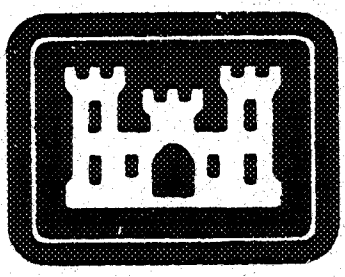

TI 809-05
November 1999

US Army Corps
of Engineers

SEISMIC EVALUATION
AND
REHABILITATION FOR BUILDINGS

Prepared for:
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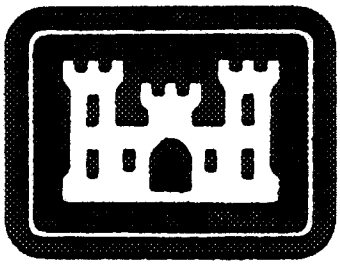

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U.S. Army Corps of Engineers
Washington, D.C. 20314-1000

SEISMIC EVALUATION AND REHABILITATION FOR BUILDINGS

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CHAPTER 1
INTRODUCTION

1-1. Purpose and Scope

a. Purpose. This document provides criteria and furnishes guidelines for the seismic evaluation and upgrading or strengthening of structural and nonstructural systems and components in existing buildings. The rehabilitation provisions of this document presuppose that structural rehabilitation has been selected as the most appropriate and cost-effective mitigation option after consideration and evaluation of other available options for mitigation of the seismic hazard. These guidelines are not specifically intended for the repair of seismically damaged building components or systems.

b. Scope. The guidelines presented in this document for the evaluation and strengthening or upgrading apply to existing structural and nonstructural components and systems that were found to be deficient with respect to their performance objectives. The guidelines are generally in accordance with Federal Emergency Management Agency (FEMA) 310 for evaluation; FEMA 273 and TI 809-04 for analysis and acceptance criteria; and FEMA 302 for design and detailing requirements for the addition of new structural components or systems.

1-2. Applicability

a. General. The criteria in this document are applicable to all entities responsible for the design of military construction in the United States and its territories and possessions. The procedures in this document may be used to verify the performance objectives of any existing construction.

b. Exempted buildings. A military building is exempted from the seismic structural evaluation requirements given herein if any of the following apply, and the building is:

(1) Originally designed according to the 1982 or later edition of Technical Manual (TM) 5-809-10 or the 1988 edition of TM 5-809-10-1, and the design of an alteration does not reduce the strength or increase the earthquake loading of any existing structural system component by more than 10%.

(2) Scheduled for replacement within 5 years.

(3) Classified for agriculture use, or intended only for incidental human occupancy, or occupied by persons for a total of less than 2 hours a day.

(4) A detached one- or two-family dwelling that is located in an area having a short-period spectral response acceleration parameter, S_{DS}; less than 0.4g.

(5) A one-story light steel frame or wood construction with an area less than $280m^2$ (3,000 square feet).

Buildings meeting these structural evaluation exemption requirements must have at least a Tier 1 Screening for geologic site hazards and foundations, and if deemed applicable, a Tier 1 Screening of nonstructural elements.

c. Nonapplicability. Non-building structures and hazardous critical facilities (e.g., nuclear power plants, piers, wharves, dams, and liquefied gas facilities) are not within the scope of this document.

d. Design team. When rehabilitation in accordance with this document is required, the selected design team will include an engineer knowledgeable in seismic design. That engineer will be included in the rehabilitation design process from the beginning to provide guidance in the selection of the appropriate seismic resisting system. Early input and a special peer review team are required when seismic isolation or energy dissipation devices are a potential alternative.

e. Incremental rehabilitation. Incremental rehabilitation may be performed only if, because of a funding shortage, the work required for a complete rehabilitation meeting the criteria prescribed in this document has to be phased and performed in successive fiscal years. In that case, the work will be phased, and the most critical structural deficiencies are the first to be addressed. Partial rehabilitation or rehabilitation to criteria less than prescribed by this document is not permitted.

1-3. References

Appendix A contains a list of references pertaining to this document.

1-4. Basis for Evaluation and Rehabilitation

a. Seismic design criteria. In recent years, developments in earthquake engineering have resulted in substantial changes in seismic design criteria. In the 1960s, major changes began to occur in the seismic design codes. In 1966, the first edition of "Seismic Design for Buildings," also known as the Basic Design Manual (BDM), was introduced (TM 5-809-10/NAVDOCKS P-355/AFM 88-3, Chapter 13, March 1966). In 1973, a new revised and expanded edition of the manual was published (TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13, April, 1973) that included ductility provisions for moment-resisting space frames. In the February 1982 edition, substantial changes were made in force levels and seismic detailing requirements. Many of these changes were in response to experiences from the 1971 San Fernando, California earthquake. In the late 1970s, areas in the United States outside of California and the Pacific Coast area began to be aware of the need for earthquake-resistant design requirements for their facilities. In 1978, "Tentative Provisions for the Development of Seismic Regulations for Buildings" was published by the National Bureau of Standards (NBS SP-510; Applied Technological Council, ATC 3-06; and National Science Foundation, 78-8). These provisions were developed through a nationwide effort to improve seismic design and construction building practices, and are evaluated and updated every three years by a national committee, and approved by the Building Seismic Safety Council (BSSC), a non-profit organization sponsored by the National Institute of Standards and Technology (NIST). The 1997 edition of these provisions is designated as FEMA 302, and is the basis for the design and detailing provisions in this document for new structural components or systems. The 1988 edition of the Uniform Building Code (UBC) adopted many of the FEMA/BSSC provisions, including a response reduction factor, R_w,

but retained the allowable stress basis as opposed to the strength (i.e., yield stress) basis in the FEMA documents. The 1997 edition of the UBC adopts the R factor and strength design and generally mirrors FEMA 302. The 1992 edition of TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13, essentially reflected the 1988 UBC provisions. TI 809-04, which has superseded that document, adopts FEMA 302 provisions for standard occupancy buildings, and modifies FEMA 273 provisions for essential and hazardous occupancies.

b. Existing buildings. Major changes in structural criteria based upon building failures in past earthquakes naturally raise the question of the adequacy of existing buildings. A building designed and constructed prior to the recent changes in seismic design criteria, especially those in areas of high seismicity, will probably not conform to the requirements of today's criteria. In some cases, the general structural system does not conform, and there are some cases where the lateral force levels can be 3 or more times greater than forces used in the original design. This does not necessarily mean that all these buildings are unsafe, or will not be able to perform adequately when subjected to a major or moderate earthquake. Some of the older buildings may actually perform better than new ones that conform to the latest provisions. Many of the performance capabilities of buildings depend on configuration, details, and ability to act in a tough, ductile, energy-absorbing manner rather than on conformance to the minimum standards of the code provisions.

c. Evaluation and rehabilitation. Current codes are developed for new construction and are not necessarily applicable to existing buildings. New construction criteria can more easily be based on system performance parameters than can existing building evaluation criteria. The "R-value" assumptions used in new building designs establish "conforming system" responses by including detailing requirements in the design criteria to provide the level of post-yield ductility associated with each system type. For existing buildings with "nonconforming systems," the evaluation of post-yield seismic response requires assessment of the deformation capacity of individual components of the structural lateral-force-resisting system. This is termed "deformation-based assessment," and is the basis for the evaluations and rehabilitation designs in this document as depicted in Figure 1-1. An existing building should be evaluated on the basis of its actual performance characteristics, as best as they can be determined, when subjected to a realistic postulated earthquake. Modifications of existing buildings must take into account the performance characteristics of the existing materials interacting with the new material used to upgrade the structure. FEMA 178 provided a rapid evaluation technique using true/false responses to sets of statements intended to identify deficiencies in the seismic response of various structural systems. FEMA 310 is an update of FEMA 178, and has been expanded to include performance-based analyses and acceptance criteria adapted from FEMA 273. As indicated in paragraph 1-1b, this document will incorporate provisions from FEMA 310, 273, 302, and TI 809-04. Performance-based evaluation and rehabilitation techniques have been adopted for this document, which means the evaluation of structural adequacy is based on component-based rather than system-based behavior. Although the behavior of individual structural

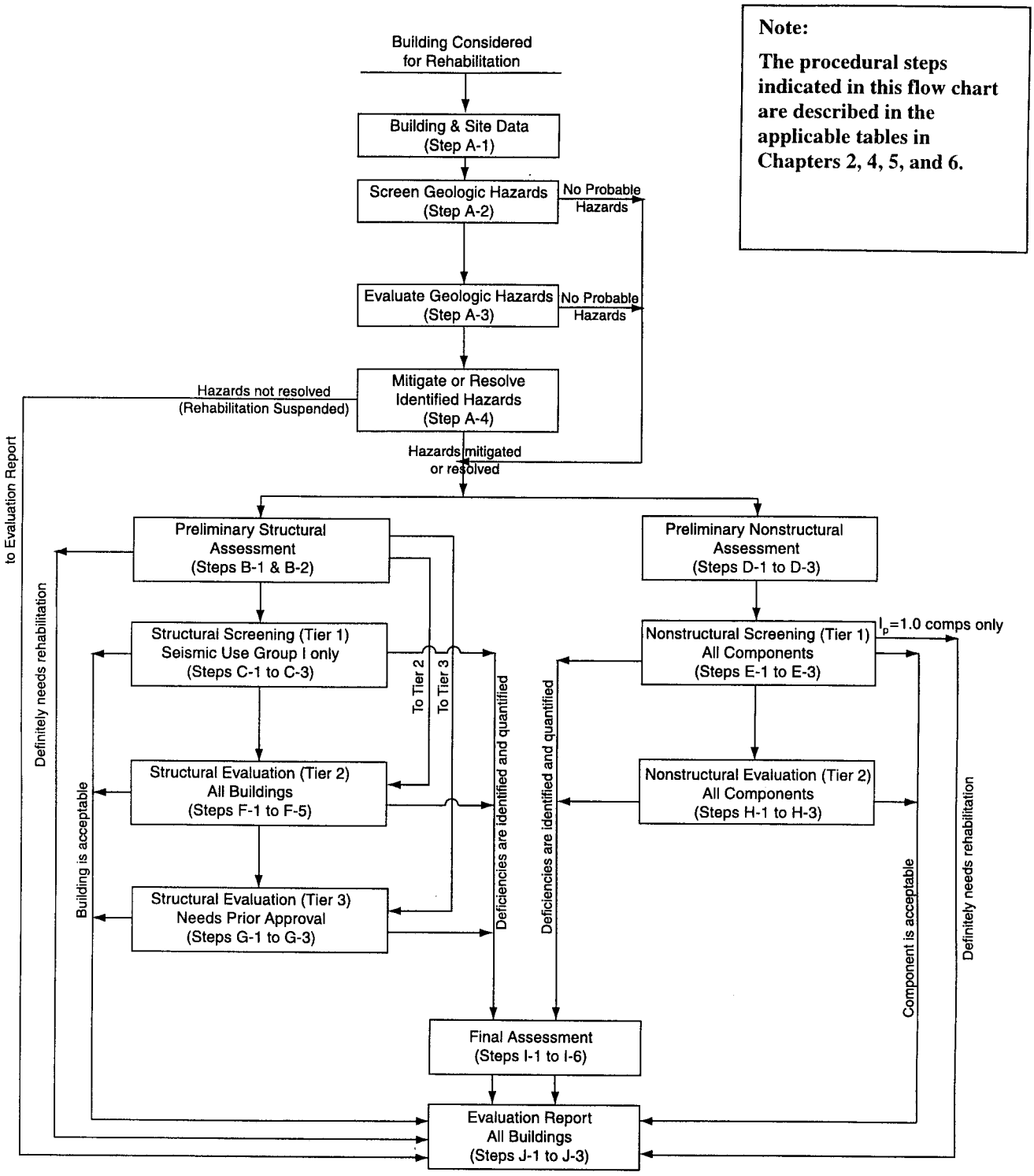


Figure 1-1. Flow Chart for Structural and Nonstructural Evaluation

elements and the damage they sustain during an earthquake are important, the failure of one or more isolated elements to meet specific acceptance criteria for a particular performance objective should not necessarily imply the overall building will not perform to the desired performance objective level. This fact indicates that the subjective qualitative judgment of the engineer is necessary to properly assess the overall performance of the building. Since engineering judgment is widely variant, it is quite possible that engineers can employ the same quantitative evaluation and design methodology, yet arrive at very different predictions about structural performance based on a particular evaluation or design. The combined quantitative/qualitative assessment of building performance involves a number of parameters with inherently associated uncertainties and variabilities. It is difficult to predict precisely the character of the ground motion a building will experience during an earthquake, the strength of existing materials, the quality of construction, the amount of force to individual building elements, the deformation individual building elements will tolerate, and the combined capacities of all elements reacting plastically in a building's total structural system. We must employ a methodology to characterize, in a routine manner, all of these uncertainties and variabilities in a way that can be consistently applied by designers and understood by owner/occupants of the building.

1-5. Background

a. National Earthquake Hazards Reduction Program (NEHRP)

(1) Basis of program. The National Earthquake Hazards Reduction Program (NEHRP) Act, Public Law 101-614, requires that the following be determined; (1) The number of buildings owned or leased [by each federal agency], (2) The seriousness of the seismic risk [to each building], and (3) The value of the buildings at risk. All of these public law requirements were addressed in a general way in the GAO/GGD-92-62 report to Congress. Specific guidance to implement the NEHRP public law concerning seismic safety standards for existing federally owned or leased buildings is given in the federal interagency report, ICSSC RP4, which is adopted for use within the federal government by Executive Order No. 12941.

(2) Historic military buildings are buildings that are listed in a national or state register of historic places or have been designated by the installation commander for historic listing. In general, the buildings are required to meet the same minimum life-safety objectives as all other buildings in the federal inventory, and as such, are not exempted from the hazard reduction program. When dealing with historic structures, however, special considerations must be made that significantly affect costs and methods for mitigating seismic hazards. Section 106 of the National Historic Preservation Act of 1966, as amended, requires a Federal agency head with jurisdiction over a Federal undertaking to take into account the effects of the agency's undertakings on properties included or eligible for National Register of Historic Places, and prior to approval of an undertaking, to afford the Advisory Council on Historic Preservation a reasonable opportunity to comment on the undertaking. Section 110(f) of the Act requires that Federal agency heads, to the

maximum extent possible, undertake such planning and actions as may be necessary to minimize harm to any National Historic Landmark that may be directly and adversely affected by an undertaking, and prior to approval of such undertaking, afford the Council a reasonable opportunity to comment. The 106 process, as it is known, and its implications on the military seismic hazard mitigation program, are beyond the scope of this document. Regulations for compliance with the 106 process are found in "36 CFR Part 800: Protection of Historic Properties, Regulations of the Advisory Council on Historic Preservation Governing the Section 106 Review Process," by the Advisory Council on Historic Preservation, effective October 1, 1986.

b. The Military Risk Reduction Program

In response to Executive Order No. 12941, screening and evaluation of representative buildings at selected military installations was performed in accordance with guidelines prescribed by ICSSC RP4. Documentation of the data pertaining to the screening and evaluation of buildings, and in a few cases, including screening and evaluation of geological hazards and nonstructural components, is available at the installation or division or district offices of the proponent agency. This information, pertaining to specific buildings designated for rehabilitation, shall be used to complement or supplement the screening and evaluation procedures prescribed in Chapters 4 and 5.

CHAPTER 2
BUILDING DATA ACQUISITION AND CLASSIFICATION

2-1. General

This chapter provides guidance for the acquisition of the site and building data required for seismic evaluation and rehabilitation of buildings. It is recognized that some of these data may not be complete or available. It is strongly recommended, however, that a concerted effort be made to acquire all that is available from the various potential sources in order to minimize the on-site physical measurements and documentation of the building attributes that will be necessary for the seismic evaluation and rehabilitation.

2-2. Data Acquisition

Acquisition of available data pertaining to the building, site seismicity, and soil characteristics is designated as Step 1 in the preliminary determination outlined in Table 2-1. The data shall be obtained, preferably prior to the initial site visit, and shall be confirmed during the site visit. The data shall include:

a. Exemptions criteria. The exemption criteria in paragraph 1-2b shall be reviewed for applicability. If any of the criteria apply, the building will be exempt from the provisions of this document.

b. Prior evaluation. The evaluator shall obtain and review copies of all prior evaluations. This is particularly relevant for military buildings that may have been previously screened or evaluated in compliance with Executive Order No. 12491 [paragraph 1-5a(1)].

c. Construction documents. As-built drawings and specifications. Structural shop drawings may also provide useful information.

d. Seismicity. Determine S_S and S_1 from MCE maps (Chapter 3 in TI 809-04).

e. Soil data. Obtain soil capacities from drawings or soil reports for building or from data for adjacent buildings. Determine F_a and F_v.

f. Historical significance. Determine if any of the building features have been classified as being of historical significance [paragraph 1-5a(2)].

g. Building description. When drawings are incomplete or unavailable, a general description of the building, to be developed at the site, shall include:

(1) Building name and identification number

(2) Building dimensions

(3) Photographs of building exterior

(4) Number of stories and story heights

(5) Date constructed

(6) Structural systems description (framing, lateral-load-resisting system, gravity-load-framing system, floor and roof diaphragm construction, basement and foundation systems)

(7) Visual assessment of structural condition

(8) Nonstructural element descriptions (nonstructural elements that interface with the seismic performance of the structure)

Step	Procedure A. Preliminary Determinations (All buildings)	References		
		This Document	FEMA 310	TI 809-04
1.	Obtain building and site data Determine: a. Seismic Use Group b. Structural Performance Levels c. Applicable Ground Motions d. Seismic Design Category	para. 2-2 Table 2-2 Table 2-3 Table 2-4 Tables 2-5a & 2-5b		
2.	Screen for geologic hazards and foundations	para. 3-2	Sec. 3.8	para. F-3
3.	Evaluate geologic hazards (if necessary)	para. 3-3	Sec. 4.7	para. F-4
4.	Mitigate or resolve geologic hazards (if necessary)	para. 3-4		para. F-5

Table 2-1. Preliminary Determinations for Structural and Nonstructural Evaluations

(9) NEHRP building type (Table 2-2 in FEMA 310).

2-3. Performance Classifications

a. General. Seismic performance objectives for a building are defined by a desired performance level for the building (e.g., damage state or ability to perform an essential function) when subjected to a specified seismic hazard (i.e., deterministic or probabilistic ground motion). A performance objective for each of the four Seismic Use Groups (Table 2-2) is prescribed in the following paragraphs. The performance objectives (Table 2-4) are derived from appropriate combinations of three performance levels (Table 2-3) and the design ground motion.

b. Seismic use groups. The following Seismic Use Groups are established based on the occupancy or function of a building.

(1) Group IIIE. Seismic Use Group IIIE buildings are those containing essential facilities that are required for post-earthquake recovery and/or those structures housing mission-essential functions. Mission-essential functions are those absolutely critical to mission continuation of the activity (there is no redundant back-up facility on- or off-site) as determined by the Commanding Officer at the activity and/or the Major Claimant.

(2) Group IIIH. Seismic Use Group IIIH buildings are those containing substantial quantities

Seismic Use Group	Occupancy or Function of Structure
I. Standard Occupancy Structures	All structures having occupancies or functions not listed below.
II. Special Occupancy Structures	Covered structures whose primary occupancy is public assembly with a capacity greater than 300 persons.
	Day care centers with a capacity greater than 150 persons.
	Educational buildings through the 12th grade with a capacity greater than 250 persons.
	Buildings for colleges or adult education schools with a capacity greater than 500 students.
	Medical facilities with 50 or more resident incapacitated patients, but not otherwise designated as Seismic Use Group IIIE facility.
	Jails and detention facilities.
	All structures with occupancy capacity greater than 5,000 persons.
	Structures and equipment in power-generating stations and other public utility facilities not included in Seismic Use Group IIIE, and are required for continued operation.
	Water treatment facilities required for primary treatment and disinfecting of potable water.
	Wastewater treatment facilities required for primary treatment.
	Facilities having high-value equipment, when justification is provided by the using agency.

Table 2-2. Seismic Use Groups

III H. Hazardous Facilities	Structures housing, supporting, or containing sufficient quantities of toxic or explosive substances to be dangerous to the safety of the general public if released.
III E. Essential Facilities	Facilities involved in handling or processing sensitive munitions, nuclear weaponry or materials, gas and petroleum fuels, and chemical or biological contaminants.
	Facilities involved in operational missile control, launch, tracking, or other critical defense capabilities.
	Mission-essential and primary communication or data handling facilities.
	Hospitals and other medical facilities having surgery and emergency treatment areas.
	Fire, rescue, and police stations.
	Designated emergency prepared centers.
	Designated emergency operations centers.
	Designated emergency shelters.
	Power-generating stations or other utilities required as emergency back-up facilities for Seismic Use Group IIIE facilities.
	Emergency vehicle garages and emergency aircraft hangars.
	Designated communications centers.
	Aviation control towers and air traffic control towers.
	Water treatment facilities required to maintain water pressure for fire suppression.

Table 2-2. Seismic Use Groups - Continued

Performance Level	Building Response
CP	Collapse Prevention – The building barely remains standing, with significant structural and nonstructural damage. This level of performance, where collapse is imminent, is an unacceptable performance level for all military buildings.
LS	Life Safety – The building remains stable with significant reserve capacity. Structural damage is moderate, requiring significant post-earthquake repairs; however, collapse is precluded. This is the basic level of performance for all military buildings, except as defined below.
SE	Safe Egress – The building structural system remains fully safe for occupancy following the earthquake. Essential functions are sufficiently disrupted to prevent immediate post-earthquake occupancy of the building. Structural damage is light, allowing fairly rapid post-earthquake repairs.
IO	Immediate Occupancy – The building structure remains safe to occupy and all essential functions remain operational. It may be used for post-earthquake recovery and to perform essential operational military missions within a few hours following an earthquake. The building has limited structural damage, which may be repairable while occupied.

Table 2-3. Structural Performance Levels

Seismic Use Group	Performance Level	Ground Motion
I	Life Safety	2/3 MCE
II	Safe Egress	2/3 MCE
IIIH	Safe Egress	2/3 MCE
IIIE	Immediate Occupancy	2/3 MCE

Table 2-4. Performance Objectives

of hazardous substances that could be dangerous to the safety of the public, if released.

(3) Group II. Seismic Use Group II buildings are those that constitute a substantial public hazard because of the occupancy or use of the building.

(4) Group I. Seismic Use Group I buildings are those that are not assigned to Seismic Use Groups II or III.

(5) Hazardous Critical Facilities. These facilities (e.g., nuclear power plants, dams and LNG facilities are not included within the scope of this document, but are covered by other publications or regulatory agencies. For any facilities housing hazardous items not covered by criteria in this document, guidance should be requested from DAEN-ECE-D (Army); NAVFAC Code 04BA (Navy); or HQ AFCESA/LES (Air Force).

Examples of buildings or structures in each of the above groups are provided in Table 2-2. Buildings with multiple occupancies will be categorized according to the most important occupancy unless the portion of the building that houses the most important occupancy can be shown to satisfy all of the requirements for that occupancy.

c. Performance levels. Three structural performance levels, as described in Table 2-3, are considered by this document. Life Safety is the minimum performance level prescribed for buildings in Seismic Use Group I. Safe Egress is the enhanced performance level prescribed for buildings in Seismic Use Groups II and III H. Immediate Occupancy is the enhanced performance level prescribed for buildings in Seismic Use Group IIIE. The physical significance of these performance levels is indicated in Figures 2-1 and 2-2.

d. Design ground motion. The ground motion derived from 2/3 MCE is the basic ground motion for the FEMA 302 provisions, and is the design ground motion prescribed by this document for the performance levels prescribed for the various seismic use groups in Table 2-2. The derivation of design ground motion is discussed in Chapter 3 of T1 009-04.

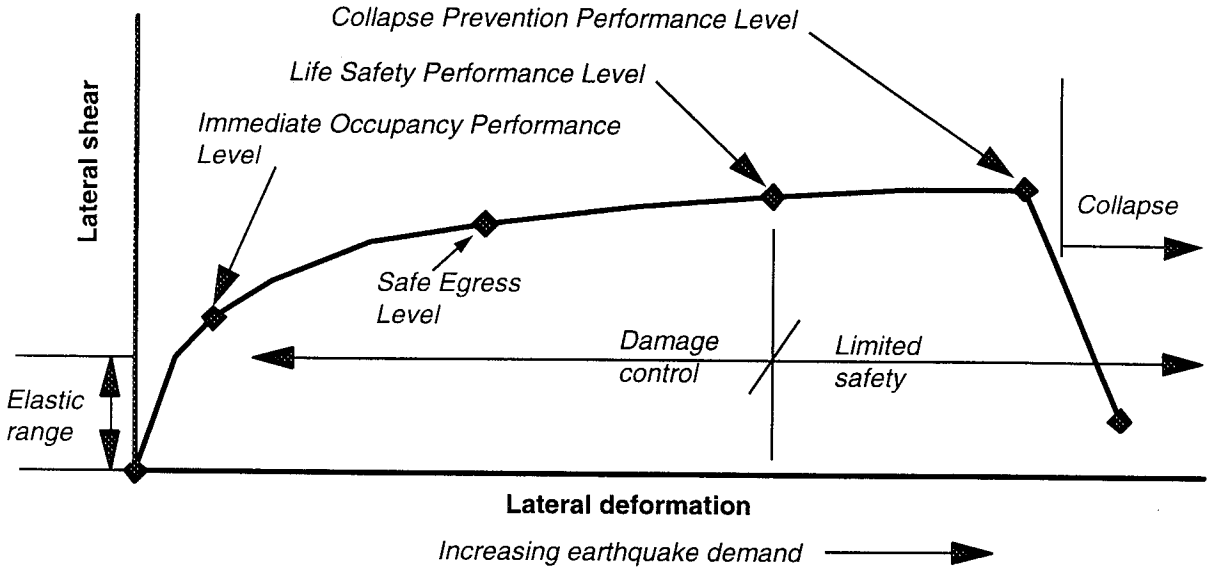


Figure 2-1. Performance and Structural Deformation Demand for Ductile Structures

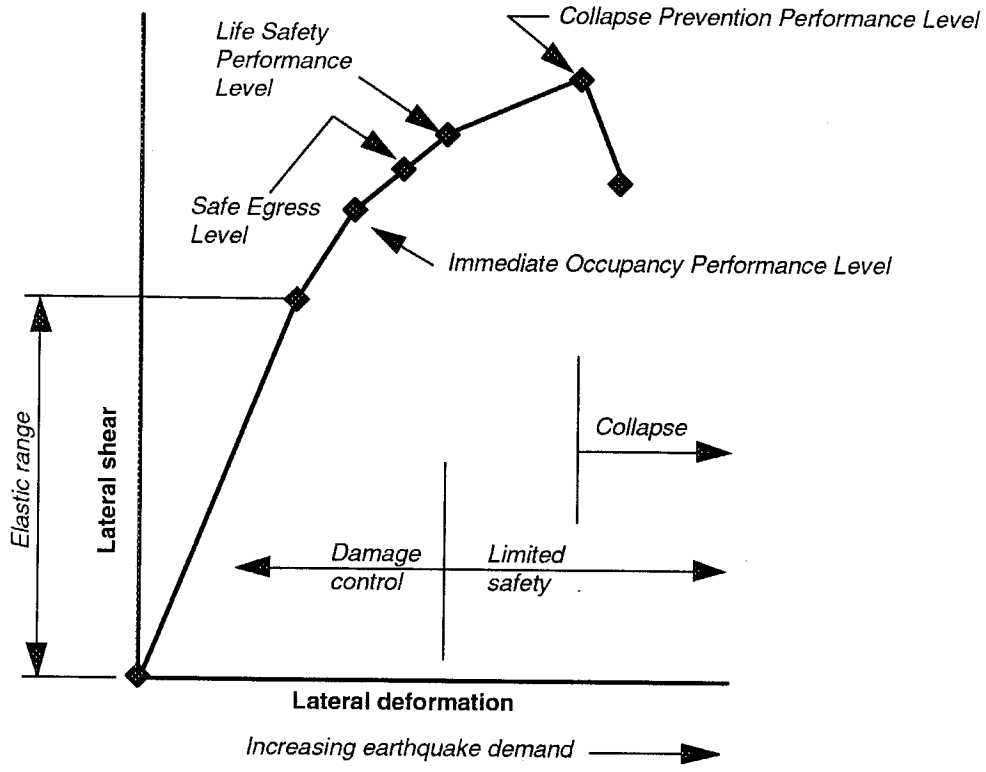


Figure 2-2. Performance and Structural Deformation Demand for Nonductile Structures

e. Performance objectives. The seismic performance objectives for the various seismic use groups in Table 2-2 are indicated in Table 2-4. These performance objectives consist of the combination of the performance levels in Table 2-3 with ground motion derived from 2/3 MCE as described in Chapter 3 of TI 809-04.

f. Seismic design categories. All buildings shall be assigned a Seismic Design Category based on their assigned Seismic Use Group, and their applicable spectral acceleration coefficients S_{DS} and S_{DI} for the ground motion based on 2/3 MCE. Each building or structure shall be assigned to the more severe Seismic Design Category in accordance with Table 2-5a or 2-5b. The category designations are used to define prescriptive reduction in the evaluation and rehabilitation procedures for certain buildings in lower seismic areas.

Value of S_{DS}	**Seismic Use Group**		
	I	II	III
$S_{DS} < 0.167g$	A	A	A
$0.167g \leq S_{DS} < 0.33g$	B	B	C
$0.33g \leq S_{DS} < 0.50g$	C	C	D
$0.50g \leq S_{DS}$	D[a]	D[a]	D[a]

[a]See footnote on Table 2-5b.

Table 2-5a. Seismic Design Category Based on Short-Period Response Accelerations

Value of S_{DI}	**Seismic Use Group**		
	I	II	III
$S_{DI} < 0.067g$	A	A	A
$0.067g \leq S_{DI} < 0.133g$	B	B	C
$0.133g \leq S_{DI} < 0.20g$	C	C	D
$0.20g \leq S_{DI}$	D[a]	D[a]	D[a]

[a] Seismic Use Group I and II structures located on sites with mapped maximum considered earthquake spectral response acceleration at 1-second period, S_1, equal to or greater than 0.75g, shall be assigned to Seismic Design Category E; Seismic Use Group III structures located on such sites shall be assigned to Seismic Design Category F.

Table 2-5b. Seismic Design Category Based on 1-Second Period Response Accelerations

CHAPTER 3
GEOLOGIC HAZARDS EVALUATION

3-1. General

This chapter prescribes screening and evaluation procedures for geologic site hazards. Evaluation of geologic hazards is required for all buildings designated for seismic evaluations, except that buildings in Seismic Design Category A are exempt from the procedures. All identified geologic hazards must be mitigated or otherwise resolved (e.g., the risk associated with the identified geological hazard is considered to be acceptable) by the agency headquarters proponent prior to proceeding with the structural evaluation of the building or the nonstructural components. Screening, evaluation, and mitigation of geologic hazards are indicated as Steps 2, 3, and 4 of the preliminary determinations outlined in Table 2-1.

3-2. Screening for Geologic Hazards

Screening for geologic hazards shall be performed in accordance with paragraph F-3 of Appendix F in TI 809-04, and by completion of the Tier 1 Geologic Site Hazards and Foundations Checklist in FEMA 310, when required by Table 4-3.

3-3. Evaluation of Geologic Hazards

Geologic hazards that cannot be eliminated by the screening procedures prescribed above shall be evaluated by a geotechnical engineer in accordance with paragraph F-4 of Appendix F in TI 809-04.

3-4. Mitigation of Geologic Hazards

Mitigation procedures for geologic hazards shall be in accordance with paragraph F-5 of Appendix F in T1 809-04.

CHAPTER 4
TIER 1 EVALUATION (SCREENING)

4-1. Preliminary Assessment for Structural Evaluations

At this point, the evaluator has reviewed the available drawings, test reports, and other documents pertaining to the design and construction of the building. The evaluator has also visited the site and conducted a visual inspection of the building and has determined that the building does not comply with any of the exemption criteria in paragraph 1-2b. For buildings required by Table 4-3 to be evaluated by the "Geologic Site Hazards and Foundation Checklist" (Section 3.8 of FEMA 310), the evaluator shall confirm that all identified hazards have been mitigated or otherwise resolved before initiating any structural or nonstructural evaluations. Based on these preliminary observations, the evaluator shall make a judgmental decision as to whether the building definitely requires rehabilitation without further evaluation, or whether further evaluation might indicate that the building can be considered acceptable without rehabilitation. These decisions are indicated as steps B1 or B2 in Table 4-1.

a. Definitely requires rehabilitation. Examples that could facilitate this decision include:

(1) Lack of a continuous load path for seismic forces. A common deficiency is the lack of adequate connection between the floor and roof diaphragms and the vertical-resisting elements for in-plane or out-of-plane seismic forces.

(2) Obvious signs of structural distress: excessive cracking of concrete walls or framing members; checking and splitting of timber structural members; or other significant deterioration of the building.

The above are examples of deficiencies that definitely require rehabilitation. Obviously, further evaluation will be required to determine the nature and extent of the required rehabilitation, but such evaluation would not be performed unless structural rehabilitation is the selected option for mitigation of the seismic hazard.

b. Evaluation is required. If it can be reasonably determined that continuous load paths exist to resist lateral forces, and no significant structural distress is observed, evaluation is required to determine whether the building meets the minimum acceptance criteria to mitigate the seismic hazard. FEMA 310 provides three tiers of evaluation that are described in paragraph 4-2. The evaluator needs to understand the advantages and the limitations of each tier so that a selection can be made as to the most effective level of evaluation that will provide conclusive results regarding the seismic adequacy of the building.

c. Quality control/quality assurance. The quality control/quality assurance procedures outlined in Chapter 10 will apply to all evaluation and rehabilitation performed in accordance with this document.

Step	Procedure	References		
		This Document	FEMA 310	TI 809-04
	B. Preliminary Structural Assessment (All buildings)			
1.	Definitely needs rehabilitation without further evaluation	para. 4-1a		
2.	Requires evaluation a. Screening (Tier 1 evaluation for Seismic Use Group I buildings only) b. Tier 2 evaluation c. Tier 3 evaluation	paras. 4-1b and 4-2		

Table 4-1. Preliminary Assessment for Structural Evaluations

4-2. Selection of Structural Evaluation Levels

a. General. Table 3-3 in FEMA 310 indicates the limitations of a Tier 1 evaluation for the various FEMA model building types in regions of low,moderate, and high seismicity. Table 2-1 in FEMA 310 defines these regions of seismicity in terms of S_{DS} and S_{D1}. For evaluations performed in accordance with this document, a Tier 2 or Tier 3 evaluation may be performed in lieu of the Tier 1 evaluation, when it is considered that the lower-tier evaluation would not produce conclusive results. Seismic Use Group IIIE buildings will be evaluated only by Tier 2 or Tier 3 evaluations, and the I0 performance level in Table 3-3 and in the Tier 1 evaluations of FEMA 310 will be interpreted as representing the Safe Egress performance level for Seismic Use Groups II and IIIH. Tier 2 evaluations will be adequate for most buildings that bypass, or cannot be accepted by, the Tier 1 evaluation. The m factors for Tier 2 evaluation of Seismic Use Group II and III H buildings with a Safe Egress (SE) performance objective shall be assumed to be midway between the values for the IO and LS performance levels tabulated in Chapters 3 and 4 of FEMA 310. Highly irregular or unusual buildings may require a Tier 3 evaluation using nonlinear analytical procedures, and may be designated to bypass both the Tier 1 and Tier 2 evaluations with the prior approval.

b. Tier I structural screening. This evaluation, as outlined in Table 4-2, requires compliance with selected checklist statements in Chapter 3 of FEMA 310, as indicated in Table 4-3. For unreinforced masonry (URM) bearing-wall buildings to be evaluated in accordance with this document, Table 3-3 of FEMA 310 shall be modified to permit Tier 1 structural screening for such Seismic Use Group I buildings with flexible diaphragms in all regions of seismicity, and for all such buildings with rigid diaphragms in a low region of seismicity.

Step	Procedure C. Structural Screening (Tier 1)	References This Document	FEMA 310	TI 809-04
1.	Determine applicable checklist	para. 4-3a Table 4-3		
2.	Complete applicable checklist	para. 4-3a	Sec. 3.6, 3.7 or 3.7S	
3.	Evaluate screening results a. Building is acceptable b. Deficiencies have been identified and need to be assessed for rehabilitation c. Needs further evaluation	para. 4-3b		

Table 4-2. Structural Screening (Tier 1)

Seismic Design Category	(2) Required Checklist					
	(1) Region of Low Seismicity (Sec. 3.6)	(1) Basic Structural (Sec. 3.7)	(1) Supplemental Structural (Sec. 3.7S)	Geologic Site Hazard & Foundation (Sec. 3.8)	(3) Basic Nonstructural (Sec. 3.9.1)	(3) Supplemental Nonstructural (Sec. 3.9.1S)
A	✓					
B & C		✓		✓	✓	
D, E & F		✓	✓	✓	✓	✓

(1) Limited to Seismic Use Group I only.
(2) Section numbers indicated refer to FEMA 310.
(3) See paragraph 4-4-b(1) for exemption of nonstructural components.

Table 4-3. Checklist Required for a Tier 1 Evaluation

Seismic Use Group I URM bearing-wall buildings with rigid diaphragms in other regions of seismicity may be evaluated by Tier 1 structural screening, provided they do not exceed 6 stories in height in moderate regions of seismicity, or 3 stories in regions of high seismicity. Basic and supplemental structural checklists for URM bearing-wall buildings are provided in Appendix H.

c. Tier 2 structural evaluation. Buildings selected to bypass the Tier 1 screening phase, or that have seismic deficiencies identified by the screening phase and designated for evaluation, shall be evaluated in accordance with the procedures prescribed in Chapter 4 of FEMA 310, as modified by Chapter 5 of this document. The evaluation may be "deficiencies only" or "full building," based on the nature and extent of the deficiencies and the judgment of the evaluator. All buildings in Seismic Use Group IIIE shall be subjected to a "full building" evaluation.

d. Tier 3 structural evaluation. This evaluation consists of performing either a nonlinear static procedure (NSP), or a nonlinear dynamic procedure (NDP), in accordance with Sections 3.3.3 and 3.3.4, respectively, of FEMA 273. The NDP is not recommended for buildings governed by this document, and the NSP will require prior authorization.

4-3. Tier 1 Structural Checklists

a. General. When a Tier 1 evaluation has been selected in accordance with paragraph 4-2, the evaluation of structural systems will consist of completing the Region of Low Seismicity (Section 3.6), Basic Structural (Section 3.7), and Supplemental Structural (Section 3.75) Checklists in FEMA 310 as required by Table 4-3. These checklist statements shall be marked as being compliant (C), non-compliant (NC), or not applicable (NA). Quick checks that are required to complete a checklist statement shall be performed in accordance with Section 3.5 of FEMA 310.

b. Tier 1 structural screening results. The results of a Tier 1 evaluation will be:

(1) The building is acceptable (Seismic Use Group I buildings only).

(2) Identified deficiencies require assessment for rehabilitation.

(3) The Tier 1 evaluation is inconclusive, and further evaluation may indicate that the building meets the acceptance criteria. The evaluator should determine whether a Tier 2 evaluation will be conclusive, or whether a Tier 3 evaluation is required.

4-4. Tier 1 Nonstructural Evaluation (Screening)

The seismic evaluation procedures for nonstructural systems and components described in this chapter are adapted from the provisions of FEMA 310, and are intended to be performed by the engineer responsible for the evaluation of the building, and to be accomplished concurrently with the structural evaluation.

a. Scope. Nonstructural features to be included are permanent nonstructural components, the attachments for them, and the attachments for equipment supported by a structure, the failure of which poses a threat to human life. Nonstructural elements, hereinafter referred to as items, include architectural features, fire protection systems, mechanical and electrical equipment, utilities, storage racks, communication systems, exterior cladding, and tanks. The scope of the vulnerability assessments described in this chapter includes the adequacy of the supports, anchorage, or bracing of the nonstructural systems or components in a building with respect to

protection of the life-safety of the occupants, or precluding the interruption of an essential function in the building. The survivability of function of the internal components of adequately anchored and supported essential equipment is beyond the scope of this document. If assurance of survivability is necessary, it must be obtained by appropriate testing performed by the equipment manufacturer.

b. Preliminary assessment. The evaluator shall perform a preliminary assessment of the nonstructural components at the building site, based upon available drawings and visual inspection of the accessible components. The assessment procedures are outlined in Table 4-4, and described in the following paragraphs. Most nonstructural components in military buildings are either visible, or representative installation is accessible in unfinished spaces (e.g., janitor's closets and storerooms). For inaccessible components, the removal and repair of finishes and the disruption of the personnel in the building may not be warranted. The evaluator may be able to extrapolate adequate information from similar accessible components in the same or similar buildings.

(1) Classification of components. All non-structural components not exempted by the provisions of paragraph 4-4b(1) above shall be assigned an importance factor, I_p, as indicated below. The architectural, mechanical, and electrical components and systems of an historic building may be very significant, especially if they are original to the building, very old, or innovative. An assessment of their importance by the installation commander may be necessary, in addition to the evaluation procedure prescribed in this document.

$I_p = 1.5$ Life-safety component is required to provide safe egress.

$I_p = 1.5$ Component contains hazardous contents.

$I_p = 1.5$ Storage racks in occupancies open to the general public (e.g., warehouse retail stores).

$I_p = 1.0$ All other components.

In addition, for structures in Seismic Use Group IIIE:

$I_p = 1.5$ All components needed for continued operation of the facility or whose failure could impair the continued operation of the facility.

(2) Exempt components. The following components are exempt from the requirements of this chapter.

(a) All components in Seismic Design Category A;

(b) Architectural components in Seismic Design Category B other than parapets supported by bearing walls or shear walls when the importance factor (I_p) is equal to 1.00;

(c) Mechanical and electrical components in Seismic Design Category B;

(d) Mechanical and electrical components in Seismic Design Category C when the importance factor (I_p) is equal to 1.00;

(e) Mechanical and electrical components in Seismic Design Categories D, E, and F that are mounted at 4 ft (1.22 m) or less above a floor level and weigh 400 lb. (1780 N) or less, and are not critical to the continued operation of the structure; or

Step	Procedure	References		
		This Document	FEMA 310	TI 809-04
	D. Preliminary Nonstructural Assessment (All buildings)			
1.	Determine component classification	para. 4-4b(1)		
2.	Determine exemption status	para. 4-4b(2)		
3.	Determine component disposition a. I_p = 1.0 components Tier 1 screening b. I_p = 1.5 components Tier 1 screening Tier 2 evaluation	para. 4-4b(3)		

Table 4-4. Preliminary Nonstructural Assessment

(f) Mechanical and electrical components in Seismic Design Categories C, D, E, and F that weigh 20 lb. (95 N) or less, or for distribution systems, weigh 5 lb./ft (73 N/m) or less.

Note that most components in Seismic Use Group I buildings will have an I_p of 1.0, but may also have components required for safe egress with an I_p of 1.5. Similarly, components in Seismic Use Group IIIE buildings may have components identified for normal service (I_p = 1.0) and for safe egress (I_p = 1.5), as well as continued operation (I_p = 1.5).

(3) Disposition. All nonstructural components, except those exempted by the criteria in paragraph 4-4b(2), shall be screened by the Tier 1 evaluation of FEMA 310.

c. Nonstructural screening (Tier 1).

(1) General. Screening of all nonstructural components shall be performed by completion of the Basic Nonstructural Component Checklist (Section 3.9.1) and the Supplemental Nonstructural Component Checklist (Section 3.9.15), as required by Table 4-3, and as outlined in Table 4-5.

(2) Results of the screening. The results of the Tier 1 evaluation shall be:

(a) All nonstructural components are compliant. No further evaluation or rehabilitation is required (I_p = 1.0 components only).

Step	Procedure	References		
		This Document	FEMA 310	TI 809-04
	E. Nonstructural Screening (Tier 1) (All components)			
1.	Determine applicable checklist	para. 4-4c Table 4-3		
2.	Complete applicable checklist	para. 4-4c(1)	Sec. 3.9.1 and 3.9.1S	
3.	Evaluate screening results a. Component is acceptable b. Needs further evaluation c. Definitely needs rehabilitation	para. 4-4c(2)		

Table 4-5. Nonstructural Screening (Tier 1)

(b) All nonstructural components are compliant, but the building contains some I_p = 1.5 components that require a Tier 2 evaluation.

c) Some noncompliant components have been identified in the Tier 1 evaluations that may be found to be acceptable by a Tier 2 evaluation.

(d) Some noncompliant components definitely need rehabilitation without further evaluation (e.g., complete omission of required bracing or anchorage).

4-5. Assessment of Tier 1 Screening Results

a. Structural. The results of the Tier 1 structural screening that are categorized by paragraph 4-3b(3) need to be assessed as to the appropriate analytical procedure for the detailed evaluation. A Tier 2 evaluation will generally be appropriate for most military buildings, but a Tier 3 evaluation may be required for highly irregular or unusual buildings. Guidance as to when a Tier 3 nonlinear evaluation is required is provided in paragraph 5-4b of T1 809-04.

b. Nonstructural. The results of the Tier 1 nonstructural screening that are categorized by paragraph 4-4c(2)(c) need to be assessed as to whether the noncompliant components can be shown to be acceptable by the Tier 2 evaluation, or whether the deficient components should be designated for the final assessment procedure described in paragraph 6-2.

CHAPTER 5
TIER 2 AND TIER 3 EVALUATIONS

5-1. General

Tier 2 and Tier 3 evaluations shall be performed in accordance with the provisions of Chapters 4 and 5 in FEMA 310. Paragraph 4-2a of this document provides guidance for the selection of the appropriate Tier for structural evaluation. Evaluation of nonstructural deficiencies identified by Tier 1 screening is performed only with a Tier 2 evaluation.

a. Ground motion. The ground motion for all Tier 2 and Tier 3 evaluations shall be derived from 2/3 MCE as defined in Section 3.5.2.3.1 of FEMA 310.

b. Tier 2 evaluation shall be performed in accordance with the provisions of Chapter 4 of FEMA 310.

(1) Structural evaluations.

(a) Buildings designated for Tier 2 evaluation based on results of Tier 1 screening may be evaluated by a "deficiencies only" evaluation or a "full-building" evaluation.

(b) Buildings that were designated to bypass the Tier 1 evaluation shall be evaluated by a Tier 2 "full building" evaluation.

(c) Unreinforced masonry (URM) bearing wall buildings with flexible diaphragms shall be evaluated by the Tier 2 Special Procedure.

(2) Nonstructural evaluations shall be performed in accordance with the provisions of Section 4.8 of FEMA 310.

c. Tier 3 structural evaluation. This static nonlinear procedure may be appropriate for some highly irregular or unusual buildings. Guidance as to when nonlinear procedures are required is provided in paragraph 5-4 of T1 809-04. Implementation of this procedure requires prior approval.

d. Directional effects. The lateral-load-resisting system shall be demonstrated to be capable of responding to lateral forces in any horizontal direction. For buildings with orthogonal primary axes, structural response in each orthogonal direction may be considered independently. In addition, the combined effect of simultaneous response in both directions shall be considered when prescribed by Section 4.2.3.5 of FEMA 310.

e. P-Δ effects. The building shall be investigated to ensure that lateral drifts induced by earthquake response do not result in a condition of global instability under gravity loads. Potential instability shall be investigated in each direction of seismic loading in accordance with Section 2.11.2 of FEMA 273.

f. Torsion. Buildings with stiff or rigid diaphragms, as defined in paragraph 7-7b of T1 809-04, shall be investigated for real and accidental torsion, as prescribed in Section 4.2.3.2 of FEMA 310.

5-2. Structural System Evaluations

The primary purpose of the structural evaluations is to determine whether an existing building is acceptable for its designated performance objective, or if it has deficiencies that could be mitigated by rehabilitation. If the identified deficiencies are obvious, no further structural evaluation should be performed, if the additional expenditure of available funds would be better employed in assessing the adequacy of the structural retrofit in the rehabilitation phases, rather than further quantifying the degree of deficiency of the structural members in the evaluation phase. It should be noted that prior FEMA evaluation documents (e.g., FEMA 178) prescribed seismic evaluations with linear analyses using R factors, nominal strength, and reduced seismic demands (i.e., reduced C_S factors for base shear). FEMA 273 prescribes unreduced probabilistic seismic demands (10 percent probability of exceedance in 50 years) with linear analyses using expected strength values, Q_{CE}, modified by m factors for deformation-controlled components and lower-bound strength values, Q_{CL}, for force-controlled components. FEMA 310 also uses unreduced seismic demands (2/3 MCE) amplified by a modification factor, C, with linear analyses that increase the capacity of structural components, as compared to FEMA 273, by modifying the m factors for deformation-controlled components, and by the use of expected strength, Q_{CE}, rather than the lower-bound strength, Q_{CL}, for force-controlled components. Tier 2 and Tier 3 evaluations performed in accordance with this document are generally in accordance with the provisions of FEMA 310, except as noted in the following paragraphs.

a. Tier 2 procedures.

(1) Scope.

(a) "Deficiencies-only" evaluation consists of a limited structural analysis in accordance with the referenced Chapter 4 sections of FEMA 310 for each noncompliant statement in the applicable Tier 1 checklist.

(b) "Full-building" evaluation consists of a detailed structural analysis as outlined in Table 5-1, and prescribed in Chapter 4 of FEMA 310.

(2) Analytical procedures. The analysis may be performed by either the Linear Static Procedure (LSP), or the Linear Dynamic Procedure (LDP), as described in Sections 4.2.2 and 4.2.3, respectively, of FEMA 310. Guidance for the selection of the LSP or the LDP is provided in paragraphs 5-2 and 5-3 of TI 809-04. The ground motions to be used in the analysis shall be as indicated in Table 2-4. Seismic shear forces shall be calculated in accordance with Section 3.5.2 of FEMA 310. The Special Procedure, as prescribed in Section 4.2.6 of FEMA 310, shall be used for URM bearing wall buildings.

(3) Nominal strength values for structural materials based on the available drawings and/or test reports can be used as a basis for evaluation, provided the values are reasonably consistent with the observed structural condition. In the absence of available material strength data, default values provided in the various material chapters of FEMA 273 shall be used, again subject to reasonable correlation with visual observation during the site visit. Should the

Step	Procedure	References		
		This Document	FEMA 310	TI 809-04
	F. Structural Evaluation (Tier 2)			
1.	(All Seismic Use Group II and III buildings Designated Seismic Use Group I buildings) Select appropriate analytical procedure a. Linear static procedure (LSP) b. Linear dynamic procedure (LDP) c. Special procedure (URM bearing wall buildings only)	para. 5-2a(2)	Sec. 4.2.2 Sec. 4.2.3 Sec. 4.2.6	
2.	Determine applicable ground motion	Table 2-4		
3.	Perform structural analysis a. LSP and LDP b. Special Procedure	para. 5-2a(1)	Sec. 4.2.2 and 4.2.3 Sec. 4.2.6	
4.	Acceptance criteria a. LSP and LDP (1) Deformation-controlled actions (2) Force-controlled actions b. Special procedure	para. 5-2a(4)(a) para. 5-2a(4)(b) para. 5-2a(4)(c)	Sec. 4.2.4 and 4.2.5 Sec. 4.2.5 and 4.2.6	
5.	Evaluation results a. Building is acceptable b. Structural deficiencies have been identified and quantified c. Evaluation is inconclusive, needs Tier 3 evaluation	para. 5-2a(5)		

Table 5-1. Structural Evaluation (Tier 2)

evaluation indicate that the evaluation results are sensitive to these assumed strength values, destructive or nondestructive testing shall be performed prior to rehabilitation design.

(4) Acceptance criteria

(a) Deformation-controlled actions. Deformation-controlled actions in primary and secondary components and elements shall satisfy Equation 5-1.

$$mQ_{CE} \geq Q_{UD} \qquad (5\text{-}1)$$

where:

Q_{UD} = Action due to combined gravity and earthquake loading calculated in accordance with Section 4.2.4.3.1 of FEMA 310.

m = Component or element demand modifier to account for expected ductility of the deformation associated with this action at the selected performance level. Tables 4-3 to 4-6 in FEMA 310 provide m values for various structural components.

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

For Q_{CE}, the expected strength shall be determined considering all coexisting actions acting on the component under the design loading condition. Procedures to determine the expected strength are given in Chapters 4 through 8 of FEMA 273. In the absence of prescribed values for Q_{CE}, the default value of 1.25 times the nominal strength (1.25 Q_{CN}) shall be assumed.

(b) Force-controlled actions. Force-controlled actions in primary and secondary components and elements shall satisfy Equation 5-2. (This equation replaces Equation 4-13 in FEMA 310).

$$Q_{CN} \geq Q_{UF} \qquad (5\text{-}2)$$

where:

Q_{CN} = Nominal strength of the component or element.

Q_{UF} = Action due to combined gravity and earthquake loading calculated in accordance with Section 4.2.4.3.2 of FEMA.

(c) Special Procedure. Acceptability of structural components in URM bearing wall buildings shall be in accordance with the provisions of Section 4.6 of FEMA 310.

(d) Out-of-plane wall forces shall be computed in accordance with Section 4.5 of FEMA 310.

(5) Evaluation results. The results of a Tier 2 evaluation will be:

(a) The building is acceptable.

(b) Structural deficiencies have been identified and quantified.

(c) The Tier 2 evaluation is inconclusive, but a Tier 3 evaluation may indicate that the building meets the acceptance criteria.

b. Tier 3 procedures.

(1) General. This procedure shall be used for the evaluation of structures in Seismic Use Groups II and III, with the characteristics described in Paragraph 5-4b of TI 809-04. Acceptance criteria are also provided for this procedure to satisfy the Life-Safety performance objective, but the use of this procedure for that performance objective requires specific authorization. Step-by-step procedures for this evaluation are outlined in Table 5-2.

(2) Analytical procedures. This evaluation consists of performing either a Nonlinear Static Procedure (NSP), or a Nonlinear Dynamic Procedure (NDP), in accordance with Sections 3.3.3 or 3.3.4, respectively, of FEMA 273. The NDP is not recommended for buildings governed by this document, and the NSP will require prior authorization.

(3) Acceptance criteria. The acceptance criteria for the Tier 3 evaluation shall be as prescribed in paragraph 7-2f(5)(d)2 for structural rehabilitation except that the spectral ordinates, S_a, to establish the target displacement, δ_t, shall be reduced to 75 percent of the prescribed values in accordance with paragraphs 5.2.1 and 5.2.2 of FEMA 310. For Tier 3 evaluations performed in accordance with this document, this exception shall apply only to Seismic Use Group I buildings.

(4) Evaluation results. The results of Tier 3 evaluation will be:

(a) The building is acceptable.

(b) Deficiencies have been identified and quantified.

		References		
Step	**Procedure** G. Structural Evaluation (Tier 3)	**This Document**	**FEMA 273**	**TI 809-04**
1.	(Requires prior approval) Perform static nonlinear analysis a. Construct "push-over" curve b. Determine target displacement c. Check interstory drift d. Check inelastic responses	para. 5-2b(2)	Sec. 3.3.3	Table 4-7
2.	Acceptance criteria a. Deformation-controlled components b. Force-controlled components	para. 5-2b(3)		Chap. 7
3.	Evaluation results a. The building is acceptable b. Structural deficiencies have been identified and quantified	para. 5-2b(4)		

Table 5-2. Tier 3 Structural Evaluation

5-3. Nonstructural Systems Evaluation

a. General. The Tier 2 evaluation of nonstructural components found to be noncompliant with the Tier 1 screening checklist statements shall be in accordance with applicable provisions of Section 4.8 of FEMA 310 referenced by the checklist statements, except that Equation 4-36 in FEMA 310 shall be replaced by Equation 10-1 in TI 809-04. Step-by-step procedures are outlined in Table 5-3.

b. Seismic demands on nonstructural components shall be calculated in accordance with Section 4.2.7 of FEMA 310.

(2) Some components have deficiencies that are identified and quantified.

c. Drift ratios and displacements shall be determined in accordance with Section 4.2.7 of FEMA 310, and shall be evaluated against the allowable values in Section 11.9 and 11.10 of FEMA 273.

d Evaluation results. The results of the Tier 2 nonstructural evaluation will be:

(1) All components are acceptable.

(2) Some components have deficiencies that are identified and quantified.

		References		
Step	**Procedure** H. Nonstructural Evaluation (Tier 2) (All $I_p = 1.5$ components and designated $I_p = 1.0$ components)	**This Document**	**FEMA 310**	**TI 809-04**
1.	Determine component importance factor	para. 4-4b		
2.	Perform structural analysis	para. 5-3b para. 5-3c	Sec 4.8	para. 10-1
3.	Evaluation results a. All components are acceptable b. Some components have deficiencies that have been identified and quantified	para. 5-3d		

Table 5-3. Nonstructural Evaluation (Tier 2)

CHAPTER 6
FINAL ASSESSMENT AND REPORT

6-1. Final Structural Assessment

The following paragraphs describe the final assessment of the seismic screening and/or evaluation of a building. The procedures are outlined in Table 6-1, Steps 1, 2, and 3.

a. Structural evaluation assessment. Upon completion of the structural screening and/or evaluation, the results need to be reviewed so that an appropriate recommendation can be formulated as to the disposition of the building. The assessment to be made by the evaluator shall be based on the following evaluation results:

(1) Quantitative.

(a) The building is acceptable.

(b) Deficiencies exist in the structural components and are identified and quantified.

(c) Deficiencies exist in the global structural system responses (i.e., drift, torsion, etc.) and are identified and quantified.

(2) Qualitative.

(a) The building is acceptable. In recognition of the fact that the costs of rehabilitation are not always directly proportional to the benefits derived, the evaluator shall review the deficiencies identified by the quantitative results of the evaluation to determine whether costly and disruptive rehabilitation procedures were "triggered" by marginal deficiencies in a single structural component. In such cases, a 10 to 15 percent reduction in the calculated seismic demands will be permissible, if the reduction can eliminate the need for the rehabilitation of the component.

(b) The building needs rehabilitation but is not a serious hazard to life safety. This assessment may be based on the following results of the evaluation:

1. The deficiencies are minor and can be mediated with a "quick fix."

2. Load paths for lateral forces are indirect, but provide significant capacity.

3. A valid structural system to resist lateral forces exists, but requires additional strength and/or stiffness.

(c) The building is a serious life safety hazard and rehabilitation is required.

1. The load paths are incomplete or discontinuous.

2. The existing structural systems require strengthening and/or additional stiffness.

3. A new structural system (i.e., shear walls or braced frames) is required to supplement the existing systems.

b. Structural rehabilitation strategy. When assessment of the results of the evaluation indicate that rehabilitation is required, the evaluator shall

Step	Procedure I. Final Assessment	References This Document
1.	Structural evaluation assessment Quantitative Building is acceptable. Deficiencies in structural components are identified and quantified. Deficiencies in structural responses are identified and quantified. Qualitative Building is acceptable. Building needs rehabilitation but is not a serious hazard to life safety. Building is a serious life safety hazard and rehabilitation is required.	6-1a
2.	Structural rehabilitation strategy.	6-1b
3.	Structural rehabilitation concept.	6-1c
4.	Nonstructural evaluation assessment Quantitative Bracing and/or support of all components is compliant. Deficiencies exist and are identified and quantified. Qualitative Bracing and/or support of all components is acceptable. Some deficiencies exist, but failure would not affect essential functions or life safety. Deficiencies could effect life safety or essential functions.	6-2a
5.	Nonstructural rehabilitation strategy.	6-2b
6.	Nonstructural rehabilitation concept.	6-2c

Table 6-1. Final Assessment

investigate the optional strategies discussed in Tables 8-1 through 8-5 of Chapter 8, and qualitatively determine the impact of each applicable strategy on:

(1) Expected seismic performance of the rehabilitation.

(2) Required alteration to the existing structural system.

(3) Required demolition and replacement of building finishes.

(4) Disruption of building functions.

(5) Architectural/historic considerations.

(6) Relative costs.

c. Structural rehabilitation concept. A feasible rehabilitation concept, based on the optimum strategy, shall be developed. The purpose of the concept is to define the nature and extent of the rehabilitation in sufficient detail to allow the preparation of a preliminary cost estimate to establish program budget. The preparation of the concept shall include the definition of any of the major structural components that have a significant impact on construction costs, and adequate plans, sections, and representative details to define the rehabilitation. The concept shall include a brief narrative description of the rehabilitation, the design criteria, and the preliminary cost estimate. It should be noted that the structural rehabilitation will be based on forces and/or deformations larger than those recognized by the evaluation, and that the extent and cost of the rehabilitation may therefore exceed that suggested by the evaluation.

6-2. Final Nonstructural Assessment

The following paragraphs describe the final assessment of the seismic screening and/or evaluations of non-structural components. The step-by-step procedures are outlined in Table 6-1 as Steps 4, 5 and 6.

a. Nonstructural evaluation assessment. An assessment of the results of the nonstructural evaluation shall be based on the following evaluation results:

(1) Quantitative.

(a) Bracing and/or support of all the nonstructural components is compliant.

(b) Deficiencies exist and are identified and quantified.

(2) Qualitative.

(a) Bracing and/or support of all of the nonstructural components is acceptable. As discussed for structural deficiencies in paragraph 6-1a(2)(a), the evaluator shall evaluate the quantitative results to determine whether a 10 to 15 percent reduction in the seismic demand forces for a few components can avoid a costly and/or disruptive rehabilitation.

(b) Some components need rehabilitation but component failure would not affect essential functions in the building, and the components are not a serious life safety hazard.

(c) The deficient components are a serious life safety hazard, and/or their failure could affect essential functions. Rehabilitation is required.

b. Nonstructural rehabilitation strategy. General rehabilitation options for nonstructural components are discussed in paragraph 9-1. Various rehabilitation strategies for architectural components are presented in paragraph 9-3, and for mechanical and electrical components in paragraph 9-4.

c. Nonstructural rehabilitation concept. A preliminary rehabilitation concept shall be developed to implement the selected rehabilitation option for each of the deficient components. This concept shall be coordinated so as to be compatible with the selected structural rehabilitation strategy. If feasible, the nonstructural rehabilitation shall be indicated on the structural drawings by an appropriate symbol, and described in a legend [e.g., (1) Provide bolts for emergency motor generator; (2) Add new brace for fan unit]. Graphic detail of the components to be rehabilitated may not be necessary if photographs of the deficiencies and descriptions of the rehabilitation are provided in the descriptive narrative that accompanies the concept. As for the structural concept, in addition to a descriptive narrative, the nonstructural concept shall include the design criteria and a preliminary cost estimate. Design is not necessary for this concept. The sizes of members and connections can be estimated by the evaluator based on the observed deficiencies; however, the nature and extent of the necessary demolition and repair of existing materials to perform the rehabilitation must be described in the descriptive narrative, and reflected in the cost estimate.

6-3. Evaluation Report

a. General. An evaluation report, as outlined in Table 6-2, shall be prepared to summarize the results of the evaluation of structural systems and nonstructural components in each building that is designated for evaluation as a potential candidate for rehabilitation. The following paragraphs describe the executive summary, the descriptive narrative portions, and the appendices that constitute the report.

b. Executive summary. The body of the report shall be preceded by an executive summary that provides a brief summary of the following:

(1) Description of the building, its structural systems, and nonstructural components.

(2) Results of geologic hazard evaluation and resolution of identified hazards.

(3) Levels of evaluation performed (e.g., Tier 1 and Tier 2).

(4) General descriptions of structural deficiencies and rehabilitation concept, including preliminary estimate.

(5) General description of nonstructural deficiencies, including preliminary cost estimate.

c. Descriptive narrative.

(1) General. Summarize the following:

(a) Building and site data in paragraph 2-2.

(b) Performance classifications in paragraph 2-3.

Step	Procedure J. Evaluation Report	References This Document
1.	Executive Summary	6-3b
2.	Descriptive narrative Building and site data Geologic hazards Structural evaluations Nonstructural evaluations	6-3c
3.	Appendices Prior evaluations Available drawings and other construction documents Geotechnical report Structural evaluation data Nonstructural evaluation data	6-3d

Table 6-2. Evaluation Report

(2) Geologic hazards. Summarize results of screening and evaluation of geological hazards. Discuss resolution of any identified hazards.

(3) Structural evaluations. Summarize the results of

(a) Preliminary structural assessment.

(b) Tier 1 structural screening.

(c) Tier 2 or Tier 3 structural evaluations.

(d) Final structural assessment.

1. Structural evaluation assessment.
2. Structural rehabilitation strategy.
3. Structural rehabilitation concept.

(4) Nonstructural evaluations. Summarize the results of:

(a) Preliminary nonstructural assessment.

(b) Nonstructural Tier 1 screening.

(c) Tier 2 nonstructural evaluation.

(d) Final nonstructural assessment.

1. Nonstructural evaluation assessment.
2. Nonstructural rehabilitation strategy.
3. Nonstructural rehabilitation concept.

d. Appendices to the evaluation report shall include:

(1) Copies of prior evaluations.

(2) Location and listing of available drawings and other construction documents.

(3) Geotechnical report regarding evaluation and mitigation of geologic hazards (if evaluation was found necessary).

(4) Structural evaluation data.

(a) Completed checklists for the Tier 1 evaluation.

(b) Supporting calculations and analytical data pertaining to a Tier 2 or Tier 3 evaluation.

(c) Supporting calculations and drawings for the preliminary rehabilitation concept.

(d) Back-up detail for the preliminary cost estimate.

(5) Nonstructural evaluation data.

(a) Completed checklists for the Tier 1 evaluation.

(b) Supporting calculations for the Tier 2 evaluation.

(c) Supporting conceptual drawings for the preliminary rehabilitation concept.

(d) Back-up detail for the preliminary cost estimate.

CHAPTER 7
REHABILITATION OF STRUCTURAL SYSTEMS

7-1. Introduction

a. Scope. This chapter describes the general procedures and the applicable criteria for the rehabilitation of structural systems as indicated in Table 7-1 and Figure 7-1. It is assumed that seismic deficiencies have been identified by the evaluation process described in Chapters 4 and 5, and that mitigation by structural rehabilitation is the authorized option. It should be noted that the acceptance criteria for rehabilitation are more restrictive than those specified in Chapter 4 and 5 for evaluation. While existing buildings that comply with the evaluation criteria are considered acceptable, buildings that are designated for rehabilitation shall comply with the more stringent criteria prescribed in this chapter. Although this chapter is limited to the rehabilitation of structural systems, the rehabilitation of nonstructural components would normally be accomplished concurrently. Rehabilitation techniques for structural systems are described in Chapter 8, and rehabilitation techniques and procedures for nonstructural components are described in Chapter 9.

b. The rehabilitation process is generally an iterative process, as indicated in Figure 7-1, because it is very difficult to anticipate the combined response of new or strengthened structural components interacting with an existing structural system. Although the desired response will eventually be obtained by trial and error, design experience and training in structural dynamics will reduce the number of iterations required to obtain an acceptable response.

7-2. General Rehabilitation Procedures

When rehabilitation is authorized to mitigate seismic deficiencies, the general procedures outlined in Table 7-1 and in the flow-chart in Figure 7-1 shall be followed. These procedures shall include:

a. Review of evaluation data. The designer shall review the Evaluation Report, the available construction documents, and the results of any prior evaluations.

b. Site visit. After reviewing the Evaluation Report and the available construction documents, the designer shall visit the building to:

(1) Visually confirm the results of the evaluation.

(2) Visualize the nature and extent of alterations required to implement the rehabilitation concept.

(3) Investigate the feasibility of alternative rehabilitation concepts.

(4) Make preliminary determination of required destructive and nondestructive testing.

c. Quality assurance /quality control. The quality assurance/quality control procedures outlined in Chapter 10, applicable to the rehabilitation design and preparation of construction documents, shall be implemented prior to initiation of the design. Any required engineering during construction (EDC) that will be performed by the structural designer shall be identified at the inception of the design work.

Step	Procedure K. Rehabilitation	References		
		This Document	FEMA 273	TI 809-04
1.	Review Evaluation Report and other available data	7-2a		
2.	Site visit	7-2b		
3.	Supplementary analysis of existing building (if necessary)	7-2d		
4.	Rehabilitation concept selection	7-2e		
5.	Rehabilitation design a. Rehabilitation techniques (FEMA 172) b. Detailing requirements for new construction (FEMA 302)	7-2f Chaps. 8 and 9	Chap. 4-11	Chap. 7
6.	Confirming evaluation of rehabilitation a. Analytical procedures b. Acceptable criteria	7-2g	Secs. 2.9 & 3.3 Secs. 3.4 and Chap. 4-11	Chap. 5 Chap. 7
7.	Prepare construction documents			
8.	Quality assurance/quality control	Chap. 10		

Table 7-1. Rehabilitation Procedures

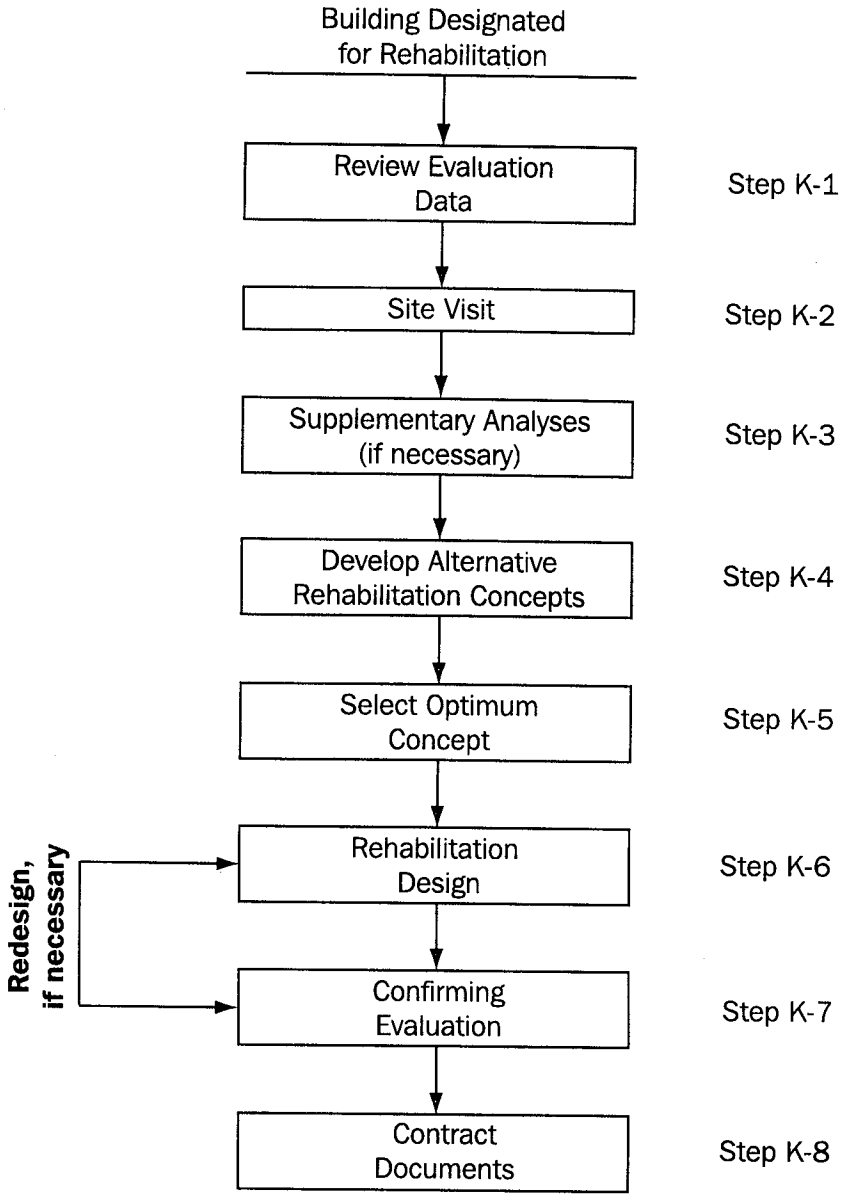


Figure 7-1. Rehabilitation Procedures

d. Supplementary analysis. The evolution of seismic provisions in building codes has been toward more severe and restrictive requirements, and very few of the older existing buildings can be expected to be in compliance with a rigorous evaluation. Based on the review of the evaluation documents, the designer may consider that the identified deficiencies were marginal, or that certain aspects of the evaluation were inconclusive or based on overly conservative assumptions, and that supplementary analyses should be performed to confirm or invalidate the evaluation. In such cases, approval should be requested to perform the supplementary analysis. If the evaluation was based on default structural material properties, and it was determined that the evaluation results were sensitive to these assumed properties, destructive or nondestructive testing shall be performed to establish properties that are more representative of the structural materials for the supplementary analysis.

e. Rehabilitation concept selection.

Paragraph 6-1a requires the development of a preliminary concept with a preliminary construction cost estimate in the preparation of the Evaluation Report. The purpose of the preliminary concept is to establish a reasonable cost basis for programming the rehabilitation. While a selected concept may be feasible in terms of engineering and construction, it may not be the most cost effective solution, and it may not address all of the functional or aesthetic restrictions of the installation authority (e.g., avoiding functional disruption of all or portions of the building during construction, or retaining historical or architectural features). When the rehabilitation is authorized, particularly if the seismic rehabilitation is triggered by other considerations (e.g., building expansion, handicap access, asbestos abeyance, etc.), the preliminary concept needs to be re-evaluated and coordinated with other structural alterations. Except for those buildings for which the strengthening or retrofit is a simple and obvious fix (e.g., inadequate bracing in a steel braced-frame structure mitigated by additional bracing, or strengthening or replacement of the existing bracing), at least three retrofit concepts should be developed within one or more retrofit strategies that address all of the above considerations. Representative rehabilitation techniques for structural systems are provided in Chapter 8. The optimum retrofit strategy will be the concept that provides the desired seismic performance (i.e., life safety or protection of an essential function); complies with the functional and/or aesthetic restrictions; and is the most cost-effective of the available retrofit strategies. The alternative concepts shall be compared and evaluated on the basis of construction cost, and the construction impacts on the functional occupants of the building. The designer shall select and recommend the optimum concept, with justification for the selection.

f. Rehabilitation design procedures.

(1) General. The design of the seismic rehabilitation consists of implementing the approved concept. For Seismic Group I buildings with only deficiencies that have been identified as requiring a "quick fix," the rehabilitation may consist of simply addressing the deficiency that would result in the building being "acceptable" by the deterministic evaluation criteria. In most cases governed by this document, however, rehabilitation will be an iterative process, as indicated in paragraph 7-1b, and analysis

will be required to confirm that, with the addition of the new or strengthened structural systems or components, the rehabilitated building meets the acceptance criteria prescribed in paragraph 7-2f(5)(d).

(2) Analytical Procedures. The analytical procedure for confirmation of the rehabilitation will generally be one of the following procedures that were used in the Tier 2 or Tier 3 evaluations:

(a) Linear Static Procedure (LSP) shall be performed in accordance with Section 3.3.1 of FEMA 273. Limitations on the use of the procedure shall be in accordance with paragraph 5-2b of TI 809-04.

(b) Linear Dynamic Procedure (LDP) shall be performed in accordance with Section 3.3.2 of FEMA 273.

(c) Nonlinear Static Procedure (NSP) shall be performed in accordance with Section 3.3.3 of FEMA 273. Guidelines on when a nonlinear procedure is required are provided in paragraph 5-4b of TI 809-04.

(d) Nonlinear Dynamic Procedure (NDP) as described in Section 3.3.4 of FEMA 273 is not recommended for use with buildings governed by this document.

For most military buildings, the LSP and LDP will provide the required analytical results.

(3) Mathematical model. A mathematical model shall be developed in accordance with Section 3.2.2 of FEMA 273. The model shall be consistent with the selected analytical procedure and shall be capable of providing the structural responses required by the acceptance criteria.

(4) Structural detailing requirements. The primary references for structural detailing of new construction associated with the rehabilitation of existing buildings are the applicable requirements of FEMA 302 and its incorporated reference documents (i.e., ACI, AISC, etc.). Additional guidance for the design and detailing of new structural components and systems is provided in Chapter 7 of TI 809-04.

(5) Rehabilitation design criteria.

(a) Design ground motion. The ground motion derived from 2/3 MCE is the basic ground motion in the FEMA 302 provisions; is approximately equivalent to that with a 10 percent probability of excedance in 50 years; and is the ground motion prescribed for all performance objectives by this document. It should be noted that, for the Life-Safety performance objective, FEMA 273 prescribes probabilistic ground motion with 10 percent probability of exceedance in 50 years with the Life-Safety acceptance criteria (m values) as well as compliance with the Collapse Prevention acceptance criteria for the MCE ground motion. This document has adopted the single-level criteria for the Life-Safety performance objective, as prescribed in FEMA 302 and TI 809-04 for new construction, and FEMA 310 for screening and evaluation of existing buildings. For many structural components, compliance with the Life-Safety acceptance criteria at 2/3 MCE will provide reasonable compliance with the Collapse Prevention criteria at the MCE level. This may not apply, however, to force-controlled components where the applied forces are not limited

by the yielding of the component or other connecting components (e.g., shear critical reinforced concrete beams or columns). The engineer responsible for the rehabilitation design shall evaluate the structural system to identify these vulnerable components, and shall strengthen them, as required, to comply with the exception in paragraph 7-2f(5)(d)1ii.

(b) Gravity load combinations shall be in accordance with Section 3.2.8 of FEMA 273, except that Equation 3-2 shall be replaced by the following:

$$Q_G = 1.2Q_D + 0.5Q_L + 0.2Q_S \qquad (7\text{-}1)$$

(c) Seismic forces shall be represented by the pseudo-lateral load defined by Equation 3-6 in FEMA 273.

(d) Seismic demands and capacities for structural components shall be as defined in the following subparagraphs. As indicated in paragraph 6-1a(2), a 10 to 15 percent reduction in the seismic demand of a deficient component is permitted in the structural evaluation if such reduction can preclude the rehabilitation of an otherwise deficient building. If, however, rehabilitation is found to be necessary, no reduction in the seismic demand is permitted.

1. Linear procedures.

i. Deformation-controlled actions. Deformation-controlled actions in primary and secondary components and elements shall satisfy Equation 7-2.

$$mQ_{CE} \geq Q_{UD} \qquad (7\text{-}2)$$

where:

m = Component or element demand modifier to account for expected ductility of the deformation associated with this action at the selected performance level. Chapter 7 of T1 809-04 provides tables of m values for various structural components. The tables are reproduced from FEMA 273, with the addition of values for the Safe Egress (SE) performance level.

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

Q_{UD} = Design action due to combined gravity loads and seismic loads as defined in Section 3.4.2.1A of FEMA 223.

For Q_{CE}, the expected strength shall be determined considering all coexisting actions acting on the component under the design loading condition. Procedures to determine the expected strength are given in Chapters 4 through 8 of FEMA 273. In the absence of prescribed values for Q_{CE}, the default value of 1.25 times the nominal strength (1.25 Q_{CN}) shall be assumed.

ii. Force-controlled actions. Force-controlled actions in primary and secondary components and elements shall satisfy Equation 7-3.

$$Q_{CN} \geq Q_{UF} \qquad (7\text{-}3)$$

where:

Q_{CN} = Nominal, or specified, strength of a component or element

Q_{UF} = Design actions due to combined gravity and seismic loads as defined by Section 3.4.2.1B of FEMA 273.

Exception:

The design action, Q_{UF}, for vulnerable components, as defined in paragraph 7-2f(5)(a), shall be defined by

$$Q_{UF} = Q_{G\pm} \frac{1.25Q_E}{C_1C_2C_3}$$

Equation 7-4.

(7-4)

Note that the lower bound strength, Q_{CL}, in FEMA 273, is defined here as the nominal or specified strength, Q_{CN}.

2. Nonlinear procedure.

i. General. This procedure shall be used for the evaluation of structures in Seismic Use Groups II and III, with the characteristics described in Paragraph 5-4b of TI 809-04. Acceptance criteria are also provided for this procedure to satisfy the Life-Safety performance objective, but the use of this procedure for that performance objective requires specific authorization.

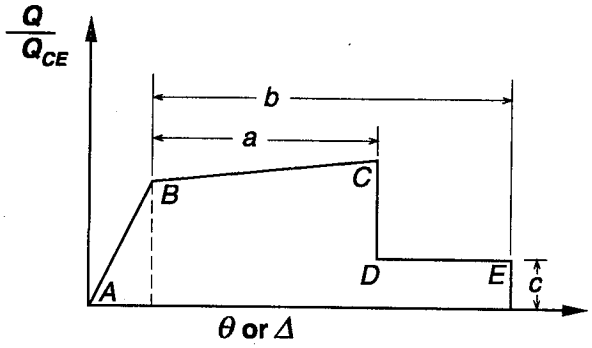
ii. Actions and Deformations. With the procedures as described in Paragraph 5-4 of TI 809-04, compliance with the performance objective requires compliance with the global displacement criteria for the structure as a whole, and the local deformation criteria for individual structural elements.

- Global displacement. The displacement for the control node of the structure in the force/displacement plot (i.e., pushover analysis) must equal or exceed the target displacement, δt, described in Section 3.3.3 of FEMA 273.

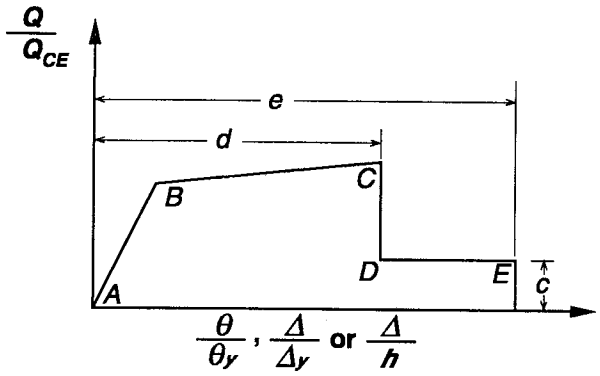
- Deformation-controlled actions. Primary and secondary components shall have expected deformation capacities not less than the deformations derived from the pushover analysis when the target displacement, δt, is attained. Modeling parameters and numerical acceptance criteria are provided for each performance objective for the structural systems described in Chapters 7 through 10 of TI 809-04. The acceptance criteria are provided in terms of rotations, θ, in radians; rotation ratios, $\theta/\theta y$; or deformation ratios $\Delta/\Delta y$, as depicted in Figure 7-2.

- Force-controlled actions. Acceptance criteria for force-controlled actions shall be as prescribed for the linear procedures in paragraph 7-2f(5)(d)1.

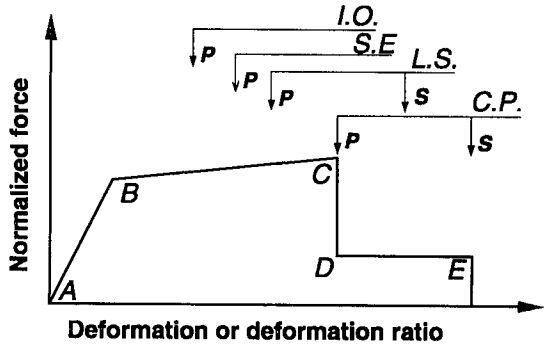
3. The knowledge factor κ, in Equation 3-18 of FEMA 273 is assumed to be 1.0,



(a) Deformation



(b) Deformation ratio



(c) Component or element deformation limits

Figure 7-2. Idealized Component Load Versus Deformation Curves for Depicting Component Modeling and Acceptability

based on the consideration that adequate construction documents and records are generally available for military buildings. However, a $\kappa = 0.75$ must be used to modify the capacity of existing structural components if adequate structural details and material property parameters required to perform the analyses cannot be determined from the available construction documents.

4. Allowable story drift. The component-based procedures prescribed by this document implicitly limit story drift by the limits on component deformation; however, global building drift needs to be monitored for P-Δ effects as prescribed in paragraph 5-1e, and the story drifts need to be monitored for some nonstructural components as prescribed by paragraph 5-3c.

g. Confirming evaluation. Structural rehabilitation will generally result in a change in the weight, stiffness and strength of the rehabilitated structural members, which with any added structural components and systems, will tend to modify the seismic response of the building, and the distribution of seismic forces within the building. If the rehabilitation measures are nominal (i.e., a "quick fix"), the modification of the seismic responses may be negligible, and no further evaluation is required. In most cases, it is advisable to perform a confirming evaluation to confirm that the rehabilitated structure complies with the acceptance criteria. New and strengthened existing components shall be modified as required to comply with the confirming evaluation. However, in recognition of the fact that the cost of rehabilitation is a step function, (i.e., a large incremental cost may be required for small incremental benefit), as indicated in paragraph 6-1a(2), a 10 to 15 percent reduction in the seismic demand on a previously acceptable existing component will be permitted if such reduction can preclude the need to strengthen or replace the component.

7-3. Preparation of Contract Documents

The preparation of construction drawings, specifications, and other contract documents for rehabilitation shall be in accordance with established proponent agency guidelines for the preparation of contract documents, and shall comply with the QA/QC procedures prescribed in paragraph 10-3. The contract documents shall also incorporate the construction QA/QC provisions indicated in paragraph 10-6.