# 1.0 General Provisions

## 1.1 Scope

This Handbook provides a three-tiered process for seismic evaluation of existing buildings in any region of seismicity. Buildings are evaluated to either the Life Safety or Immediate Occupancy Performance Level.

Use of this Handbook and mitigation of deficiencies identified using this Handbook are voluntary or as required by the authority having jurisdiction. The design of mitigation measures is not addressed in this Handbook.

This Handbook does not preclude a building from being evaluated by other well-established procedures based on rational methods of analysis in accordance with principles of mechanics and approved by the authority having jurisdiction.

**Commentary:**

This Handbook provides a process for seismic evaluation of existing buildings. A major portion is dedicated to instructing the evaluating design professional on how to determine if a building is adequately designed and constructed to resist seismic forces. All aspects of building performance are considered and defined in terms of structural, nonstructural and foundation/geologic hazard issues.

Prior to using this Handbook, a rapid visual screening of the building may be performed to determine if an evaluation is needed using the following document:

- *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook* (FEMA 154 and 155).

Mitigation strategies for rehabilitating buildings found to be deficient are not included in this Handbook; additional resources should be consulted for information regarding mitigation strategies.

<u>Handbook Basis</u>

This Handbook is based on the *NEHRP Handbook for Seismic Evaluation of Existing Buildings* (FEMA 178). This Handbook was written to:

- reflect advancements in technology,
- incorporate design professional experience,
- incorporate lessons learned during recent earthquakes,
- be nationally applicable, and
- provide evaluation techniques for varying levels of building performance.

Since the development and publication of FEMA 178, numerous significant earthquakes have occurred: the 1985 Michoacan Earthquakes that affected the Mexico City area, the 1989 Loma Prieta Earthquake in the San Francisco Bay Area, the 1994 Northridge Earthquake in the Los Angeles area, and the 1995 Hyokogen-Nanbu Earthquake in the Kobe area. While each earthquake validated the fundamental assumptions underlying the procedures presented in FEMA 178, each also offered new insights into the potential weaknesses in certain systems that should be mitigated. (It should be noted that while the publication of FEMA 178 occurred after the Mexico City and Loma Prieta Earthquakes, data and lessons learned from them were unable to be incorporated into the document prior to publication.)

<u>Extent of Application</u>

Model building codes typically exempt certain classes of buildings from seismic requirements pertaining to new construction. This is most often done because the building is unoccupied or it is of a style of construction that is naturally earthquake resistant. It is reasonable to expect that these classes of buildings may be exempt from the requirements of this Handbook as well.

No buildings are automatically exempt from the evaluation provisions of this Handbook; exemptions

exemptions should be defined by public policy. However, based on the exemption contained in the codes for new buildings, jurisdictions may exempt the following classes of construction:

- Detached one- and two-family dwellings located where the design short-period spectral response acceleration parameter, $S_{DS}$, is less than 0.4g.
- Detached one- and two-family wood frame dwellings located where the design short-period response acceleration parameter, $S_{DS}$, is equal to or greater than 0.4g that satisfy the light-frame construction requirements of the *1997 NEHRP Recommended Provisions for Seismic Regulations for New Buildings*; and
- Agricultural storage structures that are intended only for incidental human occupancy.

Application to Historic Buildings

Although the principles for evaluating historic structures are similar to those for other buildings, special conditions and considerations may exist of which the design professional should be aware.

Historic structures often include archaic materials, systems, and details. It may be necessary to look at handbooks and building codes from the year of construction to determine details and material properties.

Another unique aspect of historic building evaluation is the need to consider architectural elements or finishes. Testing that damages the historic character of the building generally is not acceptable.

In addition, an appropriate level of performance for historic structures needs to be chosen that is acceptable to the local jurisdiction. Some feel that historic buildings should meet the safety levels of other buildings since they are a subset of the general seismic safety needs. Others feel that historic structures, because of their value to society, should meet a higher level of performance. And in some cases a reduced level of performance has

some cases a reduced level of performance has been allowed to avoid damaging historic fabric.

The following resources may be useful when evaluating historic structures:

- *Secretary of the Interior's Standards for the Treatment of Historic Properties*, and
- *National Park Service Catalog of Historical Preservation Publications.*

Alternative Methods

Alternative documents that may be used to evaluate existing buildings include:

- *Uniform Code for Building Conservation* (UCBC, 1997),
- *Los Angeles Division 91*, *Los Angeles Division 95*, and
- *Seismic Evaluation and Retrofit of Concrete Buildings.*

Some users have based the seismic evaluation of buildings on the provisions of new buildings. While this may seem appropriate, it must be done with full knowledge of the inherent assumptions. Codes for new buildings contain three basic types of requirements including strength, stiffness, and detailing. The strength and stiffness requirements are easily transferred to existing buildings; the detailing provisions are not. If the lateral-force-resisting elements of an existing building do not have the proper details of construction, the basic expectations of the other strength and stiffness provisions will not be met. Lateral-force-resisting elements that are not properly detailed should be omitted during an evaluation using a code for new buildings.

ATC-14 offered the first technique for adjusting the evaluation for the lack of proper detailing by using a three-level acceptance criteria, FEMA 178 used reduced R-factors to accomplish the same thing. FEMA 273 contains the most comprehensive procedure with its element-based approach. This Handbook follows the lead of FEMA 273 with a new style of analysis procedure tailored to the Tier 1 and Tier 2 evaluation levels.

## 1.2 Basic

Mitigation Strategies

Potential seismic deficiencies in existing buildings may be identified using this Handbook. If the evaluation is voluntary, the owner may choose to accept the risk of damage from future earthquakes rather than upgrade, or demolish the building. If the evaluation is required by a local ordinance for a hazard-reduction program, the owner may have to choose between rehabilitation, demolition, or other options.

The following documents may be useful in determining appropriate rehabilitation or mitigation strategies:

- *NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings* (FEMA 172),
- *NEHRP Benefit-Cost Model for the Seismic Rehabilitation of Buildings* (FEMA 227 and 228),
- *NEHRP Typical Costs for Seismic Rehabilitation of Existing Buildings* (FEMA 156 and 157), and
- *NEHRP Guidelines and Commentary for the Seismic Rehabilitation of Buildings* (FEMA 273 and 274).

## Requirements

Prior to conducting the seismic evaluation, the evaluation requirements of Chapter 2 shall be met.

A Tier 1 evaluation shall be conducted for all buildings in accordance with the requirements of Chapter 3. Checklists, as applicable, of compliant/non-compliant statements related to structural, nonstructural and foundation conditions, shall be selected and completed in accordance with the requirements of Section 3.3 for a Tier 1 Evaluation. Potential deficiencies shall be summarized upon completion of the Tier 1 evaluation.

Structural Tier 1 checklists are not provided for unreinforced masonry bearing wall buildings with flexible diaphragms. The structural evaluation of unreinforced masonry bearing wall buildings with flexible diaphragms shall be completed using the Tier 2 Special Procedure of Section 4.2.6; a Tier 1 Evaluation for foundations and non-structural elements remains applicable for this type of building.

For those buildings identified in Section 3.4, a Full-Building Tier 2 Evaluation or a Tier 3 Evaluation shall be performed upon completion of the Tier 1 Evaluation.

For those buildings not identified in Section 3.4 as requiring a Full Building Tier 2 Evaluation or a Tier 3 Evaluation, but for which potential deficiencies were identified in Tier 1, a Deficiency-Only Tier 2 Evaluation may be performed. For a Deficiency-Only Tier 2 Evaluation, only the procedures associated with non-compliant checklist statements need be completed. Potential deficiencies shall be summarized upon completion of the Tier 2 Evaluation. Alternatively, the design professional may choose to end the investigation and report the deficiencies in accordance with Chapter 1.

A Tier 3 evaluation shall be performed in accordance with the requirements of Chapter 5 for buildings identified in Section 3.4 or when the design professional chooses to further evaluate buildings for which potential deficiencies were identified in Tier 1 or Tier 2. Potential deficiencies shall be summarized upon completion of the Tier 3 Evaluation.

After a seismic evaluation has been performed, a final report shall be prepared. As a minimum, the report shall identify: the building and its character, the tier(s) of evaluation used, and the findings.

The three-tiered process for seismic evaluation of buildings is depicted in Figure 1-1.

**Commentary:**

Prior to conducting the seismic evaluation based on this Handbook, the design professional should understand the evaluation process and the basic requirements specified in this section.

The evaluation process consists of the following three tiers, which are shown in Figure 1-1: Screening Phase (Tier 1), Evaluation Phase (Tier 2), and Detailed Evaluation Phase (Tier 3). As indicated in Figure 1-1, the design professional may choose to (i) report deficiencies and screening recommend mitigation or (ii) conduct further evaluation, after any tier of the evaluation process.

The screening phase, Tier 1, consists of 3 sets of checklists that allow a rapid evaluation of the structural, nonstructural and foundation/geologic hazard elements of the building and site conditions. It shall be completed for all building evaluations conducted in accordance with this Handbook. The purpose of a Tier 1 evaluation is to screen out buildings that comply with the provisions of this Handbook or quickly identify potential deficiencies. In some cases "Quick Checks" may be required during a Tier 1 evaluation, however, the level of analysis necessary is minimal. If deficiencies are identified for a building using the checklists, the design professional may proceed to Tier 2 and conduct a more detailed evaluation of the building or conclude the evaluation and state that potential deficiencies were identified. In some cases a Tier 2 or Tier 3 evaluation may be required.

Based on the ABK research (ABK, 1984), unreinforced masonry buildings with flexible diaphragms were shown to behave in a unique manner. Special analysis procedures provided in Section 4.2.6 were developed to predict the behavior. Since this special procedure does not lend itself to the checklist format of Tier 1, no Structural Checklists are provided. The design professional must perform the Tier 2 Special Procedure as the first step of the evaluation. The Special Procedure only applies to the structural aspects of the building; Tier 1 Checklists provided for the nonstructural elements and for the foundation and geologic hazards issues still apply.

For Tier 2, a complete analysis of the building that addresses all of the deficiencies identified in Tier 1 shall be performed. Analysis in Tier 2 is limited to simplified linear analysis methods. As in Tier 1, evaluation in Tier 2 is intended to identify buildings not requiring rehabilitation. If deficiencies are identified during a Tier 2 evaluation, the design professional may choose to either conclude the evaluation and report the deficiencies or proceed to Tier 3 and conduct a detailed seismic evaluation.

Available methods and references for conducting a Tier 3 detailed evaluation are described in Chapter 5 of this Handbook. Recent research has shown that certain types of complex structures can be shown to be adequate using nonlinear analysis procedures even though other common procedures do not. While these procedures are complex and expensive to carry out, they often result in construction savings equal to many times their cost. The use of Tier 3 procedures must be limited to appropriate cases.

The final report serves to communicate the results to the owner and record the process and assumptions used to complete the evaluation. Each section should be carefully written in a manner that is understandable to its intended audience. The extent of the final report may range from a letter to a detailed document. The final report should include at least the following items:

1) Scope and Intent: a list of the tier(s) followed and level of investigation conducted;
2) Site and Building Data:
   - General building description (number of stories and dimensions),
   - Structural system description (framing, lateral load resisting system, floor and roof diaphragm construction, basement, and foundation system),
   - Nonstructural element description (nonstructural elements that could interact with the structure and affect seismic performance)
   - Building type,
   - Performance Level,
   - Region of Seismicity,
   - Soil Type,
   - Building Occupancy, and
   - Historic Significance;
3) List of Assumptions: material properties, site soil conditions;
4) Findings: list of deficiencies;
5) Recommendations: mitigation schemes or further evaluation;
6) Appendix: references, preliminary calculations.

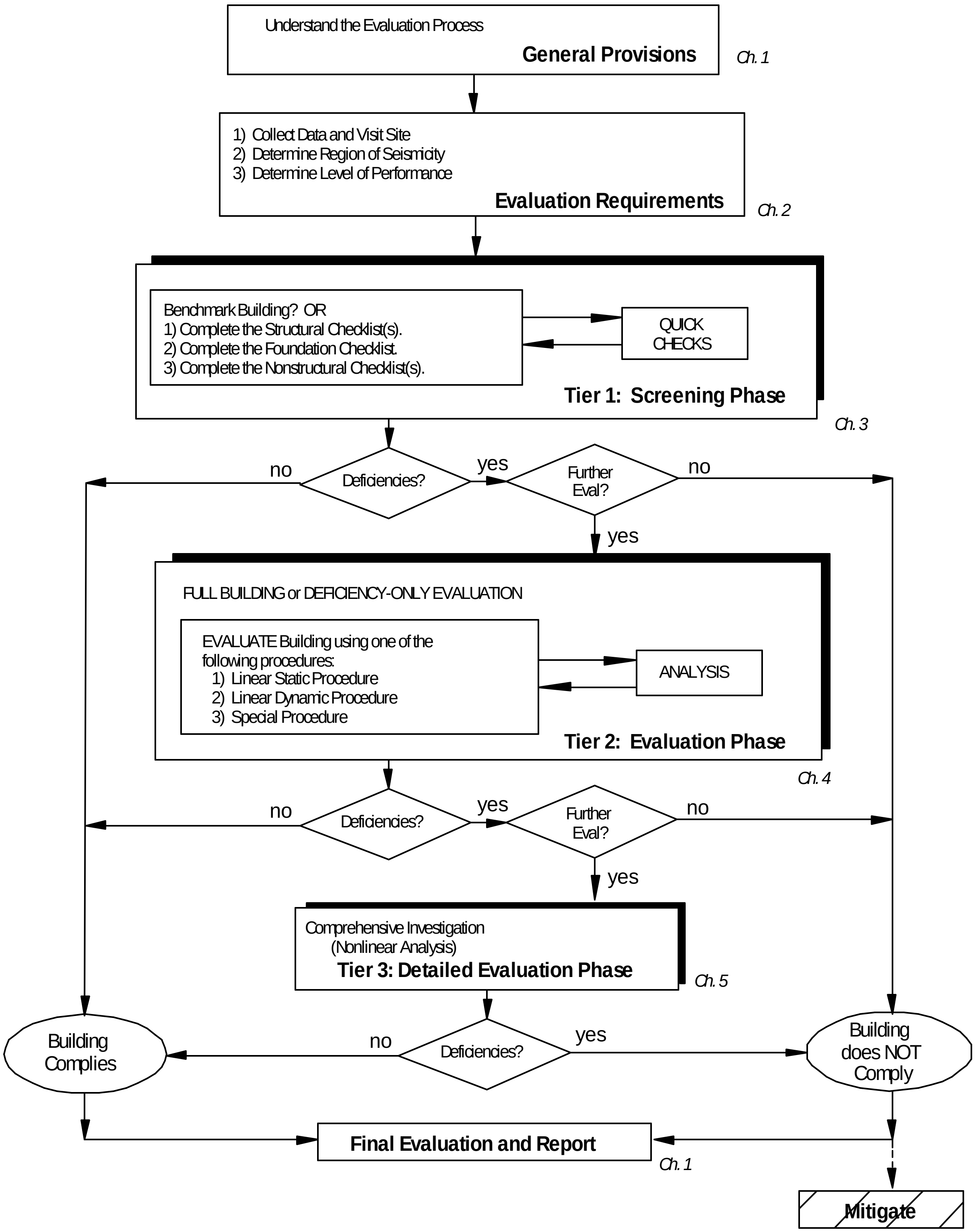


Figure 1-1. Evaluation Process

<u>Judgment by the Design Professional</u>

While this Handbook provides very prescriptive direction for the evaluation of existing buildings, it is not to be taken as the only direction. This Handbook provides direction for common details, deficiencies and behavior observed in past earthquakes that are found in common building types. However, every structure is unique and may contain features and details not covered by this Handbook. It is important that the design professional use judgment when applying the provisions of this Handbook. The design professional should always be looking for uncommon details and behavior about the structure not covered by this Handbook that may have the potential for damage or collapse.

## 1.3 Definitions

**ACTION:** Forces or moments that cause displacements and deformations.

**ASPECT RATIO:** Ratio of full height to length for shear walls; ratio of span to depth for horizontal diaphragms.

**BASIC NONSTRUCTURAL CHECKLIST:** Set of evaluation statements that shall be completed as part of the Tier 1 Evaluation. Each statement represents a potential nonstructural deficiency based on performance in past earthquakes.

**BASIC STRUCTURAL CHECKLIST:** Sets of evaluation statements that shall be completed as part of the Tier 1 Evaluation. Each statement represents a potential structural deficiency based on performance in past earthquakes.

**BENCHMARK BUILDING:** A building designed and constructed or evaluated to a specific performance level using an acceptable code or standard listed in Table 3-1.

**BUILDING TYPE:** A building classification defined in Section 2.6, that groups buildings with common lateral-force-resisting systems and performance characteristics in past earthquakes.

**CAPACITY:** The permissible strength or deformation for a component action.

**COLLECTOR:** A member that transfers lateral forces from the diaphragm of the structure to vertical elements of the lateral-force resisting system.

**CROSS WALL:** A wood-framed wall sheathed with lumber, structural panels, or gypsum wallboard.

**DEFICIENCY-ONLY TIER 2 EVALUATION:** An evaluation, beyond the Tier 1 Evaluation, that investigates only the non-compliant checklist evaluation statements.

**DESIGN EARTHQUAKE:** See Maximum Considered Earthquake.

**DIAPHRAGM**: A horizontal structural system that serves to interconnect the building and acts to transmit lateral forces to the vertical resisting elements.

**DIAPHRAGM EDGE:** The intersection of the horizontal diaphragm and a shear wall.

**DISPLACEMENT-CONTROLLED ACTION:** An action that has an associated deformation that is allowed to exceed the yield value of the element being evaluated. The extent of permissible deformation beyond yield is based on component modification factors (m-factors).

**EXPECTED STRENGTH:** The actual strength of a material, not the specified minimum or nominal strength. For purposes of an evaluation using this Handbook, the expected strength shall be taken equal to the nominal strength multiplied by 1.25. Alternatively, actual statistically based test data may be used.

**FLEXIBLE DIAPHRAGM:** A diaphragm where the maximum lateral deformation along its length is more than twice the average inter-story drift.

**FORCE-CONTROLLED ACTION:** An action that has an associated deformation that is not allowed to exceed the yield value of the element being evaluated. The action is not directly related to the pseudo seismic forces used in the evaluation, rather it is based on the maximum action that can be delivered to the element by the yielding structural system.

**FULL-BUILDING TIER 2 EVALUATION:** An evaluation beyond a Tier 1 Evaluation that involves a complete analysis of the entire lateral-force-resisting system of the building using the Tier 2 analysis procedures defined in Section 4.2. While special attention should be given to the potential deficiencies identified in the Tier 1 evaluation, all lateral force resisting elements must be evaluated. This evaluation is required when triggered by Table 3-3.

**GEOLOGIC SITE HAZARDS AND FOUNDATIONS CHECKLIST:** Set of evaluation statements that shall be completed as part of the Tier 1 Evaluation. Each statement represents a potential foundation or site deficiency based on the performance of buildings in past earthquakes.

**IMMEDIATE OCCUPANCY PERFORMANCE LEVEL:** Building performance that includes very limited damage to both structural and nonstructural components during the design earthquake. The basic vertical and lateral-force-resisting systems retain nearly all of their pre-earthquake strength and stiffness. The level of risk for life-threatening injury as a result of damage is very low. Although some minor repairs may be necessary, the building is fully habitable after a design earthquake, and the needed repairs may be completed while the building is occupied.

**LATERAL FORCE RESISTING SYSTEM:** The collection of frames, shear walls, bearing walls, braced frames and interconnecting horizontal diaphragms that provides earthquake resistance to a building.

**LIFE SAFETY PERFORMANCE LEVEL:** Building performance that includes significant damage to both structural and nonstructural components during a design earthquake, though at least some margin against either partial or total structural collapse remains. Injuries may occur, but the level of risk for life-threatening injury and entrapment is low.

**LINEAR DYNAMIC PROCEDURE (LDP):** A Tier 2 response spectrum based modal analysis procedure shall be used for buildings taller than 100 feet, buildings with vertical or geometric irregularities, and buildings where the distribution of the lateral forces departs from that assumed for the Linear Static Procedure.

**LINEAR STATIC PROCEDURE (LSP):** A Tier 2 lateral force analysis procedure where the pseudo lateral force is equal to the force required to impose the expected actual deformation of the structure in its yielded state when subjected to the design earthquake motions. It shall be used for buildings for which the Linear Dynamic or the Special Procedure is not required.

**MAXIMUM CONSIDERED EARTHQUAKE:** An earthquake with a 2% probability of exceedance in 50 years with deterministic-based maximum values near known fault sources.

**MOMENT-RESISTING FRAME (MRF):** A frame capable of resisting horizontal forces because the members (beams and columns) and joints are capable of resisting forces primarily by flexure.

**PRIMARY COMPONENT:** A part of the lateral-force-resisting system capable of resisting seismic forces.

**PSEUDO LATERAL FORCE (V):** The calculated lateral force used for the Tier 1 Quick Checks and for the Tier 2 Linear Static Procedure. The pseudo lateral force represents the force required, in a linear analysis, to impose the expected actual deformation of the structure in its yielded state when subjected to the design earthquake motions. It does not represent an actual lateral force that the building must resist in traditional code design.

**QUICK CHECK:** Analysis procedure used in Tier 1 Evaluations to determine if the lateral-force-resisting system has sufficient strength and/or stiffness.

**REGION OF LOW SEISMICITY CHECKLIST:** Set of evaluation statements that shall be completed as part of the Tier 1 Evaluation for buildings in regions of low seismicity being evaluated to the Life Safety Performance Level.

**REGION OF SEISMICITY:** An area with similar expected earthquake hazard. For this Handbook, all regions are categorized as low, moderate, or high, based on mapped acceleration values and site amplification factors as defined in Section 2.5.

**RIGID DIAPHRAGM:** A diaphragm where the maximum lateral deformation is less than half the average inter-story drift associated with the story.

**SECONDARY COMPONENT:** An element that is capable of resisting gravity loads, but is not able to resist seismic forces it attracts, though is not needed to achieve the designated performance level.

**SITE CLASS:** Groups of soil conditions that affect the site seismicity in a common manner. The soil types used are defined in Section 3.5.2.3.1; designated as A, B, C, D, E, or F.

**SPECIAL PROCEDURE:** Analysis procedure, used for unreinforced masonry bearing wall buildings with flexible diaphragms, that properly characterizes the diaphragm motion, strength and damping.

**SPECIAL PROCEDURE TIER 2 EVALUATION:** An evaluation procedure specifically written for unreinforced masonry bearing wall buildings with flexible diaphragms using the special procedure.

**STIFF DIAPHRAGM:** A diaphragm that is not classified as either flexible or rigid.

**STORY SHEAR FORCE:** Portion of the pseudo lateral force carried by each story of the building.

**SUPPLEMENTAL NONSTRUCTURAL CHECKLIST:** Set of nonstructural evaluation statements that shall be completed as part of the Tier 1 Evaluation for buildings in regions of moderate or high seismicity being evaluated to the Immediate Occupancy Performance Level.

**SUPPLEMENTAL STRUCTURAL CHECKLIST:** Set of evaluation statements that shall be completed as part of the Tier 1 Evaluation for buildings in regions of moderate seismicity being evaluated to the Immediate Occupancy Performance Level, and for buildings in regions of high seismicity.

**TIER 1 EVALUATION:** Completion of checklists of evaluation statements that identifies potential deficiencies in a building based on performance in past earthquakes.

**TIER 2 EVALUATION:** The specific evaluation of potential deficiencies to determine if they represent actual deficiencies that may require mitigation. Depending on the building type, this evaluation may be a Full-Building Tier 2 Evaluation, Deficiency-Only Tier 2 Evaluation, or a Special Procedure Tier 2 Evaluation.

**TIER 3 EVALUATION:** A comprehensive building evaluation implicitly or explicitly recognizing nonlinear response.

## 1.4 Notation

| | |
|---|---|
| $a_p$ | Component amplification factor, |
| $A_{br}$ | Average cross-sectional area of the diagonal brace, |
| $A_c$ | Summation of the cross-sectional area of all columns in the story under consideration, |
| $A_n$ | Area of net mortared/grouted section ($in^2$), |
| $A_w$ | Summation of the horizontal cross-sectional area of all shear walls in the direction of loading, |
| $A_x$ | Amplification factor to account for accidental torsion, |
| C | Modification factor to relate expected maximum inelastic displacements calculated for linear elastic response, |
| C | Compliant, |
| $C_p$ | Horizontal force factor, |
| $C_t$ | Modification factor, based on earthquake records, used to adjust the building period to account for the characteristics of the building system, |
| $C_{vx}$ | Vertical distribution factor, based on story weights and heights, that defines a triangular loading pattern, |

**D** In-plane width dimension of masonry (in.) or depth of diaphragm (ft.),

**DCR** Demand-capacity ratio,

$D_p$ Relative displacement,

**DR**, $D_r$ Drift ratio,

**E** Modulus of Elasticity;

$F_a$ Site Coefficient defined in Table 3-6,

$f_{br}$ Average axial stress in diagonal bracing elements,

$F_i$ Lateral force applied at floor level i,

$F_{px}$ Total diaphragm force at level x,

$F_v$ Site Coefficient defined in Table 3-5,

$F_{wx}$ Force applied to a wall at level x (lb.),

$F_x$ Total story force at level x,

$F_y$ Yield Stress,

**h** Story height,

$h_i$,$h_x$ Height (ft.) from the base to floor level i or x,

$h_n$ Height (in feet) above the base to the roof level,

**H** Least clear height of opening on either side of pier (in.),

**I** Moment of Inertia,

**IO** Immediate Occupancy Performance Level,

**j** number of story level under consideration,

**J** Force-delivery reduction factor,

**k** Exponent related to the building period,

$k_b$ Stiffness of a representative beam (I/L);

$k_c$ Stiffness of a representative column (I/h);

**L** Length;

$L_{br}$ Average length of the diagonal brace,

**LS** Life-Safety Performance Level,

**m** Component modification factor,

$M_g$ Moment in girder (k-ft),

**n, N** number of stories above ground,

**N/A** Not Applicable,

$N_{br}$ Number of diagonal braces in tension and compression if the braces are designed for compression; Number of diagonal braces in tension if the braces are designed for tension only,

$n_c$ Total number of columns,

$n_f$ Total number of frames,

**NC** Non-Compliant,

**NL** No Limit,

$P_{CE}$ Expected gravity compressive force applied to a wall or pier component stress,

$P_D$ Superimposed dead load at the top of the pier under consideration (lb.),

$P_W$ Weight of wall (lb.),

$Q_{CE}$ Expected strength,

$Q_D$ Actions due to effective dead load,

$Q_E$ Actions due to earthquake loads,

$Q_G$ Actions due to effective gravity load,

$Q_L$ Actions due to effective live load,

$Q_S$ Actions due to effective snow load,

$Q_{UD}$ Deformation-controlled design actions,

$Q_{UF}$ Force-controlled design actions,

$R_p$ Component response modification factor,

s Average span length of braced spans (ft.),

$S_a$ Response spectral acceleration,

$S_{DS}$ Design short-period spectral response acceleration parameter,

$S_{D1}$ Design spectral response acceleration parameter at a one-second period,

$S_S$ Short-period spectral response acceleration parameter,

$S_1$ Spectral response acceleration parameter at a one-second period,

**t** Thickness of wall (in.)

**T** Fundamental period of vibration of the building,

**T1** Tier 1 Evaluation,

**T2** Tier 2 Evaluation,

**T3** Tier 3 Evaluation,

$\mathbf{v_{avg}}$ Average shear stress,

$\mathbf{v_{me}}$ Expected masonry shear strength (psi),

$\mathbf{v_u}$ Unit shear strength for a diaphragm (lb./ft.),

$\mathbf{v_{te}}$ Average bed-joint shear strength (psi), not to exceed 100 psi,

**V** Pseudo lateral force,

$\mathbf{V_a}$ Shear strength of an unreinforced masonry pier (lb.),

$\mathbf{V_c}$ Column shear force,

$\mathbf{V_{ca}}$ Total shear capacity of cross walls in the direction of analysis immediately above the diaphragm level being investigated (lb.),

$\mathbf{V_{cb}}$ Total shear capacity of cross walls in the direction of analysis immediately below the diaphragm level being investigated (lb.),

$\mathbf{V_d}$ Diaphragm shear (lb.),

$\mathbf{V_j}$ Story shear force,

$\mathbf{V_p}$ Shear force on an unreinforced masonry wall pier (lb.),

$\mathbf{V_r}$ Pier rocking shear capacity of an unreinforced masonry wall or wall pier (lb.),

$\mathbf{V_{wx}}$ Total shear force resisted by a shear wall at the level under consideration (lb.),

$\mathbf{w_i}$, $\mathbf{w_x}$ Portion of the total building weight assigned to floor level i or x,

**W** Total seismic weight,

$\mathbf{W_d}$ Total dead load tributary to a diaphragm (lb.),

$\mathbf{W_j}$ Total seismic weight of all stories above level j,

$\mathbf{W_p}$ Component operating weight,

$\mathbf{W_w}$ Total dead load of an unreinforced masonry wall above the level under consideration or above an open front of a building,

$\mathbf{W_{wx}}$ Dead load of an unreinforced masonry wall assigned to level x halfway above and below the level under consideration (lb.),

**x** Height in structure of highest point of attachment of component,

**X,Y** Height of lower support attachment at level x or y as measured from grade,

$\mathbf{D_d}$ Diaphragm displacement,

$\mathbf{D_w}$ In-plane wall displacement,

$\mathbf{d_{avg}}$ the maximum dispalcement at any point of diaphragm at level x,

$\mathbf{d_{max}}$ the algebraic average of displacements at the extreme points of the diaphragm at level x,

$\mathbf{d_{xA}}$, $\mathbf{d_{yA}}$ Deflection at building level x or y of building A,

$\mathbf{d_{xB}}$ Deflection at building level x of building B,

**r''** Volumetric ratio of horizontal confinement reinforcement in a joint.

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