations; for example, a bending moment action causes flexural deformation in a beam; an axial force action in a column causes axial deformation in the column; and a torsional moment action on a building causes torsional deformations (displacements) in the building.

Assembly: Two or more interconnected components.

BSE-1: Basic Safety Earthquake-1, which is the lesser of the ground shaking at a site for a 10%/50 year earthquake or two-thirds of the Maximum Considered Earthquake (MCE) at the site.

BSE-2: Basic Safety Earthquake-2, which is the ground shaking at a site for an MCE.

BSO: Basic Safety Objective, a Rehabilitation Objective in which the Life Safety Performance Level is reached for the BSE-1 demand and the Collapse Prevention Performance Level is reached for the BSE-2.

Building Performance Level: A limiting damage state, considering structural and nonstructural building components, used in the definition of Rehabilitation Objectives.

Capacity: The permissible strength or deformation for a component action.

Coefficient of variation: For a sample of data, the ratio of the standard deviation for the sample to the mean value for the sample.

Components: The basic structural members that constitute the building, such as beams, columns, slabs, braces, piers, coupling beams, and connections. Components, such as columns and beams, are combined to form elements (e.g., a frame).

Corrective measure: Any modification of a component or element, or the structure as a whole, intended to reduce building vulnerability.

Critical action: That component action that reaches its elastic limit at the lowest level of lateral deflection, or loading, for the structure.

Demand: The amount of force or deformation imposed on an element or component.

Diaphragm: A horizontal (or nearly horizontal) structural element used to distribute inertial lateral forces to vertical elements of the lateral-force-resisting system.

Diaphragm chord: A diaphragm component provided to develop shears at the edge of the diaphragm, resisted either in tension or compression.

Diaphragm collector: A diaphragm component provided to transfer lateral force from the diaphragm to vertical elements of the lateral-force-resisting system or to other portions of the diaphragm.

Element: An assembly of structural components that act together in resisting lateral forces, such as moment-resisting frames, braced frames, shear walls, and diaphragms.

Flexible diaphragm: A diaphragm with stiffness characteristics indicated in Section 3.2.4.

Hazard level: Earthquake shaking demands of specified severity, determined on either a probabilistic or deterministic basis.

Lateral-force-resisting system: Those elements of the structure that provide its basic lateral strength and stiffness, and without which the structure would be laterally unstable.

Maximum Considered Earthquake (MCE): An extreme earthquake hazard level used in the formation of Rehabilitation Objectives. (See BSE-2.)

Mean return period: The average period of time, in years, between the expected occurrences of an earthquake of specified severity.

Nonstructural Performance Level: A limiting damage state for nonstructural building components used to define Rehabilitation Objectives.

Primary component: Those components that are required as part of the building's lateral-force-resisting system (as contrasted to secondary components).

Primary element: An element that is essential to the ability of the structure to resist earthquake-induced deformations.

Rehabilitation Method: A procedural methodology for the reduction of building earthquake vulnerability.

Rehabilitation Objective: A statement of the desired limits of damage or loss for a given seismic demand, usually selected by the owner, engineer, and/or relevant public agencies.

Rehabilitation strategy: A technical approach for developing rehabilitation measures for a building to reduce its earthquake vulnerability.

Secondary component: Those components that are not required for lateral force resistance (contrasted to primary components). They may or may not actually resist some lateral forces.

Secondary element: An element that does not affect the ability of the structure to resist earthquake-induced deformations.

Seismic demand: Seismic hazard level commonly expressed in the form of a ground shaking response spectrum. It may also include an estimate of permanent ground deformation.

Simplified Rehabilitation Method: An approach, applicable to some types of buildings and Rehabilitation Objectives, in which analyses of the entire building's response to earthquake hazards are not required.

Strength: The maximum axial force, shear force, or moment that can be resisted by a component.

Stress resultant: The net axial force, shear, or bending moment imposed on a cross section of a structural component.

Structural Performance Level: A limiting structural damage state, used in the definition of Rehabilitation Objectives.

Structural Performance Range: A range of structural damage states, used in the definition of Rehabilitation Objectives.

Subassembly: A portion of an assembly.

Systematic Rehabilitation Method: An approach to rehabilitation in which complete analysis of the building's response to earthquake shaking is performed.

2.15 Symbols

B_S Coefficient used to adjust short period spectral response for the effect of viscous damping

B_1 Coefficient used to adjust one-second period spectral response for the effect of viscous damping

C_1 Modification factor to relate expected maximum inelastic displacements to displacements calculated for linear elastic response, calculated in accordance with Section 3.3.1.3.

C_2 Modification factor to represent the effect of hysteresis shape on the maximum displacement response, calculated in accordance with Section 3.3.1.3.

C_3 Modification factor to represent increased displacements due to second-order effects, calculated in accordance with Section 3.3.1.3.

DCR Demand-capacity ratio, computed in accordance with Equation 2-12 or required in Equation 2-13

$\overline{DCR}$ Average demand-capacity ratio for a story, computed in accordance with Equation 2-13

F_a Factor to adjust spectral acceleration in the short period range for site class

F_v Factor to adjust spectral acceleration at one second for site class

H Thickness of a soil layer in feet

J Coefficient used in linear procedures to estimate the maximum earthquake forces that a component can sustain and correspondingly deliver to other components. The use of *J* recognizes that the framing system cannot likely deliver the force Q_E because of nonlinear response in the framing system

LDP Linear Dynamic Procedure—a method of lateral response analysis

LSP Linear Static Procedure—a method of lateral response analysis

M_{ST} The stabilizing moment for an element, calculated as the sum of the dead loads acting on the element times the distance between the lines of action of these dead loads and the toe of the element.

M_{OT} The overting moment on an element, calculated as the sum of the lateral forces applied on the element times the distance between the lines of action of these lateral forces and the toe of the element.

N Blow count in soil obtained from a standard penetration test (SPT)

$\overline{N}$ Average blow count in soil within the upper 100 feet of soil, calculated in accordance with Equation 2-6

NDP Nonlinear Dynamic Procedure—a method of lateral response analysis

NSP Nonlinear Static Procedure—a method of lateral response analysis

P_{E50} Probability of exceedance in 50 years

PI Plasticity Index for soil, determined as the difference in water content of soil at the liquid limit and plastic limit

P_i The total weight of the structure, including dead, permanent live, and 25% of transient live loads acting on the columns and bearing walls within story level *i*

P_R Mean return period

Q_{CE} Expected strength of a component or element at the deformation level under consideration for deformation-controlled actions

Q_{CL} Lower-bound estimate of the strength of a component or element at the deformation level under consideration for force-controlled actions

Q_D Calculated stress resultant in a component due to dead load effects

Q_E Calculated earthquake stress resultant in a component

Q_{UD} The dead load force on a component.

Q_y Yield strength of a component

S_S Spectral response acceleration at short periods, obtained from response acceleration maps, *g*

S_{XS} Spectral response acceleration at short periods for any hazard level and any damping, *g*

S_{X1} Spectral response acceleration at a one-second period for any hazard level and any damping, *g*

S_a Spectral acceleration, *g*

S_{aD} Design BSE-1 spectral response acceleration at any period T, *g*

S_{aM} Design BSE-2 spectral response acceleration at any period T, *g*

S_1 Spectral response acceleration at a one-second period, obtained from response acceleration maps, *g*

T Fundamental period of the building in the direction under consideration

T_0 Period at which the constant acceleration and constant velocity regions of the design spectrum intersect

V_i Total calculated lateral shear force in story *i* due to earthquake response, assuming that the structure remains elastic

d_i Depth, in feet, of a layer of soils having similar properties, and located within 100 feet of the surface

h_i Height, in feet, of story *i*; this may be taken as the distance between the centerline of floor framing at each of the levels above and below, the distance between the top of floor slabs at each of the levels above and below, or similar common points of reference

m Modification factor used in the acceptance criteria of deformation-controlled components or elements, indicating the available ductility of a component action

s_i Horizontal distance, in feet, between adjacent buildings at the height above ground at which pounding may occur

s_u Undrained shear strength of soil, pounds/ft^2

$\bar{s}_u$ Average value of the undrained soil shear strength in the upper 100 feet of soil, calculated in accordance with Equation 2-6, pounds/ft^2

v_s Shear wave velocity in soil, in feet/sec

$\bar{v}_s$ Average value of the soil shear wave velocity in the upper 100 feet of soil, calculated in accordance with Equation 2-6, feet/sec

w Water content of soil, calculated as the ratio of the weight of water in a unit volume of soil to the weight of soil in the unit volume, expressed as a percentage

β Modal damping ratio

Δ_{i1} Estimated lateral deflection of building 1 relative to the ground at level *i*

Δ_{i2} Estimated lateral deflection of building 2 relative to the ground at level *i*

δ_i The lateral drift in story *i*, at its center of rigidity

θ_i A parameter indicative of the stability of a structure under gravity loads and earthquake-induced lateral deflection

κ A reliability coefficient used to reduce component strength values for existing components based on the quality of knowledge about the components' properties. (See Section 2.7.2.)

σ Standard deviation of the variation of the material strengths

ϕ A capacity reduction coefficient used to reduce the design strength of new components to account for variations in material strength, cross-section dimension, and construction quality

χ A coefficient used to determine the out-of-plane forces required for anchorage of structural walls to diaphragms

2.16 References

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