2. General Requirements

2.1 Scope

This chapter sets forth general requirements for data collection, analysis procedures, methods, and strategies for the design of seismic rehabilitation projects.

Section 2.2 specifies data collection procedures for obtaining required as-built information on buildings. Section 2.3 outlines the Simplified and Systematic Methods for seismic rehabilitation of buildings. Section 2.4 specifies limitations on selecting analysis procedures, and defines component behavior types and corresponding acceptance criteria. Section 2.5 identifies acceptable rehabilitation strategies. Section 2.6 contains general design requirements for rehabilitation designs. Section 2.7 specifies construction quality assurance requirements. Section 2.8 specifies procedures for developing alternative modeling parameters and acceptance criteria.

2.2 As-Built Information

The configuration of the structural system, as well as the type, detailing, connectivity, material strength and condition of the structural elements comprising the building shall be determined in accordance with this section. Data shall also be obtained for all nonstructural elements of the building that affect the forces and deformations experienced by the structural elements during response to earthquake ground motion. This data shall be obtained from available drawings, specifications, and other documents for the existing construction, and shall be supplemented and verified by on-site investigations including nondestructive examination and testing of building materials and components as required in Section 2.2.6.

At least one site visit shall be made to observe exposed conditions of building configuration, building components, site and foundation conditions, and adjacent structures, and to verify that as-built information obtained from other sources is representative of the existing conditions.

C2.2 As-Built Information

Existing building characteristics pertinent to seismic performance should be obtained from the following sources, as appropriate:

1. Field observation of exposed conditions and configuration.
2. Construction documents, engineering analyses, reports, soil borings and test logs, maintenance histories, and manufacturers' literature and test data available from the owner and/or the code official.
3. Reference standards and codes from the period of construction as cited in Chapters 5 through 8.
4. Destructive and nondestructive examination and testing of selected building materials and components as specified in Section 2.2.6.
5. Interviews with building owners, tenants, managers, the original architect and engineer, contractor(s), and the local building official as arranged by the code official.

The information required for an existing building may also be available from a previously conducted seismic evaluation of the building. For situations where seismic rehabilitation has been mandated according to building construction classification, familiarity with the building type and typical seismic deficiencies is recommended. Such information is available from several sources, including *FEMA 310*. Such information may be sufficient for Simplified Rehabilitation. Additional as-built information may be needed for Systematic Rehabilitation.

When a destructive and nondestructive testing program is necessary to obtain as-built information, it is prudent to perform preliminary calculations to select key locations or parameters prior to establishing a detailed testing program. These obtain knowledge at a reasonable cost and with as little disruption as possible of construction features and materials properties at concealed locations.

If the building is a historic structure, it is also important to identify the locations of historically significant features and fabric which should be thoroughly investigated. 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 Appendix A. The services of a historic preservation expert may be necessary.

2.2.1 Building Configuration

The as-built building configuration information shall include data on the type and arrangement of existing structural elements and components of the gravity- and lateral-load-resisting systems, and the nonstructural components of the building that affect either the stiffness or strength of the structural elements, or the structural load path. The structural elements and components shall be identified and categorized as either primary or secondary, using the criteria described in Section 2.4.4.2.

The as-built building configuration shall be examined to identify the gravity and lateral load paths. These load paths shall be evaluated to identify seismic deficiencies prior to conducting a detailed rehabilitation design.

C2.2.1 Building Configuration

Identifying the building configuration will identify both the intended load-resisting elements and effective load-resisting elements. Effective load-resisting elements may include structural elements and nonstructural elements that participate in resisting lateral loads, whether or not they were intended to do so by the original designers. Potential seismic deficiencies in intended and effective load resisting elements may include discontinuities in the load path, weak links, irregularities and inadequate strength and deformation capacities.

FEMA 310 is one example of a seismic evaluation tool that offers guidance on building configuration.

2.2.2 Component Properties

Sufficient as-built information shall be collected on component properties and their interconnection with other components to permit computation of strengths and deformation capacities. To account for any uncertainty associated with component as-built information, a knowledge factor κ shall be used in the capacity evaluation as specified in Section 2.2.6.4.

C2.2.2 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 specified 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.

2.2.3 Site Characterization and Geotechnical Information

Data on foundation configuration and soil surface and subsurface conditions at the site shall be obtained from existing documentation, visual site reconnaissance, or a program of site-specific subsurface investigation in accordance with Chapter 4. A site-specific subsurface investigation shall be performed when Enhanced Rehabilitation Objectives are selected, or when insufficient data are available to quantify foundation capacities or determine the presence of geologic site hazards identified in Section 4.2.2. When historic information indicates geologic site hazards have occurred in the vicinity of the site, a site-specific subsurface investigation shall be performed to investigate the potential for geologic site hazards at the site. Use of applicable existing foundation capacity or geologic site hazard information available for the site shall be permitted.

A site reconnaissance shall be performed to observe variances from existing building drawings, foundation modifications not shown on existing documentation, the presence of adjacent development or grading activities, and evidence of poor foundation performance.

C2.2.3 Site Characterization and Geotechnical Information

Sources of applicable existing geotechnical information include original design information, foundation capacity information included on the drawings, and previous geotechnical reports located at, or in the immediate vicinity, of the site.

Adjacent building development or grading activities that impose loads or reduce the lateral support of the structure can affect building performance in a future earthquake. Evidence of poor foundation performance can include settlement of building floor slabs and foundations, or differential movement visible at adjacent exterior sidewalks or other miscellaneous site construction.

2.2.4 Adjacent Buildings

Sufficient data shall be collected on the configuration of adjacent structures to permit analysis of the interaction issues identified in Section 2.2.4.1 through 2.2.4.3. If the necessary information on adjacent structures is not available, the building owner shall be informed of the potential consequences of the interactions which are not being evaluated.

2.2.4.1 Building Pounding

Data shall be collected to permit investigation of the effects of building pounding in accordance with Section 2.6.10, whenever a portion of an adjacent structure is located within 4% of the height above grade at the location of potential impact.

C2.2.4.1 Building Pounding

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.

2.2.4.2 Shared Element Condition

Data shall be collected on adjacent structures that share common vertical or lateral load-resisting elements with the building to permit investigation in accordance with Section 2.6.9.

C2.2.4.2 Shared Element Condition

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.

2.2.4.3 Hazards from Adjacent Buildings

Data on adjacent buildings shall be collected to permit consideration of the potential for damage due to hazards such as falling debris, aggressive chemical leakage, fire, or explosion that might occur as a result of an earthquake. If the potential for such hazards exists, the building owner shall be notified of the potential impact on the ability to meet the selected Rehabilitation Objective.

C2.2.4.3 Hazards from Adjacent Buildings

Hazards from adjacent buildings that may impact building performance or the operation of the building after an earthquake should be considered and discussed with the building owner. 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 suitably resistant access to the building. Sufficient information should 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* may be adequate for this purpose.

Table 2-1 Data Collection Requirements

Data	Level of Knowledge							
	Minimum		Usual				Comprehensive	
Rehabilitation Objective	BSO or Lower		BSO or Lower		Enhanced		Enhanced	
Analysis Procedures	LSP, LDP		All		All		All	
Testing	No Tests		Usual Testing		Usual Testing		Comprehensive Testing	
Drawings	Design Drawings	Or Equivalent	Design Drawings	Or Equivalent	Design Drawings	Or Equivalent	Construction Documents	Or Equivalent
Condition Assessment	Visual	Compre-hensive	Visual	Compre-hensive	Visual	Compre-hensive	Visual	Compre-hensive
Material Properties	From Drawings or Default Values	From Default Values	From Drawings and Tests	From Usual Tests	From Drawings and Tests	From Usual Tests	From Documents and Tests	From Compre-hensive Tests
Knowledge Factor (κ)	0.75	0.75	1.00	1.00	0.75	0.75	1.00	1.00

2.2.5 Primary and Secondary Elements and Components

Data shall be collected to classify elements and components as primary or secondary in accordance with Section 2.4.4.2. Data on primary and secondary elements and components shall be collected in sufficient detail to permit modeling and analysis of such components in accordance with the requirements of this standard.

2.2.6 Data Collection Requirements

Data on the as-built condition of the structure, components, site, and adjacent buildings shall be collected in sufficient detail to perform the selected analysis procedure. The extent of data collected shall be consistent with minimum, usual, or comprehensive levels of knowledge as specified in Sections 2.2.6.1, 2.2.6.2, or 2.2.6.3. The required level of knowledge shall be determined considering the selected Rehabilitation Objective and analysis procedure in accordance with Table 2-1.

2.2.6.1 Minimum Data Collection Requirements

As a minimum, collection of as-built information shall consist of the following:

1. Information shall be obtained from design drawings with sufficient information to analyze component demands and calculate component capacities. For minimum data collection, design drawings need not be complete, but shall communicate the configuration of the gravity and lateral-force-resisting system and typical connections with sufficient detail to carry out linear analysis procedures. When design drawings are available, information shall be verified by a visual condition assessment in accordance with Chapters 5 through 8.

2. In the absence of sufficient information from design drawings, incomplete or non-existent information shall be supplemented by a comprehensive condition assessment including destructive and nondestructive investigation in accordance with Chapters 5 through 8.

3. In the absence of material test records and quality assurance reports, use of default material properties in accordance with Chapters 5 through 8 shall be permitted.

4. Information needed on adjacent buildings, referenced in Section 2.2.4, shall be gained through field surveys and research of available as-built information.

5. Information on foundation and site related concerns shall be collected in accordance with Section 2.2.3.

2.2.6.2 Usual Data Collection Requirements

Usual collection of as-built information shall consist of the following:

1. Information shall be obtained from design drawings with sufficient information to analyze component demands and calculate component capacities. For usual data collection, design drawings need not be complete, but shall communicate the configuration of the gravity and lateral-force-resisting system and typical connections with sufficient detail to carry out any analysis procedure. When design drawings are available, information shall be verified by a visual condition assessment in accordance with Chapters 5 through 8.

2. In the absence of sufficient information from design drawings, incomplete or non-existent information shall be supplemented by a comprehensive condition assessment including destructive and nondestructive investigation in accordance with Chapters 5 through 8.

3. In the absence of material test records and quality assurance reports, material properties shall be determined by usual materials testing in accordance with Chapters 5 through 8.

4. Information needed on adjacent buildings, referenced in Section 2.2.4, shall be gained through field surveys and research of available as-built information.

5. Information on foundation and site related concerns shall be collected in accordance with Section 2.2.3.

2.2.6.3 Comprehensive Data Collection Requirements

Comprehensive collection of as-built information shall consist of the following:

1. Information shall be obtained from construction documents including design drawings, specifications, material test records, and quality assurance reports covering original construction and subsequent modifications to the structure. When construction documents are available, information shall be verified by a visual condition assessment in accordance with Chapters 5 through 8.

2. If construction documents are incomplete, missing information shall be supplemented by a comprehensive condition assessment including destructive and nondestructive investigation in accordance with Chapters 5 through 8.

3. In the absence of material test records and quality assurance reports, material properties shall be determined by comprehensive materials testing in accordance with Chapters 5 through 8. The coefficient of variation in material test results shall be less than 20%.

4. Information needed on adjacent buildings, referenced in Section 2.2.4, shall be gained through field surveys and research of available as-built information.

5. Information on foundation and site related concerns shall be collected in accordance with Section 2.2.3.

2.2.6.4 Knowledge Factor

2.2.6.4.1 General

To account for uncertainty in the collection of as-built data, a knowledge factor, κ, shall be selected from Table 2-1 considering the selected Rehabilitation Objective, analysis procedure, and data collection process. Knowledge factors shall be applied on a component basis as determined by the level of knowledge obtained for individual components during data collection.

C2.2.6.4.1 General

The κ factor is used to express the confidence with which the properties of the building components are known, when calculating component capacities. The value of the factor is established from the knowledge obtained based on access to original construction documents, or condition assessments including destructive or nondestructive testing of representative components. The values of the factor have been established, indicating whether the level of knowledge is “minimum,” “usual,” or “comprehensive.”

2.2.6.4.2 Linear Procedures

When linear procedures are used, data collection consistent with the minimum level of knowledge shall be permitted.

2.2.6.4.3 Nonlinear Procedures

When nonlinear procedures are used, data collection consistent with either the usual or comprehensive levels of knowledge shall be performed.

2.2.6.4.4 Assumed values of Knowledge Factor

Selected κ values shall be supported by data collection performed at any time prior to implementation of a rehabilitation strategy. It shall be permitted to perform an analysis in advance of the data collection process using an assumed value of κ, provided the value of κ is substantiated by data collection in accordance with the requirements of Section 2.2.6 prior to implementation of the rehabilitation strategies.

If the assumed value of κ is not supported by subsequent data collection, the analysis shall be revised to include a revised κ consistent with the data collected in accordance with the requirements of Section 2.2.6.

If an analysis using an assumed value of κ will result in no required rehabilitation of the structure, the value of κ shall be substantiated by data collection in accordance with the requirements of Section 2.2.6 before the analysis is finalized.

2.3 Rehabilitation Methods

Seismic rehabilitation of the building shall be performed to achieve the selected Rehabilitation Objective in accordance with the requirements of the Simplified Rehabilitation Method of Section 2.3.1 or the Systematic Rehabilitation Method of Section 2.3.2.

2.3.1 Simplified Rehabilitation Method

The Simplified Rehabilitation Method shall be permitted for buildings that conform to one of the Model Building Types contained in Table 10-1, and all limitations in that table with regard to building size and seismic zone.

Use of the Simplified Rehabilitation Method shall be restricted to Limited Rehabilitation Objectives consisting of the Life Safety Building Performance Level (3-C) at the BSE-1 Earthquake Hazard Level, or Partial Rehabilitation as defined in Section 1.4.3.2.

The Simplified Rehabilitation Method shall be performed in accordance with the requirements of Chapters 2, 10, and 11.

C2.3.1 Simplified Rehabilitation Method

Simplified Rehabilitation may be applied to certain buildings of regular configuration that do not require advanced analytical procedures. The primary intent of Simplified Rehabilitation is to reduce seismic risk efficiently, where possible and appropriate, by seeking Limited Objectives. Partial Rehabilitation measures, which target high-risk building deficiencies such as parapets and other exterior falling hazards, are included as Simplified Rehabilitation techniques.

The Simplified Rehabilitation Method is less complicated than the complete analytical rehabilitation design procedures found under Systematic Rehabilitation. In many cases, Simplified Rehabilitation represents a cost-effective improvement in seismic performance, and often requires less detailed evaluation or partial analysis to qualify for a specific performance level.

2.3.2 Systematic Rehabilitation Method

If the Simplified Rehabilitation Method is not applicable, the Systematic Rehabilitation Method shall be used as specified below:

1. An analysis procedure shall be selected in accordance with the requirements and limitations of Section 2.4.

2. A preliminary rehabilitation scheme shall be developed using one or more of the rehabilitation strategies defined in Section 2.5.

3. An analysis of the building, including rehabilitation measures, shall be performed, and the results of the analysis shall be evaluated in accordance with the requirements of Chapters 2 through 9 and 11 to verify the rehabilitation design meets the selected Rehabilitation Objective.

C2.3.2 Systematic Rehabilitation Method

Systematic Rehabilitation may be applied to any building and involves thorough checking of each existing structural element or component, the design of new ones, and verification of acceptable overall performance represented by expected displacements and internal forces. The Systematic Rehabilitation Method focuses on the nonlinear behavior of structural response, and employs procedures not previously emphasized in seismic codes.

The Systematic Rehabilitation Method is intended to be complete and contains all requirements to reach any specified performance level. Systematic Rehabilitation is an iterative process, similar to the design of new buildings, in which modifications of the existing structure are assumed for the purposes of a preliminary design and analysis, and the results of the analysis are verified as acceptable on an element and component basis. If either new or existing components or elements still prove to be inadequate, the modifications are adjusted and, if necessary, a new analysis and verification cycle is performed. A preliminary design is needed to define the extent and configuration of corrective measures in sufficient detail to estimate the interaction of the stiffness, strength, and post-yield behavior of all new, modified, or existing elements to be used for lateral force resistance. The designer is encouraged to include all elements with significant lateral stiffness in a mathematical model to assure deformation capability under realistic seismic drifts. However, just as in the design of new buildings, it may be determined that certain components or elements will not be considered part of the lateral-force-resisting system, as long as deformation compatibility checks are made on these components or elements to assure their adequacy.

A mathematical model, developed for the preliminary design, must be constructed in connection with one of the analysis procedures defined in Chapter 3. These are the linear procedures (Linear Static and Linear Dynamic) and the nonlinear procedures (Nonlinear Static and Nonlinear Dynamic). With the exception of the Nonlinear Dynamic Procedure, this standard defines the analysis and rehabilitation design procedures sufficiently that compliance can be checked by a building department in a manner similar to design reviews for new buildings. Modeling assumptions to be used in various situations are given in Chapters 4 through 9, and in Chapter 11 for nonstructural components. Requirements for seismic demand are given in Chapter 1. Requirements are specified for use of the Nonlinear Dynamic Procedure; however, considerable judgment is required in its application. Criteria for applying ground motion for various analysis procedures is given, but definitive rules for developing ground motion input are not included in this standard.

This standard specifies acceptance criteria for stiffness, strength, and ductility characteristics of structural elements and components for three discrete structural performance levels in Chapters 4 though 8 for use in the Systematic Rehabilitation Method, and acceptance criteria for the performance of nonstructural components or architectural, mechanical, and electrical components in Chapter 11 for use in Systematic and Simplified Rehabilitation Methods.

Inherent in the concept of performance levels and ranges is the assumption that performance can be measured using analytical results such as story drift ratios or strength and ductility demands on individual components or elements. To enable structural verification at the selected performance level, stiffness, strength, and ductility characteristics of many common elements and components have been derived from laboratory tests and analytical studies and are presented in a standard format in Chapters 4 through 8 of this standard.

This standard specifies two new technologies in Chapter 9: seismic isolation and energy dissipation, for use in seismic rehabilitation of buildings using the Systematic Rehabilitation Method.

It is expected that testing of existing materials and elements will continue and that additional corrective measures and products will be developed. It is also expected that systems and products intended to modify structural response beneficially will be advanced. The format of the analysis techniques and acceptability criteria of this standard allows rapid incorporation of such technology. Section 2.8 gives specific requirements in this regard. It is expected that this standard will have a significant impact on testing and documentation of existing materials and systems as well as on new products.

2.4 Analysis Procedures

An analysis of the building, including rehabilitation measures, shall be conducted to determine the forces and deformations induced in components of the building by ground motion corresponding to the selected Earthquake Hazard Level, or by other seismic geologic site hazards specified in Section 4.2.2.

The analysis procedure shall comply with one of the following:

1. Linear analysis subject to limitations specified in Section 2.4.1, and complying with the Linear Static Procedure (LSP) in accordance with Section 3.3.1, or the Linear Dynamic Procedure (LDP) in accordance with Section 3.3.2.

2. Nonlinear analysis subject to limitations specified in Section 2.4.2, and complying with the Nonlinear Static Procedure (NSP) in accordance with Section 3.3.3, or the Nonlinear Dynamic Procedure (NDP) in accordance with Section 3.3.4.

3. Alternative rational analysis in accordance with Section 2.4.3.

The analysis results shall comply with the applicable acceptance criteria selected in accordance with Section 2.4.4.

C2.4 Analysis Procedures

The linear procedures maintain the traditional use of a linear stress-strain relationship, but incorporate adjustments to overall building deformations and material acceptance criteria to permit better consideration of the probable nonlinear characteristics of seismic response. The Nonlinear Static Procedure, often called “pushover analysis,” uses simplified nonlinear techniques to estimate seismic structural deformations. The Nonlinear Dynamic Procedure, commonly known as nonlinear time history analysis, requires considerable judgment and experience to perform, and may be used only within the limitations described in Section 2.4.2.2 of this standard.

2.4.1 Linear Procedures

Linear procedures shall be permitted for buildings which do not have an irregularity defined in Section 2.4.1.1. For buildings that have one or more of the irregularities defined in Section 2.4.1.1, linear procedures shall not be used unless the earthquake demands on the building comply with the demand capacity ratio (DCR) requirements in Section 2.4.1.1. For buildings incorporating base isolation systems or supplemental energy dissipation systems, the additional limitations of Section 9.2.4 or Section 9.3.4 shall apply.

C2.4.1 Linear Procedures

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. The procedures of Section 2.4.1.1 are intended to evaluate whether the building is capable of nearly elastic response.

2.4.1.1 Method to Determine Limitations on Use of Linear Procedures

The methodology presented in this section shall be used to determine the applicability of linear analysis procedures based on four conditions of irregularity defined in Section 2.4.1.1.1 through Section 2.4.1.1.4. The determination of irregularity shall be based on the configuration of the rehabilitated structure. A linear analysis to determine irregularity shall be performed by either an LSP in accordance with Section 3.3.1 or an LDP in accordance with Section 3.3.2. The results of this analysis shall be used to identify the magnitude and uniformity of distribution of inelastic demands on the primary elements and components of the lateral-force-resisting system.

The magnitude and distribution of inelastic demands for existing and added primary elements and components shall be defined by demand-capacity ratios (DCRs) and computed in accordance with Equation (2-1):

$$DCR = \frac{Q_{UD}}{Q_{CE}} \tag{2-1}$$

where:

Q_{UD} = Force due to the gravity and earthquake loads calculated in accordance with Section 3.4.2.

Q_{CE} = Expected strength of the component or element, calculated as specified in Chapters 5 through 8.

DCRs shall be calculated for each action (such as axial force, moment, shear) of each primary component. The critical action for the component shall be the one with the largest DCR. The DCR for this action shall be termed the critical component DCR. The largest DCR for any element at a particular story is termed the critical element DCR at that story. If an element at a particular story is composed of multiple components, then the component with the largest computed DCR shall define the critical component for the element at that story.

The applicability of linear procedures shall be determined as follows:

1. If all component DCRs $\leq$ 2.0, then linear procedures are applicable.

2. If one or more component DCRs exceed 2.0, and no irregularities described in Sections 2.4.1.1.1 through 2.4.1.1.4 are present, then linear procedures are applicable.

3. If one or more component DCRs exceed 2.0 and any irregularity described in Section 2.4.1.1.1 through Section 2.4.1.1.4 is present, then linear procedures are not applicable, and shall not be used.

C2.4.1.1 Method to Determine Limitations on Use of Linear Procedures

The magnitude and distribution of inelastic demands are indicated by demand-capacity ratios (DCRs). 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 along with the acceptance criteria provided 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.

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.

2.4.1.1.1 In-Plane Discontinuity Irregularity

An in-plane discontinuity irregularity shall be considered to exist in any primary element of the lateral-force-resisting system whenever a lateral-force-resisting element is present in one story, but does not continue, or is offset within the plane of the element, in the story immediately below. Figure 2-1 depicts such a condition.

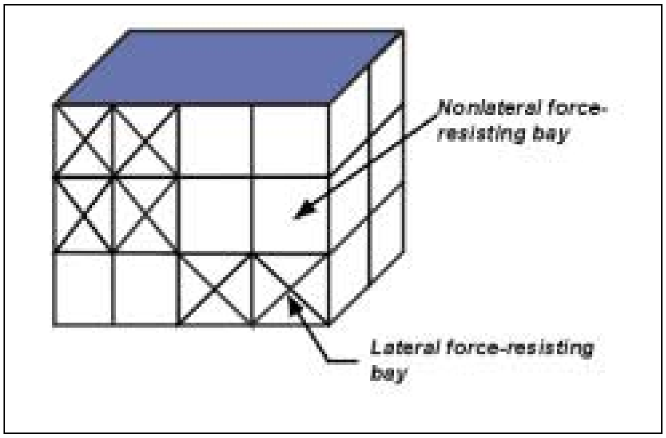

Figure 2-1 In-Plane Discontinuity in Lateral System

2.4.1.1.2 Out-of-Plane Discontinuity Irregularity

An out-of-plane discontinuity irregularity shall be considered to exist in any primary element of the lateral-force-resisting system when an element in one story is offset out-of-plane relative to that element in an adjacent story, as depicted in Figure 2-2.

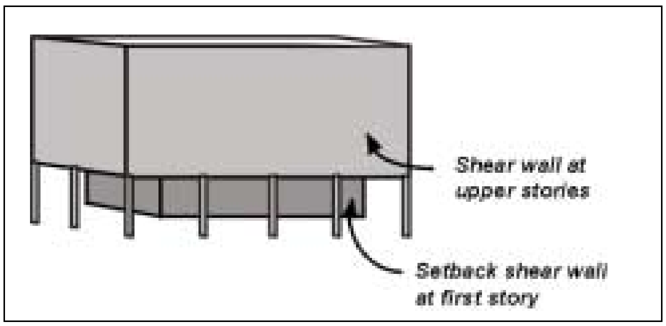

Figure 2-2 Typical Building with Out-of-Plane Offset Irregularity

2.4.1.1.3 Severe Weak Story Irregularity

A severe weak story irregularity shall be considered to exist in any direction of the building if the ratio of the average shear DCR of any story to that of an adjacent story in the same direction exceeds 125%. The average DCR of a story shall be calculated by Equation (2-2):

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

where:

$\overline{DCR}$	=	Average DCR for the story
$DCRi$	=	Critical action DCR for element *i* of the story
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 shall be independently evaluated.

2.4.1.1.4 Severe Torsional Strength Irregularity

A severe torsional strength irregularity shall be considered to exist in any story if the diaphragm above the story under consideration is not flexible and, for a given direction, the ratio of the critical element DCRs for primary elements on one side of the center of resistance of a story, to those on the other side of the center of resistance of the story, exceeds 1.5.

2.4.1.2 Limitations on Use of the Linear Static Procedure

The Linear Static Procedure shall not be used for a building with one or more of the following characteristics:

1. The fundamental period of the building, T, is greater than or equal to 3.5 times T_s.

2. The ratio of the horizontal dimension at any story to the corresponding dimension at an adjacent story exceeds 1.4 (excluding penthouses).

3. The building has a severe torsional stiffness irregularity in any story. A severe torsional stiffness irregularity exists in a story if the diaphragm above the story under consideration 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.

4. The building has a severe vertical mass or stiffness irregularity. A severe vertical mass or stiffness irregularity exists when the average drift in any story (except penthouses) exceeds that of the story above or below by more than 150%.

5. The building has a nonorthogonal lateral-force-resisting system.

For buildings in which linear procedures are applicable, but the Linear Static Procedure is not permitted, use of the Linear Dynamic Procedure shall be permitted.

C2.4.1.2 Limitations on Use of the Linear Static Procedure

For buildings that have irregular distributions of mass or stiffness, irregular geometries, or nonorthogonal lateral-force-resisting systems, the distribution of demands predicted by an LDP analysis will be more accurate than those predicted by the LSP. Either the response spectrum method or time history method may be used for evaluation of such structures.

2.4.2 Nonlinear Procedures

Nonlinear procedures shall be permitted for any of the rehabilitation strategies contained in Section 2.5. Nonlinear procedures shall be used for analysis of buildings when linear procedures are not permitted. Data collection for use with nonlinear procedures shall be in accordance with Section 2.2.6.

2.4.2.1 Nonlinear Static Procedure

The NSP shall be permitted for structures in which higher mode effects are not significant, as defined in this section. To determine if higher modes are significant, a modal response spectrum analysis shall be performed for the structure using sufficient modes to capture 90% mass participation. A second response spectrum analysis shall also be performed, considering only the first mode participation. Higher mode effects shall be considered significant if the shear in any story resulting from the modal analysis considering modes required to obtain 90% mass participation exceeds 130% of the corresponding story shear considering only the first mode response.

If higher mode effects are significant, the NSP shall be permitted if an LDP analysis is also performed to supplement the NSP. Buildings with significant higher mode effects must meet the acceptance criteria of this standard for both analysis procedures, except that an increase by a factor of 1.33 shall be permitted in the LDP acceptance criteria for deformation-controlled actions (*m*-factors) provided in Chapters 5 through 9. A building analyzed using the NSP, with or without a supplementary LDP evaluation, shall meet the acceptance criteria for nonlinear procedures specified in Section 3.4.3.

C2.4.2.1 Nonlinear Static Procedure

The NSP is generally a more reliable approach to characterizing the performance of a structure than are linear procedures. However, it is not exact, and cannot accurately account for changes in dynamic response as the structure degrades in stiffness or account for higher mode effects. When the NSP is utilized on a structure that has significant higher mode response, the LDP is also employed to verify the adequacy of the design. When this approach is taken, less restrictive criteria are permitted for the LDP, recognizing the significantly improved knowledge that is obtained by performing both analysis procedures.

2.4.2.2 Nonlinear Dynamic Procedure

The NDP shall be permitted for all structures. An analysis performed using the NDP shall be reviewed and approved by an independent third-party engineer with experience in seismic design and nonlinear procedures.

2.4.3 Alternative Rational Analysis

Nothing in this standard shall be interpreted as preventing the use of any approved alternative analysis procedure that is rational and based on fundamental principles of engineering mechanics and dynamics. Such alternative analyses shall not adopt the acceptance criteria contained in this standard without first determining their applicability. All projects using alternative rational analysis procedures shall be reviewed and approved by an independent third-party engineer with experience in seismic design.

2.4.4 Acceptance Criteria

2.4.4.1 General

The acceptability of force and deformation actions shall be evaluated for each component in accordance with the requirements of Section 3.4. Prior to selecting component acceptance criteria for use in Section 3.4, each component shall be classified as primary or secondary in accordance with Section 2.4.4.2, and each action shall be classified as deformation-controlled (ductile) or force-controlled (nonductile) in accordance with Section 2.4.4.3. Component strengths, material properties, and component capacities shall be determined in accordance with Sections 2.4.4.4, 2.4.4.5, and 2.4.4.6, respectively. Component acceptance criteria not presented in this standard shall be determined by qualification testing in accordance with Section 2.8.

The rehabilitated building shall be provided with at least one continuous load path to transfer seismic forces, induced by ground motion in any direction, from the point of application to the final point of resistance. All primary and secondary components shall be capable of resisting force and deformation actions within the applicable acceptance criteria of the selected performance level.

2.4.4.2 Primary and Secondary Elements and Components

Elements and components that affect the lateral stiffness or distribution of forces in a structure, or are loaded as a result of lateral deformation of the structure, shall be classified as primary or secondary, even if they are not part of the intended lateral-force-resisting system.

2.4.4.2.1 Primary Elements and Components

Elements and components that provide the capacity of the structure to resist collapse under seismic forces induced by ground motion in any direction shall be classified as primary.

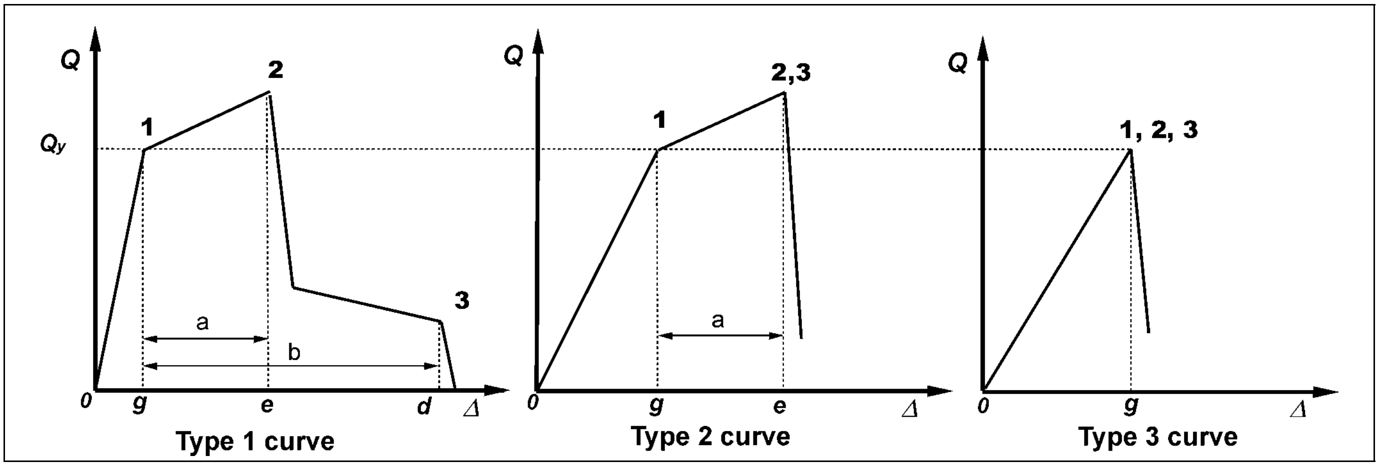

Figure 2-3 Component Force Versus Deformation Curves

2.4.4.2.2 Secondary Elements and Components

Other elements and components shall be classified as secondary.

C2.4.4.2 Primary and Secondary Elements and Components

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.

The secondary designation typically will be used when a component or element does not contribute significantly or reliably in resisting earthquake effects because of low lateral stiffness, strength, or deformation capacity.

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 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.

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. For a given performance level, acceptance criteria for primary elements and components will typically be more restrictive than those for secondary elements and components.

Use of the secondary classification will allow certain components to experience greater damage and larger displacements than would otherwise be permitted for primary elements, as explained below.

1. Although damage to the primary elements and some degradation of their stiffness may be permitted to occur, the overall function of these elements in resisting structural collapse should not be compromised.

2. For some structural performance levels, substantial degradation of the lateral-force-resisting stiffness and strength of secondary elements and components is permissible. However, the ability of these secondary elements and components to support gravity loads under the maximum induced deformations must be preserved.

2.4.4.3 Deformation- and Force-Controlled Actions

All actions shall be classified as either deformation-controlled or force-controlled using the component force versus deformation curves shown in Figure 2-3.

2.4.4.3.1 Deformation-Controlled and Force-Controlled Behavior

The Type 1 curve depicted in Figure 2-3 is representative of ductile behavior where there is an elastic range (point 0 to point 1 on the curve) followed by a plastic range (points 1 to 3) with non-negligible residual strength and ability to support gravity loads at point 3. The plastic range includes a strain hardening or softening range (points 1 to 2) and a strength-degraded range (points 2 to 3). Primary component actions exhibiting this behavior shall be classified as deformation-controlled if the strain-hardening or strain-softening range is such that $e > 2g$; otherwise, they shall be classified as force-controlled. Secondary component actions exhibiting Type 1 behavior shall be classified as deformation-controlled for any e/g ratio.

The Type 2 curve depicted in Figure 2-3 is representative of ductile behavior where there is an elastic range (point 0 to point 1 on the curve) and a plastic range (points 1 to 2) followed by loss of strength and loss of ability to support gravity loads beyond point 2. Primary and secondary component actions exhibiting this type of behavior shall be classified as deformation-controlled if the plastic range is such that $e \geq 2g$; otherwise, they shall be classified as force-controlled.

The Type 3 curve depicted in Figure 2-3 is representative of a brittle or nonductile behavior where there is an elastic range (point 0 to point 1 on the curve) followed by loss of strength and loss of ability to support gravity loads beyond point 1. Primary and secondary component actions displaying Type 3 behavior shall be classified as force-controlled

C2.4.4.3.1 Deformation-Controlled and Force-Controlled Behavior

Acceptance criteria for primary components that exhibit Type 1 behavior are typically within the elastic or plastic ranges between points 0 and 2, depending on the performance level. Acceptance criteria for secondary elements that exhibit Type 1 behavior can be within any of the performance ranges.

Acceptance criteria for primary and secondary components exhibiting Type 2 behavior will be within the elastic or plastic ranges, depending on the performance level.

Acceptance criteria for primary and secondary components exhibiting Type 3 behavior will always be within the elastic range.

Table C2-1 provides some examples of possible deformation- and force-controlled actions in common framing systems. Classification of force- or deformation-controlled actions are specified for foundation and framing components in Chapters 4 through 8.

A given component may have a combination of both force- and deformation-controlled actions.

Classification as a deformation-controlled action is not up to the discretion of the user. Deformation-controlled actions have been defined in this standard by the designation of m-factors or nonlinear deformation capacities in Chapters 4 through 8. In the absence of component testing justifying Type 1 or Type 2 behavior, all other actions are to be taken as force-controlled.

Table C2-1 Examples of Possible Deformation-Controlled and Force-Controlled Actions

Component	Deformation-Controlled Action	Force-Controlled Action
Moment Frames • Beams • Columns • Joints	 Moment (M) M --	 Shear (V) Axial load (P), V V[1]
Shear Walls	M, V	P
Braced Frames • Braces • Beams • Columns • Shear Link	 P -- -- V	 -- P P P, M
Connections	P, V, M[3]	P, V, M
Diaphragms	M, V[2]	P, V, M

1. Shear may be a deformation-controlled action in steel moment frame construction.
2. If the diaphragm carries lateral loads from vertical seismic resisting elements above the diaphragm level, then M and V shall be considered force-controlled actions.
3. Axial, shear, and moment may be deformation-controlled actions for certain steel and wood connections.

Figure C2-1 shows the generalized force versus deformation curves used throughout this standard to specify component modeling and acceptance criteria for deformation-controlled actions in any of the four basic material types. 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.

The sharp transition as shown on idealized curves in Figure C2-1 between points *C* and *D* can result in computational difficulty and an inability to converge when used as modeling input in nonlinear computerized analysis software. In order to avoid this computational instability, a small slope may be provided to the segment of these curves between points *C* and *D*.

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 vs. deformation curves are used in Figures C2-1 (a) and (b). Figure C2-1(a) shows normalized force (Q/Q_{CE}) versus deformation (θ or Δ) and the parameters *a*, *b*, and *c*. Figure C2-1(b) shows normalized force (*Q/QCE*) 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. Acceptance criteria for deformation or deformation ratios for primary members (P) and secondary members (S) corresponding to the target Building Performance Levels of Collapse Prevention (CP), Life Safety (LS), and Immediate Occupancy (IO) as shown in Figure 2-1(c) are given in Chapters 5 through 8.

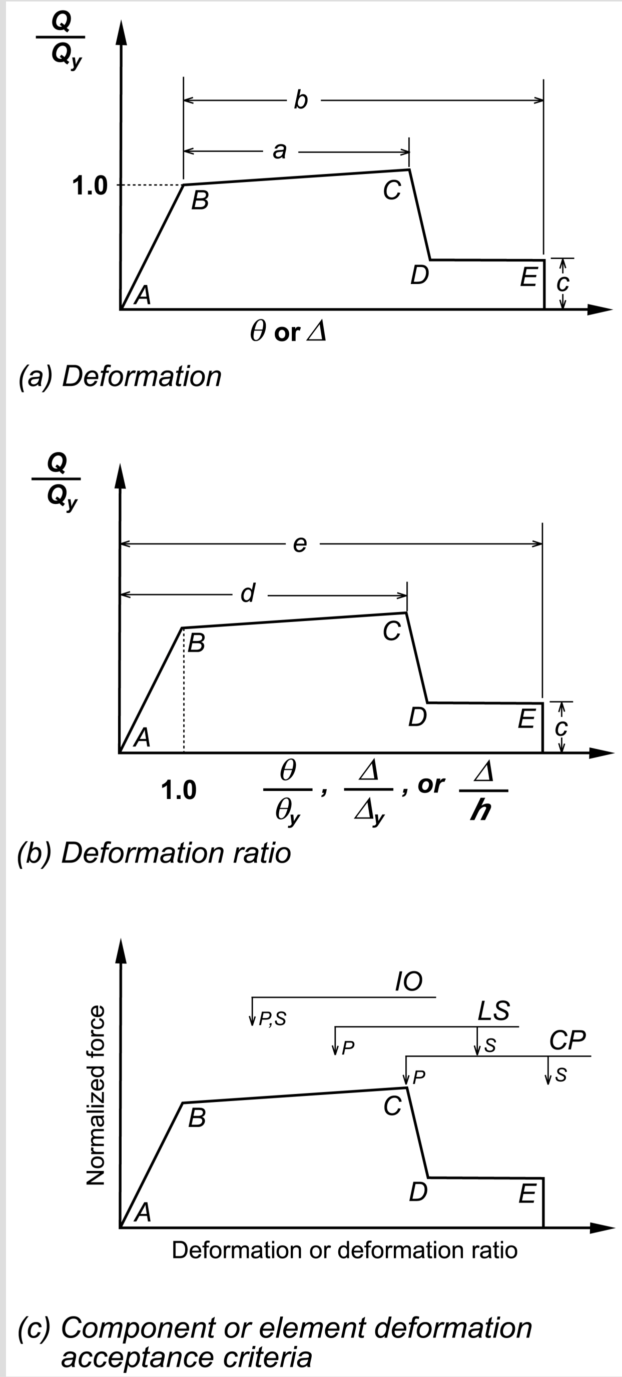

Figure C2-1 **Generalized Component Force-Deformation Relations for Depicting Modeling and Acceptance Criteria**

2.4.4.4 Expected and Lower-Bound Strength

In Figure 2-3, Q_y represents the yield strength of the component. When evaluating the behavior of deformation-controlled actions, the expected strength, Q_{CE}, shall be used. Q_{CE} is defined as the statistical mean value of yield strengths, Q_y, for a population of similar components, and includes consideration of strain hardening and plastic section development. When evaluating the behavior of force-controlled actions, a lower bound estimate of the component strength, Q_{CL}, shall be used. Q_{CL} is defined as the statistical mean minus one standard deviation of the yield strengths, Q_y, for a population of similar components.

C2.4.4.4 Expected and Lower-Bound Strength

In Figure 2-3, the yield strength of the component, Q_y, will vary because of inherent variability in the material strength comprising the individual elements as well as differences in workmanship and physical condition. See Chapters 5 through 8 for specific direction regarding the calculation of expected and lower-bound strengths of components.

2.4.4.5 Material Properties

Expected material properties shall be based on mean values of tested material properties. Lower bound material properties shall be based on mean values of tested material properties minus one standard deviation (σ).

Nominal material properties, or properties specified in construction documents, shall be taken as lower bound material properties unless otherwise specified in Chapters 5 through 8. Corresponding expected material properties shall be calculated by multiplying lower-bound values by appropriate factors specified in Chapters 5 through 8 to translate from lower bound to expected values.

C2.4.4.5 Material Properties

When calculations are used to determine expected or lower-bound strengths of components, expected or lower-bound materials properties, respectively, shall be used.

2.4.4.6 Component Capacities

2.4.4.6.1 General

Detailed criteria for calculation of individual component force and deformation capacities shall comply with the requirements in individual materials chapters as follows:

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

2.4.4.6.2 Nonlinear Procedures

If nonlinear procedures are used, component capacities for deformation-controlled actions shall be taken as permissible inelastic deformation limits, and component capacities for force-controlled actions shall be taken as lower-bound strengths, Q_{CL}, as summarized in Table 2-2.

2.4.4.6.3 Linear Procedures

If linear procedures are used, capacities for deformation-controlled actions shall be defined as the product of m-factors and expected strengths, Q_{CE}. Capacities for force-controlled actions shall be defined as lower-bound strengths, Q_{CL}, as summarized in Table 2-3.

Table 2-2 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 Component	N/A	Q_{CL}

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

Table 2-3 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 mean value -1σ level)
Existing Action Capacity	$\kappa \cdot Q_{CE}$	$\kappa \cdot Q_{CL}$
New Material Strength	Expected material strength	Specified material strength
New Action Capacity	Q_{CE}	Q_{CL}

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

2.5 Rehabilitation Strategies

A Rehabilitation Objective shall be achieved by implementing rehabilitation measures based on a strategy of addressing deficiencies identified by a prior seismic evaluation. Each rehabilitation measure shall be evaluated in conjunction with other rehabilitation measures, and the existing structure as a whole, to assure that the complete rehabilitation scheme achieves the target Building Performance Level for the selected Earthquake Hazard Level. The effects of rehabilitation on stiffness, strength, and deformability shall be taken into account in an analytical model of the rehabilitated structure. The compatibility of new and existing components and elements shall be checked at displacements consistent with the demands produced by the selected Earthquake Hazard Level and geologic site hazards present at the site.

C2.5 Rehabilitation Strategies

Although not specifically required by any of the strategies, it is very beneficial for the rehabilitated 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.

2.5.1 Local Modification of Components

Local modification of deficient components shall be permitted as an applicable rehabilitation strategy.

C2.5.1 Local Modification of Components

Some existing buildings have substantial strength and stiffness, but some of their components may 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 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 rehabilitation approach when only a few of the building’s components are inadequate.

Local strengthening allows one or more under-strength 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.

2.5.2 Removal or Lessening of Existing Irregularities

Removal or lessening of existing irregularities shall be permitted as an applicable rehabilitation strategy.

C2.5.2 Removal or Lessening of Existing Irregularities

Removal or lessening of existing irregularities may be an effective rehabilitation strategy if a seismic evaluation shows that the irregularities result in the inability of the building to meet the selected Structural Performance Level.

The results of analysis should be reviewed to detect existing irregularities. Stiffness, mass, and strength irregularities may be detected either by reviewing the results of a linear analysis, examining the distribution of structural displacements and DCRs, or reviewing the results of a nonlinear analysis by examining the distribution of structural displacements and inelastic deformation demands. If the distribution of values of structural displacements, DCRs, or inelastic deformation demands predicted by the analysis is nonuniform with disproportionately high values within one story relative to the adjacent story, or at one side of a building relative to the other, 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, such as soft or weak stories, include the addition of braced frames or shear walls within the soft or 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.

2.5.3 Global Structural Stiffening

Global stiffening of the structure shall be permitted as an applicable rehabilitation strategy.

C2.5.3 Global Structural Stiffening

Global stiffening of the structure may be an effective rehabilitation strategy if the results of a seismic evaluation show deficiencies attributable to excessive lateral deflection of the building, and critical components do not have adequate ductility to resist the resulting deformations.

Construction of new braced frames or shear walls within an existing structure are effective measures for adding stiffness.

2.5.4 Global Structural Strengthening

Global strengthening of the structure shall be permitted as an applicable rehabilitation strategy.

C2.5.4 Global Structural Strengthening

Global strengthening of the structure may be an effective rehabilitation strategy if the results of a seismic evaluation show unacceptable performance attributable to a global deficiency in structural strength. This can be identified when the onset of global inelastic behavior occurs at levels of ground shaking that are substantially less than the selected level of ground shaking or large DCRs (or inelastic deformation demands) are present throughout the structure. By providing supplemental strength to such a 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, but they may be significantly stiffer than the structure to which they are added, which requires their design 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.

2.5.5 Mass Reduction

Reduction of mass in the building shall be permitted as an applicable rehabilitation strategy.

C2.5.5 Mass Reduction

Mass reduction may be an effective rehabilitation strategy if the results of a seismic evaluation show deficiencies attributable to excessive building mass, global structural flexibility, or global structural weakness. Mass and stiffness control the amount of force and deformation induced in a structure by ground motion. Reductions in mass can 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.

2.5.6 Seismic Isolation

Seismic isolation of the building shall be permitted as an applicable rehabilitation strategy in accordance with Chapter 9.

C2.5.6 Seismic Isolation

Seismic isolation may be an effective rehabilitation strategy if the results of a seismic evaluation show deficiencies attributable to excessive seismic forces or deformation demands, or if it is desired to protect important contents and nonstructural components from damage. 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 a 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 are 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 the 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.

2.5.7 Supplemental Energy Dissipation

Installation of supplemental energy dissipation devices shall be permitted as an applicable rehabilitation strategy in accordance with Chapter 9.

C2.5.7 Supplemental Energy Dissipation

)Installation of supplemental energy dissipation devices may be an effective rehabilitation strategy if the results of a seismic evaluation show deficiencies attributable to excessive deformations due to global structural flexibility in a building. Many available technologies allow the energy imparted to a structure by ground motion to be dissipated in a controlled manner through the action of special devices—fluid viscous dampers (hydraulic cylinders), yielding plates, or friction pads—resulting in an overall reduction in the displacements of the structure. The most commonly used 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.

2.6 General Design Requirements

The requirements of this section shall apply to all buildings for which the systematic rehabilitation method is selected for any target Building Performance Level and any selected seismic hazard unless specified otherwise.

2.6.1 Multidirectional Seismic Effects

Elements and components shall be designed to resist seismic forces acting in any horizontal direction. Seismic forces in the vertical direction shall be considered when required by Section 2.6.11. Multidirectional seismic effects shall be considered in the analysis as specified in Section 3.2.7.

2.6.2 P-Δ Effects

Elements and components of buildings shall be designed for P-Δ effects, defined as the combined effects of gravity loads acting in conjunction with lateral drifts due to seismic forces, as specified in Section 3.2.5.

2.6.3 Horizontal Torsion

Elements and components of buildings shall be designed to resist the effects of horizontal torsion as specified in Section 3.2.2.2.

2.6.4 Overturning

Elements and components of buildings shall be designed to resist the effects of overturning at each intermediate level as well as the base of the structure. Stability against overturning shall be evaluated as specified in Section 3.2.10. Effects of overturning on foundations shall be evaluated as specified in Section 4.4.

2.6.5 Continuity

All elements and components shall be tied together to form a complete load path for the transfer of inertial forces generated by the dynamic response of portions of the structure to the rest of the structure. Inertial forces specified in this section shall be considered force-controlled.

1. Smaller portions of a structure, such as an outstanding wing, shall be connected to the structure as a whole. Component connections shall be capable of resisting horizontal force in any direction calculated using Equation (2-3). These connections are not required if the individual portions of the structure are self-supporting and are separated by a seismic joint permitting independent movement during dynamic response.

$$F_p = 0.133 S_{XS} W \tag{2-3}$$

where:

F_p = Horizontal force in any direction for the design of connections between two portions of a structure

S_{XS} = Spectral response acceleration parameter at short periods for the selected Earthquake Hazard Level and damping, adjusted for site class

W = Weight of the smaller portion of the structure

2. Components shall be connected to the structure to resist a horizontal force in any direction calculated using Equation (2-4) unless specified otherwise in Sections 2.6.6 and 2.6.7.

$$F_p = 0.08 S_{XS} W \tag{2-4}$$

where:

F_p = Horizontal force in any direction for the design of component connections to the structure

S_{XS} = Spectral response acceleration parameter for short periods for the selected Earthquake Hazard Level and damping adjusted for site class

W = Weight of the component

exceptions:

1. For discrete connections resisting concentrated forces, F_p shall not be less than 1120 pounds.

2. For continuous connections, F_p shall not be less than 280 pounds per lineal foot.

3. Where a sliding support is provided at the end(s) of a component, the bearing length shall be sufficient to accommodate the expected differential displacement between the component and the support.

2.6.6 Diaphragms

Diaphragms shall be defined as horizontal elements that transfer earthquake-induced inertial forces to vertical elements of the lateral-force-resisting systems through the collective action of diaphragm components including chords, collectors, and ties.

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 of the building shall account for the behavior of the diaphragms as specified in Section 3.2.4.

Diaphragms and their connections to vertical elements providing lateral support shall comply with the design requirements specified in Section 5.9 for metal diaphragms, Section 6.11 for concrete diaphragms, Section 6.12 for precast concrete diaphragms, and Section 8.6 for wood diaphragms.

2.6.6.1 Diaphragm Chords

Except for diaphragms evaluated as “unchorded” as specified in Chapter 8, 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. At re-entrant corners in diaphragms, and at the corners of openings in diaphragms, diaphragm chords shall be extended a distance sufficient to develop the accumulated diaphragm boundary stresses into the diaphragm beyond the corner.

2.6.6.2 Diaphragm Collectors

At each vertical element a diaphragm collector shall be provided to transfer to the element accumulated diaphragm forces that are in excess of the forces transferred directly to the element in shear. The diaphragm collector shall be extended beyond the element and attached to the diaphragm to transfer the accumulated forces.

2.6.6.3 Diaphragm Ties

Diaphragms shall be provided with continuous tension ties between chords or boundaries. Ties shall be spaced at a distance not exceeding three times the length of the tie. At a minimum, ties shall be designed for an axial tensile force calculated using Equation (2-5) as a force-controlled action.

$$F_p = 0.4 S_{XS} W \tag{2-5}$$

where:

F_p = Axial tensile force for the design of ties between the diaphragm and chords or boundaries

S_{XS} = Spectral response acceleration parameter at short periods for the selected hazard level and damping adjusted for site class

W = Weight tributary to that portion of the diaphragm extending half the distance to 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 2.6.7 for the area of wall tributary to the diaphragm tie.

2.6.7 Walls

Walls shall be evaluated for out-of-plane inertial forces as required by this section and as further required for specific structural systems in Chapters 5 through 8. Forces specified in this section shall be considered force-controlled actions.

2.6.7.1 Out-of-Plane Anchorage to Diaphragms

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 horizontally between the supports for greater distances. Anchorage of walls to diaphragms shall be designed for forces calculated using Equation (2-6), which shall be developed in the diaphragm. If sub-diaphragms are used, each sub-diaphragm shall be capable of transmitting the shear forces due to wall anchorage to a continuous diaphragm tie. Sub-diaphragms shall have length-to-depth ratios not exceeding 3:1. Where wall panels are stiffened for out-of-plane behavior by pilasters or 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 and accumulation of forces at these elements. Wall anchor connections shall be considered force-controlled.

$$F_p = \chi S_{XS} W \qquad (2\text{-}6)$$

where:

F_p = Design force for anchorage of walls to diaphragms

χ = Factor from Table 2-4 for the selected Structural Performance Level. Increased values of χ shall be used when anchoring to flexible diaphragms

S_{XS} = Spectral response acceleration parameter at short periods for the selected hazard level and damping adjusted for site class

W = Weight of the wall tributary to the anchor

exceptions:

1. F_p shall not be less than the minimum of 400 lb/ft or 400 S_{XS} (lbs/foot).

Table 2-4 Coefficient χ for Calculation of Out-of-Plane Wall Forces

	χ[1]	
Structural Performance Level	**Flexible Diaphragms**	**Other Diaphragms**
Collapse Prevention	0.9	0.3
Life Safety	1.2	0.4
Immediate Occupancy	1.8	0.6

1. Values of χ for flexible diaphragms need not be applied to out-of-plane strength of walls in Section 2.6.7.2.

2.6.7.2 Out-of-Plane Strength

Wall components shall have adequate strength to span between locations of out-of-plane support when subjected to out-of-plane forces calculated using Equation (2-7).

$$F_p = \chi S_{XS} W \qquad (2\text{-}7)$$

where:

F_p = Out-of-plane force per unit area for design of a wall spanning between two out-of-plane supports

χ = Factor from Table 2-4 for the selected performance level. Values of χ for flexible diaphragms need not be applied to out-of-plane strength of wall components

S_{XS} = Spectral response acceleration at short periods for the selected hazard level and damping adjusted for site class

W = Weight of the wall per unit area

2.6.8 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.

2.6.9 Structures Sharing Common Elements

Buildings sharing common vertical or lateral load-resisting elements shall be rehabilitated considering interconnection of the two structures, or they shall be separated as specified in this section.

2.6.9.1 Interconnection

Buildings sharing common elements, other than foundation elements, 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 specified in Section 2.6.5. Analyses of the combined response of the buildings shall account for the interconnection of the structures and shall evaluate the structures as one integral unit.

If the shared common elements are foundation elements, and the superstructures meet the separation requirements of Section 2.6.10, the structures need not be tied together. Shared foundation elements shall be designed considering an analysis of the combined response of the two buildings.

2.6.9.2 Separation

Buildings sharing common elements shall be completely separated by introducing seismic joints between the structures meeting the requirements of Section 2.6.10. Independent lateral-force-resisting systems shall be provided for each structure. Independent vertical support shall be provided on each side of the seismic joint, unless slide bearings are used and 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 move out of phase with each other in opposite directions 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 2.6.5.

2.6.10 Building Separation

2.6.10.1 Minimum Separation

Buildings shall be separated from adjacent structures to prevent pounding by a minimum distance s_i at any level i given by Equation (2-8) unless exempted as specified in Section 2.6.10.2.

$$s_i = \sqrt{\Delta_{i1}^2 + \Delta_{i2}^2} \qquad (2\text{-}8)$$

where:

Δ_{i1} = Lateral deflection of the building under consideration, at level i, relative to the ground, calculated in accordance with the provisions of this standard for the selected hazard level

Δ_{i2} = Lateral deflection of an adjacent building, at level i, relative to the ground, estimated using the provisions of this standard or other approved approximate procedure. Alternatively, it shall be permitted to assume $\Delta_{i2} = (0.03)(h_i)$ for any structure in lieu of a more detailed analysis, where h_i is the height of level i above grade

The value of s_i need not exceed 0.04 times the height of the level under consideration above grade at the location of potential impact.

2.6.10.2 Exceptions

For Structural Performance Levels of life safety or lower, buildings adjacent to structures that have diaphragms located at the same elevation, and differ in height by less than 50% of the height of the shorter building, need not meet the minimum separation distance specified in Section 2.6.10.1.

Buildings rehabilitated using an approved analysis procedure that accounts for the change in dynamic response of the structures due to impact need not meet the minimum separation distance specified in Section 2.6.10.1. Such an analysis shall demonstrate that:

1. The structures are capable of transferring forces resulting from impact when diaphragms are located at the same elevation; or

2. The structures are capable of resisting all required vertical and lateral forces considering the loss of any elements or components damaged by impact of the structures.

C2.6.10.2 Exceptions

This standard permits rehabilitated buildings to experience pounding as long as the effects are adequately considered by analysis methods that account for the transfer of momentum and energy between the structures as they impact.

Approximate methods of acounting for these effects can be obtained by performing nonlinear time history analyses of both structures (Johnson 1992). Approximate elastic methods for evaluating these effects have also been developed and are presented in the literature (Kasai 1990).

Buildings that are likely to experience significant pounding should not be considered capable of meeting Enhanced Rehabilitation Objectives. This is because signficant local crushing of building components is likely to occur at points of impact. Further, the very nature of the impact is such that high frequency shocks can be transmitted through the structures and potentially be very damaging to architectural elements, and mechanical and electrical systems. Such damage is not consistent with the performance expected of buildings designed to Enhahced Rehabilitation Objectives.

2.6.11 Vertical Seismic Effects

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

1. Cantilever elements and components of structures.

2. Pre-stressed elements and components of structures.

3. Structural components in which demands due to gravity loads specified in Section 3.2.8 exceed 80% of the nominal capacity of the component.

2.7 Construction Quality Assurance

Construction of seismic rehabilitation work shall be checked for quality of construction and general compliance with the intent of the plans and specifications of the rehabilitation design. Construction quality assurance shall conform to the requirements of this section and the additional testing and inspection requirements of the building code and reference standards of Chapters 5 through 11.

C2.7 Construction Quality Assurance

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.

2.7.1 Construction Quality Assurance Plan

A Quality Assurance Plan (QAP) shall be prepared by the design professional and approved by the code official. The QAP shall identify components of the work that are subject to quality assurance procedures and identify special inspection, testing, and observation requirements to confirm construction quality. The QAP shall also include a process for modifying the rehabilitation design to reflect unforeseen conditions discovered during construction.

C2.7.1 Construction Quality Assurance Plan

The QAP should, as a minimum, include the following:

1. Required contractor quality control procedures.
2. Required design professional construction quality assurance services, including but not limited to the following:
    - 2.1. Review of required contractor submittals.
    - 2.2. Monitoring of required inspection reports and test results.
    - 2.3. Construction consultation as required by the contractor on the intent of the construction documents.
    - 2.4. Construction observation in accordance with Section 2.7.2.1.

2.7.2 Construction Quality Assurance Requirements

2.7.2.1 Requirements for the Design Professional

The design professional shall be responsible for preparing the QAP applicable to the portion of the work for which they are in responsible charge, overseeing the implementation of the plan, and reviewing special inspection and testing reports.

The design professional shall be responsible for performing periodic structural observation of the rehabilitation work. Structural observation shall be performed at significant stages of construction, and shall include visual observation of the work for substantial conformance with the construction documents and confirmation of conditions assumed during design. Structural observation shall be performed in addition to any special inspection and testing that is otherwise required for the work.

The design professional shall be responsible for modifying the rehabilitation design to reflect conditions discovered during construction.

C2.7.2.1 Requirements for the Design Professional

Following structural observations, the design professional should report any observed deficiencies in writing to the owner's representative, the special inspector, the contractor, and the code official. Upon completion of the work, the design professional should submit to the code 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 been resolved or rectified.

2.7.2.2 Special Inspection

The owner shall engage the services of a special inspector to observe construction of the following rehabilitation work:

1. Items designated in Section A.9.3.3 of Appendix A of *ASCE 7*
2. All other elements and components designated for such special inspection by the design professional.

2.7.2.3 Testing

The special inspector shall be responsible for verifying that special test requirements, as described in the QAP, are performed by an approved testing agency for the following rehabilitation work:

1. All work described in Section A.9.3.4 of Appendix A of *ASCE 7*
2. Other work designated for such testing by the design professional.

2.7.2.4 Reporting and Compliance Procedures

The special inspector shall furnish copies of progress reports to the owner's representative and the design professional, noting any uncorrected deficiencies and corrections of previously reported deficiencies. All observed deficiencies shall be brought to the immediate attention of the contractor for correction.

Upon completion of construction, the special inspector shall submit a final report to the owner's representative and the design professional, indicating the extent to which inspected work was completed in accordance with approved construction documents. Non-compliant work shall have been corrected prior to completion of construction.

2.7.3 Responsibilities of the Code Official

The code official shall be responsible for reviewing and approving the QAP and specifying minimum special inspection, testing, and reporting requirements.

C2.7.3 Responsibilities of the Code Official

The code official 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.

1. Construction Document Submittals— Permitting

As part of the permitting process, the code official 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 2.7.1. Appropriate structural construction specifications are also recommended, if structural requirements are not adequately defined by notes on drawings.

The code official 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 this standard, and/or accepted engineering principles. The code official should be aware that compliance with the building code provisions for new structures is often not possible and is not required by this standard. It is not intended that the code official assure compliance of the submittals with the structural requirements for new construction.

The code official 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. Construction Phase Role

The code official should monitor the implementation of the QAP. In particular, the following actions should be taken.

2.1 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 2.7.2.2, and those submitted by inspectors employed by the code official.

2.2 Prior to issuance of certificates of occupancy, the code official 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 that are consistent with the general intent of the construction documents.

2.3 Files of test reports prepared in accordance with Section 2.7.2.4 should be maintained for a defined length of time following completion of construction and issuance of a certificate of occupancy.

2.8 Alternative Modeling Parameters and Acceptance Criteria

For elements, components, systems, and materials for which structural modeling parameters and acceptance criteria are not provided in this standard, it shall be permitted to derive the required parameters and acceptance criteria using the experimentally obtained cyclic response characteristics of the assembly, determined in accordance with this section. Approved independent review of this process shall be conducted.

2.8.1 Experimental Setup

When relevant data on the inelastic force-deformation behavior for a structural subassembly (elements or components) are not available, such data shall be obtained from experiments consisting of physical tests of representative subassemblies as specified in this section. Each subassembly shall be an identifiable portion of the structural element or component, the stiffness of which is required to be modeled as part of the structural analysis process. The objective of the experiment shall be to estimate the lateral-force-displacement relationships (stiffness) for the subassemblies at different loading increments, together with the strength and deformation capacities for the desired Structural Performance Levels. These properties shall be used in developing an analytical model of the structure to calculate its response to earthquake ground shaking and other hazards, and in developing acceptance criteria for strength and deformations. The limiting strength and deformation capacities shall be determined from the experimental program using the average values of a minimum of three tests performed for the same design configuration and test conditions.

The experimental setup shall replicate the construction details, support and boundary conditions, and loading conditions expected in the building. The loading shall consist of fully reversed cyclic loading at increasing displacement levels with the number of cycles and displacement levels based on expected response of the structure to the design earthquake. Increments shall be continued until the subassembly exhibits complete failure, characterized by the loss of lateral- and gravity-load resistance.

2.8.2 Data Reduction and Reporting

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

1. Description of the subassembly being tested.
2. Description of the experimental setup, including:
   - 2.1. Details on fabrication of the subassembly,
   - 2.2. Location and date of experiment,
   - 2.3. Description of instrumentation employed,
   - 2.4. Name of the person in responsible charge of the test, and
   - 2.5. Photographs of the specimen, taken prior to testing.
3. Description of the loading protocol employed, including:
   - 3.1. Increment of loading (or deformation) applied,
   - 3.2. Rate of loading application, and
   - 3.3. Duration of loading at each stage.
4. Description, including photographic documentation, and limiting deformation value for all important behavior states observed during the test, including the following, as applicable:
   - 4.1. Elastic range with effective stiffness reported,
   - 4.2. Plastic range,
   - 4.3. Onset of visible damage,
   - 4.4. Loss of lateral-force-resisting capacity,
   - 4.5. Loss of vertical-load-carrying capacity,
   - 4.6. Force-deformation plot for the subassembly (noting the various behavior states), and
   - 4.7. Description of limiting behavior states defined as the onset of specific damage mode, change in stiffness or behavior (e.g., initiation of cracking or yielding) and failure modes.

2.8.3 Design Parameters and Acceptance Criteria

The following procedure shall be followed to develop structural modeling parameters and acceptance criteria for subassemblies based on experimental data.

1. An idealized lateral-force-deformation pushover curve shall be developed from the experimental data for each experiment and for each direction of loading with unique behavior. The curve shall be plotted in a single quadrant (positive force versus positive deformation, or negative force versus negative deformation). The curve shall be constructed as follows:
   1.1. The appropriate quadrant of data from the lateral-force-deformation plot from the experimental report shall be taken.
   1.2. A smooth "backbone" curve shall 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 2-4.
   1.3. The backbone curve so derived shall be approximated by a series of linear segments, drawn to form a multi-segmented curve conforming to one of the types indicated in Figure 2-3.
2. The multilinear curves derived for all experiments involving the subassembly shall be compared and an average multilinear representation of the subassembly behavior shall be derived based on these curves. Each segment of the composite curve shall be assigned the average stiffness (either positive or negative) of the similar segments in the 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 multilinear curves for the various experiments terminate.
3. The stiffness of the subassembly for use in linear procedures shall be taken as the slope of the first segment of the composite curve.
4. For the purpose of determining acceptance criteria, assemblies shall be classified as being either force-controlled or deformation-controlled. Assemblies shall be classified as force-controlled unless any of the following apply.
   4.1. The composite multilinear force-deformation curve for the assembly, determined in accordance with requirements in paragraph 2 above, conforms to either Type 1 or Type 2, as indicated in Figure 2-3, and the deformation parameter e, as indicated in Figure 2-3, is at least twice the deformation parameter g, as indicated in Figure 2-3.
   4.2. The composite multilinear force-deformation curve for the assembly determined in accordance with requirements in paragraph 2 above, conforms to Type 1, as indicated in Figure 2-3, 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 the assembly shall be either classified as force-controlled, or classified as deformation-controlled but with acceptance criteria 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 2-5. The parameters a' and $Q'y$ and points 1′ and 2′ shall be taken as shown in Figure 2-5 and shall be used in place of parameters a and Qy_1 and points 1 and 2 in Figure 2-3.
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 Structural 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 deformations corresponding with the following points on the curves of Figure 2-3:
   6.1. Primary Elements
      - 6.1.1 Immediate Occupancy: the deformation at which permanent, visible damage occurred in the experiments but not greater than 0.67 times the deformation limit for Life Safety specified in 6.1.2.
      - 6.1.2 Life Safety: 0.75 times the deformation at point 2 on the curves.
      - 6.1.3 Collapse Prevention: The deformation at point 2 on the curves but not greater than 0.75 times the deformation at point 3.

6.2. Secondary Elements

- 6.2.1 Immediate Occupancy: the deformation specified in 6.1.1.
- 6.2.2 Life Safety: 75% of the deformation at point 3.
- 6.2.3 Collapse Prevention: 100% of the deformation at point 3 on the curve.

7. The *m*-factors used as acceptance criteria for deformation-controlled assemblies in linear procedures shall be determined as follows: (a) obtain the deformation acceptance criteria given in paragraph 6 above; (b) then obtain the ratio of this deformation to the deformation at yield, represented by the deformation parameter *g* in the curves shown in Figure 2-3; (c) then multiply this ratio by a factor 0.75 to obtain the acceptable *m*-factor.

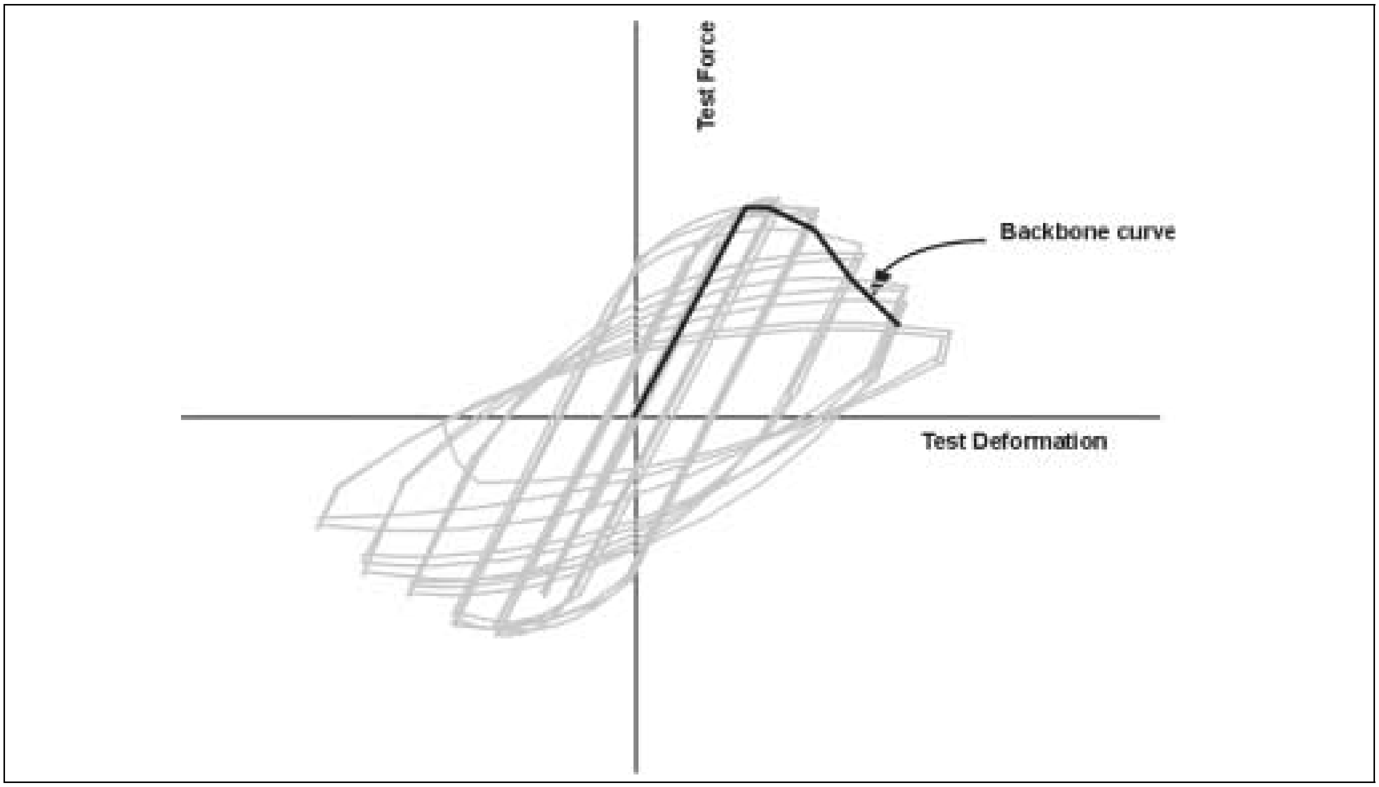

Figure 2-4 Backbone Curve for Experimental Data

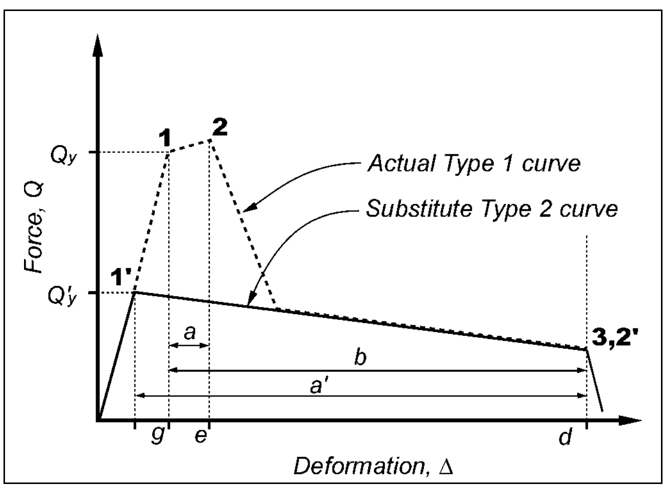

Figure 2-5 Alternative Force-Deformation Curve