C11. Architectural, Mechanical, and Electrical Components (Simplified and Systematic Rehabilitation)

C11.1 Scope

This chapter establishes minimum design criteria for the nonstructural components of architectural, mechanical, and electrical systems permanently installed in buildings, including supporting structures and attachments. Only a few selected contents and equipment components introduced into a building by occupants or owners are included, and these typically (though not always) would be included in the building construction documents, and as such would be subject to review by a building department.

Other equipment and contents that may be installed in the building after completion, which are not subject to building department review, are not included, even though their failure or damage may also pose significant threats to safety, building function, or property. The attempt to list all such items would result in many ambiguities and difficulties and, since they are not subject to building department review or within the typical architectural or engineering scope of services, little would be gained. The threat posed by such items must be evaluated by the engineer to the extent that the nature of such items is known through initial evaluation of the building.

In general, this chapter's component scope is similar to that of the *NEHRP Recommended Provisions* for new buildings and other model codes and standards.

C11.2 Procedural Steps

The core of this section is provided by Table 11-1, which enables the reader to establish which nonstructural components must be rehabilitated to achieve a Life Safety or Immediate Occupancy Performance Level. These requirements are also related to seismic zone. In general, the acceptance criteria are not different for the three seismic zones, but the number of types of nonstructural components that must be rehabilitated increase with the severity of the zone.

Table 11-1 also shows what kind of Analysis Method must be used for each component: a Prescriptive Procedure, a force analysis, or a combined force and relative displacement analysis. The determination of which kind of analysis is required is based on an assessment of the sensitivity of the component to acceleration or deformation, or to both. Table C11-1 shows the assumed sensitivity of the list of nonstructural components in Table 11-1 in the *Guidelines*, and which kinds of response are of primary or secondary concern.

C11.3 Historical and Component Evaluation Considerations

C11.3.1 Historical Perspective

C11.3.1.1 Background

This historical perspective presents the background for the development of building code provisions, together with a historical review of professional and construction practices related to the seismic design and construction of nonstructural components. From a historical perspective, it is important to note that mechanical engineers J. Marx Ayres and Terry Sun were among the first professionals to recognize the importance of mitigation of nonstructural hazards. After assessing building damage in Anchorage following the 1964 Alaska earthquake, they made this observation relative to building occupants:

> "If, during an earthquake, they must exit through a shower of falling light fixtures and ceilings, maneuver through shifting and toppling furniture and equipment, stumble down dark corridors and debris-laden stairs, and then be met at the street by falling glass, veneers, or facade elements, then the building cannot be described as a safe structure." (Ayres and Sun, 1973a)

Since the 1964 Alaska earthquake, and especially since the 1971 San Fernando earthquake, the poor performance of nonstructural elements has been identified in earthquake reconnaissance reports. Subsequent editions of the *Uniform Building Code* (ICBO, 1994), as well as California and federal codes and laws have increased both the scope and strictness of nonstructural seismic provisions in an attempt to achieve better performance.

Each earthquake teaches certain special lessons concerning the vulnerability of nonstructural elements to seismic forces and displacements. Some earthquakes reveal new vulnerabilities, while most earthquakes

Table C11-1 Nonstructural Components: Response Sensitivity

COMPONENT		Sensitivity Acc.	Sensitivity Def.	COMPONENT		Sensitivity Acc.	Sensitivity Def.
A. ARCHITECTURAL				**B. MECHANICAL EQUIPMENT**			
1.	**Exterior Skin**			**1.**	**Mechanical Equipment**		
	Adhered Veneer	S	P		Boilers and Furnaces	P	
	Anchored Veneer	S	P		General Mfg. and Process Machinery	P	
	Glass Blocks	S	P		HVAC Equipment, Vibration Isolated	P	
	Prefabricated Panels	S	P		HVAC Equipment. Nonvibration Isolated	P	
	Glazing Systems	S	P				
2.	**Partitions**				HVAC Equipment, Mounted In-line with Ductwork	P	
	Heavy	S	P				
	Light	S	P	**2.**	**Storage Vessels and Water Heaters**		
3.	**Interior Veneers**				Structurally Supported Vessels (Category 1)	P	
	Stone, Including Marble	S	P				
	Ceramic Tile	S	P		Flat Bottom Vessels (Category 2)	P	
4.	**Ceilings**			**3.**	**Pressure Piping**	P	S
	a. Directly Applied to Structure	P		**4.**	**Fire Suppression Piping**	P	S
	b. Dropped, Furred, Gypsum Board	P		**5.**	**Fluid Piping, not Fire Suppression**		
	c. Suspended Lath and Plaster	S	P		Hazardous Materials	P	S
	d. Suspended Integrated Ceiling	S	P		Nonhazardous Materials	P	S
5.	**Parapets and Appendages**	P		**6.**	**Ductwork**	P	S
6.	**Canopies and Marquees**	P					
7.	**Chimneys and Stacks**	P					
8.	**Stairs**	P	S				

Acc.=Acceleration-Sensitive
Def.=Deformation-Sensitive
P = Primary Response
S = Secondary Response

present the same lessons that have yet to be learned and applied. The 1906 San Francisco, 1925 Santa Barbara, and 1933 Long Beach earthquakes pointed out the vulnerability of unreinforced brick parapets and exterior walls to seismic forces. It was obvious that—depending on the time of day and the resultant activity without and within the buildings—falling debris from the buildings might cause as great a number of casualties to pedestrians or motorists as to building occupants. It was with such potential exterior hazards in mind that the City of Los Angeles enacted a “parapet ordinance” in 1949, which required the strengthening or removal of hazardous parapets and appendages to buildings. The potential falling parapet hazard was demonstrated again during the 1952 Bakersfield, 1971 San Fernando, 1987 Whittier-Narrows, 1989 Loma Prieta, and 1994 Northridge earthquakes.

The 1952 Bakersfield, 1964 Alaska, 1983 Coalinga, and 1994 Northridge earthquakes revealed that pendant-hung and concentric ring light fixtures can fall. The 1964 Alaska earthquake first pointed out the vulnerability of modern exterior precast wall panels, elevators, and suspended ceilings. The 1971 San Fernando earthquake provided examples of the collapse of metal library shelving, debris on exit stairways, and more failures of suspended ceilings, light fixtures, and HVAC ducts. The 1989 Loma Prieta earthquake showed the dangerous collapse of some heavy plaster ceilings and ornamentation, the severe economic losses created by water damage, and the continued vulnerability of lighting grids and their supported fixtures. The 1994 Northridge earthquake produced severe problems with fire suppression sprinkler and water supply lines that failed and flooded critical hospitals, which were thus unable to perform their post-earthquake emergency response functions.

The scope of current nonstructural codes and provisions has been derived from these experiences of nonstructural failures in earthquakes, primarily in the United States, since the 1964 Alaska earthquake. Tables C11-2 and C11-3 provide a comprehensive list of nonstructural hazards that have been observed in these earthquakes.

Table C11-2 Nonstructural Architectural Component Seismic Hazards

Component	Principal Concerns
Suspended ceilings	Dropped acoustical tiles, perimeter damage, separation of runners and cross runners
Plaster ceilings	Collapse, local spalling
Cladding	Falling from building, damaged panels and connections, broken glass
Ornamentation	Damage leading to a falling hazard
Plaster and gypsum board walls	Cracking
Demountable partitions	Collapse (i.e., falling over)
Raised access floors	Collapse, separation between modules
Recessed light fixtures and HVAC diffusers	Dropping out of suspended ceilings
Unreinforced masonry walls and partitions	Parapet and wall collapse and spalling, partitions debris and falling hazard

Source: DOE, 1995

In reviewing the design and construction of architectural nonstructural components, it is useful to look at the chronological evolution of design and construction practice for these nonstructural components as part of the evolution of overall building design in this century. Focusing on office buildings as an example, four general phases can be distinguished.

Table C11-3 Mechanical And Electrical Equipment Seismic Hazards

Equipment/ Component	Principal Concerns
Boilers	Sliding, broken gas/fuel and exhaust lines, broken/bent steam and relief lines
Chillers	Sliding, overturning, loss of function, leaking refrigerant
Emergency generators	Failed vibration isolation mounts; broken fuel, signal, and power lines, loss of function, broken exhaust lines
Fire pumps	Anchorage failure, misalignment between pump and motor, broken piping
On-site water storage	Tank or vessel rupture, pipe break
Communications equipment	Sliding, overturning, or toppling leading to loss of function
Main transformers	Sliding, oil leakage, bushing failure, loss of function
Main electrical panels	Sliding or overturning, broken or damaged conduit or electrical bus
Elevators (traction)	Counterweights out of guide rails, cables out of sheaves, dislodged equipment
Other fixed equipment	Sliding or overturning, loss of function or damage to adjacent equipment
Ducts	Collapse, separation, leaking, fumes
Piping	Breaks, leaks

Source: DOE, 1995

A. Phase 1: 1900 to 1920s

Buildings featured monumental classical architecture, generally with a steel frame structure using stone facing with a backing of unreinforced masonry and concrete. Interior partitions were of unreinforced hollow clay tile or brick unit masonry, or wood partitions with wood lath and plaster. These buildings had natural (later forced-air) ventilation systems with hot water radiators, and surface or pendant mounted incandescent light fixtures.

B. Phase 2: 1930s to 1950s

Buildings were characterized by poured-in-place reinforced concrete or steel frame structures, employing columns and (in California) limited exterior and interior shear walls. Windows were large and horizontal. Interior partitions of unreinforced hollow clay tile or concrete block unit masonry, or light wood frame partitions with plaster, are gradually replaced by gypsum. Suspended ceilings and fluorescent lights arrived, generally surface-mounted or pendant. Air conditioning (cooling) was introduced and HVAC systems became more complex, with increased demands for duct space.

C. Phase 3: 1950s to 1960s

This phase saw the advent of simple rectangular metal or reinforced concrete frame structures ("International Style"), and metal and glass curtain walls with a variety of opaque claddings (porcelain enamel, ceramic tile, concrete, cement plaster). Interior partitions became primarily metal studs and gypsum board. Proprietary suspended ceilings were developed using wire-hung metal grids with infill of acoustic panels, lighting fixtures, and air diffusion units. HVAC systems increased in size, requiring large mechanical rooms and increased above-ceiling space for ducts. Sprinklers and more advanced electrical control systems were introduced, and more HVAC equipment was spring-mounted to prevent transmission of motor vibration.

D. Phase 4: 1960s to Date

Competitive battles ensued between steel and concrete frame industries. This period saw the advent of exterior precast concrete and (in the 1980s) glass fibre reinforced concrete (GFRC) cladding. Interior partition systems of metal studs and gypsum board, demountable partitions, and suspended ceiling systems become catalog proprietary items. The evolution of the late 1970s architectural style ("Post-Modern") resulted in less regular forms and much more interior and exterior decoration, much of it accomplished by nonstructural components: assemblies of glass, metal panel, GFRC, and natural stone cladding for the exteriors, and use of gypsum board for exaggerated structural concealment and form-making in interiors. Suspended ceilings and HVAC systems changed little, but the advent of office landscaping often reduced floor-to-ceiling partitions to almost nothing in general office space. After a flurry of new building forms in the late 1970s to respond to energy reduction needs—employing solar collector arrays, trombe walls, and natural ventilation systems—office building forms generally reverted to functionally or aesthetically determined configurations. In general, energy reduction is now taken care of primarily by system improvements such as insulation, lighting design, and energy-reflecting glazing. Starting in the 1980s, the advent of the "smart" office greatly increased electrical and communications needs and the use of raised floors, and increased the need for the mechanical and electrical systems to remain functional after earthquakes.

In general, seismic rehabilitation is much more likely to apply to buildings designed and constructed prior to the 1960s, with the possible exception of nonductile concrete frame buildings designed prior to the new building codes implemented in the mid-1970s. Rehabilitation may possibly apply to steel moment frame buildings found to have deficiencies in joint design or construction, but these are, for the most part, recent buildings in which nonstructural components are likely to be installed with reasonable concern for seismic performance.

C11.3.1.2 Background to Mechanical and Electrical Considerations

Prior to the 1964 Alaska earthquake, mechanical and electrical systems for buildings had been designed with little, if any, regard to stability when subjected to seismic forces. The change in design from the heavily structured and densely partitioned structures of the pre-war era, with their simple mechanical, electrical and lighting systems, to the light frame and curtain wall, gypsum board and integrated ceiling buildings of the 1950s onward, had been little reflected in the seismic building codes. The critical yet fragile nature of the new nonstructural systems was not fully realized, except for nuclear power plant design and other special-purpose and high-risk structures. Equipment supports were generally designed for gravity loads only, and attachments to the structure itself were often deliberately designed to be flexible to allow for vibration isolation or thermal expansion.

Few building codes, even in regions with a history of seismic activity, have contained provisions governing the behavior of mechanical and electrical systems until relatively recently. One of the earliest references to seismic bracing can be found in NFPA-13, *Standard for the Installation of Sprinkler Systems*. This pamphlet has been updated periodically since 1896, and seismic bracing requirements have been included since 1947. Piping systems for building sprinklers are static and do not require vibration isolation. They do, however, require flexibility where the service piping enters the building. The issue of protecting flexibly mounted piping was not studied until after the 1964 Alaska earthquake.

The designers of building mechanical systems must also address the seismic restraints required for emergency generators, fire protection pumps, and plumbing systems that are vital parts of an effective fire suppression system. The effectiveness of the requirements in NFPA-13 have been questioned based on the poor performance of some sprinkler systems in the 1989 Loma Prieta and 1994 Northridge earthquakes; opinions vary as to whether the problems lie in the requirements, in their application, or in quality control on the job. Subsequent to the Loma Prieta earthquake, the requirements were changed and augmented, but in Northridge very few buildings had sprinkler piping installed according to the 1991 NFPA standards, so the earthquake again largely tested older installations.

C11.3.1.3 Mechanical and Electrical Systems

The first systematic examination of earthquake damage to building mechanical and electrical systems occurred after the 1964 Alaska earthquake. A study by Ayres and Sun (1973a) carefully documented the damage and developed recommended corrective measures. The study was completed in 1967 but was not formally published until 1973. With the occurrence of the 1971 San Fernando earthquake, the information in this study was so important and timely that the Consulting Engineers Association of California chose to reproduce and distribute the draft report early in 1971 rather than wait for its formal publication in 1973.

Similar studies were published by the U.S. Department of Commerce following the San Fernando earthquake (Ayres and Sun, 1973b). These reports all indicated that buildings that sustained only minor structural damage became uninhabitable and hazardous to life due to failures of mechanical and electrical systems.

C11.3.1.4 HVAC Systems

The Ayres and Sun (1973b) study clearly identified the need to anchor tanks and equipment that did not require vibration isolations, and to provide lateral restraints on equipment vibration isolation devices. Some of these suggested corrective measures are now incorporated into manufactured products. The HVAC system designers had to become aware of the earthquake-induced forces on the system’s components and the need for seismic restraints to limit damage; they also had to understand the requirements for the suspension and bracing of ceilings and light fixtures because of their adjacency to and interaction with the HVAC system components.

Recent significant advances in earthquake-resistive design for building mechanical systems and other nonstructural building elements have been stimulated by recurring earthquakes and the more aggressive enforcement of new building regulations, particularly by agencies such as the California Office of Statewide Health Planning and Development, and the Veterans Administration. To meet the demands of the building industry, new and improved products have been developed that assist the HVAC system designer in the preparation of construction documents. Manufacturers of vibration isolation components, hangers, supports, and restraints now offer equipment that is specifically designed to protect HVAC systems and other mechanical equipment during earthquakes. Following the 1971 San Fernando earthquake that severely damaged several hospitals, the state of California required new hospitals to be provided with the necessary seismic restraints for nonstructural components to increase the probability of hospitals remaining operational after earthquakes.

To provide technical guidance to HVAC system designers and installers, the Sheet Metal Industry Fund of Los Angeles published its first manual, *Guidelines for Seismic Restraint of Mechanical Systems* (Sheet Metal Industry Fund, 1976). This manual was updated in 1982 with assistance from the Plumbing and Piping Industry Council (PPIC) (SMACNA, 1982). The most recent manual, *Seismic Restraint Guidelines for Mechanical Equipment* (SMACNA, 1991), is designed for use in California as well as other locations with lower seismic hazard levels.

Secondary effects of earthquakes (fires, explosions, and hazardous materials releases resulting from damaged mechanical and electrical equipment) have only recently being considered. In addition, the potential danger of secondary damage from falling architectural and structural components, which could inflict major damage to adjacent equipment and render it unusable, needs to be carefully assessed.

These secondary effects can represent a considerable hazard to the building, its occupants, and its contents. Steam and hot water boilers and other pressure vessels can release fluids at hazardous temperatures. Hot water boilers operating above 212°F/100°C, in particular, represent a hazard, as the sudden decrease in pressure caused by a rupture of the vessel can result in instantaneous conversion of superheated hot water to steam, with explosive disintegration of the remainder of the vessel. Mechanical systems often include piping systems filled with flammable, toxic, or noxious substances, such as ammonia or other refrigerants. Some of the nontoxic halogen refrigerants used in air-conditioning apparatus can be converted to a poisonous gas (phosgene) upon contact with open flame. Hot parts of disintegrating boilers, such as portions of the burner and firebrick, are at high enough temperatures to ignite combustible materials with which they might come in contact (ATC, 1978).

C11.3.1.5 Building Code Provisions

The basic function of earthquake design provisions in the building code is to protect the life and safety of the public. From as early as the 1927 edition of the *Uniform Building Code* (*UBC*) until the 1961 edition, the lateral force provisions, referred to as "Lateral Bracing (Earthquake Regulations)," were only included in the *UBC* Appendix. This Appendix contained suggestions and explanatory material with reference to various details in the body of the Code, but was not considered as a legal part of the Code. Unless a locality adopted the "Lateral Bracing" provisions in the Appendix, it is reasonable to assume that there are many existing buildings that were designed without any consideration of seismic design criteria. In the 1927 *UBC*, nonstructural lateral bracing requirements were not addressed explicitly, but the Code had general wording:

> (b) Bonding and Tying. All buildings shall be firmly bonded and tied together as to their parts and each one as a whole in such manner that the structure will act as a unit. All veneer finish, cornices and ornamental details shall be bonded in the structure so as to form an integral part of it. This applies to the interior as well as the exterior of the building.

In the later editions of the *UBC*, the general wording of the 1927 *UBC* Appendix was changed to more specific horizontal force requirements for specific nonstructural components, such as nonbearing walls, partitions, curtain walls, enclosure walls, panel walls, cantilever parapet and other cantilever walls, exterior and interior ornamentation, and appendages. The first model seismic code or guideline was published in 1959 by the Seismology Committee of the Structural Engineers Association of California (SEAOC). The model codes have historically provided for lateral design of the building frame, but the evolution of provisions for nonstructural components is quite recent.

When the Lateral Bracing (Earthquake Regulations) were incorporated in the body of the *UBC* in 1961, the seismic provisions for the nonstructural components were incorporated explicitly for the first time. The horizontal lateral force that a nonstructural component and its connections were required to resist was expressed by the equation, $F_p = C_p W_p$. This equation has remained basically unchanged through the 1994 *UBC*.

Nonstructural components were referred to in the 1961 *UBC* as "parts and portions of buildings" and the scope of requirements was limited almost entirely to architectural components: nonbearing walls and partitions, masonry and concrete fences over six feet in height, cantilever parapets, and interior and exterior ornamentations and appendages. Also included were "contents, chimneys, smokestacks and penthouses, elevated tanks, and tanks resting on the ground."

There was no change in the 1964 *UBC*. In the 1967 edition "connections for exterior panels" were added, with specific requirements for these "elements" called out. There was no change in 1970. The 1973 edition added storage racks and suspended ceiling systems. In 1976 the existence of mechanical equipment was recognized by the inclusion of "rigid and rigidly mounted equipment and machinery."

Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC-3-06 (ATC, 1978), presented a seismic force formula for architectural systems, mechanical and electrical components, and their attachments. This formula had five variables, including an amplification factor that increased with the height or vertical location of the component in the building. The use of such an amplification factor was not recognized in the *UBC* provisions. This amplification factor is only now fully recognized in the 1994 *NEHRP Provisions* (BSSC, 1995). Both documents include amplification factors for flexibly mounted equipment.

Some of the development in recent codes and provisions has focused on distinguishing between nonstructural components whose failure represents a life hazard, those whose failure represents primarily economic loss, and those whose failure results in loss of building function.

Particular attention has been focused on the economic consequences of nonstructural damage. The need for proper anchorage of building nonstructural elements has been clearly demonstrated by the staggering property damage and repair costs that have followed every recent earthquake. During the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes, code-designed buildings suffered serious damage, particularly to their nonstructural systems and components. After the 1989 Loma Prieta earthquake, the Applied Technology Council sponsored a seminar (ATC, 1992) that resulted in a series of papers that presented the latest information on the seismic design and performance of equipment and nonstructural elements. The overall conclusion of the seminar was not only to identify the problems, design deficiencies, and costs, but to restate the fact that the costs of proper restraints are minor in relation to the overall cost of the building and its contents.

C11.3.1.6 Historic Buildings

As stated in the *Guidelines*, the architectural, mechanical, and electrical components and systems of a historic building may be highly significant, especially if they are original to the building, very old, or innovative. Indeed, in many instances, both interior and exterior architectural materials and finishes may be the major argument for the preservation of the building. If this is so, than a careful assessment of their significance may be necessary by an appropriate professional such as an architectural historian, historical preservation architect, or an expert in historic material and finishes.

Sometimes removal of later finishes may reveal materials or finishes of historic value in a building not specifically identified as historic. Again, careful assessment by a qualified expert is necessary.

A careful nonstructural mitigation plan is necessary to ensure that historic materials and finishes are preserved, while still meeting the requirements for the specified Rehabilitation Objective.

While the architectural materials and finishes in historic buildings are commonly of major historic interest, it is also possible that mechanical or electrical components, or plumbing fixtures, will be of historic value and should be preserved. On the other hand, historic buildings may also have materials—usually concealed, such as lead pipes or asbestos—that may pose a hazard, depending on their location, condition, use or abandonment, and/or disturbance during the rehabilitation. Such problems must also be identified as part of the rehabilitation plan, and steps taken to ensure requisite safety for workers and occupants.

C11.3.2 Component Evaluation

A suggested general procedure for developing a mitigation plan for the rehabilitation of nonstructural components is as follows.

1. It is assumed that the building has been evaluated in a feasibility phase, using a procedure such as that described in FEMA 178 (BSSC, 1992b). For nonstructural components, use of this procedure will have provided a broad list of deficiencies generally, but not specifically, related to a Rehabilitation Objective.

   Issues related to other objectives and possible nonstructural components not discussed in FEMA 178 (BSSC, 1992b), as well as issues raised by nonstructural rehabilitation unaccompanied by structural rehabilitation (e.g., planning, cost-benefit) are outlined in this *Commentary*, and references are provided for more detailed investigation.

2. The decision is made to rehabilitate the building, either structurally, nonstructurally, or both.

3. From Chapter 2 in the *Guidelines*, the designer reviews Rehabilitation Objectives and, in concert with the owner, determines the Objective; alternatively, the Objective may already have been defined in an ordinance or other policy.

4. Armed with a decision on the Rehabilitation Objective, which includes Performance Level or Range as well as ground motion criteria, the designer consults Chapter 11 of the *Guidelines*.

5. Using Chapter 11, the designer prepares a definitive list of nonstructural components that are within the scope of the rehabilitation, based on the selected Performance Level and an assessment of component condition. For the Life Safety Level and, to some extent, the Immediate Occupancy Level, Chapters 2 and 11 in the *Guidelines* specify requirements. However, for other levels and ranges, there is a need to evaluate and prioritize. A suggested procedure is outlined in Sections C11.3.2.1 through C11.3.2.9.

6. From the list of nonstructural components within the project scope, a design assessment is made to

determine if the component requires rehabilitation and, from Table 11-1 in the *Guidelines*, the rehabilitation Analysis Method (Analytical or Prescriptive) for each component or component group is determined.

7. For those components that do not meet the criteria, an appropriate analysis and design procedure is undertaken, with the aim of bringing the component into compliance with the criteria appropriate to the Performance Level or Range and the ground motion criteria.

8. Nonstructural rehabilitation design documents are prepared.

C11.3.2.1 Overview

The nonstructural evaluation procedure set out in this section can be used for the development of a mitigation plan incorporating priorities related to achieving a selected Rehabilitation Objective (or Objectives) within available resources.

A formal evaluation procedure is suggested in order to establish the real relative risks posed by the nonstructural components. While Table 11-1 in the *Guidelines* identifies the relationship between nonstructural components, seismic zones, and the rehabilitation requirement and analysis procedures to meet the Life Safety and Immediate Occupancy Performance Levels, it is necessary to prepare a definitive list of nonstructural components for rehabilitation, based on assessment of risk, priority, and available budget.

A suggested nonstructural evaluation procedure is summarized in Figure C11-1. The procedure includes the following steps:

1. A preliminary evaluation based on FEMA 178 (BSSC, 1992b)

2. Selection of a desired Rehabilitation Objective for the building

3. A building “walk-down” to establish an inventory of nonstructural components that includes:

   a. Locations and quantities of selected components, and vulnerabilities and consequences of failure of each component

   b. Development of a seismic risk rating for each component

4. Development of a mitigation priorities list

5. Establishment of Analysis Method from Table 11-1

6. Development of appropriate rehabilitation design concepts

7. Preparation of a performance-related mitigation plan

A final mitigation plan, developed in concert with the owner, must also relate costs to available budget and possible time constraints. When these factors are considered, the selected Rehabilitation Objective may have to be modified, planned to be accomplished in a phased program, or both. These additional steps are shown in Figure C11-1.

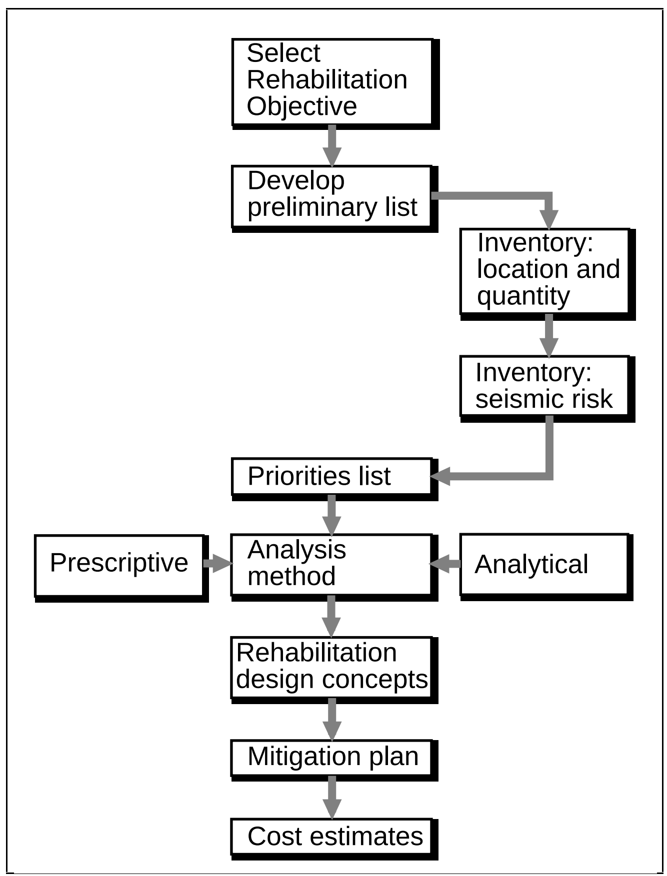

Figure C11-1 Nonstructural Evaluation Procedure

C11.3.2.2 Preliminary Evaluation

The *NEHRP Handbook for the Seismic Evaluation of Existing Buildings*, Chapter 10, "Evaluation of Elements that Are Not Part of the Lateral-Force-Resisting System" (FEMA 178) (BSSC, 1992b), provides the basic criteria for the evaluation of nonstructural elements. If a FEMA 178 nonstructural evaluation has been performed on the building, a copy should be obtained and its findings evaluated as a preliminary to using the "walk-down" procedures discussed in Section C11.3.2.4.

It is important to note that the FEMA 178 (BSSC, 1992b) evaluation statements and performance characteristics are all-inclusive, and do not differentiate between nonstructural elements that are specifically life-safety hazards and those elements whose seismic performance relates more to Damage Control and Immediate Occupancy goals.

For buildings with Life Safety Performance Level goals, no further evaluation work need be undertaken for systems for which the FEMA 178 (BSSC, 1992b) evaluation statements can all be answered "True," resulting in a "Low" vulnerability rating. When evaluation statements receive "False" answers, additional investigation needs to be undertaken in accordance with the following procedure.

For buildings with Enhanced Rehabilitation Objectives, the vulnerability assessment described above must be augmented with an assessment of seismic risk that considers property loss and loss of building function. This is done by use of information in FEMA 74 (FEMA, 1994) as described in Section C11.3.2.4.

C11.3.2.3 Rehabilitation Objectives

One or more Rehabilitation Objectives must be selected, prior to further evaluation of in-place conditions or analysis of rehabilitation measures.

C11.3.2.4 Building Walk-Down: Inventory, Location, Quantity, and Seismic Risk

In order to assess the extent of the real nonstructural problems in an existing building that is under evaluation for seismic rehabilitation, a formal "diagnosis" is necessary. This ensures that all items are accounted for, and that a reasonably standardized procedure is followed that will result in a balanced assessment of risk, cost, and priority.

One effective diagnostic measure is the seismic survey or "walk-down" inspection. The walk-down inspection process begins by developing an inventory of important architectural components and mechanical and electrical equipment. The list of components in Table 11-1 of the *Guidelines* provides the basis for this, but items may be added or subtracted depending on the Rehabilitation Objective and the nature of the specific building.

The nonstructural seismic "walk-down" has two main objectives:

1. To inventory the nonstructural items that are considered important, and to establish their location and quantity

2. To establish for each component, item, or system, its seismic risk, which is a combination of seismic vulnerability and the consequences in relation to the seismic Rehabilitation Objectives

Appendix A of FEMA 74 (FEMA, 1994) provides a suitable inventory form, together with an example of how it is used. Teams involved in the development of inventories may wish to design forms appropriate to their office practice, the nature of the project, and the level of detail that the owner requires.

Not all data need be collected in every instance. For Limited Rehabilitation Objectives—or in situations where rehabilitation does not depend on particular information, such as quantity—only sample data are necessary.

The seismic risk assessment of each item is best accomplished by a two-person team of architects and/or engineers experienced in seismic design and evaluation of the seismic performance of the building's structural and nonstructural elements. The Checklist of Nonstructural Earthquake Hazards in Appendix B of FEMA 74 (FEMA, 1994), and the Nonstructural Risk Ratings of Appendix C, can be used to assess whether the nonstructural components present a danger to building occupants (in cases where their proximity to occupied space is critical) or are likely to cause financial loss or operational interruption following an earthquake.

For more guidance on the assessment of nonstructural risk rating, refer to the beginning of Appendices B and C in FEMA 74.

C11.3.2.5 Priority Setting

If a Rehabilitation Objective other than the BSO, or voluntary rehabilitation with objectives defined by the owner, is being pursued, it will be necessary to establish priorities for the rehabilitation of nonstructural components. To do this, some of the items in the inventory (determined by the building walk-down) may need a further level of evaluation. The level of formality in this evaluation may vary from some discussion among the principal participants for a small project, to preparation of a carefully prepared list for a large project. The setting of priorities is of particular importance in a large project for which the budget for nonstructural rehabilitation is limited.

In the preparation of a careful prioritized list that can form the basis for budgetary discussion, the information derived from the use of the two checklists in Appendices B and C of FEMA 74 (FEMA, 1994) to establish a risk rating for each component can be further refined by recognizing that seismic risk is a combination of “vulnerability” and “consequences.”

“Vulnerability” is an estimate of the likelihood of component failure; it is assessed as a measure of:

1. The characteristics of the ground motion
2. The response of the building in terms of acceleration and displacement
3. The size and weight of the element
4. Its location in the building (e.g., the first floor or roof)
5. The type of building lateral-force-resisting system and the relative stiffness of the structure and the nonstructural element
6. The adequacy of the connection or lack of connection of the nonstructural component to the structure and other supporting nonstructural elements

“Consequences” is an estimate of the effect of component failure; it relates to:

1. The item’s location in the building
2. The building occupancy and function, and the potential impact on life safety and/or building function if the component or equipment were to fail

In addition, some components, such as appendages and cladding, must be evaluated in relation to adjacent—and possibly lower—buildings, alleys, parking areas, sidewalks, plazas, parks, and landscaped areas.

Typically, the assessments are made on the basis of visual observation and engineering judgment, either during the building walk-down, or as a separate activity after it is conducted. For the most part, no formal seismic calculations are performed or reviewed in these assessments. However, when faced with items of high consequence and questionable seismic resistance, it may be necessary to do a structural analysis using the default equation (Equation 11-1) in the *Guidelines*. This is the only reasonably sure way to establish that a particular element has the desired level of seismic resistance, particularly in the high seismic areas of the United States.

The Seismic Vulnerability ratings are as follows:

Low Seismic Vulnerability: The identified component is reasonably well anchored, and there is a low probability of it failing under the design forces and deformations of the building.

Moderate Seismic Vulnerability: The identified component is anchored, but there is a moderate probability of it failing under the design forces and deformations of the building.

High Seismic Vulnerability: The identified component is either poorly anchored or not anchored, and there is a high probability of it failing under the design forces and deformations of the building.

The Seismic Consequence of Failure ratings are as follows:

Low Seismic Consequence: The identified component is so located in the building or is of such a type that its failure represents a low risk (no injury or minor injury) to the occupants and a low adverse impact on the seismic Performance Level for the building.

Moderate Seismic Consequence: The identified component is so located in the building or is of such a type that its failure represents a moderate risk (minor to moderate injury) to the occupants and a moderate adverse impact on the seismic Performance Level of the building.

High Seismic Consequence: The identified component is so located in the building or is of such a type that its failure represents a high risk (death or serious injury) to the occupants and a high adverse impact on the seismic Performance Level of the building.

In a nonstructural seismic rehabilitation project, the obvious nonstructural risks to be rehabilitated first would be those hazards that have a high probability of causing injury and/or death to the occupants, or to those people entering, leaving, or adjacent to the building. These hazards would have High Seismic Consequence ratings. These High Seismic Consequence nonstructural hazards should then be further ranked for rehabilitation according to their High, Moderate, and Low Seismic Vulnerability ratings. To assist in the evaluation, the ratings of Vulnerability and Consequences for components whose priority is not clear can be tabulated as shown in Table C11-4.

Table C11-4 Nonstructural Rehabilitation Priority Ratings

Vulnerability Rating	Consequence Rating		
	High	Moderate	Low
High	1	4	7
Moderate	2	5	8
Low	3	6	9

Given the combined Seismic Vulnerability and Consequence rating, the order in which the nonstructural hazards should be rehabilitated is provided by the rank order of the number in Table C11-4: 1 is the highest priority, 2 is the second, 3 is the third, and so on.

The priority setting of the seismic rehabilitation of the nonstructural element is primarily governed by the level of the Seismic Consequence rating, and second by the Seismic Vulnerability rating. Since the determination of the consequences of a nonstructural element failing can generally be made with a higher degree of certainty than its seismic vulnerability—because the evaluation criteria earthquakes could be exceeded—the seismic consequence rating is the key predictor variable.

A nonstructural element with a Low Seismic Consequence rating would not have a high priority for rehabilitation regardless of its Seismic Vulnerability rating.

An example would be a heavy concrete exterior cladding panel, improperly attached to the structure, which would have a High Seismic Vulnerability rating. However, if this cladding panel were located above a light well where occupant and public access were restricted, it would have a Low Seismic Consequence rating. As long as the restriction were maintained, this cladding panel would have low priority, a ranking of 7, for rehabilitation, with a Limited Safety Performance Level goal for the building. If the Performance Level goal for the building was Immediate Occupancy and the local climatic conditions were such that proper enclosure of the building from the weather was necessary, then the seismic rehabilitation of the inadequately anchored heavy panel would probably have a high priority.

In buildings with Life Safety Performance Level goals, the potential falling hazard of an improperly anchored heavy light fixture in an exit corridor, with a High Seismic Vulnerability rating, and a High Seismic Consequence rating, should have a higher priority for rehabilitation than a similar light fixture in an infrequently occupied storage area with a lower Seismic Consequence Rating. The same argument can be made that improperly installed lay-in T-bar ceiling systems in exit corridors should have a higher rehabilitation priority than similar ceiling systems over office work areas.

In buildings for which the Damage Control Performance Range or Immediate Occupancy Performance Level is a goal, it would be necessary to rehabilitate all nonstructural hazards throughout the building—regardless of the Consequence Rating—starting with the rehabilitation of the High Seismic Vulnerability rated elements, to reduce the vulnerability to less than Low.

Many other patterns of priority—based on specific Rehabilitation Objectives, building conditions, resources, and site seismicity—can be envisaged.

C11.3.2.6 Analysis

For those components requiring rehabilitation, an analysis should be undertaken, based on the procedures described in Section 11.7.3 or 11.7.4 and in sections relating to specific components.

C11.3.2.7 Rehabilitation Concept Development

Based on the rehabilitation procedure, a design concept can be assigned and quantified.

C11.3.2.8 Cost Estimating

A cost estimate should be prepared for each identified component and priority ranking.

C11.3.2.9 Nonstructural Component Hazard Mitigation Plan

Based on the evaluation, priorities, rehabilitation procedure, costs, and available resources, a mitigation plan should be prepared that establishes the objectives, rehabilitation type, order, estimated cost, and suggested time frame for nonstructural hazard mitigation.

C11.4 Rehabilitation Objectives, Performance Levels, and Performance Ranges

A Rehabilitation Objective combines ground motion criteria (mean return period of earthquake related to standardized maps)—which is stated in the *Guidelines* in terms of probabilities in 50-year exposure periods—with a description of acceptable behavior of the building (Performance Level or Performance Range). The Basic Safety Objective (BSO) defined in the *Guidelines* includes both structural and nonstructural requirements, because one of the two Performance Levels required for that Objective to be met is Life Safety. The BSO is a basic benchmark, and thus its inclusion of nonstructural requirements is a significant part of the *Guidelines*.

The two ground motion analyses required in the BSO, BSE (Basic Safety Earthquake)-1 and BSE-2, are applied to the Life Safety and Collapse Prevention Performance Levels, respectively. (See Chapter 2.) However, Collapse Prevention criteria relate—with one exception—only to the building structure, although nonstructural components that modify the structural response (such as nonstructural infill walls) must also be considered. The exception is that parapets and appendages should also be rehabilitated at the Collapse Prevention Performance Level, because the result of their failure—massive falling debris—is analogous to that of the structure. It would not make sense to rehabilitate a structure without also dealing with parapet and appendage problems.

Typically, the Rehabilitation Objective for nonstructural components will be the same as for the building structure. However, an owner might choose to rehabilitate nonstructural components to a higher level in a given project, for purposes of damage control (to reduce economic losses). In another case, a structure might be adequate to meet the Life Safety Performance Level or even Immediate Occupancy, but because nonstructural rehabilitation would be very costly to achieve for those levels, the owner may choose not to attempt it.

It is also possible for nonstructural rehabilitation to be provided in the absence of any structural rehabilitation; for example, where the structure is already found acceptable, or where seismic risk is relatively low and structural performance is likely to be good. In these cases, nonstructural rehabilitation may be justified, because nonstructural damage can occur at relatively low accelerations in minor to moderate events, and reducing nonstructural damage can be very cost-effective compared to the costs of damage and business interruption if nonstructural components are left unrehabilitated.

C11.4.1 Performance Levels for Nonstructural Components

When the BSO is selected, all nonstructural components that are identified in Table 11-1 of the *Guidelines* as relevant to the Life Safety Performance Level must meet specific requirements for the BSE-1 ground motion. In some cases, judgment must be used to determine the life safety implications of certain nonstructural components for a specific building, such as the evaluation of pendant light fixtures to determine their hazard potential.

While some items—such as much mechanical equipment—pose a very low life-safety threat, and hence rehabilitation is (with some exceptions) generally not required, owners might be wise to rehabilitate these items because the techniques are simple and inexpensive, and the benefits in reduction of property loss are great.

Criteria for nonstructural components for more severe ground motion, or for the Immediate Occupancy or

Operational Performance Levels, provide for Enhanced Rehabilitation Objectives that meet and exceed the BSO.

Table 11-1 in the *Guidelines* establishes the list of nonstructural components included within the scope of the detailed requirements of the *Guidelines.* Where the Life Safety Performance Level is applicable, the components indicated in Table 11-1 as Life Safety components must meet the specific acceptance criteria given in Chapter 11 of the *Guidelines.* For individual components in Sections 11.9, 11.10, and 11.11, acceptance criteria are also provided that relate to the Immediate Occupancy Performance Level.

On a single project, Nonstructural Performance Levels may be combined. The criteria for parapets would often be those of the Life Safety Performance Level. In the same building, art objects, telephone and computer room components, or the backup motor-generator set and its associated cooling, fuel, and other components, might rationally be protected up to the Operational Performance Level. In this same building, there may be some nonstructural features listed in Table 11-1 whose rehabilitation is deferred; for example, adhered veneer in a low occupancy area might be difficult to rehabilitate, and a decision might be made to not include it within the project. Thus, unlike structural components, the nonstructural components in a single building have often been assigned a mixture of Performance Levels in the rehabilitation process, and this flexibility has been maintained in the *Guidelines*. As defined in Chapter 2, an overall Building Performance Level is the combination of one Structural Performance Level or Range and one Nonstructural Performance Level or Range. To satisfy the Life Safety Performance Level, all of the nonstructural requirements of the Nonstructural Life Safety Performance Level must be met.

It is recognized that the failure of an architectural, mechanical, or electrical component might have an adverse effect on code-required life safety systems, but the intent of the *Guidelines* for the Life Safety Performance Level is limited to ensuring that all architectural, mechanical, and electrical systems remain intact to the extent that they do not create a falling hazard, an ignition hazard, or release of materials that are hazardous for short-term exposure.

Rehabilitation to an Operational Performance Level implies a damage state in which the building is immediately suitable for occupancy and use, albeit in a somewhat impaired mode; acceptable impairments will vary depending on the building occupancy.

The Operational Performance Level represents a level above Immediate Occupancy; the focus is on maintaining utility services within the building together with essential equipment that would vary according to the building function. The structural state might be identical with Immediate Occupancy.

No specific criteria for nonstructural components for the Operational Performance Level are provided in these *Guidelines*, because the critical components and systems are building-specific, and operational capability may be dependent on equipment over which the design team has no authority. For example, the continued operation of a hospital emergency room may depend on sophisticated medical equipment, which has not been designed with the seismic problem in mind. While use of the *Guidelines* may ensure that such equipment is adequately braced or anchored, the design team cannot evaluate the resistance capacity of a closed piece of equipment—a so-called “black box”.

Depending on the importance of the equipment and the resources available to the design team, seismic testing and certification of such equipment may be requested of the manufacturer. Alternatively, special attention may be paid in the rehabilitation design to reducing the building response, and hence the likelihood of equipment failure, by use of advanced design techniques such as base isolation and energy dissipation.

Experience in recent earthquakes—notably, the 1994 Northridge event—has revealed the difficulties inherent in the attempt to ensure post-earthquake operational capacity. After the Northridge earthquake, some major new hospitals with current-practice nonstructural seismic features for essential facilities had to shut down due to nonstructural damage, because their nonstructural features were both unusually complicated and very essential. Even where good seismic detailing prevented a large amount of damage, a few seemingly small failures (for example, one or two pipe breaks) were sometimes enough to cause large disruptions in some buildings (Hall, ed., 1995). Clearly, in a complex building with thousands of feet of piping and hundreds of joints and connections, it is very hard to provide a zero-defect system.

Water leakage may have serious interactive effects, affecting the operation of an otherwise functional backup power system. At Northridge, the power outage was so extensive—affecting two million customers throughout Los Angeles and some other communities—that reliable backup power was necessary for essential facilities to operate. Even in some buildings with extensive backup power systems that functioned correctly after the earthquake (such as at the Veterans Administration Sepulveda Medical Center), water leakage caused short circuits and power was automatically shut off. At Holy Cross Hospital, one patient on life support died because the properly functioning backup system stopped when sprinkler pipe leakage caused wiring to ground out.

Experience has also shown that both approaches to the overall design of a system (besides correct detailing and installation) and managerial responses may play an important role in ensuring operational capability. Based on disruptive sprinkler and other piping leakage in the Northridge earthquake, some suggestions have been made for essential facilities (in addition to trying to prevent leakage). These are (1) zoning systems into smaller areas, so that smaller areas can be shut off; (2) providing automatic or remotely controlled valves; and (3) more rigorously training designated personnel in shut-off techniques. Even with damage to critical data processing equipment, the overall impact on facility function can be minimized with a redundant or backup site and rapid response (Holmes and Reitherman, 1994).

The lesson of the Northridge earthquake appears to be that good seismic detailing and careful installation to meet the acceptance criteria for Life Safety and Immediate Occupancy will go a long way in protecting essential equipment and services, but that complex facilities remain vulnerable to even a single failure in a complex system. If reliability of systems is critical, careful building-specific evaluation and design are necessary, and techniques such as base isolation and specially designed and redundant systems, as in nuclear power plants, must be considered.

C11.4.2 Performance Ranges for Nonstructural Components

Nonstructural rehabilitation within a Limited Safety Performance Range below the BSO might include mitigation of the hazards of some, but not all, of the nonstructural components identified as Life Safety components in Table 11-1, or for elements considered hazardous at a more probable (less intense) level of shaking than the BSE-1 criterion. Rehabilitation techniques should be designed for criteria that meet or exceed BSE-1 wherever feasible. This is not likely to incur a cost or design complexity penalty.

Included within a variety of partial rehabilitation measures is the Nonstructural Hazards Reduced Performance Level. There are numerous actual examples of nonstructural seismic rehabilitation of this type. For example, if a remodelling project afforded the inexpensive opportunity to rehabilitate the ceilings, partitions, and other components on the Life Safety list of Table 11-1, but the components in another portion of the building were not included, the project would not fully meet the Life Safety Performance Level. Alternatively, throughout a building only some of the components on the Life Safety list of Table 11-1 might be rehabilitated; for example, by some cost-benefit decision-making process, the heavy light fixtures might be restrained from falling, while the more expensive bracing of the lightweight ceiling might not be rehabilitated. This level of rehabilitation would be the Hazards Reduced Performance Level. Except for the Hazards Reduced Performance Level, the *Guidelines* do not define a particular set of components that must be rehabilitated to meet the requirements of these ranges. The *Guidelines* also do not specify which kind of risk-reduction goal—prevention of injury, protection of property, or provision for continued post-earthquake operation—must be considered for these ranges.

Nonstructural rehabilitation exceeding the Life Safety Performance Level might include post-earthquake functionality protection for nonstructural components or features such as emergency escape and rescue routes, data processing or communications equipment and services, or other activities that are occupancy-related. Protection of property—such as protecting brittle architectural features of a building from cracking even if the cracking would not be hazardous—is another example. In addition, rehabilitation within this range might focus extensively on contents, such as valuable art artifacts, that are not within the scope of the *Guidelines*.

In general, once the Life Safety Performance Level requirements are met, a significant degree of protection from functional failure and property damage is also achieved, but this varies greatly from building to building and may not approach the specific occupancy-related expectations of post-earthquake functionality.

C11.4.3 Regional Seismicity and Nonstructural Components

No commentary is provided for this section.

C11.4.4 Means of Egress: Escape and Rescue

C11.4.4.1 Background

The ability of building occupants to safely leave a building immediately after an earthquake, or for response personnel to enter it for rescue purposes, is a recognized seismic rehabilitation issue. To achieve these ends, the intent of some rehabilitation has included keeping the "means of egress" moderately free from obstruction after the earthquake. In the development of this document, an attempt has been made specifically to define this subject area, and in the process, it was found that the scope of this issue is much broader than is often assumed. As a result, the option of embedding egress criteria, or emergency escape and rescue requirements, in the *Guidelines* for the Life Safety Performance Level was rejected, primarily for two reasons.

1. Criteria for means of egress and exiting have many code implications beyond those generally thought to be relevant for the post-earthquake situation. If this document required that means of egress be provided for the post-earthquake Life Safety Performance Level, this might also trigger many code requirements not specifically related to post-earthquake safety, which would be difficult and costly to implement.

2. Previous documents' references to egress were felt broadly to imply a guarantee that virtually all circulation routes and related nonstructural features and services required by current code would be functional in the post-earthquake setting. That expectation most closely matches the definitions of the Immediate Occupancy Performance Level, or in some cases the Damage Control Performance Range, rather than the Life Safety Performance Level.

The following discussion explains the background to this issue, and offers some guidance on how to effectively include provision for this concern in designing for an Immediate Occupancy Performance Level or within a Damage Control Performance Range.

C11.4.4.2 Code Implications of Means of Egress

The term "means of egress" has a particular meaning in model building codes: that of the provision for *exits*, which include "intervening aisles, doors, doorways, gates, corridors, exterior exit balconies, ramps, stairways, pressurized enclosures, horizontal exits, exit passageways, exit courts and yards" (*Uniform Building Code* [ICBO, 1994], Chapter 10, Definitions). Other model codes use essentially the same definitions, because historically egress requirements were included because of fire hazard. Very specific criteria are provided for all the above items.

The *UBC* does not distinguish between egress (exiting) and ingress (entering), and the latter term does not appear at all in the *UBC*. For the post-earthquake situation, egress is the governing condition: if egress is preserved for the occupants, then rescue personnel—who will almost certainly have equipment (e.g., lights and tools) that the occupants may lack—should have little difficulty entering the building. In the following discussion, the term "egress" refers to both egress and ingress.

Egress differs significantly from "access" in code terminology. Access is literally the ability to approach and go into the building (that is, the same as ingress), but access and accessibility now have a specific code definition as "complies with this chapter and that can be approached, entered and used by persons with physical disabilities" (*UBC*, Chapter 11, Accessibility, Section 1102, Definitions).

In building code use, disabled accessibility refers to two-way (ingress and egress) capability: disabled people are supposed to be able to go into the building, and there are also special requirements to aid their egress, which together are called "accessibility provisions."

The imposition of requirements aimed at the post-earthquake protection of "means of egress" without qualification can thus complicate post-earthquake escape and rescue needs by triggering a long list of nonseismic code requirements. Triggering of building code requirements to upgrade exits might, for example, include the widening of corridors, addition of stair towers, or installation of wheelchair-accessible ramps.

Such nonseismic issues are not embedded in the requirements of the *Guidelines*.

To include a phrase such as “maintain all exits and exitways” in the *Guidelines* could also be construed to require installation of a complete emergency power system where none would otherwise be required, because exit signs, stairwell lights, annunciation systems, and other electrically powered components required by code for exiting concerns might not operate after an earthquake, when experience has shown that widespread power outages must be regarded as routine.

The ability to enter and circulate safely through a building in continuation of its normal operation, which is part of a building code’s intent, is not a seismic life safety-related concern and thus is distinct from the subject discussed here. Therefore, ensuring that escalators continue to function in a department store is a concern related to Immediate Occupancy and protection of business operations rather than to Life Safety, and seismic rehabilitation to protect the ability of escalators to function would be based on criteria considerably more restrictive than simply emergency post-earthquake escape and rescue.

C11.4.4.3 Life Safety Performance Level and Post-Earthquake Conditions

The Life Safety Performance Level is directed toward the limited objective of reducing, to a low but unspecified probability, casualties caused by structural or nonstructural damage. As a practical matter, the injury-prevention aim in most cases would impose more restrictive requirements on nonstructural components than any specific criteria for preventing obstruction to means of egress. The Life Safety Performance Level requires that the most hazardous nonstructural components are replaced or rehabilitated. As stated in the *Guidelines*, the items listed in Table 11-1 for achieving the Life Safety Performance Level show that typical requirements for maintaining egress—such as the items listed in the *NEHRP Handbook for the Seismic Evaluation of Existing Buildings*, pp. 91–92, and p. A-20 (BSSC, 1992b), which must apply if that document's definition of life safety is to be met—would be taken care of. These items are listed in the *Guidelines*, as well as five other potential obstructive hazards.

Beyond those provisions for architectural nonstructural components, the requirements for preserving the means of egress become very broad, and specific to the building and occupancy type. Some examples follow.

Provision of emergency power may be a wise investment; it has been required by ordinance in some communities for nonseismic safety concerns, as in the common case of battery-powered flood lamp units added to stairwells or over some exit doors in programs enforced by local fire departments.

One can argue that provision of emergency lighting could improve post-earthquake escape and rescue movement through a building as much as—or more than—prevention of the falling of some of the suspended acoustic ceiling. Various cost-benefit evaluations are possible; the results will depend on the specifics of the building and its occupancy.

Security and fire alarm systems have sometimes been falsely set off by power fluctuations caused by earthquakes; direct damage to these components, or a power outage in the absence of backup power, can also cause an outage, and adversely affect escape and rescue.

In a high-rise building, specific annunciator system requirements are stipulated by (nonseismic) building codes, and it can be argued that functionality of these systems is important for escape and rescue in the post-earthquake situation if the building catches fire. However, to insist on complete rehabilitation or replacement of building security systems as a Life Safety Performance Level item would be an expensive measure for a very low-probability event.

Similarly, building and fire codes contain numerous requirements related to fire and hazardous material safety, including provision of smoke-free shafts, hazardous material exhaust systems, and a backup supply of water for sprinkler systems.

The fire rating of a door assembly or wall can be affected by racking and seemingly minor cracking; thus, if a seismic performance definition requires a building to maintain full “fire safety,” this could imply that virtually no damage is to occur. Part of the rationale for limiting post-earthquake building egress requirements is based on the low probability that the earthquake would cause a fire or hazardous material release that would pose an immediate threat to occupants, so long as they were able to leave within a reasonable amount of time.

The *Guidelines* have carefully kept the evaluation and rehabilitation of components and systems such as the above, and others, as options separate from the basic definition of the Life Safety Performance Level, to preserve the clear meaning of the Level's intent: prevention of earthquake damage that can directly injure people.

C11.4.4.4 Issues of Maintaining Post-Earthquake Means of Egress

If the comprehensive set of building egress concerns (e.g., lighting, elevators, alarms) are selected as part of the Damage Control Range or Immediate Occupancy Level, then much more extensive rehabilitation measures would be required. Some of the major areas of concern are discussed below.

A. Critical Escape and Rescue Areas

This term has no preestablished definition, but the intended meaning is that of a hallway, stairwell, or fire escape, an entry space such as a lobby, or an exterior area outside an exit doorway. The intent is that such areas might be especially deserving of additional nonstructural seismic protection.

Occupant loads passing through a doorway that is required as part of an exit pathway can be calculated according to building codes and standards, and any doorway with a load over some particular amount might also be defined as critical. Redundancy of pathways would also be logically involved in determining which areas are most critical and deserving of nonstructural protection.

On a smaller scale, localized areas in rooms are more critical for access than others. For example, tall bookshelves and cabinets located next to an inward-opening door have toppled, blocking access to the room. After the 1989 Loma Prieta earthquake, it took approximately an hour for a rescue crew to obtain access to the Watsonville Community Hospital cafeteria, for just this reason.

Thus, to determine a rehabilitation strategy as to which circulation areas are more critical than others would require careful study of building and occupancy specifics, and coordination with locally applicable retroactive fire safety standards, to derive an appropriate design strategy.

B. Occupancy

Building codes have traditionally defined types of occupancies for purposes of setting fire safety provisions, and dozens of building and fire code requirements are keyed according to very specific occupancy classes and sub-classes, with rules for calculating numbers of occupants. Building egress provisions are then related to these occupant classes and loads. For purposes of post-earthquake escape and rescue, some of the code-determined occupancy classes and/or loads can be used for assessing the importance of critical escape and rescue areas.

C. Obstructions

Major obstruction could be defined as debris or damage that makes escape or rescue more difficult than climbing through a code-minimum rescue and escape window, which is required in U.S. building codes for sleeping rooms from the basement through the third story.

This requirement for escape windows is aimed primarily at fire: the small dimensions that the code regards as acceptable for safety (minimum height 24 inches/610 mm and minimum width 20 inches/508 mm) should be noted. For the post-earthquake situation, most occupants would probably expect a less limiting criterion.

D. Elevators

Rehabilitation of elevators is aimed at safety rather than immediate operation, and their use for immediate escape is not contemplated. Current seismic provisions for elevators are aimed at safe shutdown, rather than continued functionality. After even moderate shaking, any elevator will need inspection after shutdown before it can be regarded as safe. This fact alone means that elevators cannot be regarded as available for escape or rescue.

People in wheelchairs cannot be easily carried down stairs, so when elevator service is disrupted by an earthquake (either because of lack of backup power, disruption of a backup system, automatic shutoff without rapid inspection and restoration, or direct damage to the elevator system), the egress capability of people with movement disabilities is further impaired.

E. Sprinkler Systems

It is sometimes argued that, because of the possibility of post-earthquake fires, protection of sprinkler systems should be part of the Life Safety Performance Level requirements. However, fires in buildings are a relatively low-frequency occurrence. Moreover, fires take some time to develop, so the threat to life is minimal in the first minutes after an earthquake if the means of egress are reasonably intact. However, the bracing of sprinkler systems is a major property protection issue, and since there is a life safety issue involved, rehabilitation of sprinkler systems is required in the *Guidelines* as part of the Life Safety Performance Level acceptance criteria in high seismic areas. Again, the Life Safety Level in the *Guidelines* is limited to the threat of direct injury.

F. Water Leakage

From the standpoint of escape and rescue, minor water leakage can be considered more of a nuisance than a life safety issue, but there are cases where leaking water can make the use of stairs or other exit routes as difficult as if there were debris in the way, and there may be electrical shock concerns as well. A building-specific evaluation would be necessary to determine the likelihood of such consequences in critical escape and rescue areas of the building. Water leakage has been proven to be a major source of economic loss, and a cause of building operational loss in essential buildings such as hospitals.

While a strict adherence to the requirements for Life Safety may reduce the cost and extent of nonstructural rehabilitation, the prudent owner may in fact find that the twin objectives of safety and reduced property loss are best served by a building-specific program that encompasses a wide range of the requirements for improving the means of egress in the post-earthquake situation.

C11.5 Structural-Nonstructural Interaction

C11.5.1 Response Modification

When the nonstructural component affects structural response, the nonstructural component is treated as structural, and the relevant structural provisions apply. For example, a nonstructural masonry infill wall is regarded as structural and therefore within the scope of Chapter 7. The nonstructural component, such as cladding or heavy partitions, would typically affect the structure’s response by means of its connections to it and the stiffening or damping effect it provides. The interaction may be beneficial or detrimental depending on location. Partial infill between columns with masonry walls may create a short column effect, i.e., reduce the effective length of the column, and seriously affect the structural response.

Nonstructural components are regarded as deformation-sensitive when they are affected by the structure's deformation, typically measured by inter-story drift. For example, a stud and plaster partition, connected from floor to floor or between structural walls or columns, can be damaged by racking caused by building drift.

A recurring problem in earthquakes has been the jamming of large overhead doors in fire stations, causing delay in dispatching fire apparatus. Excessive structural drift causes the support and guide rails to distort and the door to bind. Excessive drift has also caused doors opening onto exit corridors to jam, trapping the occupants. In both these instances, the remedy lies in controlling structural drift, rather than nonstructural design measures.

When there is no structural-nonstructural interaction because of the imposed deformation problem, the nonstructural component is regarded as acceleration-sensitive. An example is an item of mechanical equipment located on a building floor. Since an item on an upper floor might incur greater forces because of its location, the force equation accounts for this. Nonstructural components of large mass—for example, large water tanks—can also affect structural response, and must be considered in estimating loads.

C11.5.2 Base Isolation

Nonstructural components that cross the isolation interface of a base-isolated structure must be designed to accommodate the large potential relative displacements that may occur. These relative displacements may exceed one foot in length, and special detailing may be necessary. Swivel joints in piping and large flexible joints in ductwork may be necessary. Stairs must be attached to one side of the interface and allowed to move freely over the other. Elevator shafts may be attached to the superstructure and allowed to project down below the interface, with no attachment below the interface level. Special detailing is necessary for architectural components that cross the interface; in some instances, sacrificial components or materials may be used that are replaced after a seismic event of sufficient magnitude to damage them.

C11.6 Acceptance Criteria for Acceleration-Sensitive and Deformation-Sensitive Components

Acceptance criteria are provided for each nonstructural component or component group, to establish conformance with Performance Levels. The first level with well-defined meaning with reference to nonstructural components is the Life Safety Performance Level, because Collapse Prevention is defined only in structural terms and the Hazards Reduced Level has no specified nonstructural requirements. In the Immediate Occupancy Performance Level, which exceeds the Life Safety Performance Level, the requirements may be either the same as, or much stricter than, those for Life Safety, depending upon the component.

Where anchorage or another rehabilitation method for a component to achieve Life Safety prevents functional damage as well, higher criteria may also be met. (The level of motion, and thus forces resisted, is a function of the ground motion criteria chosen, which is only specified by the *Guidelines* for the BSO). In other cases, the criteria become much more demanding as the level increases. Thus, precast concrete exterior cladding panels might meet acceptance criteria for the Life Safety Performance Level, but fall short of the criteria for Immediate Occupancy, because possible distortion and loss of weather protection might render the building unusable, even if panels do not fall.

In some instances, because of the nature of some nonstructural components, quantitative acceptance criteria are not justified, and qualitative statements are used. The intent is to limit the need for engineering analysis and design where simpler methods are effective.

C11.6.1 Acceleration-Sensitive Components

For acceleration-sensitive components, the force provisions given in Sections 11.7.3 and 11.7.4 are expected to result in design force levels sufficiently high (realistic) to meet the effective needs of all Performance Levels. Providing lower design force levels for lower Performance Levels may be ineffective, since nonstructural elements tend to require rehabilitation techniques such as bolts and braces that can be economically designed to be adequate for a wide range of accelerations; that is, the type and layout of the bracing or anchorage scheme is more critical to the success of a rehabilitation strategy than the design force applied to it. Consequently, a conservative design force is recommended for all Performance Levels in acceleration-sensitive elements, and will have little cost penalty because of the simple techniques (bolting and bracing) that are involved.

For heavy equipment mounted on upper floors or roof, it is recommended that Equations 11-2 and 11-3 be used, because these equations introduce the effects of amplification caused by height. It is suggested that heavy equipment mounted on the third floor or above be analyzed in this way, if the structure is flexible. Experience has shown that rooftop mechanical equipment at the third floor or over is susceptible to accelerations and may shift, causing expensive damage and probable loss of function.

C11.6.2 Deformation-Sensitive Components

For deformation-sensitive components, the deformation limits of the *Guidelines* represent, in an average case, deformations associated with severe nonstructural damage for the Life Safety Performance Level and moderate nonstructural damage for the Immediate Occupancy Performance Level.

The values for limiting structural drift ratios have been derived primarily from the NIBS *Loss Estimation Methodology* (RMS, 1995), and refer to mean estimates of actual (unreduced) drift. The values in this study are derived from test results and experience, but a single median threshold value is provided for all drift-sensitive components (RMS, 1995, Table 5A-3). In addition, median drift values for damage states are provided for drift-sensitive nonstructural components located in each of 35 building types (RMS, 1995, Table 5A-4). In this table, the median drift values vary primarily because of assumed differences in floor-to-floor height for the different building types. These median drift values are, in turn, related to calculated drift values for corresponding structures to produce fragility curves.

While the NIBS *Loss Estimation Methodology* probably represents the best attempt yet to establish drift values related to damage states, the use of a single median drift ratio value—based on very limited laboratory testing—as an acceptance criterion is a wide stretch in usage. It is suggested that the limiting drift ratio values shown in the *Guidelines* in Chapter 2 be used as guides for evaluating the probability of a given damage state for a subject building, but not be used as absolute acceptance criteria.

At higher Performance Levels it is likely that the criteria for nonstructural deformation-sensitive components may control the design of structural rehabilitation. These criteria should be regarded as a flag for the careful evaluation of the structural-nonstructural interaction and assessment of damage states, rather than the required imposition of an absolute acceptance criterion that might suggest costly redesign of the structural rehabilitation.

C11.6.3 Acceleration- and Deformation-Sensitive Components

Some components are both acceleration- and deformation-sensitive, but generally one or the other of these characteristics is dominant, as is suggested in Table C11-1. The engineer must use judgment in evaluating the need for rehabilitation and the appropriate design solution.

C11.7 Analytical and Prescriptive Procedures

The *Guidelines* establish the minimum rehabilitation procedures that relate to desired Performance Levels. Thus, where Analytical Procedures are required, Prescriptive Procedures do not apply. Where Prescriptive Procedures are permitted, Analytical Procedures may be used at the discretion of the engineer.

C11.7.1 Application of Analytical and Prescriptive Procedures

For nonstructural components, the Analytical Procedure, which consists of the Default Equation and the General Equation approaches, is applicable to any case. The Prescriptive Procedure is limited by Table 11-1 to specified combinations of seismicity and component type for compliance with the Life Safety Performance Level.

C11.7.2 Prescriptive Procedure

These procedures apply where established rehabilitation methods are defined, and analysis is not required beyond establishing weights and/or dimensions. In general, the detailed requirements can be established by reference, such as the Ceilings and Interior Systems Construction Association (CISCA) standards for suspended ceilings, or the SMACNA standards (1980, 1982, 1991) for support of ductwork and piping. It may be necessary to specify different parts of these standards as applicable to different Rehabilitation Objectives, depending on the relevant Seismic Zone. Assessment of these components involves checking whether the component is braced or attached per prescriptive requirements.

Also found in the sections for individual components is guidance on the application of separately promulgated and published references so that they can be consistently and compatibly used with the requirements of this document. In most cases, these references do not specifically refer to seismic issues. Thus, translation of Seismic Zone definitions, consideration of Performance Levels as they relate to the objectives underlying a given standard or reference, and other conversions and adaptations are often necessary.

C11.7.3 Analytical Procedure: Default Equation

The Analytical Procedure includes two methods: one is defined by Equation 11-1, the other by Equations 11-2 and 11-3. These equations are derived from the proposed *1997 NEHRP Recommended Provisions* (BSSC, 1997). In these *Provisions*, the second two equations are shown as alternates, but for this document Equation 11-1 fills the role of a simple default equation that gives conservative results, and Equations 11-2 and 11-3 provide more detailed equations that will give a more precise and generally less conservative result. For nonstructural components, the use of the Default Equation that provides for conservative force levels is unlikely to carry a cost penalty; many acceleration-sensitive components can be easily rehabilitated by simple anchoring and bracing, and designing these for larger forces will generally be more cost-effective than using a more complex Analytical Procedure.

C11.7.4 Analytical Procedure: General Equation

The use of Equations 11-2 and 11-3 to determine the forces for acceleration-sensitive components will give a more precise and generally less conservative result. For components such as heavy cladding, where connections are critical, the more precise Analytical Procedure should always be used. The expanded equation also allows for derivation of force levels to meet lower as well as higher ground motion criteria, and might, in some circumstances, result in a more economical solution. All equations were adapted from similar equations in the *NEHRP Recommended Provisions* (BSSC, 1997).

C11.7.5 Drift Ratios and Relative Displacements

For some deformation-sensitive components, where drift limits are specified as part of the acceptance criteria, the building drifts that relate to the location of these nonstructural components must be estimated and compared to the acceptance levels. Equations 11-4 and 11-5 are used for this analysis. If the drift acceptance criteria are not met, engineering judgment must be used to determine the relative economies of reducing the building drift compared to changing the nonstructural component or detailing it to accept the level of drift.

C11.7.6 Other Procedures

Nonstructural components attached to the roof, floors, walls, or ceilings of a building (such as mechanical equipment, ornamentation, piping, and partitions) respond to the building motion in much the same manner that the building responds to the ground motion. However, the building motion may vary substantially from the ground motion. The most common method of representing nonstructural support excitation is by means of roof and floor response spectra at the nonstructural support locations derived from the dynamic analysis of the building.

The development of site-specific ground motions, expressed as site-specific response spectra or acceleration time-histories, is discussed in Section 2.6.2. The use of site-specific ground motions in alternative analytical procedures would require the conversions of these site-specific ground motion parameters to building floor and roof response spectra or acceleration time-histories at the support locations of the nonstructural components.

Floor and roof response spectra can be computed most directly from a dynamic analysis of the structure conducted on a time-step-by-time-step basis using site-specific acceleration time-histories. According to Section 2.6.2, Site-Specific Ground Shaking Hazard, at least three time-histories (for each component of motion) should be used.

Nonstructural components that are supported at multiple locations throughout the building could have different floor or roof spectra for each support location. The relative displacement between supports should be considered in the evaluation of the nonstructural component's performance. There are complex analytical techniques available to calculate these relative displacements, using different spectra at each support location or using different input time-histories at each different support. Careful consideration must be given to the fact that the maximum response at various support locations might not occur at the same time.

For determining Life Safety and Immediate Occupancy Performance Levels for nonstructural components, the time-consuming and costly analytical procedures outlined above are not as cost-effective as the Prescriptive and Analytical Procedures presented in Section 11.7. Recent research by Drake and Bachman (1995), using a sample of 405 buildings and events, indicates that Sections 11.7.3 and 11.7.4, which are based on the Analytical Procedures in 1997 *NEHRP Provisions* (BSSC, 1997), will provide a reasonable upper bound for the seismic forces on the nonstructural components wherever they are located in the building. Therefore, complex analysis methods used for the structural and nonstructural components are not necessary for the evaluation and rehabilitation of typical building nonstructural components covered in Chapter 11.

C11.8 Rehabilitation Concepts

A general set of alternative methods is available for the rehabilitation of nonstructural components. These are briefly outlined in this section, in approximate order of their cost and effectiveness, together with examples of each to clarify the intent of this classification. However, the choice of rehabilitation technique and its design is the province of the design professional, and the use of alternative methods to those noted below or otherwise customarily in use is acceptable, provided it can be shown to the satisfaction of the building official that the acceptance criteria can be met.

C11.8.1 Replacement

Replacement involves the complete removal of the component and its connections, and its replacement by new components; for example, the removal of exterior cladding panels, the installation of new connections, and installation of new panels. As with structural components, the installation of new nonstructural components as part of a seismic rehabilitation project should be the same as for new construction.

C11.8.2 Strengthening

Strengthening involves additions to the component to improve its strength to meet the required force levels; for example, additional members might be welded to a support to prevent buckling.

C11.8.3 Repair

Repair involves the repair of any damaged parts or members of the component, to enable the component to meet its acceptance criteria; for example, some corroded attachments for a precast concrete cladding system might be repaired and replaced without removing or replacing the entire panel system.

C11.8.4 Bracing

Bracing involves the addition of members and attachments that brace the component internally and/or to the building structure. A suspended ceiling system might be rehabilitated by the addition of diagonal wire bracing and vertical compression struts.

C11.8.5 Attachment

Attachment refers to methods that are primarily mechanical, such as bolting, by which nonstructural components are attached to the structure or other supporting components. Typical attachments are the bolting of items of mechanical equipment to a reinforced concrete floor or base.

Supports and attachments for mechanical and electrical equipment should be designed according to good engineering principles. The following guidelines are recommended.

1. Attachments and supports transferring seismic loads should be constructed of materials suitable for the application, and designed and constructed in accordance with a nationally recognized structural code.

2. Attachments embedded in concrete should be suitable for cyclic loads.

3. Rod hangers may be considered seismic supports if the length of the hanger from the supporting structure is 12 inches or less. Rod hangers should not be constructed in a manner that would subject the rod to bending moments.

4. Seismic supports should be constructed so that support engagement is maintained.

5. Friction clips should not be used for anchorage attachment.

6. Expansion anchors should not be used for mechanical equipment rated over 10 hp, unless undercut expansion anchors are used.

7. Drilled and grouted-in-place anchors for tensile load applications should use either expansive cement or expansive epoxy grout.

8. Supports should be specifically evaluated if weak-axis bending of cold-formed support steel is relied on for the seismic load path.

9. Components mounted on vibration isolation systems should have a bumper restraint or snubber in each horizontal direction. The design force should be taken as $2F_p$.

10. Oversized washers should be used at bolted connections through the base sheet metal if the base is not reinforced with stiffeners.

Lighting fixtures resting in a suspended ceiling grid may be rehabilitated by adding wires that directly attach the fixtures to the floor above, or to the roof structure to prevent their falling.

C11.9 Architectural Components: Definition, Behavior, and Acceptance Criteria

C11.9.1 Exterior Wall Elements

C11.9.1.1 Adhered Veneer

A. Definition and Scope

This section refers to veneer that relies for its support on adhesive attachment to a backing or substrate rather than mechanical attachments. The section covers both thin units that provide a weather-resistant exterior surface, and exterior plaster (stucco) that is applied in one or more coats to the supporting substrate. Four categories of veneer are identified in the *Guidelines*.

B. Component Behavior and Rehabilitation Concepts

The typical failure mode is cracking of the adhered veneer and/or separation and falling from the backing. Any separation of the surface veneer from its substrate is critical, because it concentrates loads on areas surrounding the separation and provides a place for the weathering elements to penetrate and cause progressive failure.

The adherence of the veneer to its support substrate is generally covered by prescriptive requirements that are not specifically seismically related. For walls that do not fall within the limitations of conventional light frame construction, the supporting elements must be reviewed analytically to determine the likelihood of producing deformations that might detach the veneer materials.

The possibility of a threat to life safety depends on the height of the veneer, the level of use of adjoining areas by personnel, and the size or weight of fragments that could possibly fall from the wall. There is a distinction between the displacement (falling) of areas of veneer and the falling of individual units such as tiles. All of these factors must be evaluated in order to make a determination.

The replacement of adhered veneer that is cracked or partially separated from its substrate may be very costly. For architectural reasons it may be necessary to replace much larger areas than those that are actually vulnerable, because of the difficulty in matching new and old surfaces.

In some cases, substantial damage to the adhered veneer may be temporarily allowed while declaring the building to be ready for immediate occupancy. This will be the case when possible progressive separation of the veneer will not pose a threat to personnel using the building, and when the damage does not allow penetration of weather elements in a way that would prevent, or limit, the use of the building. The full range of options available to the client must be spelled out so that an economic determination may be made.

Critical locations for evaluation of the veneer are those where substantial deformation is possible and where discontinuity in the surface exists, such as around openings, and especially at corners. The evaluation of possible potential damage will include the existence, or lack, of reinforcing around these discontinuities and the amount of deformation that will be allowed based on analysis of the structure's deformation characteristics.

A description of Adhered Veneer Categories 1, 2, and 3 and typical structural backing may be found in MIA (1994). Information regarding nonstructural exterior plaster may be found in a reference of the Portland Cement Association (PCA, 1995).

C. Acceptance Criteria

The limiting structural drift ratio of 0.030 for the Life Safety Performance Level represents extensive damage for drift-sensitive components in the NIBS Loss Estimation Methodology (RMS, 1995) The limiting drift ratio of 0.010 for the Immediate Occupancy Performance Level represents moderate to extensive damage in the drift-sensitive components. These limits must be carefully evaluated by the engineer with respect to the estimated structural drifts and the detail of the veneer substrate and its relation to the structure.

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Cracking of any extent and some detachment in noncritical areas may occur.

Immediate Occupancy Performance Level. Some cracking and detachment of a few individual pieces in noncritical areas may occur.

C11.9.1.2 Anchored Veneer

A. Definition and Scope

This section identifies the distinguishing feature of this veneer to be the mechanical attachments and defines three categories of veneer that are included. In addition, the critical function of the mechanical fasteners is described. Prescriptive values for mechanical connectors are available from the manufacturers.

Proper identification of anchored veneer is important. It is often difficult to establish if the anchors are present. In many older buildings with multiwythe walls, a single wythe of facing brick is placed on the exterior without physical connections such as headers or anchors. While this is more likely to be considered a multiwythe, unreinforced masonry wall, the possibility exists for the separation of the entire wythe of brick from the structural wall. Where this occurs, the exterior wythe must be anchored or removed.

B. Component Behavior and Rehabilitation Concepts

Failure occurs by separation or distortion of the unit in relation to its supporting structure, brought about by pulling out, distortion, or buckling of the mechanical fasteners.

The possibility of a threat to life safety depends on the height of the veneer, the possibility of the use of adjoining areas by personnel, and the size or weight of fragments that could possibly fall from the wall. All of these factors must be evaluated in order to make a determination.

Cracking of units, in a way that does not adversely affect the attachment of the units to the structural backing, is considered to be a Damage Control Performance Range problem. As soon as the damage becomes a factor in the mechanical attachment and the veneer in question is over four feet above the adjacent floor or ground, and is in an area that is likely to be occupied, it becomes a Life Safety question.

Distinction must be made between damage that occurs to the units only, and that which affects or may affect the mechanical fasteners that support the units.

As with adhered veneer, critical locations for evaluation of the veneer are those where substantial deformation is possible and where discontinuity in the surface exists, such as around openings, and especially at corners. The evaluation will include the existence or lack thereof of reinforcing around these discontinuities, and the amount of deformation that will be allowed based on analysis of the structure's deformation characteristics.

A description of the three types of anchored veneer and their typical structural backing may be found in MIA (1994) and ASTM (1995).

C. Acceptance Criteria

The limiting structural drift ratio of 0.020 for the Life Safety Performance Level represents extensive damage for drift-sensitive components in the NIBS *Loss Estimation Methodology* (RMS, 1995). A more restrictive drift criterion is selected for this component compared to adhered veneer because of the generally larger, and potentially more life-threatening, components and materials that are used in these exterior systems. The limiting drift ratio of 0.010 for the Immediate Occupancy Performance Level represents moderate to extensive damage in the drift-sensitive components. These limits must be carefully evaluated by the design professional with respect to the estimated structural drifts, the detail of the veneer substrate, and its connection to the structure.

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Cracking of the masonry units may occur as long as it does not significantly affect the load distribution on the anchors. Failure of anchor elements that result in falling of units that are more than four feet above the ground or adjacent exterior area may not occur unless adjacent areas are inaccessible to pedestrians and all vehicles.

Immediate Occupancy Performance Level. Some cracking of masonry units is acceptable, but substantial weather protection must be maintained.

D. Evaluation Requirements

No commentary is provided for this section.

C11.9.1.3 Glass Block Units and Other Nonstructural Masonry

A. Definition and Scope

No commentary is provided for this section.

B. Component Behavior and Rehabilitation Concepts

This section refers to the generally single-wythe glass block and other masonry units that are self-supporting from a vertical load standpoint and, to a limited extent, for lateral forces—as long as very conservative height-to-thickness ratios are maintained—but which cannot resist forces imposed from other elements of the building nor significant differential deformations.

Failure occurs by cracking of the mortar joints or units and lateral displacement along those cracks. Hairline cracks due to shrinkage or small movements of the supporting structure are generally not critical. However, cracks over three to five mils (three to five thousandths of an inch, 0.007-0.012 mm.), or any cracks showing lateral displacement, signify a loss of shear capacity along that line and therefore indicate failure.

Prescriptive requirements for glass block units should be used as the criteria for rehabilitating these walls. These prescriptive requirements include type, strength of mortar, reinforcing of the joints with galvanized steel wires, limitations on the size of the panels, and the need for properly filled expansion joints around properly sized areas of panel. Refer to the 1994 *Uniform Building Code* (*UBC*), Section 2110 (ICBO, 1994) for specific prescriptive requirements that may be used. This document does not link itself to any of the model codes in use in the United States, and is, in general, coordinated with the *NEHRP Provisions for New Buildings* (BSSC, 1995), but in this case only the *UBC* reference is applicable. For walls larger than 144 square feet, analysis of drift and forces is necessary, and careful engineering design of the wall is required.

For Life Safety, the same general criteria exist for these as for other masonry units: consideration of the height of the wall, the weight of material that could fall, and the possibility of people being in the adjacent areas.

These walls should be replaced if their installation and condition significantly differ from the prescriptive requirements of current building codes, and their location is critical with respect to Life Safety.

C. Acceptance Criteria

The limiting structural drift ratio of 0.020 for the Life Safety Performance Level represents extensive damage for drift-sensitive components in the NIBS *Loss Estimation Methodology* (RMS, 1995). The limiting drift ratio of 0.010 for the Immediate Occupancy Performance Level represents moderate to extensive damage in the drift-sensitive components. These limits must be carefully evaluated by the engineer with respect to the estimated structural drifts, the detail of the glass block, and its connection to the structure.

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Hairline cracking may occur so long as the shear strength and out-of-plane bending strength of the wall are not significantly impaired. Displacement of some units may occur in noncritical areas.

Immediate Occupancy Performance Level. Hairline cracking may occur so long as the shear strength and out-of-plane bending strength of the wall are not significantly impaired. No displacement of units may occur.

D. Evaluation Requirements

No commentary is provided for this section.

C11.9.1.4 Prefabricated Panels

A. Definition and Scope

This section encompasses types of exterior panels that generally span from floor to floor or column to column and are manufactured to quality control standards, ensuring the unit has a minimum defined strength. Type 1 (precast concrete panels) and Type 2 (metal faced insulated panels) are, in effect, large building blocks that are capable of structurally withstanding the forces applied within the perimeter connections. Type 3 (steel strong-back panels with mechanically attached facings) is made up of structural elements that can be designed using typical structural analysis procedures for the materials and concept involved.

B. Component Behavior and Rehabilitation Concepts

This section defines the two different categories of failure that might occur. One is the failure of the unit itself, due to improper design or defective manufacture for the loads (primarily racking) resisted within the panel. The second mode pertains to the connecting elements that attach the panels to the building's structural system, which may fail due to either acceleration-based forces, or their inability to withstand the deformation of the structure. Criteria for new prefabricated panels require a considerable multiplier on design loads for connections, to limit the possibility of connection failure.

Often these panels must be replaced for nonseismic reasons, if their condition is such as to make them non-weather-resistant or unsightly. The possibility of some damage or cracking, if minor, under design seismic forces and deformations may, under some circumstances, limit the life of the panel but not create an immediate need for replacement for Life Safety reasons.

On upper floors of buildings, the loss of strength in the connections of these panels will create a continuing life safety problem for anyone adjacent to the building. Panels that are not hazardous may nevertheless suffer seismic damage, such as cracking or displacement, that will diminish weather and thermal resistance and limit the use of adjacent space, unless temporary covering is acceptable to meet Immediate Occupancy requirements.

The panels must be evaluated for their ability to act as the building envelope in the case of damage such as cited above. Consideration must be given to the ductility of concrete anchors where they might be used to provide attachment of the panels to the main structure. If the anchor does not exhibit adequate ductility to preclude a brittle failure, then greater care must be take in evaluating the strength of the attachments under assumed forces.

C. Acceptance Criteria

The limiting structural drift ratio of 0.020 for the Life Safety Performance Level represents extensive damage for drift-sensitive components in the NIBS *Loss Estimation Methodology* (RMS, 1995). The limiting drift ratio of 0.010 for the Immediate Occupancy Performance Level represents moderate to extensive damage in the drift-sensitive components. These limits must be carefully evaluated by the engineer with respect to the estimated structural drifts, the detail of the panels, and their connection to the structure.

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Considerable cracking and detachment of the units may occur, as long as the panels remain in place. Detachment of weather stripping may occur.

Immediate Occupancy Performance Level. Some cracking and detachment of the units may occur, as long the panels remain in place. Minimal detachment of weather stripping may occur.

D. Evaluation Requirements

No commentary is provided for this section.

C11.9.1.5 Glazing Systems

A. Definition and Scope

No commentary is provided for this section.

B. Component Behavior and Rehabilitation Concepts

Metal frames and mullions that are attached to a structure subject to large deformations will flex and twist, pulling the frame from the glass in one direction. In the return motion, the glass may be out of the frame—the result is instantaneous damage. Division bars in any system are suspect; they are seldom anchored, and even when they are, the metal often does not have enough strength to resist the twisting effect. In glazing systems where the supporting frames remain undamaged, yet the glass is damaged or has fallen out, there are four conditions that may prevail.

1. The glass is cut too small for the opening: not enough edge “bite.”
2. There is no edge blocking, causing the glass to shift too far to one side.
3. The glass is cut too large for the opening, leaving no room for expansion (inadequate edge clearance).
4. Roll-in vinyl gaskets that fall from the opening allow the glass to slide back and forth in the opening, causing shattering or falling. These gaskets create the pressure that holds snap-on stops in the opening.

Safety is also affected by the type of glass. When broken, ordinary annealed glass produces sharp-edged shards that can cause serious injury. Code provisions implemented in the 1970s now require safety glass (such as tempered, wired, or laminated glass) when the glass extends to within 18 inches of the ground or floor. Tempered glass fractures into small round-edged pieces that are significantly less dangerous than shards, and this type of glass up to ten feet in height does not represent a significant life safety threat. Laminated glass generally remains intact even if it cracks.

Guidelines on the general analysis and design of glazed walls can be found in the *Aluminum Design Guide Curtain Wall Manual* (AAMA, 1996a) and *Rain Screen Principle and Pressure Equalized Wall Design* (AAMA, 1996b).

As indicated in the definition and scope section, the evaluation of these panels must consider both the structural support provided by the mullions and the other supporting members, as well as the containment of the glazing and the method of doing that within the supports. Wherever possible, consideration should be given to converting the method of enclosure to wet glazing, which has proven to be durable, and much tougher in resisting dynamic loads than other methods.

C. Acceptance Criteria

The limiting structural drift ratio of 0.020 for the Life Safety Performance Level represents extensive damage for drift-sensitive components in the NIBS *Loss Estimation Methodology* (RMS, 1995). The limiting drift ratio of 0.010 for the Immediate Occupancy Performance Level represents moderate to extensive damage in the drift-sensitive components. These limits must be carefully evaluated by the engineer with respect to the estimated structural drifts, the detail of the glazing, and its connection to the structure.

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Considerable loss of weather stripping may occur. Shattering of glass or material falling out from more than four feet above interior floors or adjacent exterior area may not occur.

Immediate Occupancy Performance Level. Some limited loss of weather stripping may occur.

D. Evaluation Requirements

No commentary is provided for this section.

C11.9.2 Partitions

C11.9.2.1 Definition and Scope

Partitions are categorized as "heavy" or "light"; the intent is to distinguish between masonry or other heavy assemblies, and typical replaceable partitions consisting of metal or wood studs with a layer of gypsum board on each side. These lightweight assemblies weigh approximately five pounds per square foot, which establishes the category definition of "heavy" or "light".

Full-height glazed walls are similar to exterior glazing in assembly and so are required to meet the requirements of these systems.

C11.9.2.2 Component Behavior and Rehabilitation Concepts

If heavy partitions are isolated from the structure by providing a continuous gap between partition and surrounding structure, or are freestanding, the partitions will be acceleration-sensitive and should be analyzed independently to meet the material acceptance requirements (e.g. Section 7.4 for masonry). In some instances, wood stud partitions and facings may be of sufficient mass to interact with the structure and should be analyzed as structural.

In some structural types, wood frame partitions may be enhanced to become shear panels, and must be analyzed as structural elements. Partitions that span from floor to floor (roof) or floor to ceiling are deformation-sensitive. Partitions that are freestanding or span to a light metal grid hung ceiling are acceleration-sensitive in all directions. Deformation-sensitive lightweight partitions loaded in-plane can be subjected to:

1. Minor shear cracking
2. Major shear cracking and deformation at attachments to structure, with dislodgment of some applied finish materials
3. Distortion and fracturing of partition framing, and detachment and fracturing of the surface materials

Since partitions are both acceleration- and deformation-sensitive, drift analysis is required for rehabilitating partitions to meet or exceed the Life Safety Performance Level, because partition in-plane deformations must be known. For Immediate Occupancy and Operational Performance Levels, all partitions are candidates for rehabilitation. Noncritical lightweight partitions may be treated as replaceable in many instances where life safety is not an issue and special detailing is not cost-beneficial.

Heavy infill partitions should be rehabilitated according to the provisions of Chapter 7. Heavy free-standing partitions that cannot meet the force and/or displacement requirements of Section 11.7.4 will probably need to be replaced with lightweight partition materials.

Heavy partitions that can meet out-of-plane but not in-plane requirements, because they act as infill, may be rehabilitated by detailing that detaches the partitions from the surrounding structure (provided the building structure is not adversely affected by this measure). For this method of rehabilitation, a detail must be introduced that retains restraint against out-of-plane movement of the partition, since it is no longer assisted by support from the surrounding structure. Judgment must be used to determine where lightweight partitions should be detached from surrounding structure to permit differential movement. Fire wall partitions forming part of the building fire safety system that are detached from the structure must be detailed substantially to retain their fire separation capability.

C11.9.2.3 Acceptance Criteria

The limiting structural drift ratio of 0.010 for the Life Safety Performance Level represents moderate to extensive damage for drift-sensitive components in the NIBS *Loss Estimation Methodology* (RMS, 1995). This represents a more restrictive criterion than for other drift-sensitive components, because falling of heavy partition components in interiors represents a considerable life safety threat. In practice, it may be more cost-effective to replace heavy partitions with steel stud and gypsum board walls, but if the building interior is of historical significance this solution may not be acceptable. The limiting drift ratio of 0.005 for the Immediate Occupancy Performance Level represents negligible to moderate damage in the drift-sensitive components. These limits must be carefully evaluated by the engineer with respect to the estimated structural drifts, the details of the walls, and their relationship to the structure.

To confirm that the acceptance criteria are met, in addition to the required Analysis Procedures, the adequacy of the following applicable partition components must be inspected and assessed:

1. The attachment of the finish materials to the partition
2. The condition at the top of the partition, particularly as to whether or not there is a connection to the building floor or roof structure, ceiling system, and the like
3. The connection at the top of the partition (if any) to allow for the vertical deflection of the structure above, to resist out-of-plane seismic forces, and to accommodate in-plane inter-story drift displacements
4. The connection at the bottom of the partition to the building floor to resist the in-plane and out-of-plane seismic forces on the partitions
5. The partition support elements (such as wood or metal studs and solid or hollow unit masonry) to resist the in-plane and out-of-plane seismic forces and inter-story displacements

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Typical damage to light partitions is that of cracking and distortion; this is not categorized as a life safety issue, based on experience in earthquakes. In URM buildings, light frame partitions, although poorly constructed and damaged, have often succeeded in supporting damaged floors and roofs despite being theoretically quite inadequate for such a purpose. This particularly applies to residential buildings, which have a high intensity of partitions in relation to floor area. The Coalinga, California earthquake of 1983 showed many instances of this phenomenon.

For heavy masonry or hollow tile partitions, some cracking and some displacement in noncritical locations may occur. Heavy partition assemblies, particularly if used as backing for ceramic or natural stone facing, may suffer some cracking, but must be carefully evaluated against the possibility of complete collapse or shedding large fragments.

Immediate Occupancy Performance Level. Minor cracking may occur in both light and heavy partitions; no heavy partitions may be displaced.

C11.9.2.4 Evaluation Requirements

No commentary is provided for this section.

C11.9.3 Interior Veneers

C11.9.3.1 Definition and Scope

Interior veneers are decorative finishes applied primarily to interior walls, both structural and nonstructural. Heavy veneers of natural stone or marble are common in entrances, elevator lobbies, and monumental staircases of major public buildings. Veneers, such as ceramic tile, are sometimes attached to ceilings. Wood veneers are sometimes used as wall (and occasionally ceiling) paneling, or as decorative cover to columns, but their light weight results in little inherent hazard, so they are not specifically identified in the *Guidelines*.

C11.9.3.2 Component Behavior and Rehabilitation Concepts

The particular concern with interior veneers relates to the possible falling hazard of heavy veneers in heavily occupied locations. Veneers are predominately deformation-sensitive, and if their backing becomes deformed their attachment may fail, particularly if the attachment is direct. Interior veneer seismic behavior depends on:

1. Its weight and height
2. The adequacy of the connection of the interior veneer to the backup support system

3. The adequacy of the backup support system and its connection to the structure to resist the out-of-plane and in-plane seismic forces, and in-plane inter-story drift of the structure

Adhered interior veneer reflects the seismic performance of the backup system. If the rigid backup masonry or concrete walls crack, these cracks will be reflected in the interior veneer. The strength and stiffness of the structure, as well as the backup system, and their compatibility with the inherent strength of the veneer must be considered.

Drift analysis is required for rehabilitating interior veneer to meet or exceed the Life Safety Performance Level, because in-plane deformations of the backup support system must be determined. Only heavy veneer located higher than four feet from the floor need be considered for the BSO.

To confirm that the acceptance criteria are met, in addition to the required Analysis Procedures, the engineer shall inspect, and assess the adequacy of, the following applicable components of the interior veneer:

1. The attachments and connections (e.g., mortar, adhesive, wires) of the interior veneer to the backup system (e.g., metal or wood studs, solid or hollow unit masonry, or reinforced concrete)

2. The adequacy of the backup support system and its connection to the building structure to resist the out-of-plane and in-plane seismic forces, and in-plane inter-story drift

Because interior veneers are, by nature, a visually important and decorative element, the rehabilitation methods must take into account the resulting rehabilitated appearance of the veneer.

Before replacement/resetting of the interior veneer, the backup support system and building structural system shall be examined and analyzed for their ability to withstand the design seismic forces from, and displacements with, the allowable drift limitation of the interior veneer. Unlike exterior veneers, corrosion is not likely to affect mechanical fastening systems, unless water leakage has been present. After this analysis, consideration should be given to the possibility that the particular interior veneer is not compatible with the stiffness of the rehabilitated building structural system. If this is so, a determination must be made whether to replace the interior veneer and/or backup system with different materials and/or systems, or rehabilitate the main structural system to meet the acceptable drift limitations of the replaced/reset or new veneer material system. The latter action may be unrealistic in structural or economic terms unless there are additional reasons for meeting specific drift criteria.

C11.9.3.3 Acceptance Criteria

The limiting structural drift ratio of 0.020 for the Life Safety Performance Level represents extensive damage for drift-sensitive components in the NIBS *Loss Estimation Methodology* (RMS,1995). The limiting drift ratio of 0.010 for the Immediate Occupancy Performance Level represents moderate to extensive damage in the drift-sensitive components. These limits must be carefully evaluated by the engineer with respect to the estimated structural drifts and the detail of the veneer substrate and its relation to the structure.

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Some cracking and displacement of a few units may occur.

Immediate Occupancy Performance Level. Minor cracking, but no displacements, may occur.

C11.9.3.4 Evaluation Requirements

No commentary is provided for this section.

C11.9.4 Ceilings

C11.9.4.1 Definition and Scope

Section 11.9.4.1 defines the main types of ceilings typically found in existing buildings. The chief distinction is between those that are attached directly to the building structure, and those that are suspended below the structure by wires or other attachment systems.

C11.9.4.2 Component Behavior and Rehabilitation Concepts

The seismic behavior of ceilings is primarily influenced by the seismic performance of their support systems. Surface-applied ceiling finishes usually perform well. Suspended metal lath and plaster ceilings perform well if properly braced, and if the adhesion of the plaster to the lath, which deteriorates with age, is still effective. Suspended integrated ceiling systems are highly susceptible to damage unless properly braced and detailed.

This section describes the typical behavior of the variety of ceiling types, with emphasis on the high susceptibility of modern suspended integrated ceilings that have not been braced with splay wires and vertical compression struts.

Surface-applied acoustical tile, plaster, or gypsum board perform well, provided the surface to which these materials are attached does not crack or spall. Ceiling tile can fall due to adhesive failure. Plaster on wood or metal lath attached to wood framing may not perform well. Plaster may have fine cracks that could lead to spalling, particularly along the wood lath. Large areas of fallen plaster in stairways and corridors could impair routes of ingress and egress.

Gypsum board ceilings properly applied—directly to the bottom of wood joists or suspended from wood joints with short wood hangers—will perform well, because the gypsum board is inherently rigid in the plane of the ceiling. Metal lath and plaster ceilings perform well, provided they are laterally braced, the hanger wires are properly connected to the structure above, and metal lath is properly wired to the furring channels. Hanger wires may unwind and pull through their connections or break, or their connections to the structure may fail.

Suspended integrated ceiling systems are highly susceptible to damage, unless they are braced with splay wires and vertical compression struts. Earthquakes cause unbraced ceilings to swing on their hanger wires and pound against, or come off, their supports on adjacent partitions and walls. These suspended ceilings are also subjected to pounding forces from light fixtures, ceiling ventilation diffusers, sprinkler heads, and partitions, which damage the ceiling support members and panels. Ceiling systems that are flexible in the plane of the ceiling (lay-in and concealed spine) may sustain greater damage than systems with greater in-plane rigidity (metal lath and plaster, and gypsum board).

Lightweight grid/panel systems in commercial buildings such as stores and supermarkets are very susceptible to damage because these structures often suffer major deformations. Displacement and falling of lightweight ceiling tiles and the grid, although it causes much disruption and is costly to replace, is not in itself a life safety threat, and a good educational program of self-protection is likely to be a much more effective—and cost-effective—way of preventing injury than bracing an existing ceiling of this type. However, heavy items supported by the ceiling, such as lighting fixtures and air diffusers, must have an independent support that prevents their falling if the supporting grid falls or is badly distorted. Suspended ceilings in certain occupancies—such as in hospital rooms or at exit doors and lobbies—may, however, require special attention with respect to maintaining life safety.

Ceiling systems are both acceleration- and deformation-sensitive. Deformation of the diaphragm may cause horizontal distortion of a ceiling, and deformation of a vertical structure may cause the ceiling to lose its perimeter support and drop. Category a and b ceiling rehabilitation assumes that the structural backing to which the ceiling is applied has been accepted or rehabilitated as part of the structural evaluation. Inspection of the ceiling materials and attachment will determine whether they should be repaired or replaced.

Commonly used industry installation details and procedures are available for the various materials and methods involved; these will not vary with the Performance Levels desired. Category c ceilings may include large ceilings of considerable weight, e.g., in auditoria and theaters, and so a careful force and displacement analysis is necessary. Heavy ceilings of this type can be a major threat to life safety. Category d ceilings, of simple configurations, are normally installed to code and industry standards based on prescriptive details and procedures, and no analysis is required. Special ceilings—of large area, unusual configuration, or with a large space between ceiling and floor or roof above—may require special engineering and analysis.

Ceilings (Categories a and b) that are directly or closely attached to the structure depend on their attachment for seismic integrity and, if properly installed and well maintained, generally meet acceptance criteria for all performance levels without difficulty. If the supporting structure fails, the ceiling materials will also fail. Suspended ceilings (Categories c and d) also interact closely with the structure and if the structure deforms severely, ceiling elements are almost certain to fall. Rehabilitation methods are aimed at ensuring acceptable performance under the structure's forces and drifts, within the structure's acceptance range. For tall long span structures, particularly steel moment frames, the amount of drift acceptable under structural Performance Level criteria may be difficult for the ceiling system to accommodate; in such structures, special design attention should be paid to ceiling rehabilitation.

For detailed evaluation, the ceiling category—a, b, c, or d—must be determined. The condition of the ceiling finish material and its attachment to the ceiling support system, the attachment and bracing of the ceiling support system, and the potential seismic impacts of other nonstructural systems on the ceiling system must be evaluated.

Although ceilings are drift-sensitive, no structural drift limits are stated in the *Guidelines*, because the complexities of structure/ceiling interaction make the identification of numerical values unrealistic. In general, lightweight integrated ceilings appear to experience the most damage in building types with long spans and flexible structural systems, such as commercial buildings—particularly retail stores. The limited testing of integrated ceiling installations that has been conducted has been inconclusive as to the value of compression struts, but tests have been conducted on small-scale ceiling systems. Such tests have indicated that these ceilings only failed at very high accelerations (e.g., 3.57g for a ceiling with no seismic restraints but perimeter attachment) but easily achieved drift ratios for the type of buildings noted above (0.625 inches—a drift ratio of 0.0035 for a 15-foot floor-to-floor height) (Anco, 1983). Much more testing of a variety of ceiling installations is necessary before definitive numerical values can be established, and it is also questionable whether the use of one or two variables such as drift or acceleration can determine ceiling performance.

Ceiling rehabilitation generally involves replacement, with either similar materials or more up-to-date alternatives. Ceilings, particularly modern integrated ceilings, generally have a relatively short life before they become aesthetically outdated. Thus, it is usually much more economical to replace the ceiling and at the same time update its appearance. Ceilings that brace lightweight partitions and mechanical and electrical components require special analysis and rehabilitation: it is generally preferable for seismic rehabilitation not to rely on the ceiling for bracing but to brace the partitions directly to the building structure. Heavy mechanical and electrical components should similarly be braced directly to the building structure.

Ceilings that brace partitions and/or mechanical and electrical components require special analysis and rehabilitation. Ceilings that cross building seismic and expansion joints require special attention. The rehabilitation procedure is to discontinue the ceiling system on each side of the joints. If the ceiling system must continue across the joint to satisfy HVAC, fire safety, or appearance requirements, the ceiling system must be modified to accommodate the relative structural movement allowed by the joint.

C11.9.4.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. For plaster ceilings, some cracking and displacement in noncritical locations may occur, but no falling of large ceiling areas (ten square feet or larger) weighing more than two pounds per square foot. For suspended ceilings, some loss of panels and distortion of grid may occur.

Immediate Occupancy Performance Level. For plaster ceilings, minor cracking and minor displacement in noncritical locations are permissible. Minor loss of panels and distortion of grid are allowed in suspended ceilings.

C11.9.4.4 Evaluation Requirements

No commentary is provided for this section.

C11.9.5 Parapets and Appendages

C11.9.5.1 Definition and Scope

Provisions for parapets are intended to apply primarily to unreinforced masonry parapets. Procedures for the design of unreinforced masonry (URM) walls are found in Chapter 7. Instances may occur where other types of parapet are not integral with, or properly attached to, the vertical building structure, and cantilever vertically above the roof structure.

C11.9.5.2 Component Behavior and Rehabilitation Concepts

Appendages are elements that are not integral with the building structure and cantilever vertically or horizontally from the structure. Critical issues for appendages are their weight, their attachment, their location—if over an entry or exit, public walkway, or lower adjacent buildings—and their surface area as a possible wind-sensitive item. These components may easily disengage and topple, and are among the most hazardous of nonstructural building elements in an earthquake. Because of the high possibility of casualties to people adjacent to buildings, rehabilitation of parapets and heavy appendages is required to meet the Collapse Prevention Performance Level.

Balconies generally involve an extension of the building floor structure, and should be evaluated as part of the structure. Eyebrows are cantilevered—or sometimes suspended—canopies over window openings, which may be continuous, or be separate elements over each window. Cornices are decorative elements at the top of a building that may sometimes be constructed of heavy masonry and cantilever a considerable distance, representing an obvious hazard to the public if inadequately designed and constructed.

In theory, falling of appendages might be permitted in inaccessible locations such as light courts, but in practice, all of these components should be rehabilitated; rehabilitation methods are relatively inexpensive and over the life of a building previously inaccessible locations might become accessible.

Appendages take a variety of forms, and their rehabilitation will depend on their characteristics and the nature of the structure to which they are attached. Because appendages are by nature exposed to the weather, they are very prone to corrosion and other material deterioration. Cornices may be the termination of a parapet and because of their location may present a particularly high risk. They may also be of great architectural significance, so the obvious rehabilitation measure of removing them may be unacceptable. Replacement by sheet metal or glass-reinforced plastic reproductions may be an appropriate seismic and economic solution, if the historic authenticity of the facade is permitted to be compromised.

C11.9.5.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Components and elements may experience only minor displacement, except that they may fall into unoccupied areas.

Immediate Occupancy Performance Level. Components and elements may experience minor damage but no displacement of components or elements will occur.

C11.9.5.4 Evaluation Requirements

No commentary is provided for this section.

C11.9.6 Canopies and Marquees

C11.9.6.1 Definition and Scope

Canopies are horizontal, or near-horizontal, projections from an exterior wall, generally at a building entrance, to provide weather protection.

C11.9.6.2 Component Behavior and Rehabilitation Concepts

Canopies and marquees may become dislodged from their supports and collapse. On some occasions the failure of other appendages or exterior cladding may cause them to collapse.

These components may take the form of a horizontal extension of the structure (an overhang), in which case they should be analyzed as part of the building structure. Safety concerns for canopies apply to those that are attached to the building structure, and that sometimes are not part of the original structural design. Although defined as nonstructural, in the sense that they are not an integral part of the building structure, their evaluation and rehabilitation, if necessary, are a structural problem. Of particular concern are heavy canopies of reinforced concrete, with long cantilever spans designed to early seismic codes.

Canopies are sometimes designed as free-standing structures, associated with a building entrance, often with a distinctive architectural form with dramatic cantilevers; these also require a structural evaluation. Other canopies may be designed as propped cantilevers, suspended, or fully self-supporting, in which case they are defined as marquees. Marquees are typically temporary structures, such as tents, erected for special events, but the term is also used for freestanding structures covering a building entryway, which may be constructed of metal or glass or, for more formal buildings, reflect the construction and appearance of the building. Freestanding canopies and marquees may be extended to form covered walks and shelters, which should be evaluated as separate structures.

Marquees may be unengineered structures. Because of their common location at building entrances they are of concern for egress. Their evaluation and rehabilitation is a structural issue, separate from that of the main building.

Because of their locations, canopies and marquees often present a critical life safety issue. Where canopies are a horizontal extension of the structure, the structural rehabilitation must include these components and appropriate rehabilitation measures must be designed. Canopies that have been attached need careful analysis, particularly if heavy or glazed, and their attachment to the structure and bracing is critical. Permanent marquees must be rehabilitated as appropriate, depending on their design and construction characteristics.

C11.9.6.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Components may not fall, and may experience only moderate displacement.

Immediate Occupancy Performance Level. Components may not fall, and shall experience only minor displacement.

C11.9.6.4 Evaluation Requirements

No commentary is provided for this section.

C11.9.7 Chimneys and Stacks

C11.9.7.1 Definition and Scope

Large chimneys and stacks are generally engineered structures, though older unreinforced brick masonry chimneys were designed and constructed using rules of thumb derived from experience. Residential brick chimneys are typically unengineered, though more recent ones may contain some reinforcing. Smaller steel and sheet metal stacks tend to be catalog items, and in seismic regions their bracing is the main concern.

C11.9.7.2 Component Behavior and Rehabilitation Concepts

The seismic evaluation of chimneys and stacks is an engineering issue, and their rehabilitation, unless there is significant material deterioration or obvious design weakness, is accomplished with bracing and improved connection to the ground or piece of equipment.

These components may fail through flexure or shear; they may fail internally, or overturn. Chimneys may disengage from a supporting wall, roof, or floor structure and cause damage to these elements.

Engineered chimneys and stacks need to be rehabilitated according to their specific design characteristics. Large masonry and, to a lesser extent, concrete chimneys may need extensive rehabilitation; a better solution may be replacement by a new steel stack, although a masonry chimney may be an integral part of the architecture and of some historic significance.

Residential chimneys can be rehabilitated by prescriptive bracing methods, though experience has shown that, unless the chimney failure causes extensive other damage to the building roof or interior, the costs of rehabilitation are similar to those of damage repair. Thus, residential chimney rehabilitation is not cost-effective unless the chimney location is such that collateral damage is likely.

C11.9.7.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Chimneys and stacks located in public areas or critical to building function may not fall, but may suffer some distortion.

Immediate Occupancy Performance Level. Chimneys and stacks located in public areas or critical to building function may not fall and may suffer only minor distortion.

C11.9.7.4 Evaluation Requirements

No commentary is provided for this section.

C11.9.8 Stairs and Stair Enclosures

C11.9.8.1 Definition and Scope

No commentary is provided for this section.

C11.9.8.2 Component Behavior and Rehabilitation Concepts

When stairs are an integral part of the building structure, their evaluation should form part of the general structural evaluation. However, many stairs are prefabricated components, of steel or precast concrete, or both, which are inserted into the building structure. In these instances, if rigidly attached they may also act as structure by forming a diagonal brace between floors, creating a point of stress concentration and suffering disproportionate damage.

Stair enclosures may include a variety of separate components that can be either acceleration- or deformation-sensitive. Walls, windows, and other portions of the enclosure system may collapse into a stairwell, or stair structures may be dislodged from their supports. Safe exit may be prevented by the failure of any portion of the stair or stairwell system.

Rehabilitation may take the form of detaching the stair from the building structure at each floor, either at the top or bottom of the stair, to eliminate mutual interaction between stair and structure.

C11.9.8.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Stairs may experience moderate damage but should be usable.

Immediate Occupancy Performance Level. Stairs may experience only minor damage.

C11.9.8.4 Evaluation Requirements

No commentary is provided for this section.

C11.10 Mechanical, Electrical, and Plumbing Components: Definition, Behavior, and Acceptance Criteria

C11.10.1 Mechanical Equipment

C11.10.1.1 Definition and Scope

No commentary is provided for this section.

C11.10.1.2 Component Behavior and Rehabilitation Concepts

Failure of these components consists of moving or tilting of floor- or roof-mounted equipment off its base, and deformation or loss of connection (with consequent falling) for equipment attached to vertical or horizontal structures, and failure of piping or electrical wiring connected to the equipment.

The primary object of the *Guidelines* is to ensure that the equipment remains fixed in place. The *Guidelines* do not consider the effect of shaking of the building on the internal parts of the equipment. Equipment that is suspected of being critically sensitive to this motion must be evaluated independently by the engineer, using such information as may be obtainable from the manufacturer.

It is not the intent of these *Guidelines* to require the seismic design of mechanical and electrical assemblies. When the potential for a hazard to life exists, it is expected that design efforts will focus on equipment supports, including base plates, anchorages, support lugs, legs, feet, saddles, skirts, hangers, braces, and similar items.

Many items of mechanical and electrical equipment consist of complex assemblies of mechanical and/or electrical parts that are typically manufactured using an industrial process that produces similar or identical items. Such equipment may include manufacturers' catalog items and often is designed by empirical (trial-and-error) means for functional and transportation loadings. A characteristic of such equipment is that it should be inherently rugged, in the sense that its construction and assembly provide such equipment with the ability to survive strong motions, during transportation and installation, without loss of function. By examining such equipment, an experienced design professional can usually confirm the existence of ruggedness, and can determine the need for an appropriate method and extent of specific seismic design or qualification if performance beyond the Life Safety Level is required.

It is also recognized that a number of professional and industrial organizations have developed nationally recognized codes and standards for the design and construction of specific mechanical and electrical components. In addition to providing design guidance for normal and upset operating conditions and various environmental conditions, some have developed earthquake design guidance in the context of overall mechanical or electrical design. Where continued equipment function is a matter of concern, use of such codes and standards is recommended, since their developers have familiarity with the expected failure modes of their components.

In addition, even if such codes and standards do not have earthquake design guidance, it is generally accepted that construction of mechanical and electrical equipment to nationally recognized codes and standards (such as those approved by ANSI) provides adequate strength to accommodate all normal and upset operating loads. Earthquake damage surveys have confirmed this.

The determination as to which equipment is subject to the *Guidelines* is based primarily on weight and location. In general, even heavy mechanical equipment does not represent a life safety threat, unless it is located where its falling or overturning might be hazardous; for example, a large unit heater suspended over an occupied area. While mechanical equipment might be made nonfunctional, this is rarely life-threatening. It might be maintained that loss of an exhaust system used as part of a fire safety strategy represents a life safety problem, but this would imply a combination of earthquake and fire, as well as trapping of occupants in a smoke-filled area for enough time for the situation to become life-threatening. If partial or complete collapse occurred, nonstructural protection would be ineffective. Though possible, this combination of events is of very low probability and the Life Safety Performance Level is defined only in terms of prevention of injury caused by direct damage. Where fully functional post-earthquake nonstructural systems are desired, higher performance must be selected.

Rehabilitation of most mechanical equipment involves a bolting and/or bracing procedure that is simple and low-cost, and generally effective in preventing often costly damage, particularly in low to moderate earthquake shaking. Thus, although rehabilitation may not be necessary from a life safety viewpoint, it may be desirable to undertake it as part of a general rehabilitation program to reduce property loss.

When the equipment is analyzed to determine seismic forces, the Default Equation can be used, because a conservative result will have little impact on the cost of the solution. Roof-mounted equipment, such as large cooling towers and packaged HVAC units, are especially vulnerable and it is recommended that the General Equation (Equations 11-2 and 11-3) be used, since this takes into account possible force amplifications due to location.

The ductility of connections, especially anchors embedded in concrete or masonry, must be evaluated with regard to the possibility for sudden brittle failure. The possibility of interaction of different pieces of equipment and structural elements as to their deformation must be considered, particularly regarding the possibility of progressive failure of a series of units.

API (1993) and AWWA (1989) provide useful discussion and information for the anchorage of equipment.

C11.10.1.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Some damage to mechanical equipment is acceptable, with the exception of overturning or falling of heavy equipment in occupied areas.

Immediate Occupancy Performance Level. Some damage is acceptable, but should be repairable without removal and replacement of major components. Equipment should not shift position.

C11.10.1.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.2 Storage Vessels and Water Heaters

C11.10.2.1 Definition and Scope

This section defines fluid-containing vessels that may differ from equipment as defined in the previous section because of the reaction of the fluid within the vessel to the earthquake motions.

C11.10.2.2 Component Behavior and Rehabilitation Concepts

The failure mode for Category 1 (leg-supported) vessels will be stretching of anchor bolts, failure of legs, and consequent tilting over or possible overturning of the vessel. The failure mode for Category 2 (base-supported) vessels may be displacement off the foundation, or failure of the shell near the bottom of the tank by yielding that creates a visible bulge.

Flat bottom vessels, as described in Category 2, differ in their reaction to earthquake motions because the support of the contents is shared between the vessel itself and the direct action of the fluid on the supporting floor.

All vessels should be anchored to the building. This also applies to vessels of Category 2 in which the height-to-width ratio is low, which have often in the past been considered to be safe from failure or displacement. This is a different criterion than is used for flat bottom vessels located on the ground, where those with low height-to-diameter ratios (less than 0.50) are often considered safer if unanchored because of the beneficial effects of allowing the tank to slide to dissipate the energy of the earthquake. However, this strategy must allow for differential displacement of vessel, piping, and pipe valves, through flexible joints or bends. In addition, in buildings, the effect of the possible detrimental effect on the building by movement of a heavy load must be considered.

This section allows vessels of Category 1, which are entirely supported by the legs or skirt of the vessel and which are relatively small, to be treated the same way as the mechanical equipment of the previous section. This is because the effects of the movement of the fluid in these vessels is not as significant. The same proviso, requiring the use of the General Equation for analysis, relates to heavy items located on an upper floor of the building.

In relation to acceptable performance, failure of the tank may be acceptable—even if it leaks—if the contents can be held or diverted to either avoid a Life Safety problem or prevent damage to other components of the building. From a Damage Control viewpoint, consideration should be given to the value of the contents and the effect of spillage on the building and its contents, as well as the value of the vessel itself. For Immediate Occupancy, the main issues are the importance of the contents of the vessels to the functional operation of the building, and the restriction of damage to that which is easily repairable with minimum loss of contents. Similar to those for mechanical equipment, the Life Safety aspects of tank failure are generally not great, but rehabilitation of tanks by bracing is neither costly nor difficult, and may be very cost-beneficial in reducing property loss.

Water heaters should be restrained in accordance with prescriptive requirements that are generally available from the government jurisdiction responsible. Reference may be made to the *Memo for General Distribution No. 27* by the City of Los Angeles for such guidance. Typical general requirements for residential water heater bracing provide that the water heater should be restrained in at least two places—one near the top and one approximately one-third of the way up from the bottom—with galvanized steel straps that are at least one-half inch wide by 16 gauge. Straps should be attached into structural studs of at least 2" x 4" size or equivalent that are braced laterally by blocking and/or gypsum board or other sheathing material. Care must be taken to configure and install these braces so that they tightly restrain the tank in all horizontal directions.

Evaluation of existing tanks should include investigation of the strength of the primary elements, as well as the design of nozzles, appurtenances, platforms, ladders, and manways. Prescriptive guidelines for these elements are contained in API (1993) and AWWA (1989) in the *Guidelines*.

Evaluation should also include consideration of leakage due to corrosion and how this might be detected before it becomes a serious problem (see Appendix I in API, 1993).

C11.10.2.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Vessel remains in place without rupturing itself or its connections; minor, easily contained leakage is acceptable, unless special conditions of occupancy or tank location apply. Damage may require repair or replacement.

Immediate Occupancy Performance Level. Vessel remains in place without rupturing itself or its connections and/or vessel has positive shutoff or retention to prevent spill of contents. Damage is confined to minor repair.

C11.10.2.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.3 Pressure Piping

C11.10.3.1 Definition and Scope

This section sets out an arbitrary lower limit for pressure in this piping, based on that used by most codes. This is to attempt to identify piping that has sufficient pressure to produce explosive results when rupture occurs. However, judgment should be used to identify specific piping in a given building that could produce this result.

C11.10.3.2 Component Behavior and Rehabilitation Concepts

Loss of support, causing failure at joints, is generally the mode of failure through seismic causes, which may or may not be exacerbated by the effects of corrosion. Other causes are deformation of the attached structure, or breakage from impact with adjoining materials. Piping that runs between floors or across expansion or seismic joints is drift-sensitive.

Following Project B31 in 1926, the first edition of *American Tentative Standard Code for Standard Piping* was published in 1935. Since December 1978, the ANSI B31 was reorganized as the ASME Code for Pressure Piping B31 Committee, under procedures developed by ASME and accredited by ANSI. B31 Codes, along with *ASME Boiler and Pressure Vessel Code*, Sections I through XI, are the accepted codes for these components. (See *Guidelines* references, ASME, latest edition.)

In addition to adequate support and provision for differential building movement at joints, the dynamic forces in the piping system must be evaluated along with the potential effects of corrosion on this piping. Generally, these criteria will prove more demanding than the additional effects of earthquake motions, other than possible differential movement between buildings.

Seismic rehabilitation of pressure piping focuses on adequate support and bracing, with particular attention to provision for differential movement at seismic or expansion joints. Experience has shown that most piping has sufficient inherent flexibility and ductility to accommodate building drift without damage. Thus, inserting connections to vertical piping at each floor level is neither necessary nor desirable, from the standpoint of drift-sensitive considerations, because the joint is likely to be a point of vulnerability. However, attachments or braces based on acceleration-sensitive considerations are necessary, and particular attention should be paid to large diameter heavy piping.

C11.10.3.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Minor damage may occur at some joints with some leakage but system is generally intact. Some supports may be damaged, but the system remains suspended.

Immediate Occupancy Performance Level. Minor leaks may develop at a few locations, but the system is intact.

C11.10.3.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.4 Fire Suppression Piping

C11.10.4.1 Definition and Scope

This section defines piping required for fire suppression, which is treated as a separate item from other piping because of its importance and because of the large body of information that has been developed specifically for it. This section primarily applies to water sprinkler piping but also includes piping for other types of fire suppression.

C11.10.4.2 Component Behavior and Rehabilitation Concepts

Damage to this piping usually results from inadequate bracing or lack of allowance for differential movement between parts of the structure that support the piping. In addition, in recent earthquakes, sprinkler branch piping has failed because of impact with adjoining materials, typically ceiling components.

Although failure of fire suppression systems may seem an obvious instance of a Life Safety Performance Level requirement, it is not expressed as such in the *Guidelines*. For a serious life safety threat to exist, the earthquake must be accompanied by a fire that presents an immediate threat to occupants that would only be alleviated by fire sprinkler activation. Though conceivable, the probability of this combination of events is very low.

Fire sprinkler system damage, and the damage to building materials and building contents from the resulting leakage, can be extremely costly. Therefore, it is necessary that automatic, fail-safe shutoff mechanisms are in proper working order to control this potential problem. The problem of preventing water damage from sprinkler systems is particularly difficult, because a single failure in a system that may have hundreds of joints and sprinkler heads may be enough to cause extensive damage.

Observations at the 1994 Northridge earthquake (Hall, 1995), in which a number of sprinkler failures occurred, showed that failures took a number of forms. The least common, but most disruptive, was falling of pipes. A common cause of damage was incompatible motions between sprinkler piping and other ceiling or ceiling plenum components. In facilities such as garages and warehouses that lacked ceilings, failures occurred within the sprinkler system itself. These were attributed to:

- Connection deficiencies (e.g., C-clamp connections of hanger rods to beams rotated loose, or powder-driven fasteners pulled out)
- Insufficient bracing, typically in older installations
- Quality of installation work

In addition, it is possible that in some instances the building motion was too severe for even well-designed systems, properly installed according to current codes, though this point is not universally accepted. The latest (1991) *NFPA-13* edition available at the time of the earthquake (NFPA-13, 1996 in the *Guidelines*) had yet to be widely used and thus was neither validated nor invalidated by the Northridge earthquake. Some engineered sprinkler systems have more extensive bracing, not taking advantage of *NFPA-13*'s exemption of smaller branch lines.

Based on the disruptive and economic effects of sprinkler and other piping leakage in the Northridge earthquake, some suggestions have been made for the achievement of high performance in sprinkler systems, especially in essential buildings:

- Zoning systems into smaller areas, so that smaller areas can be shut off
- Using automatic or remotely controlled valves
- Requiring more rigorous training for designated personnel in immediate post-earthquake inspection and shutoff techniques

Because the requirement for sprinklers to be installed in a building is mandated from areas of the building code other than seismic, the seismic issue relates more to ensuring proper design and installation in general, rather than whether the presence of sprinklers is a Life Safety, Damage Control, or Immediate Occupancy requirement. Given that sprinklers are required, common prudence would suggest that installation issues of seismic importance be taken care of, regardless of Performance Level.

The *NFPA Fire Protection Handbook* and the *Automatic Sprinkler Systems Handbook*, both published by the National Fire Protection Association, may be used to amplify and explain that which is referenced in the *Guidelines* (NFPA, 1996). In addition, the following NFPA Standards should be used where applicable.

NFPA 11: Standard on Foam Extinguishing Systems

NFPA 12: Standard for Carbon Dioxide Extinguishing Systems

NFPA 12A, 12B: Standard for Halon Fire Extinguishing Systems

NFPA 14: Standard for the Installation of Standpipe and Hose Systems

NFPA 15: Standard for Water Spray Fixed Systems

NFPA 16: Standard for Deluge Foam-Water Sprinkler and Spray Systems

NFPA 16A: Recommended Practice for the Installation of Closed Head Foam-Water Sprinkler Systems

NFPA 17: Standard for Dry Chemical Extinguishing Systems

NFPA 17A: Standard for Wet Chemical Extinguishing Systems

C11.10.4.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Rupturing of some piping, leaving a partially functioning system. Main risers and laterals of over four inches in diameter do not fall or break. Some heads may be damaged by impact with adjoining materials, and leaks may develop at some couplings.

Immediate Occupancy Performance Level. Minor joint failures that are easily reparable; the system remains operable.

C11.10.4.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.5 Fluid Piping Other than Fire Suppression

C11.10.5.1 Definition and Scope

This section separates all fluid piping that has not been covered in previous sections into hazardous and nonhazardous material conveying systems. Systems may be low-pressure or gravity.

C11.10.5.2 Component Behavior and Rehabilitation Concepts

Generally, if the piping has been recently installed to meet code requirements, secondary containment features must be in place for piping carrying hazardous materials, due to the extreme danger that accompanies failure.

The following list of possible rehabilitation measures that should be considered when evaluating a hazardous piping system and related equipment is taken from the *Piping Handbook, Sixth Edition (*Nayyar, ed., 1992).

1. Open air process units will lessen the potential for concentrating hazardous vapors.

2. Containment dikes can be added to collect spills of hazardous liquids; a diked area should be equipped with a collection sump and means for safe removal.

3. A dedicated system can be set up to collect hazardous and toxic fluid spills, to eliminate any cross-contamination with other streams.

4. The entire process area can be physically contained, with instrumentation for remote monitoring and control.

5. Ventilation can be added to remove hazardous vapor for safe disposal during emergency conditions. Ventilation may be the most important technique for controlling toxic air contaminants. General ventilation continually exchanges a supply of fresh air while exhausting air within the entire workplace. Local ventilation removes vapors, mists, and dusts continually from around equipment where hazardous fluids are contained. Either type of ventilation will require a scrubber to strip the vented air before its release to atmosphere.

   Note: The above suggestions for ventilation presuppose that electrical power continues to be available; however, under post-earthquake conditions it is likely that power will not be available, due to local or regional power outage, or failure or absence of emergency generators.

6. The inherent piping geometry, proper location of pipe anchors, pipe loops, and other integral techniques can be used to compensate for thermal expansion and contraction. To eliminate the effects of expansion and contraction, the use of mechanical devices should be avoided. Bellows and other types of expansion joints should be used only with the utmost care and adequate safeguarding.

7. Adding a pressure relief system will allow for safe discharge during upset conditions, blowdown, or cleanout. The relief system should be piped to the hazardous fluid treatment system.

8. Double-block and bleed valve arrangements can be provided on all hard piped connections where personnel may be required to enter a vessel.

9. Engineered barriers and shields at mechanical joints can protect personnel from leakage.

10. Guards or barricades can protect the piping from accidental mechanical abuse.

11. Plant arrangement should control access to hazardous areas and provide a safe distance between the hazard and the plant and/or public populated areas.

12. The system should limit the quantity of hazardous fluid that can escape in the event of a pipe rupture. Minimizing the quantity of hazardous fluid present at any time is a means of protecting people and property in the event of a piping failure.

13. Various process controls can be used to protect the system from excursions of temperature, pressure, or flow rates.

14. A systematic monitoring and leak detection program can be implemented to determine whether harmful releases are being experienced.

Seismic rehabilitation of piping focuses on adequate support, bracing, and provision for differential movement at seismic or expansion joints.

C11.10.5.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. No failure of Category 1 piping within occupied areas; no leakage of contents into occupied areas.

Immediate Occupancy Performance Level. Limited damage to Category 2 piping, but system can be repaired rapidly.

C11.10.5.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.6 Ductwork

C11.10.6.1 Definition and Scope

This section includes rigid air ducts, which are generally light gauge metal.

C11.10.6.2 Component Behavior and Rehabilitation Concepts

Although sheet metal ducts, especially of smaller cross sections, can tolerate large distortions and undergo small inertial loads, they have little inherent strength. They must be supported so that during a seismic event they will stay together and not rupture (where the Operational Performance Level is the goal), or not fall (where Life Safety is the goal). Joints are particularly vulnerable. Failure consists of deformation or loss of supports, leading to deformation or rupture of the ducts at joints, and permitting leakage from the system and/or malfunction of in-duct controls and devices.

In general, failure of duct systems is not a Life Safety issue. As is the case with mechanical equipment, it might be argued that loss of an exhaust system used as part of a fire safety strategy represents a Life Safety problem, but this would imply a combined earthquake and fire, and trapping of occupants in a smoke-filled area long enough for the situation to become life-threatening. Though possible, this combination of events is of very low probability. General air-handling systems can be out of action for a considerable time with no more detrimental effect than slight discomfort, depending on the intensity of occupancy and the outside climate. A Performance Level of Immediate Occupancy could, in many instances, be achieved with a nonfunctioning air handling system if temporary natural ventilation can be achieved (by opening windows and doors) and the outside climate is reasonable. In other cases (e.g., the typical hospital or data processing center), the facility cannot function without HVAC systems. A mechanical engineer should be consulted to determine the extent to which parts of a duct system may be critical for the removal of toxic substances in a laboratory, industrial plant, or other such facility.

The seismic rehabilitation of these components is relatively simple and can be designed in accordance with the Prescriptive Procedure. The designer must be aware of unusual situations where there is differential movement between different parts of the structure supporting these components, or where there are very long runs in which, during seismic motion parallel to them, large lateral forces will be generated that require larger braces than specified by the Prescriptive Procedure.

Further information regarding evaluation may be obtained from the SMACNA publications referenced in the *Guidelines.*

C11.10.6.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Ductwork systems conveying hazardous materials are not damaged; other ductwork systems may be damaged.

Immediate Occupancy Performance Level. Some damage to components but system is substantially operational, or acceptable environmental conditions can be maintained by alternative means.

C11.10.6.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.7 Electrical and Communications Equipment

C11.10.7.1 Definition and Scope

No commentary is provided for this section.

C11.10.7.2 Component Behavior and Rehabilitation Concepts

The provisions for these components are very similar to those for mechanical equipment The object of the *Guidelines* is primarily to ensure ability of the equipment to remain fixed in place. The *Guidelines* do not consider the effect of shaking on the internal parts of the equipment. Equipment that is suspected of being internally sensitive to this motion must be evaluated independently by the engineer, using such information as may be obtainable from the manufacturer. Unlike much mechanical equipment, electrical and communications equipment generally does not have moving or rotating parts and is not vibration-isolated.

Failure of these components consists of moving or tilting of floor- or roof-mounted equipment off its base, deformation or loss of connection (with consequent falling) for equipment attached to vertical or horizontal structure, and failure of electrical wiring connected to the equipment.

The determination as to which equipment is subject to the *Guidelines* is based primarily on weight and location. In general, even heavy electrical and communications equipment does not represent a Life Safety threat, unless it is located where its displacement might be hazardous; a transformer suspended over an occupied area would be an example. Post-earthquake functionality issues go beyond the Life Safety Performance Level, and must be evaluated on a building-by-building basis.

Rehabilitation of most electrical and communications equipment involves prescriptive bolting and/or bracing procedures that are simple, low cost, and generally effective—particularly in low to moderate earthquakes—in preventing damage. Thus, although rehabilitation may not be necessary from a Life Safety viewpoint, it may be desirable to undertake it as part of a general rehabilitation program to reduce property loss.

The importance of each item of equipment with regard to its required Performance Level is determined by its function. Therefore, all equipment in a building must be categorized as to the effect that its failure would have on the ability of the building to satisfy criteria for the Immediate Occupancy or Operational Performance Levels.

The ductility of connections—especially large equipment anchors embedded in concrete or masonry—must be evaluated with regard to the possibility of sudden brittle failure. The possibility that different pieces of equipment and structural elements could interact, leading to their deformation, must be considered; the possible progressive failure of a series of units is a particular concern.

C11.10.7.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Some damage to equipment but heavy equipment does not detach and fall in a heavily occupied area.

Immediate Occupancy Performance Level: Some damage to components but system is substantially operational, or acceptable environmental conditions can be maintained by alternative means.

C11.10.7.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.8 Electrical and Communications Distribution Components

C11.10.8.1 Definition and Scope

No commentary is provided for this section.

C11.10.8.2 Component Behavior and Rehabilitation Concepts

Electrical and communications components generally possess considerable strength or rigidity in themselves and thus need only adequate and uniform support for their protection. Supports for these distribution components are generally similar in nature to those provided for ducts, drain lines, and other small piping. The prescriptive provisions contained in the SMACNA documents referenced in the *Guidelines* are generally usable.

Failure of these components consists of failure of transmission components due to accelerations causing movement of attached equipment. Failure may also be caused by deformation or loss of supports, deformation of the attached structure, or breakage from impact with adjoining materials.

The major secondary damage caused by failure of electrical components is that of fires caused by broken power lines. This particularly applies to the residential condition where power lines are often not protected by conduit and extreme structural distortion can result in short-circuiting of power lines, resulting in fire damage to building materials or, most seriously, ignition of gas. Good general practice in the installation of power conductors is the best nonstructural safeguard against such failures.

C11.10.8.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Some damage to components but certain transmission lines required by specifics of the building design or occupancy (based on either possible fire danger or the protection of life safety systems) are protected.

Immediate Occupany Performance Level. Some damage to components that (1) are not required for life safety purposes, and (2) can be rapidly repaired; acceptable environmental and functional conditions can be maintained by alternative means.

C11.10.8.4 Evaluation Requirements

No commentary is provided for this section.

C11.10.9 Light Fixtures

C11.10.9.1 Definition and Scope

This section differentiates between light fixtures that are integral with the ceiling system, those that are surface mounted on wall or ceiling and those suspended independently.

C11.10.9.2 Component Behavior and Rehabilitation Concepts

In general, recessed and ceiling- or wall-mounted fixtures present no specific seismic problem, provided that they are securely attached to their supporting surface. To the extent that this surface may be damaged or collapse, the fixtures may be damaged and, though a rare occurrence, if heavy fixtures should fall the Life Safety consequences can be serious.

Failure of Category 1 and 2 components occurs through failure of attachment of the light fixture and/or failure of the supporting ceiling or wall. Failure of Category 3 components occurs through loss of support from the T-bar system, by distortion caused by deformation of the supporting structure or deformation of the ceiling grid system, allowing the fixture to fall. Failure of Category 4 components is caused by excessive swinging that results in the pendant or chain support breaking on impact with adjacent materials, or the support being pulled out of the ceiling.

Fixtures supported by a ceiling grid have proven to be particularly vulnerable in recent earthquakes; their weight and hazardous design may cause injury. Such fixtures must be supported back to the structure independently of the ceiling grid. This can be easily and effectively achieved through use of backup safety wires, attached in accordance with prescriptive requirements, that are adequate at all seismic levels. Sometimes a specially designed substructure for the support of mechanical and electrical components (such as grids and trapezes) is placed between the finished ceiling and the floor or roof structure above. Bracing can generally be attached to such substructures.

Heavy chandelier fixtures should be carefully evaluated for strength of attachments, and their ability to swing safely in the event of ground motion. Suspended pendant fluorescent fixtures, often used in rows in older school rooms, have been shown to be vulnerable in recent earthquakes; these should be carefully evaluated and rehabilitated using devices that allow for movement but provide secure connections. A standard rehabilitation technique is to install backup support cables either externally—from fixture to structure above—or inside the stem.

C11.10.9.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level
Category 1 and 2. These fixtures may be damaged, depending on damage to the ceiling or wall.

Category 3. Loss of support from the T-bar systems does not result in falling of the fixture in any occupied area.

Category 4. Fixtures do not become detached nor significantly damage any other component.

Immediate Occupancy Performance Level.
Performance is similar to that for the Life Safety Performance Level.

C11.10.9.4 Evaluation Requirements

No commentary is provided for this section.

C11.11 Furnishings and Interior Equipment: Definition, Behavior, and Acceptance Criteria

C11.11.1 Storage Racks

C11.11.1.1 Definition and Scope

Storage racks are usually steel or aluminum systems engineered to support a variety of often heavy contents loads, and may approach 20 feet in height.

C11.11.1.2 Component Behavior and Rehabilitation Concepts

In many cases these designs, while sufficient for gravity loads, may have insufficient bracing or moment-resisting capacity, or may fail by overturning or failure of foundation attachments. Racks are often improperly attached to vertical supports and have weak resistance to lateral loads.

High storage racks and their contents present a hazard that is not confined to their own failure, but includes their impact on the surrounding building structure, which can be the cause of column or even wall collapse. Storage racks, if improperly braced, often collapse or overturn in moderate or greater seismic events. Historically, these elements can be a significant safety hazard, but the principal effect of their failure is property damage and collateral loss.

Storage racks sometimes are located in areas that are essentially unoccupied, except for an occasional visit for retrieval purposes; thus the threat to life is minimal. However, the advent of very large retail discount stores, with rows of high storage racks in heavily occupied areas, represents a significant threat to life safety; the realistic analysis of seismic forces and the design of these systems need particular attention.

Even a low storage rack can, if heavily loaded, represent a significant threat if it is located in close proximity to a seated person. Rehabilitation by bracing and floor attachment should also be accompanied as much as possible by good managerial practices; this means storing heavy items toward the bottom of the racks so that falling is less likely and, if it does occur, less serious.

Storage racks can be designed to resist seismic loads through either tension-only strap bracing, bracing with compression members, or partial moment connections of the horizontal and vertical members of the rack system. The vertical loads are supported on base plates that are often not attached or inadequately attached to the floor. In the case of heavy rack systems, slab support, even if properly attached, may be inadequate to prevent failure of the slab caused by overturning loads.

Rehabilitation is usually accomplished by the addition of bracing to the rear and side panels of racks and/or by improving the connection of the rack columns to the supporting slab. In rare instances, foundation improvement, may be required to remedy insufficient bearing or uplift load capacity.

C11.11.1.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. In Life Safety-critical locations with occupancy in close proximity, no upset of racks in excess of four feet in height; some damage to the rack system itself.

Immediate Occupancy Performance Level. No upset of racks or collateral damage to supporting structure but minor damage to rack system.

C11.11.1.4 Evaluation Requirements

No commentary is provided for this section.

C11.11.2 Bookcases

C11.11.2.1 Definition and Scope

Unlike storage racks, bookcases are usually under ten feet in height, but they often exist in areas—such as libraries—with high human occupancy, where their failure could result in injury or loss of life.

C11.11.2.2 Component Behavior and Rehabilitation Concepts

Bookcases may be heavily stacked and in close proximity to a seated person; even a low bookcase represents a significant threat. Bookcases are usually not engineered and, while sufficiently strong to support gravity loads, they may be inadequate to transfer lateral loads internally, and they are often inadequately attached to the supporting floors or adjacent columns, walls, or other structural members. The historic behavior of bookcases includes numerous instances of overturning failure. There have also been significant cases—in library installations of large fully loaded bookcases—of internal racking or buckling failure, usually along the longitudinal axis.

Engineering solutions for rehabilitation usually require a systematic Analytical Procedure. Options often include improvements to the longitudinal lateral stability of the bookcase by the addition of strap cross-bracing or panelized stiffening, using plywood or other materials, along with attachments to the supporting floor structure. Another common rehabilitation technique involves improving attachments to the supporting floor structure and connecting the top of the bookcases, through a series of struts, horizontally to each other and to adjacent supporting wall or column structure. This technique reduces overturning forces.

C11.11.2.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. No upset of bookcases in excess of four feet in height in occupied areas. Some damage to the system. Most volumes restrained on the shelves.

Immediate Occupancy Performance Level. No upset of bookcases or collateral damage to supporting structure. Minor damage to system.

C11.11.2.4 Evaluation Requirements

No commentary is provided for this section.

C11.11.3 Computer Access Floors

C11.11.3.1 Definition and Scope

Computer access floors are available in a variety of types, but are usually made up of two basic components. The first is a system of supporting legs or stanchions and horizontal beams, laid out to accommodate the second part of the system, an access floor panel. Supporting structures are usually designed and constructed of steel, while the floor panels can be of wood, metal, concrete, or composite construction. Access floors are designed for various and often changing arrangements. They are generally well engineered for the support of vertical loads.

C11.11.3.2 Component Behavior and Rehabilitation Concepts

Access floors rarely fail in earthquakes, but because they carry the lateral loads developed by the mass of computer or other electronic systems that they support, failure does sometimes occur, by either dislodgment of the panels, failure of the supporting stanchions and horizontal members, or both. In many of these cases, base plates of the stanchions are inadequately connected, or not connected at all, to the supporting floor system.

The implications of poor seismic performance in access floors are not usually related to Life Safety so much as to business recovery, since the equipment they support is often important to communications or data processing. Rehabilitation of access floors usually includes (1) improving attachment of computer and communication racks through the access floor panels to the supporting steel structure or to the underlying floor system, and (2) improving the lateral-load-carrying capacity of the steel stanchion system by installing braces, improving the connection of stanchion base to the supporting floor, or both.

A useful discussion of all aspects of the protection of data processing equipment will be found in Olson (1987).

C11.11.3.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Not applicable.

Immediate Occupancy Performance Level. No failure occurs; only minor displacement of supporting structure occurs. Some displacement of panels occurs.

C11.11.3.4 Evaluation Requirements

No commentary is provided for this section.

C11.11.4 Hazardous Materials Storage

C11.11.4.1 Definition and Scope

In this document, the scope is limited to engineering techniques for protecting permanently installed containers. Propane gas tanks and their supporting legs are included, while containers for hazardous materials stored on counter tops, shelves, or desktops are typically excluded due to the large variation in conditions, although these hazards may be significant. See FEMA 74 (FEMA, 1994).

C11.11.4.2 Component Behavior and Rehabilitation Concepts

The containers that hold hazardous materials are generally not engineered, with the exception of large chemical containers or gas cylinders. In many cases, the supports for even heavy tanks have not been adequately designed to resist lateral loading. The historic performance of these elements includes numerous instances of broken glass containers thrown from shelves and counter tops, as well as tanks dislodged from their supports.

These components usually fail by sliding or overturning, and break only on impact. An additional concern is the potential for rupture of connecting piping and tubing. Rehabilitation measures are usually prescriptive; solutions run from the installation of wire or transparent plastic barriers—to prevent shelf-stored hazardous materials and containers from falling—to improvements in lateral bracing and foundation attachment for heavy tanks.

C11.11.4.3 Acceptance Criteria

Compliance with the acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. No displacement, breakage, or disconnection of a container in close proximity to occupancy where leakage can cause immediate life threat.

Immediate Occupancy Performance Level. No displacement, breakage, or disconnection of a container in a functional critical area that allows a release of materials individually or collectively hazardous. Minor damage in other areas.

C11.11.4.4 Evaluation Requirements

No commentary is provided for this section.

C11.11.5 Computer and Communication Racks

C11.11.5.1 Definition and Scope

The rack systems included in this section are similar in construction to storage racks discussed in Section 11.11.1. They typically support expensive and sensitive electronic equipment, including computers, network servers, and telecommunications equipment. The equipment itself is not included in the definition, although functional and property losses may result from their failure.

C11.11.5.2 Component Behavior and Rehabilitation Concepts

Computer and communication racks are usually designed to adequately support the vertical loads of the equipment that they contain; in some cases, they are integral with that equipment and form the outer computer compartment. Historic performance includes overturning failure due to inadequate attachment to supporting access or structural floor systems, as well as racking (particularly longitudinal) associated with inadequate bracing or shear panels. Because the systems are often supported on computer access floors, a combination of measures, including both elements, may need to be implemented in order to assure adequate rack performance.

Rehabilitation measures typically require an Analytical Procedure, including the estimated weight of the rack contents, to establish forces on the components. Rehabilitation often includes bracing or additional panels within the rack itself, as well as improvements to the attachment of the rack base through the access floor panel to the supporting structure. Positive connections of equipment to rack are also frequently needed.

C11.11.5.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Not applicable.

Immediate Occupancy Performance Level. No upset of racks or collateral damage to supporting structure. Minor damage and/or distortion of racks. Distortion does not disengage electronic connectors or damage equipment.

C11.11.5.4 Evaluation Requirements

No commentary is provided for this section.

C11.11.6 Elevators

C11.11.6.1 Definition and Scope

The definition of elevators in this sections is intended to encompass the entirety of elevator machinery, shafts, cars, and supporting rooms.

C11.11.6.2 Component Behavior and Rehabilitation Concepts

Rehabilitation of elevators is typically aimed at safety rather than immediate post-earthquake operation; their use for immediate escape is not contemplated. Current seismic provisions for elevators are aimed at safe shutdown rather than continued functionality. After even moderate shaking, the majority of elevators will need inspection after shutdown before they can be regarded as safe. This fact alone means that elevators cannot be regarded as available for escape or rescue.

Many parts of elevator systems—typically, the supporting frames and members—are engineered systems, but some are not, and those that are engineered may not have been designed with seismic loads in mind. Engineered systems will have been designed for safety in ordinary operation; those of more modern construction may also include restraints or other devices that improve seismic performance. Shaft walls and the construction of machinery room walls are often not engineered and must be considered in a similar way as for other partitions. Shaft walls that are of unreinforced masonry or hollow tile must be considered with special care, since failure of these elements violates Life Safety Performance Level criteria.

Elevator machinery may be subject to the same damage as other heavy floor-mounted equipment. Shaft walls can be damaged in the same way as other partitions, and materials may fall down the shaft onto the cab. Electrical power loss renders elevators inoperable.

Rehabilitation measures include a variety of techniques taken from specific component sections for partitions, controllers, and machinery. Rehabilitation specific to elevator operation can include seismic shutoffs, cable restrainers, and counterweight retainers.

C11.11.6.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Elevators may be out of service, but counterweights are not dislodged.

Immediate Occupancy Performance Level. Minor damage occurs, but the elevators, shafts, and necessary equipment are functional. Elevators are capable of operating when power is available.

C11.11.6.4 Evaluation Requirements

No commentary is provided for this section.

C11.11.7 Conveyors

C11.11.7.1 Definition and Scope

Conveyors include the belts, supporting trusses, and machinery in material conveyors used to move merchandise, luggage, packages, or other products. The equipment is often complex and includes many pieces of equipment similar to those described in other sections of the *Guidelines.*

C11.11.7.2 Component Behavior and Rehabilitation Concepts

These systems are often both acceleration- and deformation-sensitive, and experience shows that seismic events can dislodge or deform individual pieces of the system in a manner similar to the effects on other heavy mechanical equipment.

Conveyors are engineered systems, but many are not designed with seismic loads in mind. They have been designed for ordinary operating loads; those of more modern construction may also include anchorage, restraints, or other devices that improve seismic performance. Rehabilitation measures include a variety of techniques taken from specific component sections for mechanical equipment. Rehabilitation of supporting trusses or other structures may include bracing and additional strength where necessary, based on the requirements of Chapter 5.

C11.11.7.3 Acceptance Criteria

Compliance with acceptance criteria is intended to achieve the following performance:

Life Safety Performance Level. Not applicable.

Immediate Occupancy Performance Level. Minor damage occurs, but conveyors and equipment are operable.

C11.11.7.4 Evaluation Requirements

No commentary is provided for this section.

C11.12 Definitions

No commentary is provided for this section.

C11.13 Symbols

No commentary is provided for this section.

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